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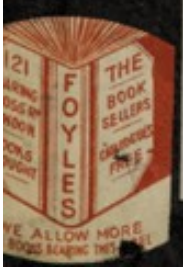
ESSENTIALS OF HISTOLOGY.

SCHÄFER.



THE ESSENTIALS

OF

HISTOLOGY

DESCRIPTIVE AND PRACTICAL

FOR THE USE OF STUDENTS

BY

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PREFACE TO THE SIXTH EDITION.

THIS Book is written with the object of supplying the student with directions for the microscopical examination of the tissues. At the same time it is intended to serve as an Elementary Text-book of Histology, comprising all the essential facts of the science, but omitting unimportant details, the discussion of which is only calculated to confuse the learner. For a similar reason references to authorities have also generally been omitted.

For conveniently accompanying the work of a class of medical students, the book is divided into forty-six lessons. Each of these may be supposed to occupy from one to three hours, according to the relative extent to which the preparations are made beforehand by the teacher, or during the lesson by the students. A few of the preparations cannot well be made by a class, but it has been thought advisable not to injure the completeness of the work by omitting mention of them.

Only those methods are recommended upon which experience has proved that full dependence can be placed, but the directions given are for the most part capable of easy verbal modification in accordance with the ideas or experience of different teachers.

The present edition has been considerably enlarged, partly by additions to the text—especially that descriptive of the structure of the central nervous system, a proper knowledge of which is essential to students of medicine—partly by the provision of new illustrations. The majority of these have been drawn expressly for this work by Mr. Richard Muir, but some are borrowed from the works of other authors, to whom, and especially to Professor Wilson and Professor Szymonowicz, the thanks of the author are due for permission to make use of this privilege. The remainder have been taken from Quain's *Anatomy* or from the author's *Course of Practical Histology*. To the book last mentioned, or to Professor Langley's *Practical Histology*, the student who desires to work independently is referred for details of method which need not be provided for those who are working under the immediate supervision of a teacher.

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THE ESSENTIALS OF HISTOLOGY.

INTRODUCTORY.

ENUMERATION OF THE TISSUES AND THE GENERAL STRUCTURE OF ANIMAL CELLS.

Animal Histology[1] is the science which treats of the minute structure of the tissues and organs of the animal body; it is studied with the aid of the microscope, and is therefore also termed *Microscopical Anatomy.*

Every part or organ of the body, when separated into minute fragments, or when examined in thin sections, is found to consist of certain textures or tissues, which differ in their arrangement in different organs, but each of which exhibits characteristic structural features.

The following is a list of the principal tissues which compose the body:—

1. **Epithelial.**
2. **Connective**: Areolar, Fibrous, Elastic, Adipose, Lymphoid, Cartilage, Bone.
3. **Muscular**: Voluntary, Involuntary or plain, Cardiac.
4. **Nervous.**

Some organs are formed of several of the above tissues, others contain only one or two.

It is convenient to include such fluids as the *blood* and *lymph* amongst the tissues, because they are studied in the same manner and contain cellular elements similar to those met with in some of the other tissues.

All the tissues are, prior to differentiation, masses of *cells* (embryonic cells). In some tissues other tissue-elements become developed which take the form of *fibres.* Thus the epithelial tissues are composed throughout life entirely of cells, only slightly modified in

[1] From *ἱστός*, a web or texture.

structure, and the nervous and muscular tissues are formed of cells which are greatly modified to form the characteristic fibres of those tissues. On the other hand, in the connective tissues an amorphous material becomes formed between the cells which is termed *intercellular substance* or *ground substance*, and in this substance fibres make their appearance, sometimes, as in the fibrous connective tissue, in so large an amount as to occupy the whole of the intercellular substance, and greatly to preponderate over the cells. This ground substance has the property of becoming stained brown or black by nitrate of silver, in which case the cells which remain unstained look like white spaces (cell-spaces) in the ground substance. When an epithelial tissue is similarly treated, the narrow interstices between the cells are also stained, from which it may be concluded that a similar substance exists in small amount between the cells of this tissue. It has here been termed cement-substance, but it is better to apply to it the general term *intercellular substance*.

The cells of a tissue are not always separate from one another, but are in many cases connected by fine threads of the cell-substance, which pass across the intercellular spaces. This is especially the case with the cells of the higher plants, but it has also been found to occur in animal tissues, as in some varieties of epithelium and in cardiac and plain muscular tissue.

Cells.—A *cell* is a minute portion of living substance or *protoplasm*, which is sometimes inclosed by a *cell-membrane* and always contains a specially differentiated part which is known as the *nucleus*.

The **protoplasm** (*cytoplasm*) of a cell (fig. 1, *p*) is composed of albuminous or nucleoproteid substances, with which *lecithin*, a

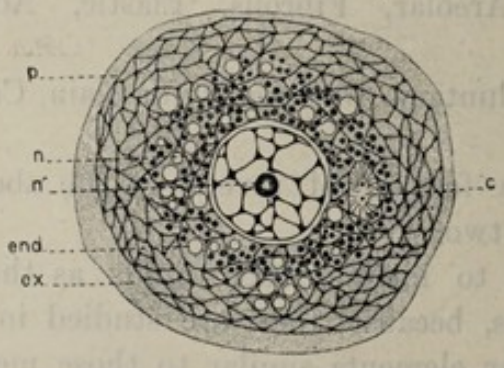


FIG. 1.—DIAGRAM OF A CELL, HIGHLY MAGNIFIED.

p, protoplasm, consisting of hyaloplasm and a network of spongioplasm; *ex*, exoplasm; *end*, endoplasm, with distinct granules and vacuoles; *c*, double centrosome; *n*, nucleus; *n'*, nucleolus.

combination of fatty acid with glycerophosphoric acid, and *cholesterin*, a monatomic alcohol, having many of the physical characters of fats, appear always to be associated. The protoplasm tends

during life to exhibit movements which are apparently spontaneous, and when the cell is uninclosed by a membrane a change in the shape, or even in the position of the cell, may be thereby produced. This is characteristically shown in the movements of the unicellular organism known as the amœba (fig. 2); hence the name *amœboid movement*, by which it is generally designated.[1] The protoplasm often exhibits a granular appearance. This is sometimes due to the fact that it contains a very fine reticulum or spongework, which appears under high powers of the microscope in the form of a network (fig. 1), the remainder of the protoplasm being a clear soft substance which occupies the interstices of the reticulum, and may also cover the

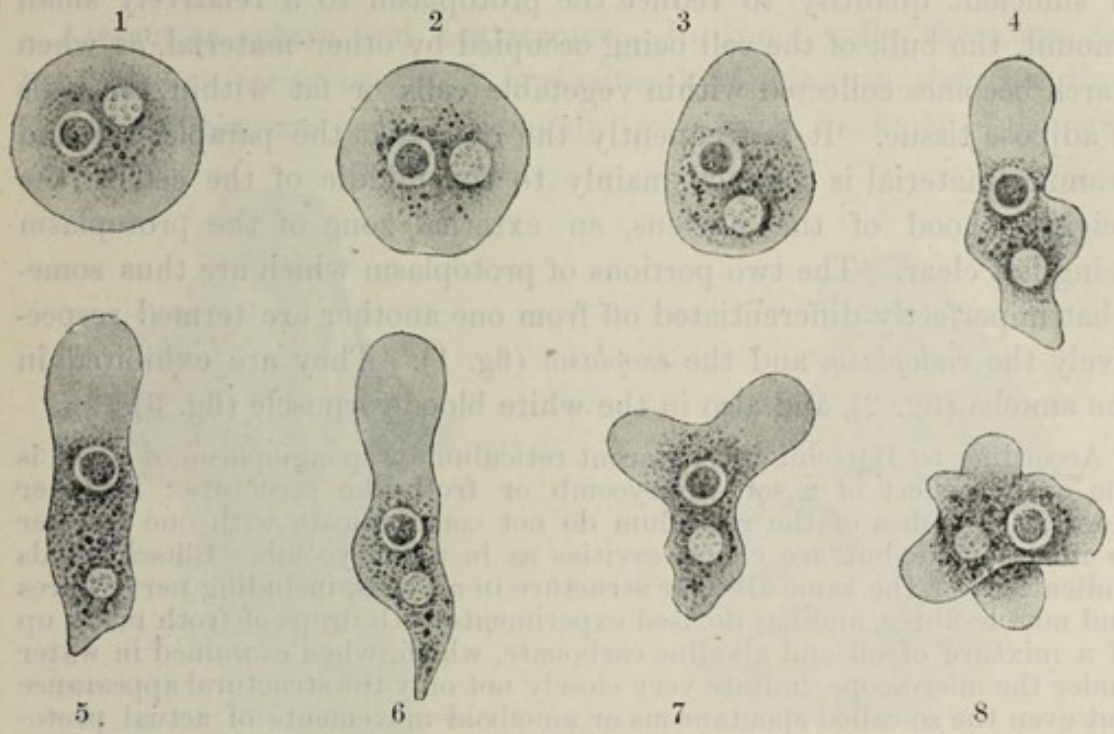


FIG. 2.—SUCCESSIVE CHANGES EXHIBITED BY AN AMŒBA. (Verworn.)

surface or project beyond the rest of the cell. The granular appearance above mentioned is often caused by the knots in the network appearing when imperfectly observed as separate granules. The material which forms the reticulum is termed *spongioplasm*; the clearer material which occupies its meshes is *hyaloplasm*. The protoplasm of a cell often, if not always, includes actual granules of a proteid nature; but it is uncertain whether such granules are essential constituents of the protoplasm (as contended by Altmann) or materials which have been formed by the protoplasm, and which are in a sense accidental inclusions. That they are of great importance appears to be evident from the fact that many of the chemical changes of cells

[1] The amœboid phenomena of cells will be studied later (in the colourless blood-corpuscles) (Lesson V.).

occur in them. Besides the granules above referred to, which may perhaps be regarded as actual constituents of the protoplasm, others occur which are not thus to be regarded, such as pigment granules, fat globules, and vacuoles containing watery fluid, with or without glycogen or other substances in solution. Materials which are thus included in the protoplasm of a cell are either stored up for the nutrition of the cell itself, or are converted into substances which are eventually extruded from the cell in order to serve some purpose useful to the whole organism, or to be got rid of from the body. The term *paraplasm* has sometimes been given to any such material within a cell other than the actual protoplasm. Paraplasm is often present in sufficient quantity to reduce the protoplasm to a relatively small amount, the bulk of the cell being occupied by other material, as when starch becomes collected within vegetable cells or fat within the cells of adipose tissue. It is frequently the case that the paraplasmic and granular material is confined mainly to the middle of the cell in the neighbourhood of the nucleus, an external zone of the protoplasm being left clear. The two portions of protoplasm which are thus somewhat imperfectly differentiated off from one another are termed respectively the *endoplasm* and the *exoplasm* (fig. 1). They are exhibited in the amœba (fig. 2), and also in the white blood-corpuscle (fig. 3).

According to Bütschli the apparent reticulum or spongioplasm of a cell is the optical effect of a soft honeycomb or froth-like structure: in other words, the meshes of the reticulum do not communicate with one another as in a sponge, but are closed cavities as in a honeycomb. Bütschli finds indications of the same alveolar structure in all cells, including nerve-fibres and muscle-fibres, and has devised experiments with drops of froth made up of a mixture of oil and alkaline carbonate, which, when examined in water under the microscope, imitate very closely not only the structural appearance but even the so-called spontaneous or amœboid movements of actual protoplasm. It may be stated, however, that although it is a matter of difficulty to determine whether microscopic reticulum is a sponge work or a honeycomb, it is probable that neither structure is essential to living substance for the outermost layer of the cell protoplasm, which is usually the most active in exhibiting movements, often shows no indication of such structure. Nor is a "froth" necessary for the imitation of amœboid movements, for similar movements due to changes in surface tension are brought about in a simple oil drop or in a drop of oil-clad albumen when brought in contact with solution of soap or of any alkali (Berthold, Quincke).

There are indeed strong physical grounds for believing that a very fine pellicle covers the exterior of the protoplasm of all free cells, and that this pellicle is composed of a material which, although not soluble in water, is permeable to watery fluids, and also allows the passage of solids into the interior of the cell. Such a material might be furnished by the lecithin and cholesterin, which are, as we have seen, constant constituents of cell-protoplasm.

Properties of living matter.—Living cells exhibit (1) *irritability* or the property of responding to stimuli; (2) chemical changes which result in *assimilation* or the taking in of nutrient matter and converting it into living

substance, and *disassimilation*, the property of breaking down or getting rid of such substance ; (3) *reproduction* resulting in the multiplication of cells. Of these properties (2) and (3) are certainly governed or influenced by the cell-nucleus, and (3) appears to be usually initiated by the centrosome (see below). The irritability of the cell depends, however, mainly upon the protoplasm itself. It is in consequence of this property that protoplasm reacts, sometimes by contraction sometimes by relaxation, to mechanical, chemical, thermal, and electrical stimuli, and in the case of some cells (*e.g.* the pigment-cells and cones of the retina) to the stimulus of light. The amœboid movements of cells are a manifestation of their irritability, being produced and influenced by various external conditions and stimuli. Sometimes the result of a stimulus is to cause a cell to move towards the source of excitation (attraction) ; in other cases the movement is in the reverse direction (repulsion). The terms positive and negative chemotaxis, phototaxis, thermotaxis, and the like, are used to indicate the nature of the effects produced by these various forms of stimulation.

Attraction-sphere and centrosome.—In some cells there are fine but distinct striæ or fibrils (*cytomitome*) running in definite directions. These are very commonly met with in fixed cells, such

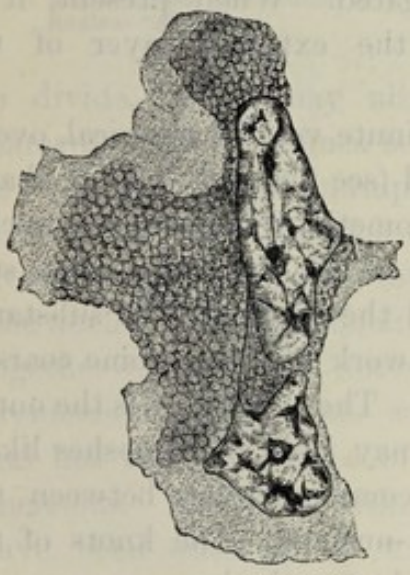


FIG. 3.—AN AMŒBOID CELL (WHITE CORPUSCLE OF NEWT) VERY HIGHLY MAGNIFIED.

Showing a double nucleus with recticulum of chromoplasm, and the protoplasm composed of two portions, a clearer exoplasm, and a granular-looking endoplasm.

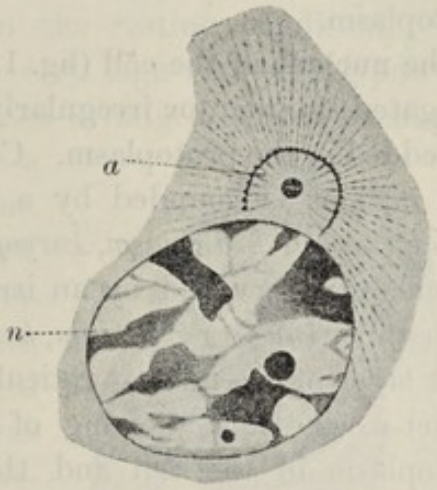


FIG. 4.—A CELL (WHITE BLOOD-CORPUSCLE) SHOWING ITS ATTRACTION-SPHERE. (Wilson, after M. Heidenhain.)

In this, as in most cases, the attraction-sphere, *a*, lies near the nucleus, *n*.

as various kinds of epithelium-cells, nerve-cells, and muscle-cells. But besides these special differentiations, which appear to be related to special functions, there are other fibril-like structures in the cell-protoplasm, associated with what is known as the *attraction-particle* or *centrosome* (figs. 1, 4). This is a minute particle, usually situated near the nucleus, and staining darkly with iron-hæmatoxylin. It is surrounded by a clear area (*attraction-sphere*), and from it radiate into the surrounding protoplasm a number of fine fibrils with dot-like enlargements at intervals. The attraction-sphere, with its central

particle, was first noticed by Ed. v. Beneden in the ovum or egg-cell, and was at first supposed to be peculiar to the ovum, but it has now been recognised (by Flemming and others) in very many cells, both animal and vegetable, and is of nearly universal occurrence. It is very frequently double (fig. 1), the twin spheres being connected by a spindle-shaped system of delicate fibrils (*achromatic spindle*): this duplication invariably precedes the division of a cell into two.

In some cells the centrosomes are multiple; this is frequently the case with leucocytes and always with the giant-cells of bone marrow. The material which immediately surrounds the centrosome, and of which the radiating fibres and the fibres of the spindle are composed, is considered by some to be distinct in nature from the general protoplasm: it has been termed the *archoplasm*. It appears clear that in some cells the centrosome and archoplasm may have an existence independent of one another; thus no centrosome has been found in the cells of the higher plants, although the archoplasmic fibres are very distinct during cell-division.

A **cell-membrane** is rarely distinct in animal cells, nor has its chemical nature been sufficiently investigated. When present, it is usually formed by transformation of the external layer of the protoplasm.

The **nucleus** of the cell (fig. 1, *n*) is a minute vesicle, spherical, ovoid, elongated, annular, or irregularly lobulated (see figs. 1, 3, 4, 5) in shape, embedded in the protoplasm. Cells have sometimes two or more nuclei. The nucleus is bounded by a membrane which incloses a clear substance (*nuclear hyaloplasm*, *karyoplasm*), and the whole of this substance is generally pervaded by an irregular network of fibres, some coarser, others finer (*nuclear reticulum*, *karyomitome*). The membrane is the outermost layer of the nuclear reticulum, and may itself have meshes like a basket-work, thus allowing of a direct communication between the hyaloplasm of the cell and that of the nucleus. The knots of the nuclear reticulum are sometimes very distinct and give an appearance of granules within the nucleus (*pseudonucleoli*). The nucleus usually contains a very distinct highly refracting spherical particle known as the **nucleolus**, which is sometimes multiple, and occasionally has a vacuole-like globule in its interior. The material of the nucleolus differs somewhat in its chemical and staining reactions from the nuclear reticulum, but prior to cell-division it becomes indistinguishable from the substance of the nuclear fibres. Whether it blends with them or becomes absorbed and removed is at present uncertain. The nuclear membrane, intranuclear fibres, and nucleoli all stain deeply with hæmatoxylin and with most basic dyes; this property distinguishes them from the nuclear matrix, and they are accordingly spoken of as *chromatic* (containing *chromatin*, which in the nucleus appears to be chemically identical with *nuclein*), the hyaloplasm being *achromatic*.

Sometimes instead of being united into a network the intranuclear fibres take the form of convoluted filaments, having a skein-like appearance (fig. 6). This is always the case when a nucleus is about

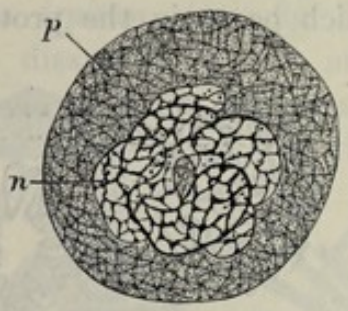


FIG. 5.—CELL FROM BONE-MARROW. (Carnoy.)

p, protoplasm with fine reticulum; *n*, nucleus, long and folded, with intranuclear network.

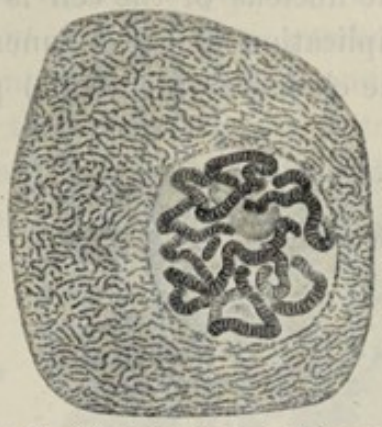


FIG. 6.—GLAND-CELL OF CHIRONOMUS. (Flemming.)

to divide, but it may also occur in the resting condition. These filaments may sometimes be seen with very high magnifying powers to be made up of fine juxtaposed particles arranged either in single or double rows (fig. 7), which may impart a cross-striated appearance to the filament. The nuclear fibres are sometimes clumped together into a solid mass which comprehends the nucleolus when present, and has the appearance of an enlarged nucleolus. The fibres within the nucleus have been observed to undergo spontaneous changes of form and arrangement, but these become much more evident during its division. The division of the protoplasm is always preceded by that of the nucleus, and the intranuclear fibres undergo during its division a series of remarkable transformations which are known collectively by the term *karyokinesis* (Schleicher) or *mitosis* (Flemming). These changes may easily be studied in the division of epithelium-cells (fig. 8), but exactly similar phenomena have been shown to occur in cells belonging to the other tissues.

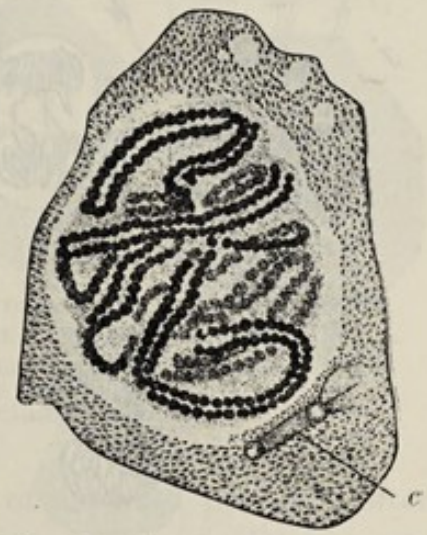


FIG. 7.—SPERMATOCYTE OF SALAMANDER, SHOWING NUCLEAR FILAMENTS, COMPOSED OF DOUBLE ROWS OF PARTICLES (CHROMOMERES). (Wilson, after Hermann.)

c, double centrosome with connecting spindle.

The simple division of a nucleus by a process of fission without karyokinetic changes is termed *amitotic division*: it occurs in com-

paratively rare instances, and is not usually followed by the division of the cell, so that it is apt to result in the formation of multi-nucleated cells like some of the giant cells of bone-marrow.

The nucleus of the cell is not only concerned with its division and multiplication in the manner shown below, but takes an active part in the chemical (metabolic) processes which occur in the protoplasm.

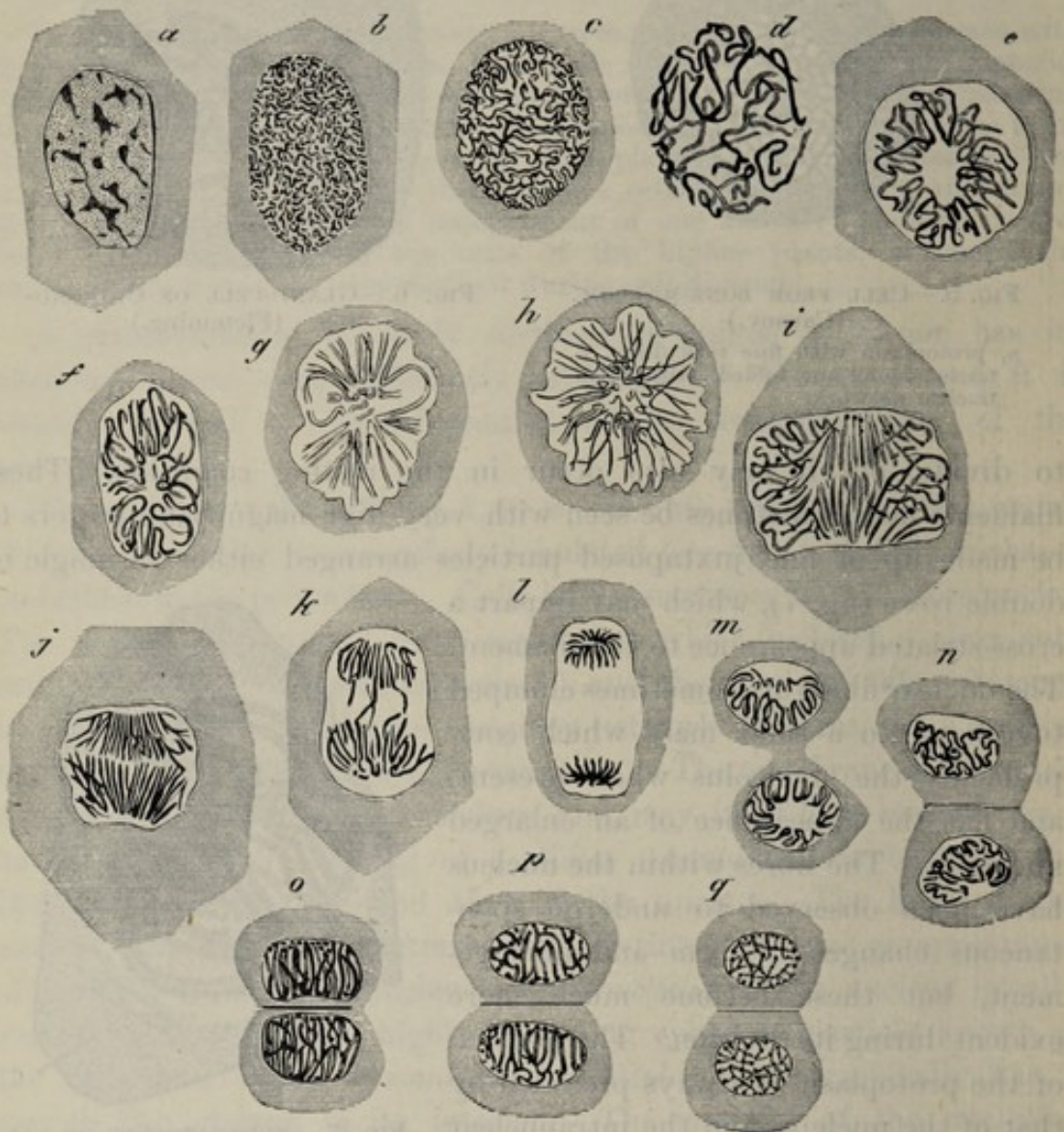


FIG. 8.—EPITHELIUM-CELLS OF SALAMANDER LARVA IN DIFFERENT PHASES OF DIVISION BY KARYOKINESIS. (Flemming.)

Hence cells deprived artificially of their nuclei do not assimilate nourishment, and lose any power of secretion they may have possessed, although the protoplasm may continue for a time to live and exhibit amœboid movements.

Division of cells.—The division of a cell is preceded by the division of its attraction-sphere, and this again appears to determine the division of the nucleus. The latter, in dividing, passes through a series of

remarkable changes (figs. 8 to 13), which may thus be briefly summarised :—

1. The network of chromoplasm-filaments of the resting nucleus becomes transformed into a sort of *skein*, formed apparently of one long convoluted filament, but perhaps in reality of a number of filaments (*spirem stage*, fig. 9, *A*); the nuclear membrane and the nucleoli disappear or are merged into the skein (fig. 8, *a* to *d*). Sometimes the skein becomes looped in and out of a central space; this form has been termed the *rosette* (*e*).

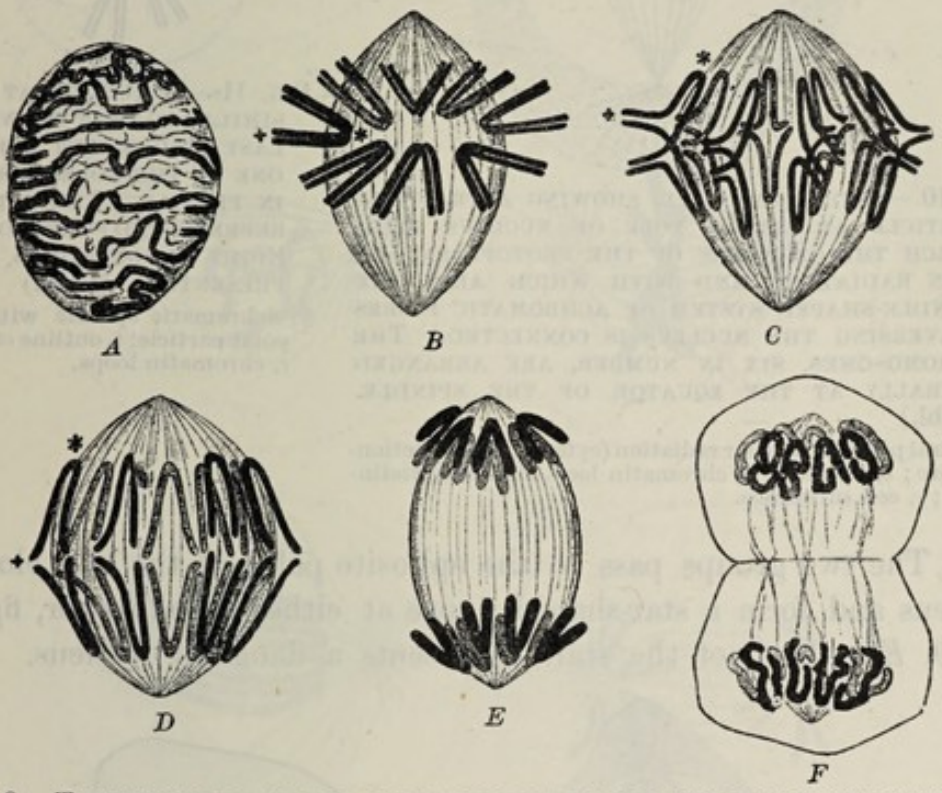


FIG. 9.—THE PRINCIPAL PHASES OF THE NUCLEAR CHROMATIN FILAMENTS IN THE PROCESS OF KARYOKINESIS SHOWN IN MORE DETAIL. (Flemming.)

A, skein or spirem stage; *B*, aster with splitting of chromosomes; *C*, separation of the split chromosomes (metakinesis); *D*, continuation of this process; *E*, dyaster; *F*, dispirem. The cell protoplasm is represented in outline in *F*: it has itself undergone division at this stage.

2. The filament breaks into a number of separate portions, often V-shaped, and termed *chromosomes*. The number of chromosomes varies with the species of animal or plant; in some animals the dividing nuclei may contain at this stage only four chromosomes; in man there are said to be sixteen; in other animals twenty-four or more. As soon as they become distinct they are usually arranged radially around the equator of the nucleus like a star (*aster*, fig. 8, *f*, *g*; fig. 9, *B*).

3. Each of the chromosomes splits longitudinally into two, so that they are now twice as numerous as before (*stage of cleavage*, fig. 8, *g*, *h*; fig. 9, *B*). This longitudinal cleavage may occur at an earlier stage.

4. The fibres separate into two groups, the ends being for a time interlocked (*stage of metakinesis*, fig. 8, *i*, *j*, *k*; fig. 9, *C*, *D*).

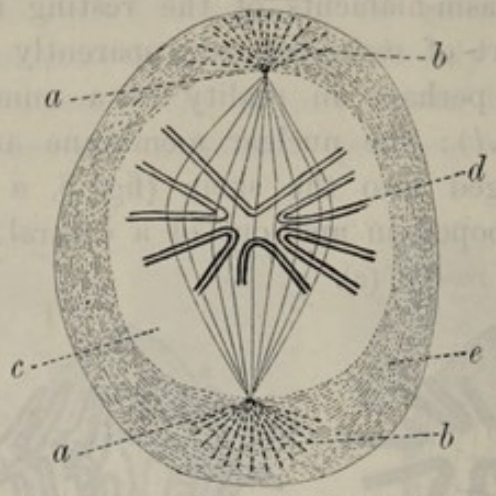


FIG. 10.—A DIVIDING CELL, SHOWING ATTRACTION-PARTICLE AT EITHER POLE OF NUCLEUS FROM WHICH THE GRANULES OF THE PROTOPLASM ARE SEEN RADIATING, AND WITH WHICH ALSO THE SPINDLE-SHAPED SYSTEM OF ACHROMATIC FIBRES TRAVERSING THE NUCLEUS IS CONNECTED. THE CHROMOSOMES, SIX IN NUMBER, ARE ARRANGED ASTRALLY AT THE EQUATOR OF THE SPINDLE. (Rabl.)

a, central particle; *b*, polar radiation (cytaster) or attraction-sphere; *c*, nucleus; *d*, chromatin loop, cleft longitudinally; *e*, cell substance.

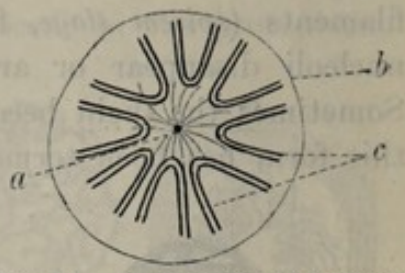


FIG. 11.—A NUCLEUS AT A STAGE SIMILAR TO THAT SHOWN IN THE LAST FIGURE, BUT SEEN FROM ONE OF THE POLES INSTEAD OF IN PROFILE. THE SPINDLE IS REPRESENTED FORESHORTENED. EIGHT CHROMOSOMES ARE REPRESENTED. (Rabl.)

a, achromatic spindle with central polar particle; *b*, outline of nucleus; *c*, chromatin loops.

5. The two groups pass to the opposite poles of the now elongated nucleus and form a star-shaped figure at either pole (*dyaster*, fig. 8, *l*; fig. 9, *E*). Each of the stars represents a daughter nucleus.

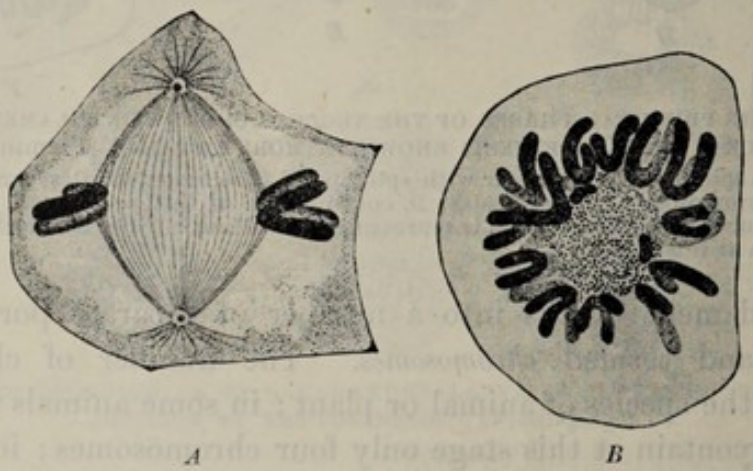


FIG. 12.—SPERMATOCYTES OF SALAMANDER SHOWING V-SHAPED CHROMOSOMES AT THE EQUATOR OF THE SPINDLE. (Wilson, after Drüner.)

A, seen in profile; four chromosomes only are represented.
B, seen end-on. All twenty-four chromosomes are represented; the fibrils of the spindle are seen in optical section.

6, 7, 8. Each star of the dyaster goes through the same changes as the original nucleus, but in the reverse order—viz. a skein, at first more open and rosette-like (fig. 8, *m*; fig. 9, *F*), then a closer skein

(fig. 8, *n*), then a network (fig. 8, *o*, *p*, *q*); passing finally into the typical reticular condition of a resting nucleus.

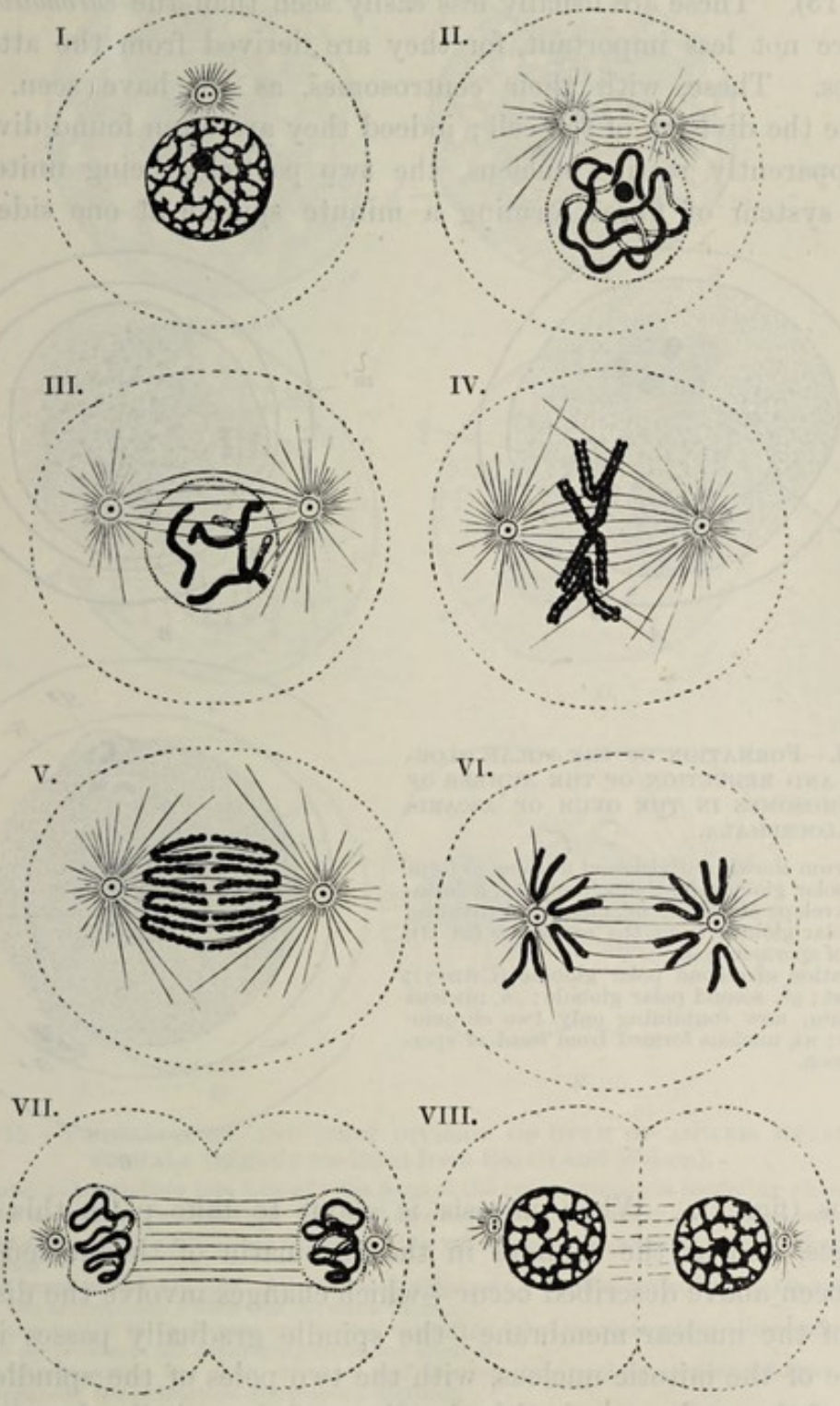


FIG. 13.—DIAGRAM SHOWING THE CHANGES WHICH OCCUR IN THE CENTROSOMES AND NUCLEUS OF A CELL IN THE PROCESS OF MITOTIC DIVISION. The nucleus is supposed to have four chromosomes.

The protoplasm of the cell divides soon after the formation of the dyaster (fig. 8, *m*). During division fine lines are seen in the protoplasm, radiating from the centrosomes at the poles of the nucleus,

and other lines forming a spindle-shaped system of *achromatic* fibres lie within the nucleus, diverging from the poles towards the equator (figs. 10 to 13). These are usually less easily seen than the *chromatic* fibres, but are not less important, for they are derived from the attraction-spheres. These, with their centrosomes, as we have seen, always initiate the division of the cell; indeed they are often found divided in the apparently resting nucleus, the two particles being united by a small system of fibres forming a minute spindle at one side of the

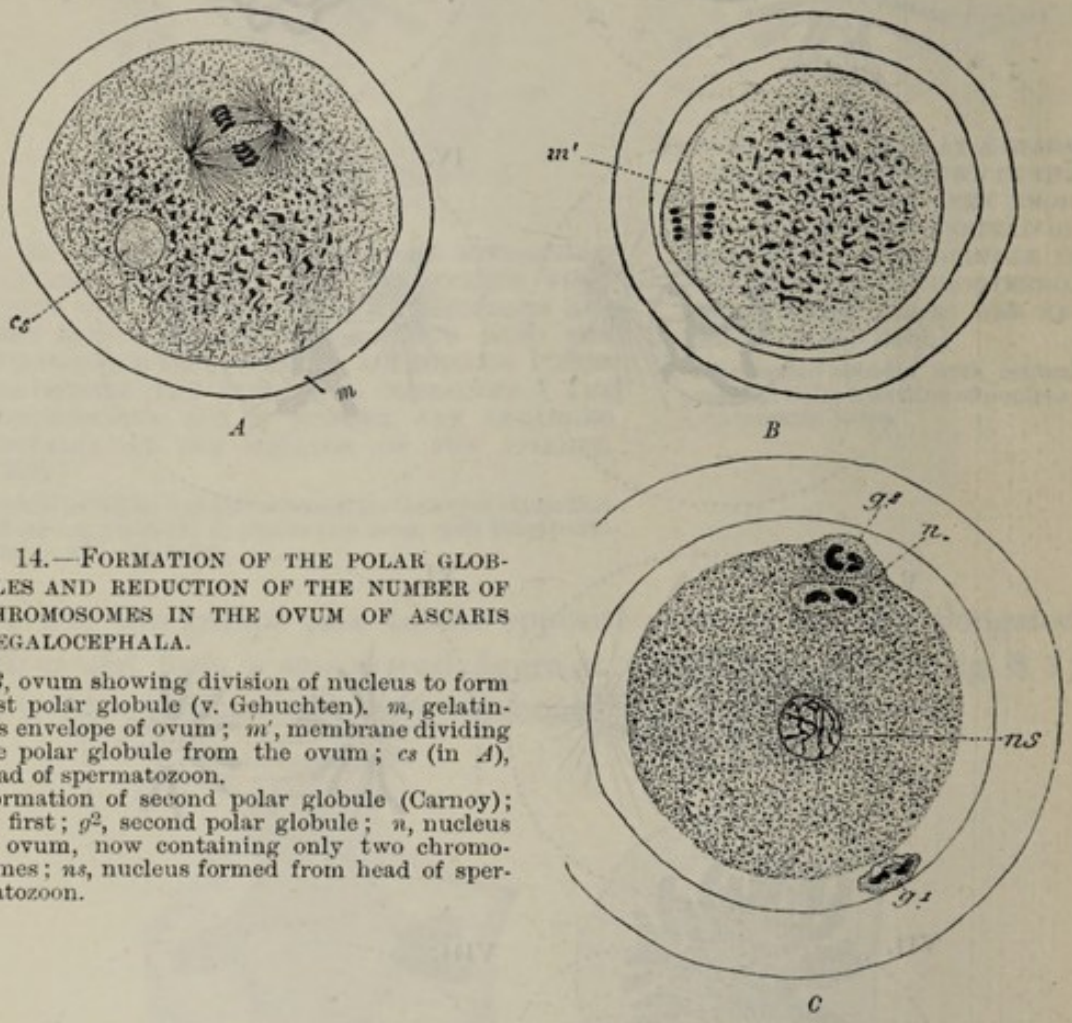


FIG. 14.—FORMATION OF THE POLAR GLOBULES AND REDUCTION OF THE NUMBER OF CHROMOSOMES IN THE OVUM OF ASCARIS MEGALOCEPHALA.

A, *B*, ovum showing division of nucleus to form first polar globule (v. Gehuchten). *m*, gelatinous envelope of ovum; *m'*, membrane dividing the polar globule from the ovum; *cs* (in *A*), head of spermatozoon.

C, formation of second polar globule (Carnoy); g', first; g^2, second polar globule; *n*, nucleus of ovum, now containing only two chromosomes; *ns*, nucleus formed from head of spermatozoon.

nucleus (fig. 1). When mitosis is about to take place this spindle enlarges, and as the changes in the chromatin of the nucleus which have been above described occur—which changes involve the disappearance of the nuclear membrane—the spindle gradually passes into the middle of the mitotic nucleus, with the two poles of the spindle at the poles of the nucleus, and with the fibres of the spindle therefore completely traversing the nucleus (fig. 13). These fibres appear to form directing lines, along which the chromosomes pass, after the cleavage, towards the nuclear poles to form the daughter nuclei. In some cells, especially in plants, the line of division of the protoplasm of the cell becomes marked out by thickenings upon the fibres of the

spindle which occur just in the plane of subsequent division,

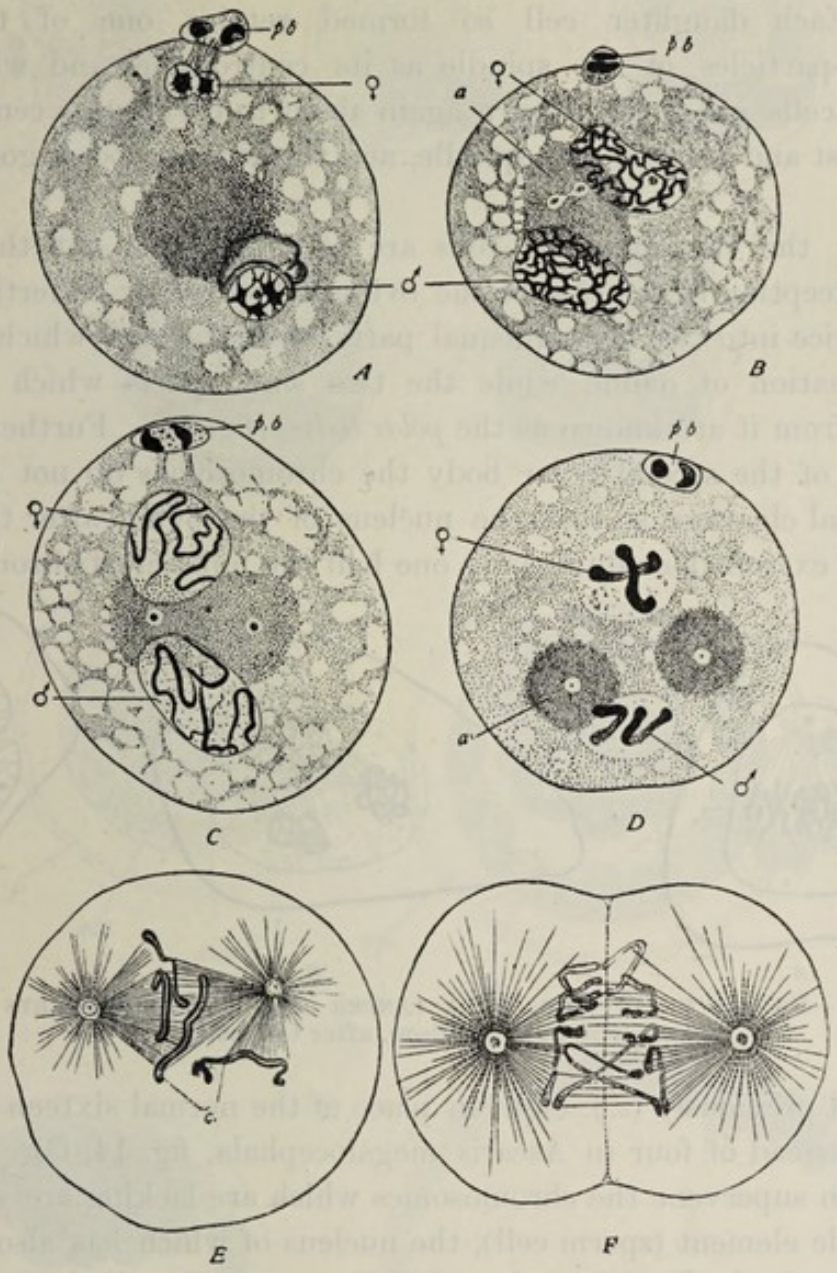


FIG. 15.—FERTILISATION AND FIRST DIVISION OF OVUM OF ASCARIS MEGALOCEPHALA (slightly modified from Boveri and Wilson).

A, second polar globule just formed; the head of the spermatozoon is becoming changed into a reticular nucleus (♂), which, however, shows distinctly two chromosomes; just above it, its archoplasm is shown: the egg-nucleus (♀) also shows two chromosomes.

B, both germ nuclei are now reticular and enlarged; a double centrosome (*a*) is visible in the archoplasm which lies between them.

C, the chromatin in each nucleus is now converted into two filamentous chromosomes; the centrosomes are separating from one another.

D, the chromosomes are more distinct and shorter; the nuclear membranes have disappeared; the attraction-spheres are distinct.

E, mingling and splitting of the four chromosomes (*c*); the achromatic spindle (*a*) is fully formed.

F, separation (towards the poles of the spindle) of the halves of the split chromosomes, and commencing division of the cytoplasm. Each of the daughter cells now has four chromosomes; two of these have been derived from the ovum nucleus, two from the spermatozoon nucleus.

and have been termed collectively the *cell-plate*. But in most animal cells no cell-plate is formed, the protoplasm simply becoming

constricted into two parts midway between the two daughter nuclei. Each daughter cell so formed retains one of the two attraction-particles of the spindle as its centrosome, and when the daughter cells are in their turn again about to divide this centrosome divides first and forms a new spindle, and the whole process goes on as before.

Usually the two daughter cells are of equal size; but there is a notable exception in the case of the ovum, which, prior to fertilisation, divides twice into two very unequal parts, the larger of which retains the designation of ovum, while the two small parts which become detached from it are known as the *polar bodies* (fig. 14). Further, in the formation of the second polar body the chromosomes do not undergo longitudinal cleavage, so that the nucleus of the ovum, after the polar bodies are extruded, contains only one half the number of chromosomes

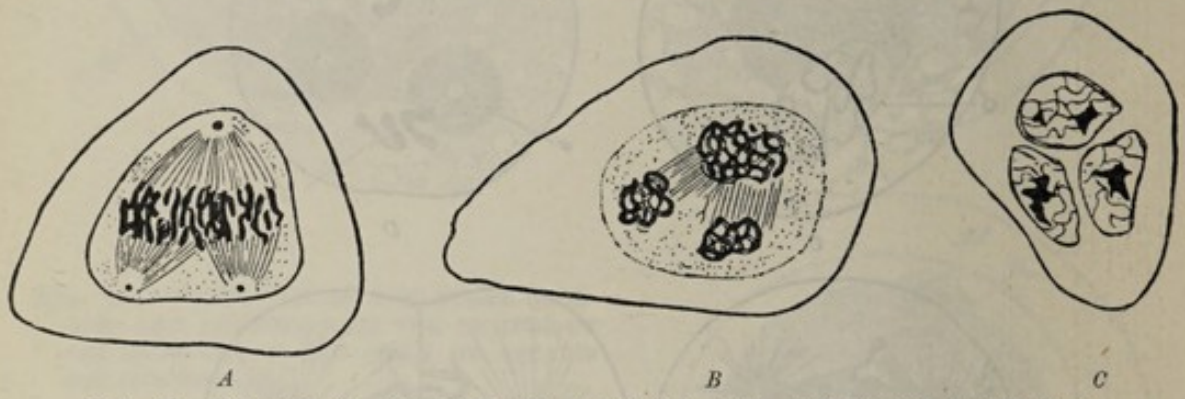


FIG. 16.—PHASES OF DIVISION OF A CANCER CELL INTO THREE PARTS (TRIPOLAR MITOSIS). (Wilson, after Galeotti.)

that it had previously (*e.g.* eight in place of the normal sixteen in man, and two instead of four in Ascaris megalocephala, fig. 14, *C*). Should fertilisation supervene the chromosomes which are lacking are supplied by the male element (sperm cell), the nucleus of which has also undergone, in the final cell division by which it was produced, the process of reduction in the number of chromosomes to one half the normal number: so that when the two reduced nuclei (which are known within the ovum as the *germ nuclei* or the *male and female pronuclei*) blend, the ovum again contains a nucleus with the number of chromosomes normal to the species (fig. 15). When it divides after fertilisation each daughter cell is found to contain the normal number of chromosomes derived from the splitting of both male and female elements, half the number from the one and half from the other.

Occasionally the division of a nucleus is into three or more parts instead of two. In such cases the centrosome becomes correspondingly multiplied and the achromatic system of fibres takes a more complex form than the simple spindle (see fig. 16).

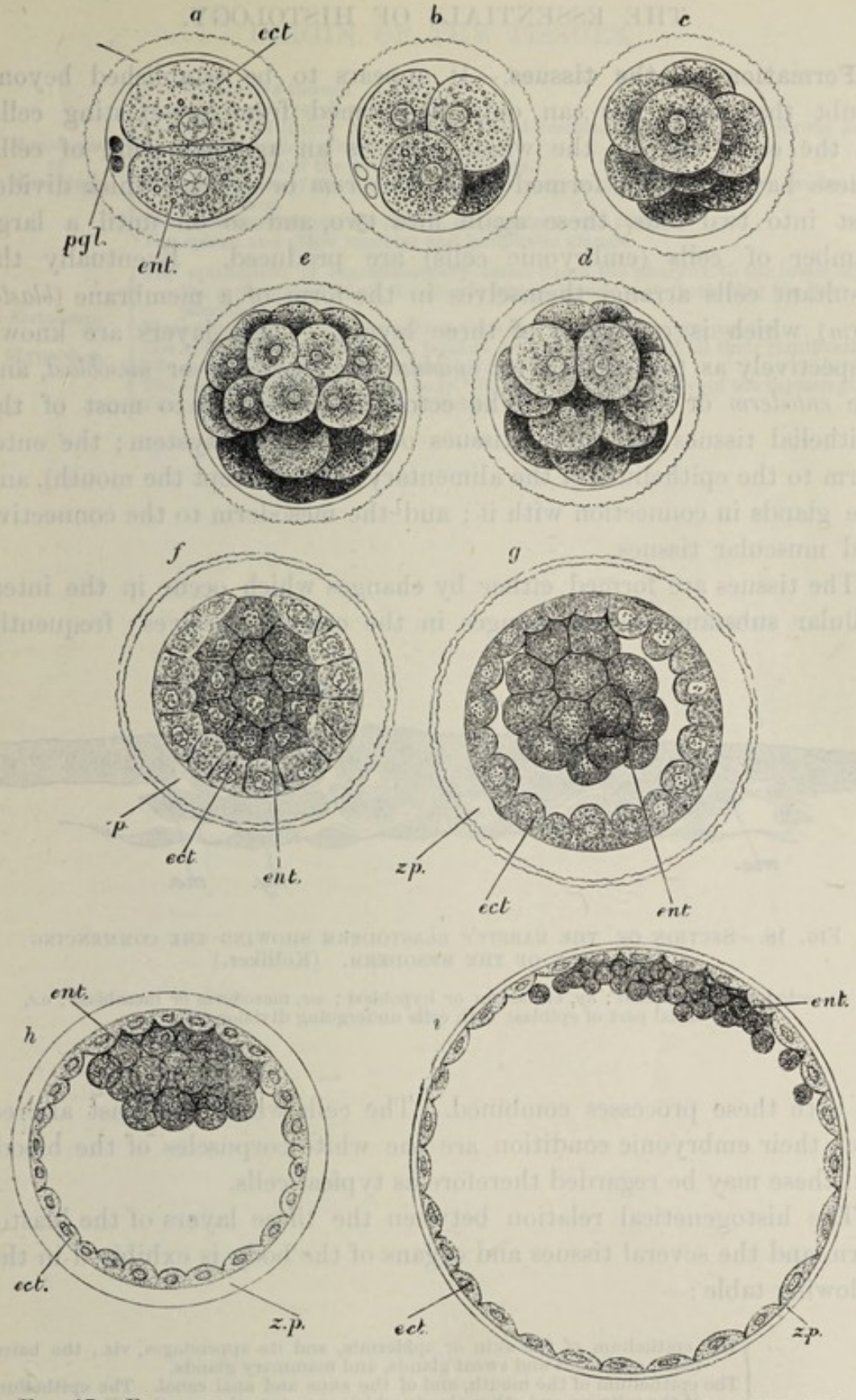


FIG. 17.—FORMATION OF BLASTODERM IN RABBIT BY DIVISION OF OVUM INTO A NUMBER OF CELLS. (Allen Thomson, after E. v. Beneden.)

a to *e*, division of ovum and formation of "mulberry mass"; *p gl*, polar globules; *ect*, *ent*, cells of primary division from which, according to v. Beneden, the ectoderm and entoderm are respectively developed. This early differentiation is not, however, accepted by most authorities. *f* to *i*, sections of the ovum in subsequent stages. *zp*, membrane of ovum (zona pellucida); *ect*, ectoderm; *ent*, entoderm. The accumulation of fluid between ectoderm and entoderm in *g*, *h*, and *i* has swollen the ovum out to form the so-called blastodermic vesicle.

Formation of the tissues.—It appears to be established beyond doubt that new cells can only be formed from pre-existing cells. In the early embryo the whole body is an agglomeration of cells. These have all been formed from the *ovum* or *egg-cell*, which divides first into two cells, these again into two, and so on until a large number of cells (embryonic cells) are produced. Eventually the resultant cells arrange themselves in the form of a membrane (*blastoderm*) which is composed of three layers. These layers are known respectively as the *ectoderm* or *epiblast*, the *mesoderm* or *mesoblast*, and the *entoderm* or *hypoblast*. The ectoderm gives rise to most of the epithelial tissues and to the tissues of the nervous system; the entoderm to the epithelium of the alimentary canal (except the mouth), and the glands in connection with it; and the mesoderm to the connective and muscular tissues.

The tissues are formed either by changes which occur in the intercellular substance, or by changes in the cells themselves; frequently

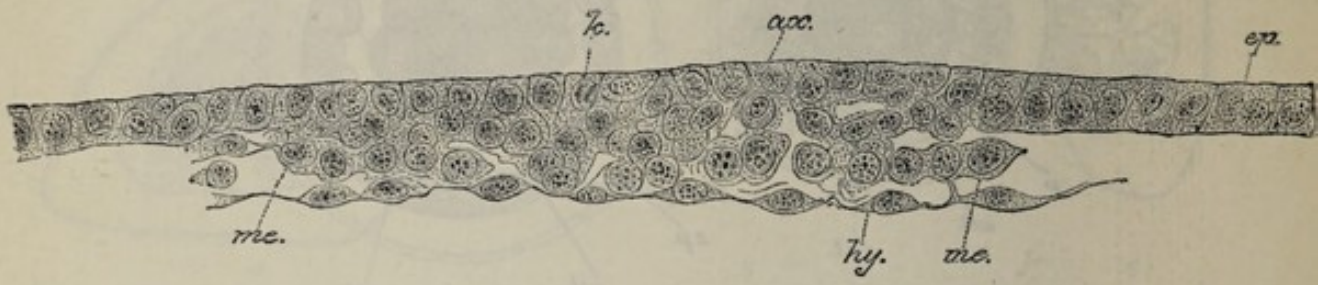


FIG. 18.—SECTION OF THE RABBIT'S BLASTODERM SHOWING THE COMMENCING FORMATION OF THE MESODERM. (Kölliker.)

ep, ectoderm or epiblast; *hy*, entoderm or hypoblast; *me*, mesoderm or mesoblast; *ax*, axial part of epiblast with cells undergoing division (*k*).

by both these processes combined. The cells which are least altered from their embryonic condition are the white corpuscles of the blood, and these may be regarded therefore as typical cells.

The histogenetical relation between the three layers of the blastoderm and the several tissues and organs of the body is exhibited in the following table:—

Ectoderm or Epiblast.	The epithelium of the skin or epidermis, and its appendages, viz., the hairs, nails, sebaceous and sweat glands, and mammary glands.
	The epithelium of the mouth, and of the anus and anal canal. The epithelium of the salivary and other glands which open into the mouth. The enamel of the teeth. The gustatory organs.
	The epithelium of the nasal passages, and the cavities and glands which open into them.
	The epithelium covering the front of the eye. The crystalline lens. The retina.
	The epithelium lining the membranous labyrinth of the ear.
	The epithelium lining the central canal of the spinal cord, the aqueduct of Sylvius, and the fourth, third, and lateral ventricles of the brain.
	The tissues of the nervous system.
	The pituitary body. The pineal gland.

Mesoderm or Mesoblast.	The connective tissues. The blood- and lymph-corpuscles. The epithelial lining of the heart, blood-vessels, lymphatics, and serous membranes (endothelium). The epithelium of the uriniferous tubules. The epithelium of the internal generative organs, and the generative products in both sexes. The muscular tissues, voluntary, involuntary, and cardiac. The spleen and other vascular and lymphatic glands.
Entoderm or Hypoblast.	The epithelium of the alimentary canal (from the pharynx to the lower end of the rectum) and of all the glands which open into it (including the liver and pancreas). The epithelium of the Eustachian tube and cavity of the tympanum. The epithelium of the larynx, trachea, and bronchi, and of all their ramifications. The epithelium of the pulmonary alveoli. The epithelium of the thyroid body. The concentric corpuscles of the thymus gland. The epithelium of the urinary bladder and ureters.

LESSON I.

USE OF THE MICROSCOPE. EXAMINATION OF CERTAIN COMMON OBJECTS.

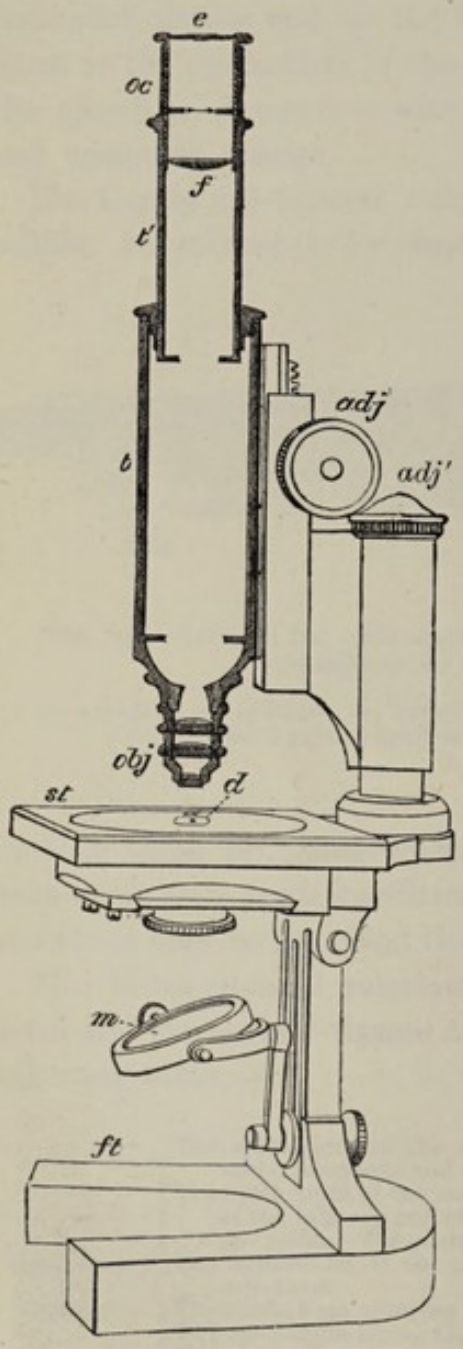


FIG. 19.—DIAGRAM OF MICROSCOPE.

THE requisites for practical histology are a good compound microscope ; slips of glass technically known as 'slides,' upon which the preparations are made ; pieces of thin glass used as covers for the preparations ; a few instruments, such as a microtome, a scalpel, scissors, forceps, and needles mounted in wooden handles ; and a set of fluid re-agents for mounting and staining microscopic preparations.[1] A sketch-book and pencil are also necessary, and must be constantly employed.

The microscope (fig. 19) consists of a tube (*t t'*) 160 millimetres long (6·4 inches) having two systems of lenses, one at the upper end termed the 'eye-piece' or 'ocular' (*oc*), the other at the lower end, termed the 'objective' (*obj*). For ordinary work there should be at least two objectives—a low power working at about 8 millimetres ($\frac{1}{3}$ inch) from the object, and a high power, having a focal distance of about 3 millimetres ($\frac{1}{6}$ inch) ; it is useful also to have a lower power (commanding a larger field of view) for readily finding objects, and two or more oculars of different power. The focus is obtained by cautiously bringing the tube and lenses down towards the object by the coarse adjustment, which is either a telescopic or a rack-and-pinion movement (*adj*), and focussing exactly by the fine adjustment, which is always a finely cut screw (*adj'*).

The stage (*st*) upon which the preparations are placed for examination, the mirror (*m*) which serves to reflect light up through the central aperture in the stage and along the tube of the instrument, and the diaphragm (*d*) below the stage

[1] The directions for making the principal fluids used in histological work will be found in the Appendix.

which is used to regulate the amount of light thus thrown up, are all parts the employment of which is readily understood. A substage condenser (not shown in the diagram), which serves to concentrate the light thrown up by the mirror to the centre of the object, is valuable when high powers and stained preparations are employed.

The combinations of objectives and oculars above referred to will generally give a magnifying power of from 50 to 400 diameters, and this is sufficient for most purposes of histology. But to bring out minute points of detail in the structure of cells and of certain tissues examination with much higher magnifying powers may be necessary. Objectives of high power are usually made as immersion-lenses ; *i.e.* they are constructed to form a proper image of the object when the lowermost lens of the system is immersed in a layer of liquid which lies on the cover-glass of the object and has a refractive index not far removed from that of the glass itself. For this purpose either water or an essential oil (oil of cedarwood) is used. The advantages obtained by the employment of these lenses, especially those for oil-immersion, are increased working distance from the object, increased angle of aperture with sharper definition of the object, and increased amount of light traversing the microscope.

The best lenses for histological work are made of the so-called 'apochromatic' glass ; specially constructed 'compensating' eye-pieces are used with these.

A scale for measuring objects should be constructed for each microscope. To do this, put a stage-micrometer (which is a glass slide ruled in the centre with lines $\frac{1}{10}$ and $\frac{1}{100}$ millimetre apart) under the microscope in such a manner that the lines run from left to right (the microscope must not be inclined). Focus them exactly. Put a piece of white card on the table at the right of the microscope. Look through the instrument with the left eye, keeping the right eye open. The lines of the micrometer will appear projected upon the paper. Mark their apparent distance with pencil upon the card, and afterwards make a scale of lines in ink, of the same interval apart. A magnified representation is thus obtained of the micrometer scale. Mark upon it the number of the eye-piece and of the objective, and the length of the microscope-tube. This scale-card will serve for the measurement of any object without the further use of the micrometer. To measure an object, place the scale-card upon the table to the right of the microscope and view the object with the left eye, keeping the right eye open. The object appears projected upon the scale, and its size in $\frac{1}{10}$ or $\frac{1}{100}$ of a millimetre can be read off. It is important that the same objective and eye-piece should be employed as were used in making the scale, and that the microscope tube should be of the same length. The lines on English stage-micrometers are often ruled $\frac{1}{100}$ and $\frac{1}{1000}$ inch apart.[1]

Before beginning the study of histology the student should endeavour to familiarise himself with the use of the microscope, and at the same time learn to recognise some of the chief objects which are liable to occur accidentally in microscopic specimens. On this account it has been considered desirable to introduce directions for the examination and recognition of starch-granules, moulds and torulæ, air-bubbles, linen, cotton, and woollen fibres, and the usual constituents of the dust of a room, into the first practical lesson.

1. Examination of starch-granules. Gently scrape the cut surface of a potato with the point of a knife ; shake the starch-granules so obtained into a drop of water upon a clean slide and apply a cover-glass.

With the low power the starch-granules look like dark specks differing

[1] For the method of measuring with an ocular micrometer, and for determining the magnifying power of a microscope, the reader is referred to the author's *Course of Practical Histology*.

considerably in size; under the high power they are clear, flat, ovoid particles (fig. 20, *St*), with a sharp outline when exactly focussed. Notice the change in appearance of the outline as the microscope is focussed up and down. On close examination fine concentric lines are to be seen in the

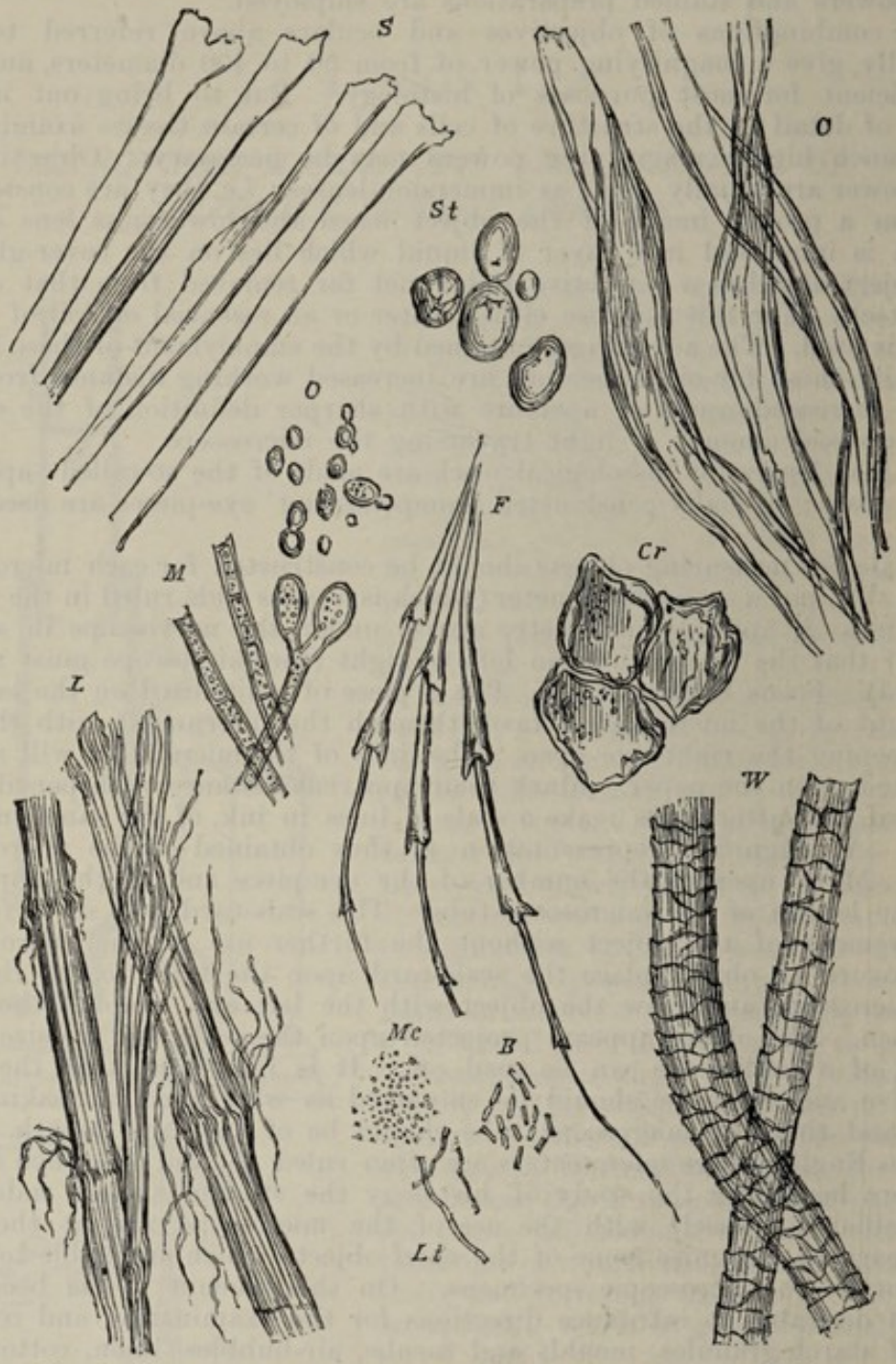


FIG. 20.—ORGANIC MATTERS FREQUENTLY PRESENT IN DUST. (Heitzmann.)
S, fibres of silk; *C*, of cotton; *L*, of linen, *W*, of wool; *F*, feather; *St*, starch-granules; *Cr*, cork; *O*, torulæ; *M*, mycelium or threads of mildew; *Mc*, micrococci; *B*, bacteria; *Lt*, leptothrix filaments (500 diameters).

granules arranged around a minute spot which is generally placed eccentrically near the smaller end of the granule. Sketch two or three starch-granules.

Notice the appearance of air-bubbles in the water. If comparatively large they are clear in the middle, with a broad dark border due to refraction of the light; if small they may look entirely dark.

2. Examine some yeast which has been grown in solution of sugar. Observe the yeast-particles or torulæ, some of them budding. Each torula contains a clear vacuole, and has a well-defined outline, due to a membrane. Sketch two or three torulæ.

3. Examine some mould (Penicillium or Mucor) in water. Notice the long branching filaments (hyphæ), and also the torula-like particles (spores) from which hyphæ may in some instances be seen sprouting. Sketch part of a hypha.

4. Examine fibres of linen and of cotton in water, using a high power. Compare the well-defined, relatively coarse, striated, and slightly twisted linen, with the longer, thinner, and more twisted cotton-fibres. Sketch one of each kind.

5. Mount two or three hairs from the head in water and look at them, first with the low, then with the high power. Examine also some fibres from any woollen material and compare them with the hairs. They have the same structure, although the wool is finer and is curled ; its structure may be partly obscured by the dye. Draw one or two woollen fibres.

6. Examine some dust of the room in water with a high power. In addition to numerous groups of black particles of carbon (soot) there will probably be seen fibres of linen, cotton, or wool, and shed epithelium-cells derived from the epidermis.

LESSON II.

STUDY OF THE HUMAN BLOOD-CORPUSCLES.

1. Having cleaned a slide and cover-glass, prick the finger and mount a small drop of blood quickly, so that it has time neither to dry nor to coagulate. Examine it at once with the high power.

Note (*a*) the coloured corpuscles mostly in rouleaux and clumps, but some lying apart seen flat or in profile ; (*b*) the colourless corpuscles, easily made out if the cover-glass is touched by a needle, on account of their tendency to stick to the glass, whilst the coloured corpuscles are driven past by the currents set up ; (*c*) in the clear spaces, fibrin-filaments and elementary particles or blood-tablets.

Sketch a roll of coloured corpuscles and one or two colourless corpuscles. Count the number of colourless corpuscles in a field of the microscope.

2. To be made like 1, but the drop of blood is to be mixed upon the slide with an equal amount of normal saline solution,[1] so that the red corpuscles tend to be less massed together, and their peculiar shape is better displayed.

Sketch a red corpuscle seen on the flat and another in profile (or optical section). Also a crenated corpuscle.

Measure ten red corpuscles, and from the results ascertain the average diameter of a corpuscle. Measure also the largest and the smallest you can find.

3. Make a preparation of blood as in § 1 and put it aside to coagulate. Keep the edges from drying by placing it in a moist chamber or by occasionally breathing upon it. After a few minutes place a drop of 1 p.c. Spiller's purple at one edge of the cover and allow this to pass in and mix with the blood : it may be drawn through the preparation by applying a small piece of blotting paper to the opposite edge. The purple stains the nuclei of the white corpuscles, the blood-platelets, the network of fibrin-filaments, and the membranes of the red blood-corpuscles.

The three preparations just described cannot be kept, but the two following will serve as permanent preparations of blood :—

4. To fix and stain the coloured corpuscles :—Place upon a slide a drop of 1 p.c. osmic acid mixed with an equal amount of saturated aqueous solution of eosin. Prick the finger, and mix the blood directly with the coloured fluid, stirring them together with a needle. Cover the mixture and put aside for an hour, protected from evaporation ; then place a drop of glycerine and water at the edge of the cover-glass. When this has passed under fix the cover-glass with gold size.

5. To study the granules of the colourless corpuscles and their different reactions to staining reagents, a film of blood is inclosed between two cover-glasses, which are at once separated and the film on each quickly dried in the air. A slide may be used instead of a cover-glass ; the drop of blood is placed close to the ground edge of one slide and this is drawn evenly over the middle of another. The films are fixed by immersion for one hour or more in a mixture of alcohol and ether, equal parts of each. They are then stained by (1) a saturated solution of eosin in 75 p.c. alcohol (three minutes),

[1] Made by dissolving from 6 to 9 grammes of common salt in 1 litre of water.

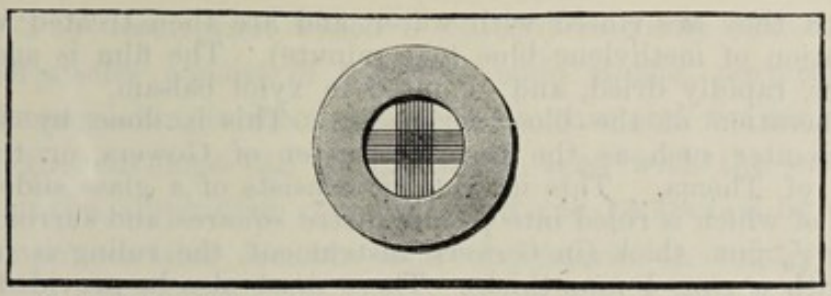


FIG. 21.—HÆMACYTOMETER SLIDE, RULED IN SQUARES FOR THE ENUMERATION OF BLOOD-CORPUSCLES.

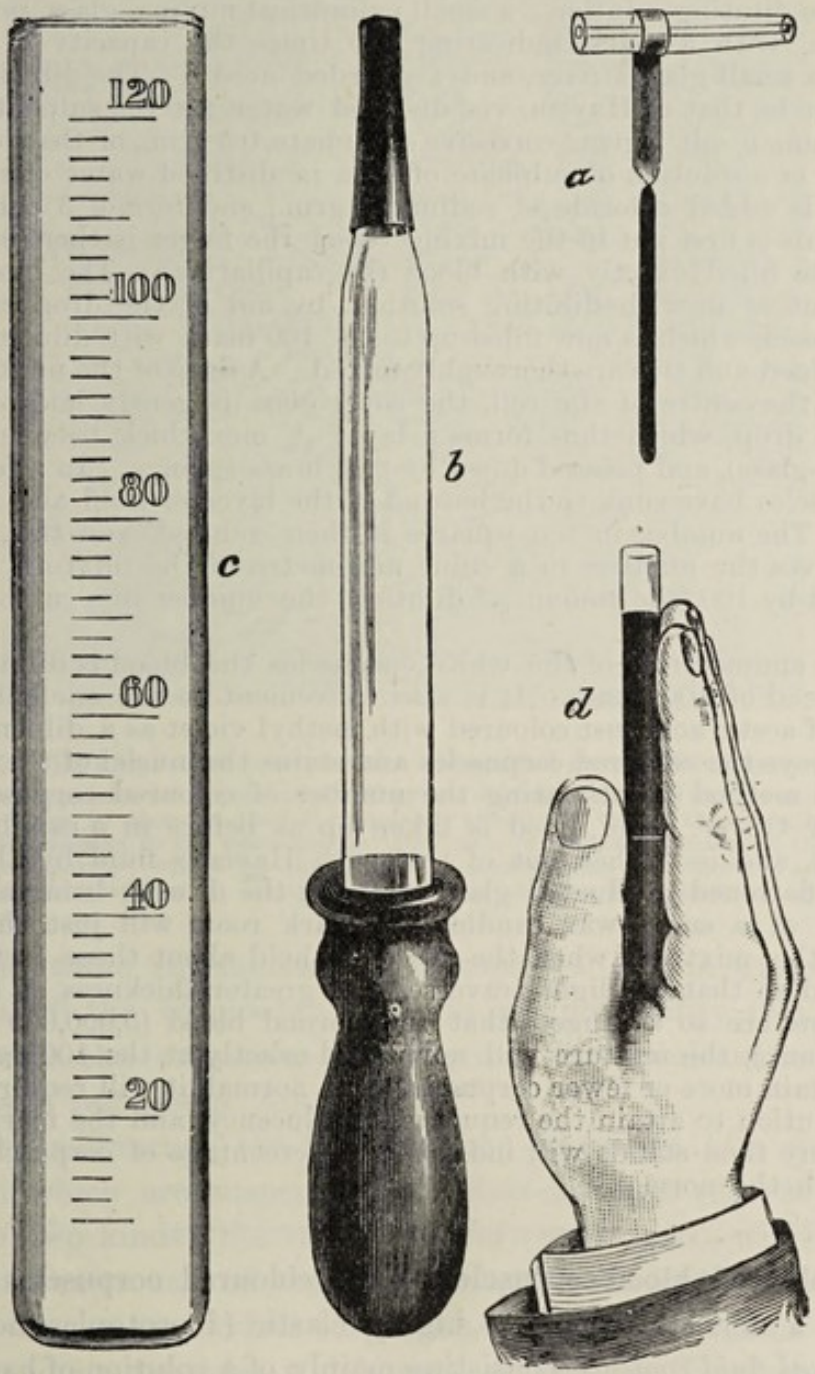


FIG. 22.—OLIVER'S APPARATUS FOR ESTIMATING THE NUMBER OF CORPUSCLES IN BLOOD BY MEANS OF THE OPACITY METHOD.

a, pipette for measuring blood : *b*, dropper for adding mixing solution ; *c*, graduated tube ; *d*, mode of observing.

a, *b*, *c*, natural size.

after which they are rinsed with water, and are then treated with (2) a 1 p.c. solution of methylene blue (one minute). The film is again rinsed with water, rapidly dried, and mounted in xylol balsam.

6. Enumeration of the blood-corpuscles. This is done by some form of blood-counter such as the hæmacytometer of Gowers, or the similar apparatus of Thoma. This instrument consists of a glass slide (fig. 21), the centre of which is ruled into $\frac{1}{10}$ millimetre squares and surrounded by a glass ring $\frac{1}{10}$ mm. thick (in Gowers' instrument, the ruling is into $\frac{1}{5}$ mm. squares with a ring $\frac{1}{5}$ mm. thick). There must also be provided a pipette for measuring the blood (a convenient form is shown in fig. 22, *a*), constructed to hold about 5 cubic millimetres of fluid ; a dropper (fig. 22, *b*) to deliver the diluting solution ; a small cylindrical mixing glass, not shown in the figure, with a mark indicating 100 times the capacity of the blood pipette ; a small glass stirrer, and a guarded needle. The diluting solution may either be that of Hayem, viz. distilled water 200 cc., sulphate of soda 5 grms., common salt 1 grm., corrosive sublimate, 0·5 grm., or that of Marcano, viz. 97 cc. of a solution of sulphate of soda in distilled water of sp. gr. 1020, to which is added chloride of sodium 1 grm., and formol 3 cub. cent. A little of this is first put in the mixing vessel, the finger is then pricked, and the pipette filled exactly with blood (by capillarity). The blood is then washed out of it with diluting solution, by aid of the dropper, into the mixing vessel, which is now filled up to the 100 mark with diluting solution, and the blood and this are thoroughly mixed. A drop of the mixture is next placed in the centre of the cell, the cover-glass is gently laid on (so as to touch the drop, which thus forms a layer $\frac{1}{10}$ mm. thick between the slide and cover-glass), and pressed down by two brass springs. In a few minutes the corpuscles have sunk to the bottom of the layer of fluid and rest on the squares. The number in ten squares is then counted, and this, multiplied by 100, gives the number in a cubic millimetre of the mixture, or if again multiplied by 100 (the amount of dilution) the number in a cubic millimetre of blood.

For the enumeration of the white corpuscles the blood is diluted only 10 times instead of 100 times. It is also convenient to use one half per cent. solution of acetic acid just coloured with methyl violet as a diluent (Thoma). This destroys the coloured corpuscles and stains the nuclei of the white.

A rapid method of estimating the number of coloured corpuscles is that devised by Oliver. The blood is taken up as before in a capillary pipette (fig. 22, *a*), and is washed out of this with Hayem's fluid by the dropper, *b*, into a flattened graduated glass mixer, *c*, the diluent being added until the flame of a small wax candle in a dark room will just show clearly through the mixture, when the vessel is held about three feet from the candle and so that the light traverses the greater thickness of fluid. The graduations are so arranged that for normal blood (5,000,000 corpuscles per cub. mm.), the mixture will now stand exactly at the 100 mark : if the blood contain more or fewer corpuscles than normal, it will require a greater or less dilution to attain the requisite translucency, and the mark at which the mixture then stands will indicate the percentage of corpuscles as compared with the normal.

The coloured blood-corpuscles.—The coloured corpuscles are composed of a delicate colourless highly elastic (? protoplasmic) *envelope*, and *coloured fluid contents*, consisting mainly of a solution of hæmoglobin. The existence of such an envelope is shown by the osmotic effect of water upon the corpuscle, which passes in through the envelope, distending, and eventually bursting the corpuscle and setting free the

contents. The description which is current in many text-books that the red corpuscles consist of a porous solid *stroma*, permeated with dissolved hæmoglobin, is incompatible with this and similar reactions. Moreover, the envelope can be distinctly seen with the microscope, especially in the amphibian corpuscle, and can be stained by reagents. The envelope contains lecithin and cholesterin in relatively large

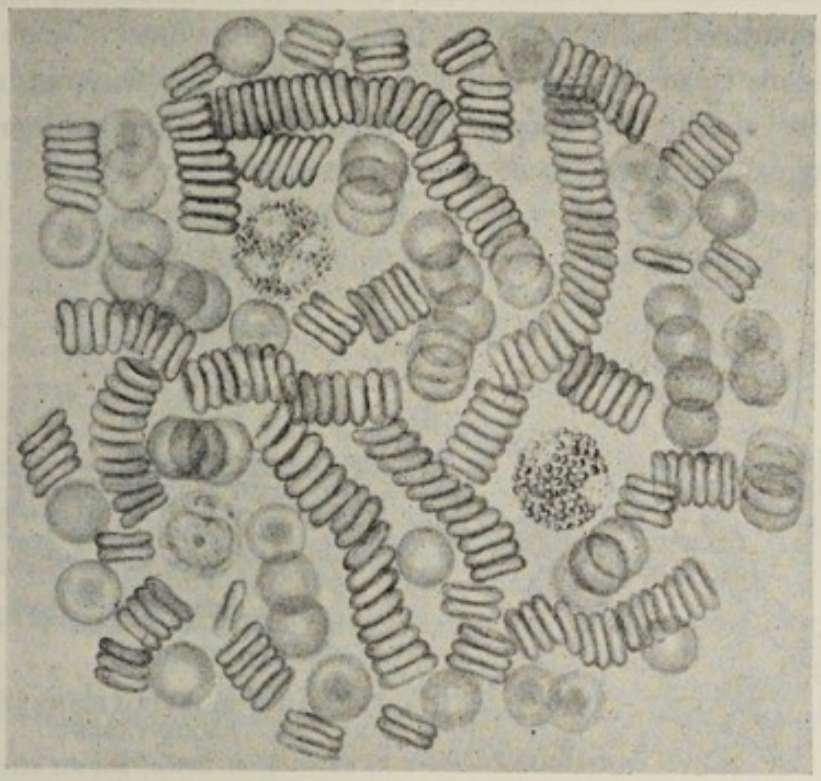


FIG. 23.—HUMAN BLOOD-CORPUSCLES. (Magnified about 1200 diameters.)
Three white corpuscles are represented. They are slightly flattened, and hence appear a little larger in diameter than if completely spherical. One of them—with coarse granules—belongs to the eosinophil variety; one—with fine granules—to the polymorphous variety; whilst the third, which is smaller than the others, is a lymph-corpuscle or lymphocyte. Its nucleus is simple and the protoplasm non-granular (hyaline).

amount, and these substances would impart a certain greasiness to the surface of the corpuscle. It is in all probability due to such greasiness that the corpuscles run together into rouleaux when the blood comes to rest (see p. 35).

Under the microscope the blood is seen to consist of a clear fluid (*plasma*), in which are suspended the *blood-corpuscles* (fig. 23). The latter are of two kinds: the *red* or *coloured* (*erythrocytes*), which are by far the most numerous, and the *white*, *pale*, or *colourless* (*leucocytes*). In addition to these more obvious corpuscles, the blood contains a variable number of minute particles which were termed by Zimmermann the *elementary particles of the blood*, but which are now more usually known as the *blood-platelets* on account of their flattened form.

Erythrocytes.—When seen singly the coloured corpuscles are not

distinctly red, but appear of a reddish-yellow tinge. In the blood of man and of all other mammals, except the Camelidæ, they are biconcave circular disks. Their central part usually has a lightly shaded aspect under a moderately high power (fig. 24, 1), but this is due to their biconcave shape, not to the presence of a nucleus. They have, as just stated, a strong tendency to become aggregated into rouleaux and clumps when the blood is at rest, but if it is disturbed they readily become separated.

If the density of the plasma is increased in any way, as by evaporation, many of the red corpuscles become shrunken and crenated by the passage of water out of the corpuscle.

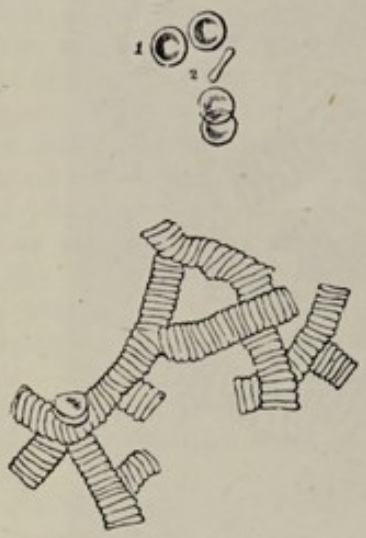


FIG. 24.—HUMAN RED CORPUSCLES LYING SINGLY AND COLLECTED INTO ROLLS. (As seen under moderately high power of the microscope.)

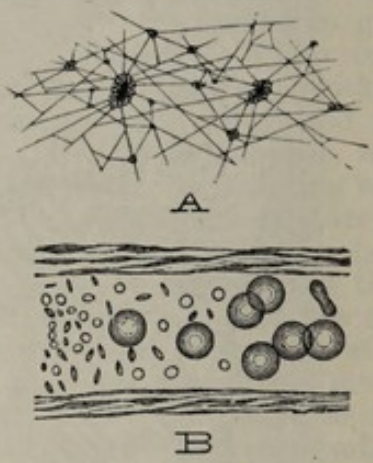


FIG. 25.—FIBRIN-FILAMENTS AND BLOOD-TABLETS.

A, network of fibrin, shown after washing away the corpuscles from a preparation of blood that has been allowed to clot; many of the filaments radiate from small clumps of blood-tablets. B (from Osler), blood-corpuscles and elementary particles or blood-platelets, within a small vein.

The average diameter of the human red corpuscle is 0·0075 millimetre[1] (about $\frac{1}{3200}$ inch), but a few will always be found somewhat larger (0·0085) and a few somewhat smaller (0·0065 mm.).[2]

There are from four to five millions of coloured corpuscles in a cubic millimetre of blood.

Leucocytes.—The colourless corpuscles of human blood are protoplasmic cells, averaging 0·01 mm. ($\frac{1}{2500}$ inch) in diameter when spheroidal, but they vary much in size. They are far fewer than the coloured corpuscles, usually numbering not more than eight to ten thousand in a cubic millimetre (about 1 to 500 red corpuscles).

[1] Also expressed as 75 μ or micromillimetres; a micromillimetre being $\frac{1}{1000}$ millimetre.

[2] The following list gives the diameter in parts of a millimetre of the red blood-corpuscles of some of the common domestic animals:—Dog, 0·0073; rabbit, 0·0069; cat, 0·0060; goat, 0·0041.

Moreover, they are specifically lighter, and tend to come to the surface of the preparation. If examined immediately the blood is drawn, they are spheroidal in shape, but soon become flattened and then irregular in form (fig. 26), and their outline continually alters, owing to the amœba-like changes to which they are subject. In some kinds the protoplasm tends to take in foreign particles with which the cells come in contact (*phagocytes*); in others there seems to be no such tendency. Some of the colourless corpuscles are very pale and finely granular, others contain coarser and more distinct granules in their protoplasm; others again have a hyaline protoplasm without any apparent granules. In some corpuscles (lymphocytes) the protoplasm forms only a relatively thin coating to the nucleus. The corpuscles are classified according to the character and appearance of the nucleus

FIG. 26.—THREE AMŒBOID WHITE CORPUSCLES OF THE NEWT, KILLED BY INSTANTANEOUS APPLICATION OF STEAM.

a, eosinophil cell; *b*, *c*, polymorphous cells. The nuclei appear multiple, but are seen to be connected with fine filaments of nuclear substance traversing the protoplasm.

and the nature and staining qualities of the granules in the protoplasm. Thus some granules are readily stained by basic dyes such as methylene blue, and such granules are accordingly termed *basophil*. Distinct coarse basophil granules are, however, rare in normal blood, although white cells with these granules are normally present in the marrow, and make their appearance in the blood in leucocythæmia. On the other hand, some granules more readily take up colour from acid dyes, such as eosin, and these have been termed *oxyphil* or *eosinophil*. Other granules (*amphophil*) are stained by both acid and basic dyes; and a fourth kind chiefly by neutral dyes (*neutrophil*). In some cells more than one kind of granule is met with. The protoplasm may also contain clear spaces or vacuoles; it has the usual reticular structure. Each leucocyte has at least one nucleus, which is difficult to see in a fresh preparation, but is easily seen after the action of most reagents and after staining. There is also a centrosome with attraction-sphere, but special methods of staining are necessary to exhibit these. (See fig. 4 on p. 5.)

The following are the chief varieties of leucocytes:—1. *Polymorphous*

cells with lobed or multipartite nuclei and a relatively large amount of protoplasm, which is highly amœboid. These are often termed multi-(poly-)nuclear, but the nucleus is scarcely ever really multiple, its several parts being nearly always joined by threads of nuclear substance. The cells in question vary in size, but when spherical are usually not quite 0·01 mm. in diameter. Their protoplasm stains with eosin, this being due to the presence of fine oxyphil granules (Kanthack and Hardy). They are highly amœboid and phagocytic, and constitute from sixty to seventy per cent. of all the leucocytes of the blood (fig. 27, *a*; fig. 26, *b*, *c*).

2. *Lymphocytes.*—These are small uninuclear cells, with a very limited amount of clear protoplasm around the nucleus, which is simple, not lobed or divided (fig. 27, *b*). The protoplasm is stained by methylene blue. They are about 0·0065 mm. in diameter, but some are larger and appear to be transitional between these and the next variety. They constitute from fifteen to thirty per cent. of the total number of leucocytes in the blood. They are relatively more numerous in infancy.

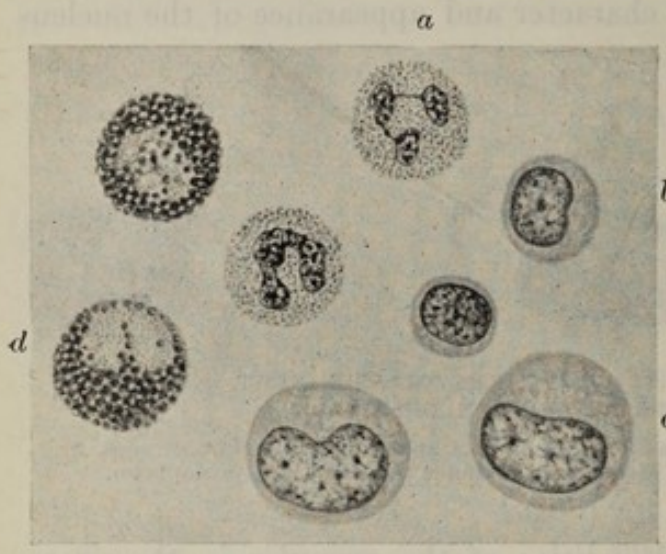


FIG. 27.—VARIOUS KINDS OF COLOURLESS CORPUSCLES, SHOWING THE DIFFERENT CHARACTERS OF THE GRANULES. (From a film preparation of normal human blood.) Two of each kind are represented.

3. *Macrocytes.* — Large uninucleated cells similar to the last, but larger, and containing much more protoplasm (fig. 27, *c*). Some, however, are smaller and are regarded as transitional forms from the last variety. The nucleus may be spherical, oval, or kidney-shaped. The protoplasm is hyaline; it stains slightly with methylene blue, perhaps due to very fine basophil granules. These cells are highly amœboid and phagocytic. Including the transitional forms, they constitute about five per cent. of all the leucocytes in blood.

4. *Eosinophil cells.*—These are characterised by their coarse granules, which stain deeply with acid dyes, such as eosin. Their average diameter in the spherical condition is 0·01 mm. The nucleus may be simple or lobed (fig. 27, *d*; fig. 26, *a*). They are amœboid, but less actively so than the finely granular cells. They are more variable in number than other varieties, constituting sometimes not more than

one per cent., and at other times as much as ten per cent. of the total leucocytes of blood.

Blood-platelets.—In the clear fluid in which the blood-corpuscles are suspended, a network of fine straight intercrossing filaments (fibrin) soon makes its appearance (fig. 25, A). There are also to be seen a number of minute round colourless discoid particles less than one-third the diameter of a red corpuscle, either separate or collected into groups or masses, which masses may be of considerable size. These are the *elementary particles* or *blood-platelets*. In the circulating blood they are discrete, but immediately clump together in drawn blood (fig. 28). If, however, the blood is drawn into salt solution of a certain specific gravity they can be kept separate, and may then better be examined

FIG. 28.—A MASS OF BLOOD-PLATELETS FROM HUMAN BLOOD. (Osler.)

A few at the edge are detached from the rest. The filaments are broken threads of fibrin. The preparation had been kept in salt solution on the warm stage for some time, thus causing a partial breaking up of the mass of platelets.

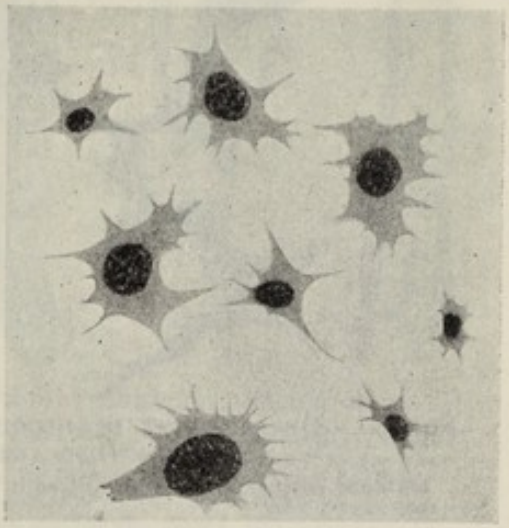


FIG. 29.—BLOOD-PLATELETS, HIGHLY MAGNIFIED, SHOWING THE AMŒBOID FORMS WHICH THEY ASSUME WHEN EXAMINED UNDER SUITABLE CONDITIONS, AND ALSO EXHIBITING THE CHROMATIC PARTICLE WHICH EACH PLATELET CONTAINS, AND WHICH HAS BEEN REGARDED AS A NUCLEUS. (After Kopsch.)

with high powers of the microscope and stained. The result of such examination seems to show that the blood-platelets are not mere inert particles, as has generally been supposed, but that they are protoplasmic and amœboid, and that each one contains a nucleus; that they are in fact minute cells (Deetjen). Fatty particles, derived from the chyle, may also occur in the plasma.

Development of blood-corpuscles.—In the embryo, the first-formed *coloured blood-corpuscles* are amœboid nucleated cells, the protoplasm of which contains hæmoglobin. These embryonic blood-corpuscles are developed within cells of the mesoderm, which are united with one another to form a protoplasmic network (fig. 30). The nuclei of

the cells multiply, and around some of them there occurs an aggregation of coloured protoplasm. Finally the network becomes hollowed out by an accumulation of fluid in the protoplasm, and thus are produced a number of capillary blood-vessels, and the coloured nucleated portions of protoplasm are set free within them as the embryonic blood-corpuscles (*erythroblasts*, fig. 30, *bl*). These within the circulation multiply by mitotic division, and thus become rapidly more numerous.

In later embryonic life, nucleated coloured corpuscles disappear from mammalian blood, and are replaced by the usual discoid corpuscles.

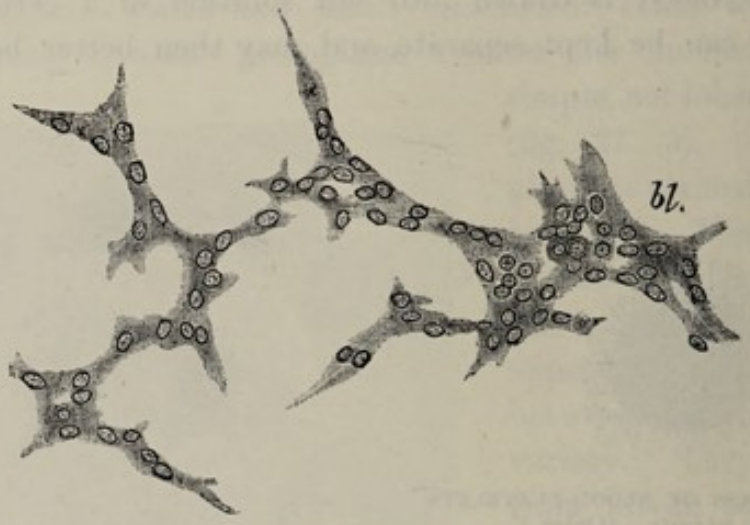


FIG. 30.—DEVELOPMENT OF BLOOD-VESSELS AND BLOOD-CORPUSCLES IN THE VASCULAR AREA OF THE GUINEA-PIG.
bl, blood-corpuscles becoming free in the interior of a nucleated protoplasmic mass.

Many of these are doubtless derived from the nucleated embryonic blood-cells, the absence of the nucleus being accounted for either by its atrophy or extrusion from the cell or by the separation of a part of the (coloured) cell-substance. Others are formed within certain cells of the connective tissue (*vasoformative cells*), a portion of the substance of the cell becoming coloured by hæmoglobin, and separated into globular particles (fig. 31, *a*, *b*, *c*), which are gradually moulded into disk-shaped red corpuscles. In the meantime the cells become hollowed out, and join with similar neighbouring cells to form blood-vessels (fig. 31, *d*, *e*, *f*). The process is therefore the same as in the early embryo, except that the cell-nuclei do not participate in it.

Although no nucleated coloured corpuscles are as a rule to be seen in the blood in late embryonic and in post-embryonic life, they continue to be formed in the marrow of the bones (see Lesson XIII.), and in some animals they have also been found in the spleen. It is probable that the red disks are formed from these by the nucleus disappearing and the coloured protoplasm becoming moulded into a

discoid shape. At what time this formation of blood-corpuscles in bone marrow commences has not been ascertained, but after it has commenced it continues throughout the whole of life—the red marrow, especially that of the ribs, being especially active in this respect. In mammals the formation of nucleated coloured corpuscles appears to take place within the tissue of the marrow, but how they pass into the

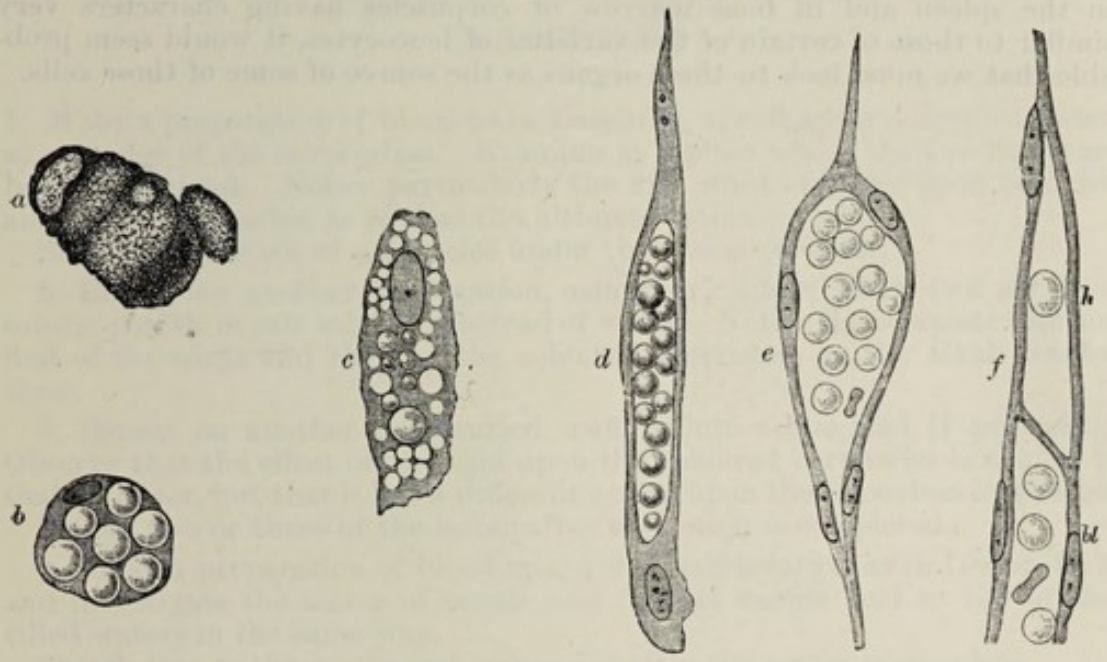


FIG 31.—BLOOD-CORPUSCLES DEVELOPING WITHIN CONNECTIVE-TISSUE CELLS.

a, a cell containing diffused hæmoglobin ; *b*, a cell filled with coloured globules; *c*, a cell containing coloured globules in the protoplasm, within which also are numerous vacuoles; *d*, an elongated cell with a cavity in its protoplasm occupied by fluid and blood-corpuscles mostly globular; *e*, a hollow cell, the nucleus of which has multiplied. The new nuclei are arranged around the wall of the cavity, the corpuscles in which have now become discoid; *f*, shows the mode of union of a 'hæmapoietic' cell, which in this instance contains only one corpuscle, with the prolongation (*bl*) of a previously existing vessel.

bloodstream is not definitely known. In birds, on the other hand, the formation of new blood-corpuscles occurs in the blood-vessels themselves of the marrow, by the division of erythroblasts which lie close to the vessel walls, and which become gradually moulded into the form and structure of the bird's erythrocyte.

The *white blood-corpuscles* and *lymph-corpuscles* occur originally as free embryonic cells, which have found their way into the vessels from the circumjacent mesoblast. They do not occur within the first-formed blood-vessels of the embryo. In later stages of fœtal life and during the whole of post-embryonic life they become formed in lymphatic glands and other organs composed of lymphoid tissue, and pass from these directly into the lymphatics and so into the blood.

From the observations of Beard in Elasmobranchs, which have been confirmed by other and independent observations in Teleosts, it appears probable that leucocytes first make their appearance when the foundation

of the *thymus* is laid; he is of opinion that they are formed from the hypoblastic epithelium of the thymus rudiment. Having once made their appearance they multiply by mitotic division and find their way into the blood-vessels, centres for their future formation becoming ultimately established in the lymphatic glands and other similar organs.

It is believed by some authorities that all the different varieties of leucocytes have a common origin in the lymphocytes which are formed in lymphoid tissue and which, passing into the blood, are thought to develop into the several kinds which are there met with. But from the occurrence in the spleen and in bone marrow of corpuscles having characters very similar to those of certain of the varieties of leucocytes, it would seem probable that we must look to these organs as the source of some of those cells.

LESSON III.

ACTION OF REAGENTS UPON THE HUMAN BLOOD-CORPUSCLES.

1. Make a preparation of blood as in Lesson II. 1, and apply a drop of water, at one edge of the cover-glass. Examine at a place where the two fluids are becoming mixed. Notice particularly the first effect of water upon both red and white corpuscles, as well as the ultimate action.

Sketch both kinds of corpuscles under the action of water.

2. Repeat on another preparation, using very dilute alkali (0·2 per cent. caustic potash in salt solution) instead of water. Notice the complete solution first of the white and then of the coloured corpuscles as the alkali reaches them.

3. Repeat on another preparation, using dilute acetic acid (1 per cent.). Observe that the effect of the acid upon the coloured corpuscles is similar to that of water, but that it has a different action upon the colourless corpuscles.

Sketch two or three of the latter after the action is completed.

4. Make a preparation of blood mixed with salt solution as in Lesson II. 2, and investigate the action of tannic acid (1 part tannic acid to 100 of distilled water) in the same way.

Sketch two or three coloured corpuscles after the action is complete.

Structure of erythrocytes.—The action of reagents upon the human red blood-corpuscles shows that, although to all appearance homogeneous, they in reality consist of an external envelope of colourless material which forms a thin film inclosing the dissolved colouring matter or *hæmoglobin*.[1] Thus, when water reaches the corpuscle, it passes through the film by osmosis and swells the corpuscle, causing it to become globular; eventually the film is burst through, and the colouring matter escapes into the serum. Salt, on the other hand, by increasing the density of the fluid in which the corpuscles float, causes a diffusion of water out of the corpuscle, and a consequent shrinking and corrugation of the surface, the crenated form (fig. 32, *f*) being thereby produced. The separation of the hæmoglobin from the corpuscle can be effected not only by water (fig. 32, *a-e*), but also by dilute acids,

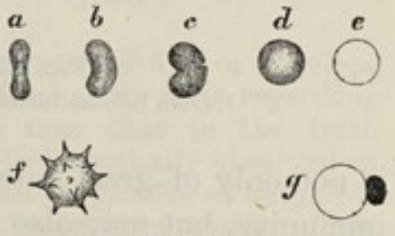


FIG. 32.

a-e, successive effects of water upon a red corpuscle; *f*, effect of solution of salt; *g*, effect of tannic acid.

[1] The membrane may perhaps be joined across the thickness of the corpuscle by delicate (protoplasmic?) threads, but if so they are quite invisible.

by the action of heat (60° C.), the freezing and thawing of blood, the action of ether or chloroform, and the passage of electric shocks. Bile and dilute alkalies rapidly cause the red corpuscles to become spherical and then almost instantly effect their complete solution. The mixing of blood from one species of animal with the blood or serum of animals of other species frequently also has a similar effect. In this case it would appear to be due to a hæmolytic action exerted by some (unknown) constituent of the foreign blood, which is special for each species and against which the "host" can render itself immune if, prior to any large quantity of the foreign blood or serum being injected, successive small and gradually increased injections be made. This fact

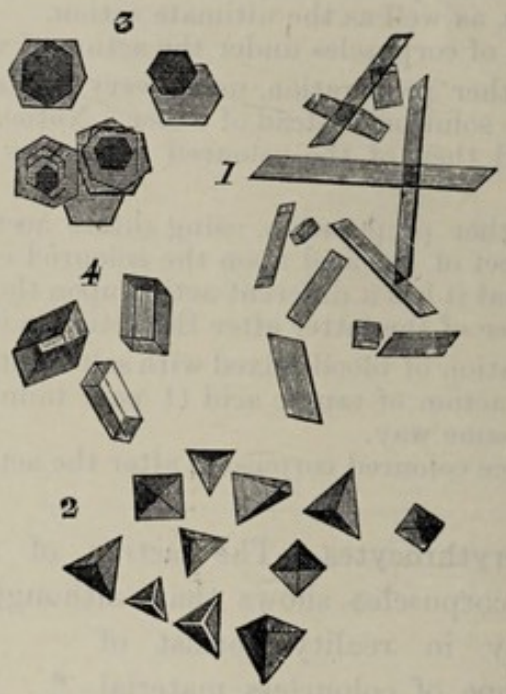


FIG. 33.—BLOOD CRYSTALS, MAGNIFIED.
1, from human blood; 2, from the guinea-pig; 3, squirrel; 4, hamster.

is not only of great interest as bearing upon the general doctrine of immunity, but may also serve to aid in detecting the source of a given sample of blood.

Tannic acid produces a peculiar effect upon the red corpuscles (fig. 32, *g*); the hæmoglobin is discharged from the corpuscle, but is immediately altered and precipitated, remaining adherent to the envelope in the form of a round or irregular globule of a brownish tinge (hematin?).

Some of these reactions occur by a process of osmosis as in the case of water, but in others a solution of the envelope of the corpuscle is produced by the reagent, and the hæmoglobin is thus allowed to escape. The film or envelope is probably in large measure composed of lecithin and cholesterin (along with a little nucleo-proteid—Halliburton), and these are substances which possess many of the physical properties of fats, although of a different

chemical composition. If we assume that such fatty substances form an external film to the corpuscle, the running of the red disks into rouleaux can readily be explained, since it has been shown by Norris that disks of any material, *e.g.* cork, suspended in a fluid, tend in the same way to adhere in rouleaux, provided their surfaces are covered with a layer which is not wetted by the fluid. We may also explain on the same hypothesis the fact that no rent is ever seen in the envelopes of the red corpuscles even when they appear to have burst after imbibition of water, for, if the film which represents an envelope is largely of a fatty nature, any rent in it would tend immediately to close up again when the opposed edges came in contact.

The more solid part of the red corpuscle is often termed the *stroma*, but this name rests upon an entirely false conception of the structure of the corpuscle. In adopting the name, it was supposed that the corpuscle is formed of a homogeneous porous material (stroma—Rollett), in the pores of which the hæmoglobin is contained, but there is no reasonable foundation for this belief, which fails to explain except on the assumption of a still more complex hypothesis, the well known osmotic phenomena of the corpuscle,

FIG. 34.—HÆMIN CRYSTALS, MAGNIFIED. (Preyer.)

FIG. 35.—HÆMATOIDIN CRYSTALS. (Frey.)

whereas the supposition that there exists a delicate external film or envelope inclosing a coloured fluid is in accordance with all the known facts regarding the action of reagents upon these bodies. It is true that in the fresh mammalian corpuscle the envelope is too delicate to be actually observed in the optical section of the corpuscle, but in the blood-corpuscles of amphibia it can be quite distinctly seen, and with any slight increase in density of the plasma it tends to become wrinkled and the creases in it are plainly visible. In these corpuscles also the nucleus becomes readily displaced in drawn blood from its position in the centre of the corpuscle and may lie quite at the side : this is a clear indication of the fluid nature of the contents of the corpuscle, and by analogy we may fairly assume a similar constitution for the mammalian corpuscle. Lastly, it is possible, in film preparations, to stain the envelope of the red corpuscles of a different colour from the remainder of the corpuscle.

Blood-crystals.—In the blood of some animals (fig. 33), crystals of hæmoglobin readily form after its separation from the red corpuscles. These crystals are rhombic prisms in man and most animals, *e.g.* the rat, but tetrahedra in the guinea-pig (2), and hexagonal plates in the squirrel (3). In these animals they at once appear on shaking up the blood with chloroform or ether, or even on the addition of water, with or without subsequent evaporation. They are most appropriately studied along with the chemical

properties of blood. The same remark applies to the minute dark-brown rhombic cystals (*hæmin*, fig. 34), which are formed when dried blood from any source whatever is heated with glacial acetic acid, and to the reddish-yellow crystals of *hæmatoidin* (fig. 35), which are found in old blood extravasations.

The **structure of the colourless corpuscles** is also brought out by the action of some of the reagents above noticed. As the water reaches them their amœboid movements cease; they become swollen out into a globular form by imbibition of fluid (fig. 36, 1), and the granules within the protoplasm can be seen to be in active Brownian motion. Their nuclei also become clear and globular, and are more conspicuous than before. With the further action of the water, the corpuscle bursts and the granules are set free.

FIG. 36.

1, first effect of the action of water upon a white blood-corpuscle; 2, 3, white corpuscles treated with dilute acetic acid; *n*, nucleus.

Acids have an entirely different action upon the white corpuscles. Their nuclei become somewhat shrunken and very distinct (fig. 36, 2 and 3), and a granular precipitate is formed in the protoplasm around the nucleus. At the same time, a part of the protoplasm generally swells out so as to form a clear bleb-like expansion (an appearance which also often accompanies the death of the corpuscle from other causes). Dilute caustic alkalies rapidly cause the destruction of the white corpuscles.

LESSON IV.

STUDY OF THE BLOOD-CORPUSCLES OF AMPHIBIA.

1. Obtain a drop of newt's blood by cutting the tail, and mix it with a very small quantity of salt solution upon a slide. Examine with the high power. Notice the shape of the coloured corpuscles both when seen flat and edgeways, and the nucleus within each.

Measure ten corpuscles (long and short diameters), and from the results obtain the average dimensions of the newt's blood-corpuscle.

Notice also the colourless corpuscles, smaller than the red, but considerably larger than the pale corpuscles of human blood, although otherwise generally resembling these.

Sketch two or three red corpuscles and as many white.

Be careful not to mistake the rounded liberated nuclei of crushed red corpuscles for pale corpuscles.

Enormous cells and nuclei belonging to the cutaneous glands as well as the granular secretion of those glands may be present in this preparation.

2. Apply a drop of water to the edge of the cover-glass of the same preparation and notice its action upon the corpuscles.

Sketch two or three corpuscles altered by the action of the water.

3. Mount another drop of blood, and apply dilute acetic acid (1 per cent.) instead of water at the edge of the cover-glass. Make sketches showing the effect of the acid upon both red and white corpuscles.

4. Examine the corpuscles of newt's blood which has been allowed to flow into boracic acid solution (2 per cent.). Notice the effect produced upon the coloured corpuscles. Sketch one or two.

5. Mount in glycerine-jelly a drop of frog's blood which has been fixed by Flemming's solution (see Appendix) and stained with picrocarmine.

6. Make a film preparation of frog's or newt's blood as described in Lesson II., 5.

The **coloured blood-corpuscles of amphibia** (fig. 37), as well as of most vertebrates below mammals, are biconvex elliptical disks, considerably larger than the biconcave circular disks of mammals.[1] In addition to the coloured body of the corpuscle, which consists, as in mammals, of hæmoglobin inclosed within an envelope, there is a colourless *nucleus*, also of an elliptical shape, but easily becoming globular, especially if liberated by any means from the corpuscle. The nucleus resembles that of other cells in structure, being bounded

[1] The following are the dimensions in parts of a millimetre of the coloured corpuscles of some oviparous vertebrates :—

	Long diameter.	Short diameter.
Pigeon,	0·0147	0·0065
Frog,	0·0223	0·0157
Newt,	0·0293	0·0195
Proteus,	0·0580	0·0350
Amphiuma,	0·0770	0·0460

by a membrane, and having a network of filaments traversing its interior (fig. 38). It is not very distinct in the unaltered corpuscle, but is brought clearly into view by the action of reagents, especially acids. The action of reagents upon the red corpuscle of amphibia is otherwise similar to that produced upon the mammalian corpuscle, water and acetic acid causing it to swell into a globular form and then to become decolorised; solution of salt causing wrinkling of the envelope, and so on. The first effect of water and watery fluids is

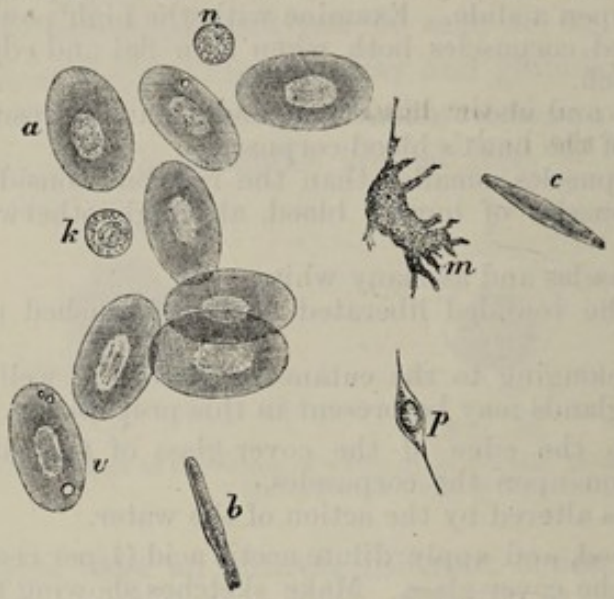


FIG. 37.—FROG'S BLOOD. (Ranvier.)

a, red corpuscle seen on the flat; *v*, vacuoles in a corpuscle; *b*, *c*, red corpuscles in profile; *k*, pale corpuscle at rest; *m*, pale corpuscle exhibiting amœboid movements; *n*, nucleus which has become set free from a coloured corpuscle; *p*, blood platelet.

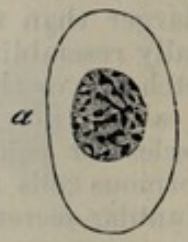


FIG. 38. — COLOURED CORPUSCLE OF SALAMANDER, SHOWING INTRANUCLEAR NETWORK. (Flemming.)

sometimes to cause the hæmoglobin to retire from the envelope at the points where the water is passing through this membrane: a stellate appearance is thereby often produced. Boracic acid causes the hæmoglobin to become partially or wholly collected around the nucleus, which may then be extruded from the corpuscle.

The colourless corpuscles of the frog (fig. 37, *k*, *n*), although larger, are very similar to those of mammals. Like them, they are either wholly pale and finely granular or inclose a number of very distinct granules of similar nature to those met with in mammals. These corpuscles vary much in size and in the activity of their amœboid movements: those which have a multilobular nucleus (fig. 26, *b*, *c*) are usually the most active. Reagents have the same effect upon them as on those of mammals. The presence of glycogen may be demonstrated in them by its reaction with iodine (port-wine colour).

The blood-platelets in the frog (fig. 37, *p*) are far fewer in number than in mammals, but are larger and their cell-nature is more distinctly visible.

LESSON V.

THE AMŒBOID PHENOMENA OF THE COLOURLESS BLOOD-CORPUSCLES.

1. Make a preparation of blood from the finger in the usual way. Draw a brush just moistened with oil around the edge of the cover-glass to check evaporation. Place the preparation upon a 'warm stage,' and heat this to about the temperature of the body (38° C.). Bring a white corpuscle under observation with the high power, and watch the changes of shape which it undergoes. To become convinced of these alterations in form, make a series of outline sketches of the same corpuscle at intervals of a minute.

The simplest form of warm stage is a copper plate of about the size of an ordinary slide, perforated in the centre and with a long tongue of the same

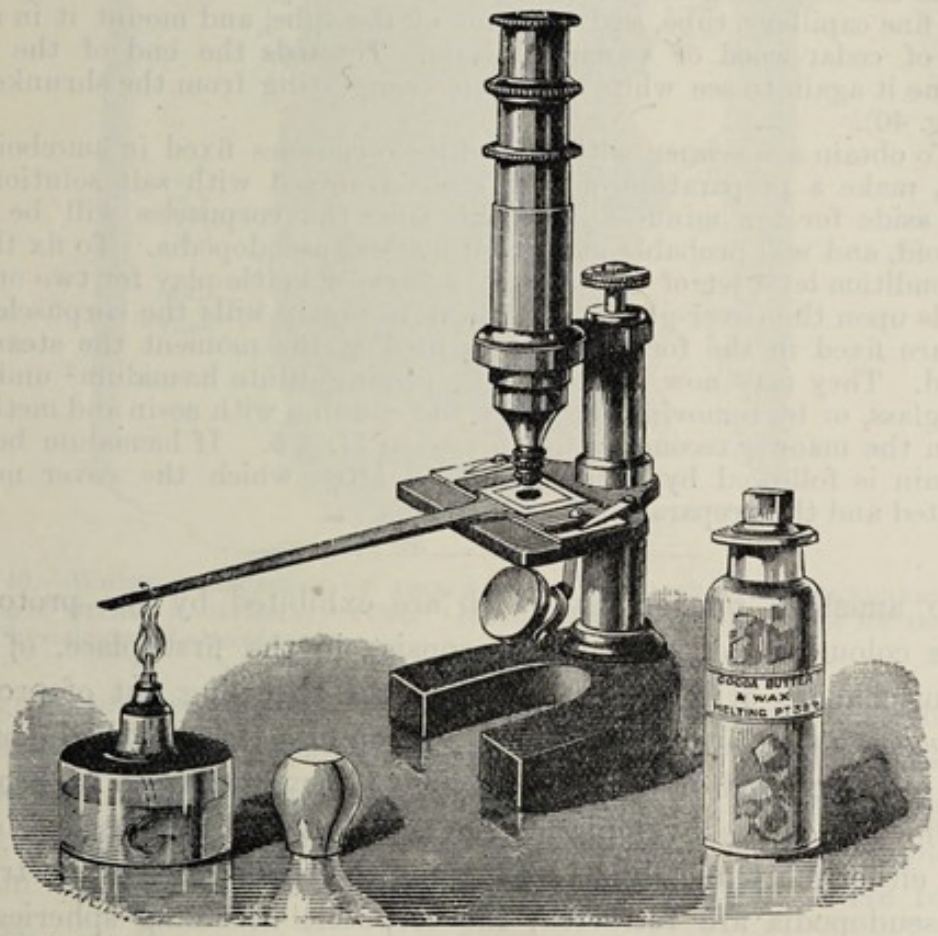


Fig. 39.—Simple warming apparatus, complete, shown in operation.

metal projecting from the middle of one edge (fig. 39). The copper plate rests upon the stage of the microscope with a piece of cloth or other non-conducting material between. The preparation is made upon an ordinary slide or on a large cover-glass, which is placed upon the warm stage and pressed into contact with it by the brass clips. Heat is applied to the copper

tongue by a small spirit-lamp flame, and a greater or less amount is conducted to the warm stage and the superjacent preparation according to the point to which the flame is applied. To ascertain that the right temperature is got and maintained, put two pieces of paraffin, one melting at 35° C. (95° F.) and another at 38° C. (100° F.), on either side of the preparation. The temperature must be such that the first piece is melted and remains so whilst the second remains unmelted.[1]

2. Mount a drop of newt's blood diluted with an equal amount of salt solution, and examine it in the same manner upon the copper stage, at first cold, afterwards warm ; the temperature must, however, be kept below 30° C. Observe the effect of heat in accelerating the amœboid movements of the pale corpuscles. Sketch one at intervals of a minute (*a*) in the cold, (*b*) whilst warmed.

3. Take some yeast which has been mixed with salt solution, and mix a very little of the yeast and salt solution with a fresh drop of newt's blood, slightly oiling the edge of the cover-glass as before. Endeavour to observe the inception of the yeast-torulæ by the white corpuscles. Sketch one or two corpuscles containing torulæ.

Milk-globules or particles of carbon or of vermilion may also be used for this experiment, but the process of inception or "feeding" is most readily observed with the yeast particles.

4. At the beginning of the lesson collect a drop of newt's or frog's blood into a fine capillary tube, seal the ends of the tube, and mount it in a drop of oil of cedar-wood or Canada balsam. Towards the end of the lesson examine it again to see white corpuscles emigrating from the shrunken clot (see fig. 40).

5. To obtain a specimen with the white corpuscles fixed in amœboid condition, make a preparation of newt's blood, mixed with salt solution, and set it aside for ten minutes. By this time the corpuscles will be freely amœboid, and will probably show well-marked pseudopodia. To fix them in this condition let a jet of steam from a flask or kettle play for two or three seconds upon the cover-glass. The heat instantly kills the corpuscles, and they are fixed in the form they presented at the moment the steam was applied. They may now be stained by passing dilute hæmalum[2] under the cover-glass, or by removing the latter and staining with eosin and methylene blue in the manner recommended in Lesson II. § 5. If hæmalum be used, the stain is followed by dilute glycerine, after which the cover may be cemented and the preparation kept.

The **amœboid phenomena** which are exhibited by the protoplasm of the colourless blood-corpuscles consist, in the first place, of spontaneous changes of form, produced by the throwing out of processes or *pseudopodia* in various directions. When first thrown out the pseudopodia are composed of hyaloplasm alone ; they appear to be produced by a flowing of the hyaloplasm (see p. 3). If the corpuscle is stimulated, either mechanically, as by tapping the cover-glass, or electrically, the pseudopodia are retracted, the corpuscle becoming spherical. A change of form caused by the protrusion of the pseudopodia, may, when

[1] For exact work, an apparatus somewhat more complex than the above is required. For description of such, see *A Course of Practical Histology*.

[2] Delafield's or Ehrlich's hæmatoxylin can be substituted for hæmalum wherever the latter is mentioned. The water used for the dilution of hæmatoxylin solutions must always be distilled.

active, be followed by changes in place or actual locomotion (migration) of the corpuscle. When a pseudopodium, or the external surface of the corpuscle, comes in contact with any foreign particle, the protoplasm tends to flow round and enwrap the particle, which is then drawn into the corpuscle; particles thus incepted may be conveyed by the corpuscle in its locomotory changes from one place to another. This property perhaps plays an important part in many physiological and

FIG. 40.—WHITE CORPUSCLES OF FROG'S BLOOD MIGRATING FROM SHRUNKEN CLOT WITHIN A CAPILLARY TUBE. (From Sanderson's Handbook for the Physiological Laboratory.)

pathological processes; thus certain cells in the spleen resembling large leucocytes—the so-called *splenic cells*—incept blood-corpuscles, which become broken down within them, and it is believed by some pathologists that pathogenic bacteria become taken into the protoplasm of certain leucocytes (on this account termed *phagocytes*), there to be destroyed.

It is probable that particles of organic matter which are taken up by the pale corpuscles may undergo some slow process of intracellular digestion within their protoplasm.

The processes of the granular corpuscles are generally quite clear at first, and the granules afterwards flow into them.

The migration of the colourless corpuscles from the blood-vessels into the surrounding tissue (which especially occurs in inflamed parts), or from a blood-clot into the surrounding serum (fig. 40), is owing to these amœboid properties.

The conditions which are most favourable to this amœboid activity of the white corpuscles are (1) the natural slightly alkaline medium, such as plasma, serum, or lymph, or faintly alkaline normal saline solution. Any increase of density of the medium produces a diminution of amœboid activity, whilst, on the other hand, a slight decrease in its density has the opposite effect; (2) a certain temperature. In

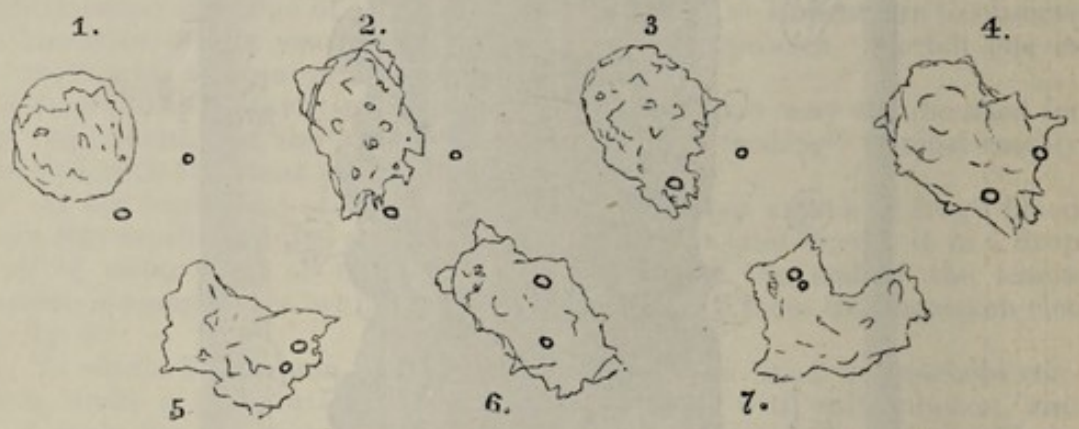


FIG. 41.—CHANGES OF FORM OF A WHITE CORPUSCLE OF NEWT'S BLOOD, SKETCHED AT INTERVALS OF A FEW MINUTES, SHOWING THE INCEPTION OF TWO SMALL GRANULES AND THE CHANGES OF POSITION THESE UNDERWENT WITHIN THE CORPUSCLE.

warm-blooded animals the phenomena cease below about 10° C. When gradually warmed the white corpuscles become more and more active up to a certain point, the maximum being a few degrees above the natural temperature of the blood. Above this point they become spheroidal and at a somewhat higher temperature their protoplasm is coagulated and killed. Acids at once kill the corpuscles and stop the movements. Narcotic gases and vapours, such as carbonic acid gas or chloroform vapour, also arrest the movement, but it recommences after a time if their action is discontinued.

LESSON VI.

EPITHELIUM.

1. Mount a drop of saliva and examine first with a low, afterwards with a high power. Observe the nucleated epithelium-cells, some single, and others still adhering together by overlapping edges. Measure three or four, and also their nuclei. Sketch one or two on the flat and one edgeways. Notice the salivary corpuscles, which are migrated white blood-corpuscles swollen out by imbibition of water.

2. Put a small shred of human epidermis into a drop of strong caustic potash solution (35 p.c.) for five minutes. Then break it up in water with needles, cover and examine. Observe the now isolated swollen cells. Measure some.

3. Study the arrangement of the cells in a section through some stratified epithelium, such as that of the mouth, skin, or cornea.[1] Notice the changes in shape of the cells as they are traced towards the free surface. Measure the thickness of the epithelium. Count the number of layers of cells.

4. Study the minute structure of epithelium-cells and their nuclei, both at rest and dividing, in sections of the skin of the newt's tail, or in shreds of peritoneum or epidermis, or in sections across the tail of the salamander-tadpole. The preparation may, for this purpose, be stained either with hæmatoxylin or with some aniline dye such as saffranin.[2]

Sketch an epithelium-cell with resting nucleus, and others with nuclei in different phases of karyokinesis.

An **epithelium** is a tissue composed entirely of cells separated by a very small amount of intercellular substance (cement substance) and generally arranged so as to form a membrane covering either an external or an internal free surface.

The structure of epithelium-cells, and the changes which they undergo in cell-division, are best seen in the epidermis of the newt or of the salamander-tadpole (fig. 42); in the latter especially, the cells and nuclei are much larger than in mammals.

Structure of the cells.—Each epithelium-cell consists of *protoplasm* containing a *nucleus*. The protoplasm may either look granular, or it may have a reticulated appearance, or may exhibit fibrils. The nucleus is spherical or ovoid. Usually there is only one, but there may be two or more. The cell-substance is often modified in its chemical nature; its external layer may become hardened to form a sort of

[1] The methods of preparing sections are given in the Appendix.

[2] A method which serves the purpose of exhibiting the division of nuclei is given in the Appendix.

membrane, or the whole cell may become horny (keratinised); or there may be a separation of materials (granules) within the cell which are ultimately used by the organism, as in some secreting glands.

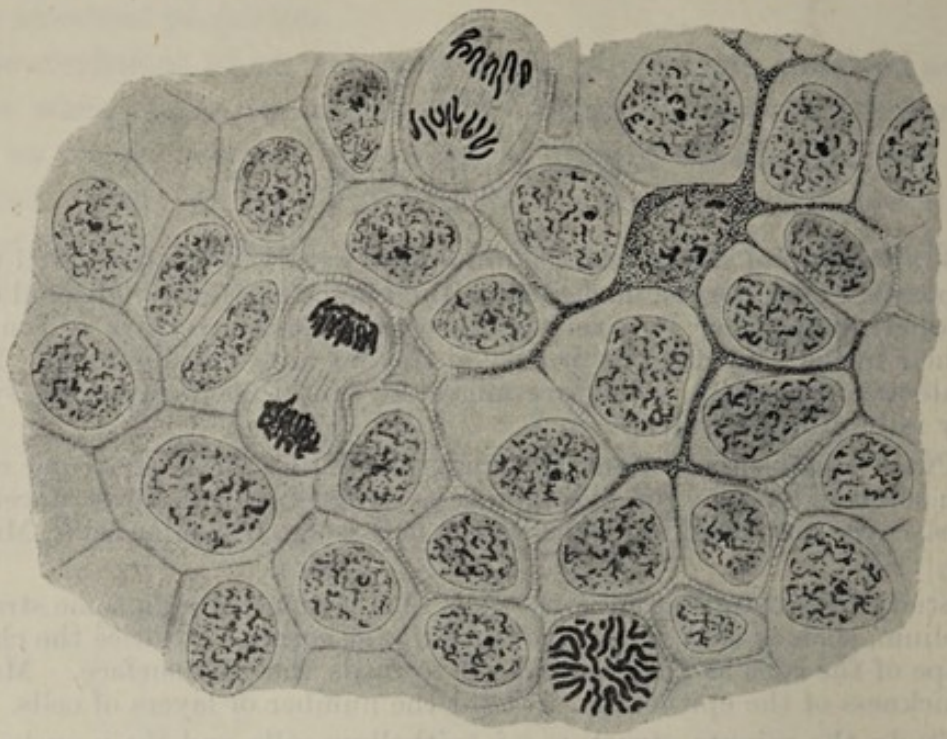


FIG. 42.—EPIDERMIS CELLS OF A LARVAL SALAMANDER.
Magnified 400 diameters. (Wilson.)

Three of the cells are undergoing division. The intercellular channels are bridged across by fine fibres. At one place a branched pigment cell is lying between the epithelium cells.

Classification of epithelia.—Epithelia are somewhat illogically classified partly according to the shape and arrangement of the cells,

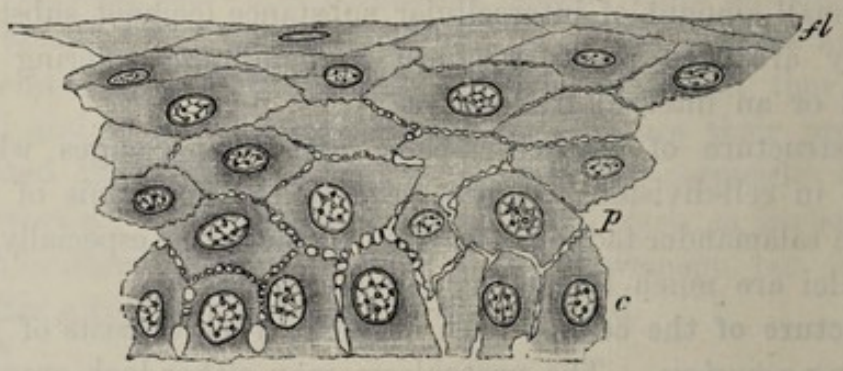


FIG. 43.—SECTION OF THE STRATIFIED EPITHELIUM COVERING THE FRONT OF THE CORNEA OF THE EYE (MAN).

c, lowermost columnar cells; *p*, polygonal cells above these; *fl*, flattened cells near the surface. Between the cells are seen intercellular channels bridged over by processes which pass from cell to cell.

partly according to their function. Thus we speak of *scaly* or *pavement*, *cubical*, *columnar*, *glandular*, and *ciliated* epithelium. Most of these are *simple* epithelia, with the cells only one layer deep. If forming

several superposed layers, the epithelium is said to be *stratified*, and then the shape of the cells differs in the different layers. Where there are only three or four layers in an epithelium, it is termed *transitional*.

Stratified epithelium covers the anterior surface of the cornea, lines the mouth, pharynx (lower part), and gullet, and forms the epidermis which covers the skin. In the female it lines the vagina and the neck of the uterus. The cells nearest the surface are always flattened and scale-like (fig. 43, *fl*; fig. 44), whereas the deeper cells are more rounded or polyhedral, and those of the deepest layer generally somewhat columnar in shape (fig. 43, *c*). Moreover, the deeper cells are soft and protoplasmic, and are separated from one another by a system of intercellular channels, which are bridged across by numerous fibres passing from cell to cell, these giving the cells, when separated, the appearance of being beset with short spines (*prickle-cells* of Max Schultze).

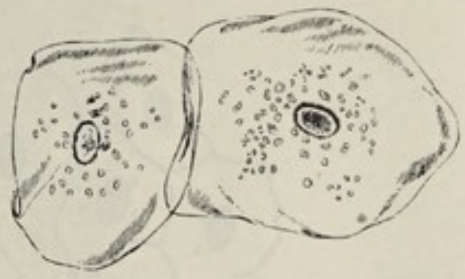


FIG. 44.—EPITHELIUM-SCALES FROM THE INSIDE OF THE MOUTH. (Magnified 260 diameters.)

Some of the deeper cells multiply by division, the nuclei first dividing in the manner already described. The newly formed cells tend as they enlarge to push those external to them nearer to the surface, from which they are eventually thrown off. As they approach the surface they become hard and horny, and in the case of the epidermis lose entirely their cellular appearance, which can, however, be in a measure restored by the action of potash (§ 2). The cast-off superficial cells of the stratified epithelium of the mouth, which are seen in abundance in the saliva (§ 1), are less altered, and the remains of a nucleus is still visible in them (fig. 44). The stratified epithelium of the human skin (epidermis) shows many peculiarities: these will be considered when the skin itself is treated of.

Simple scaly or **pavement epithelium** is found in the saccules of the lungs, in the ducts of the mammary gland, in the kidney (in the tubes of Henle, lining the capsules of the Malpighian bodies, and covering the glomeruli), and also lining the cavities of serous membranes (fig. 45), and the interior of the heart, blood-vessels, and lymphatics. When occurring on internal surfaces, such as those of the serous membranes, blood-vessels, and lymphatics, it is often spoken of as **endothelium** or **mesothelium**. According to v. Brunn the cells of a serous epithelium may be provided with a striated border on their free surface, somewhat like that which is found on columnar cells.

Columnar epithelium and **ciliated epithelium** are for the most part found covering the inner surface of mucous membranes; which are membranes moistened by *mucus* and lining passages in communication with the exterior, such as the alimentary canal and the respiratory and generative passages.

Glandular epithelium is the essential tissue of all the organs which are known as secreting glands. Glands are of two chief kinds. Those which are best known and which are termed *secreting glands proper* are furnished with a duct which ramifies in all parts of the gland and by

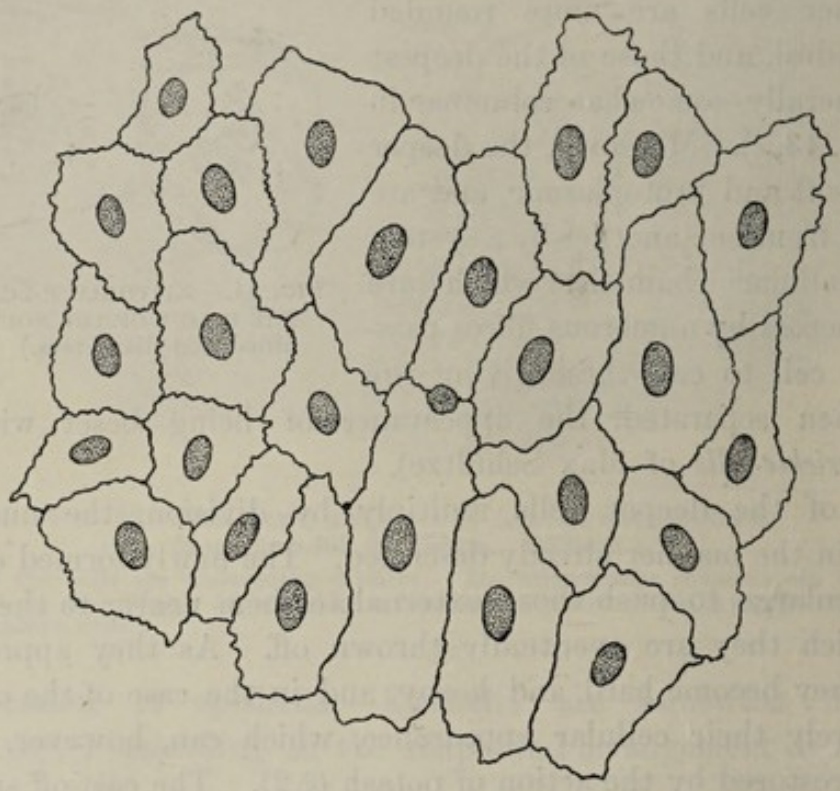


FIG. 45.—PAVEMENT EPITHELIUM OR ENDOTHELIUM OF A SEROUS MEMBRANE. NITRATE OF SILVER PREPARATION. CARMINE STAINING OF NUCLEI.

means of which the products of the secretory activity of the gland cells are brought to a free surface. Such glands have been developed as involutions of the surface upon which they open, and their epithelium is continuous with that of this surface, and is in some cases, especially where the surface upon which the gland opens is covered with columnar epithelium, of a similar character to the epithelium of the surface; in others different in character. In most glands it alters as we trace the duct back into the recesses or alveoli of the gland, and it is in these that the characteristic glandular cells, which are generally polyhedral in shape, are found. Every such involution or ingrowth of epithelium to form a gland is, when first formed, of a simple character, shaped like a test-tube or flask and filled with a solid mass of cells, but it presently becomes hollowed out and the cells remain as a lining to the con-

nective tissue membrane which bounds the involution. The gland may remain simple and unbranched (*simple tubular* and *simple saccular glands*, figs. 46, 47), or it may branch again and again until a complicated structure, in some cases small, in others of considerable size, is produced (*compound tubular* and *compound saccular* (or *racemose*) *glands*, instances of which are furnished by the kidneys and salivary glands

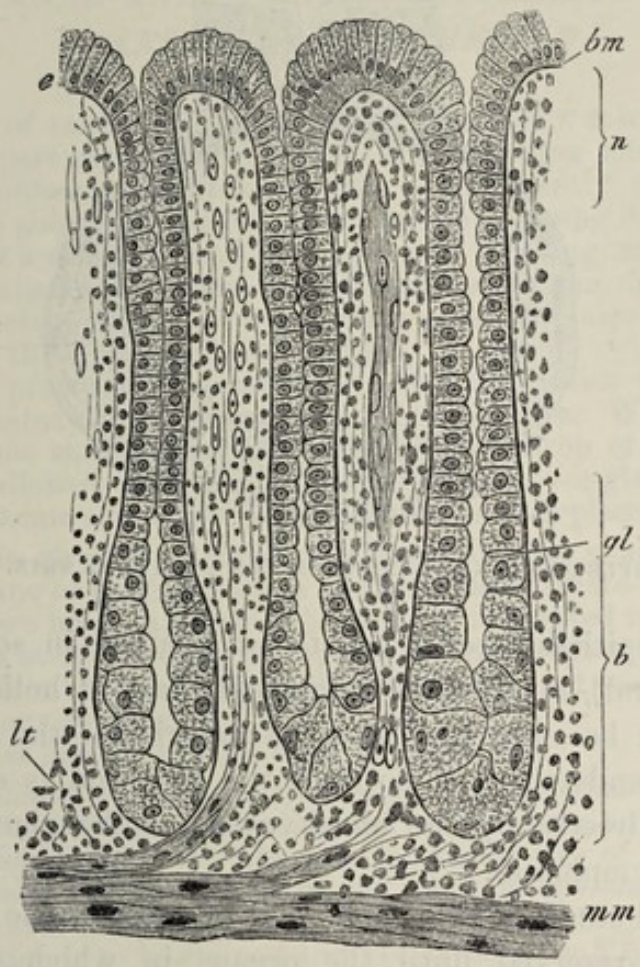


FIG. 46.—SIMPLE TUBULAR GLANDS SEEN IN A SECTION OF THE MUCOUS MEMBRANE OF THE STOMACH OF THE KANGAROO.

e, epithelium of general surface; *bm*, basement membrane; *n*, neck or duct of gland; *b*, base or fundus; *gl*, glandular epithelium; *lt*, lymphoid tissue; *mm*, muscular tissue of the mucous membrane.

respectively). The cells which furnish the secretion of the gland and which line the secreting parts of the tubules of a tubular gland, or the alveolar enlargements (acini) at the ends of the ducts of a racemose gland, are frequently partly or wholly filled with granules in the intervals of secretory activity, and these granules become discharged or dissolved and pass into the secretion during activity. Secreting glands are always abundantly supplied with blood-vessels and nerves. The former are distributed in the connective tissue which holds together the acini and groups of acini (lobules) of the gland; the

latter are supplied partly to the blood-vessels and partly ramify amongst the secretory epithelium cells.

The other kind of secreting glands, known as the *internally secreting glands*, are not furnished with ducts and are usually described (along with the spleen and the lymphoid structures) as *ductless glands*. The internally secreting glands are, like the externally secreting organs,

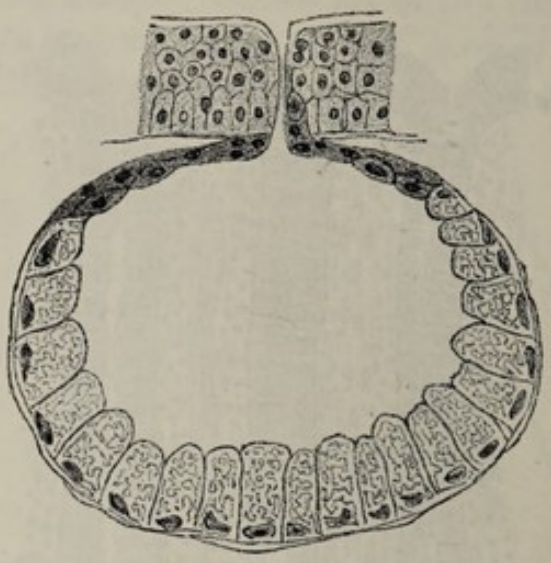


FIG. 47.—SIMPLE SACCULAR GLAND FROM THE AMPHIBIAN SKIN. (Flemming.)

composed of epithelial cells, sometimes grouped in solid masses (*e.g.* suprarenal gland), in other cases disposed around hollow vesicles (*e.g.* thyroid) which become filled with the material of the secretion. But as in these glands there is no duct the secretion is carried into the blood either directly by the blood-vessels of the gland or indirectly through the lymphatics.

The detailed study of the glands and of most of the epithelial structures may be reserved until the organs in which they occur are respectively described, but some will be dealt with in the next lessons.

The *hairs* and *nails* and the *enamel* of the teeth are modified epithelial tissues. They will be described along with the skin and mouth respectively.

LESSON VII.

COLUMNAR AND CILIATED EPITHELIUM, AND TRANSITIONAL EPITHELIUM.

1. Take a piece of rabbit's intestine which has been a few days in chromic acid solution (1 part chromic acid to 2000 normal saline solution), or in one-third alcohol, containing a little salicylic acid. Gently scrape the inner surface with the point of a scalpel, break up the scraping in a drop of water on a slide. Add a small piece of hair to avoid crushing, and cover the preparation. The tissue may then be still further broken up by tapping the cover-glass. Sketch one or two columnar cells and also a row of cells. Measure two or three cells and their nuclei.

To keep this preparation, place a drop of *very dilute* staining solution (Delafield's hæmatoxylin) at one edge of the cover-glass. When the stain has passed in and has stained the cell-nuclei, place a drop of glycerine at the same edge and allow it slowly to diffuse under the cover-glass. Cement this another day. Osmic acid (1 per cent.) may be used in place of hæmatoxylin.

2. Break up in glycerine a shred of epithelium from a minute piece of the mucous membrane of frog's intestine that has been treated with 1 per cent. osmic acid for two hours, and has subsequently macerated in water for a few days. The cells easily separate on tapping the cover-glass. They are larger than those of the rabbit, and therefore exhibit the structure better. Measure and sketch one or two cells.

The cover-glass may be at once fixed by gold size.

3. Prepare ciliated epithelium from a trachea that has been in chromic acid solution (1 to 2000 normal saline) for a few days, in the same way as columnar epithelium in § 1. Measure in one or two of the cells (*a*) the length of the cells, (*b*) the length of the cilia, (*c*) the size of the nucleus. Sketch two or three cells.

This preparation is to be stained and preserved as in § 1.

4. Make a similar teased preparation of the epithelium of the urinary bladder, which may be moderately distended with bichromate of potash solution (1 part to 800 of salt solution), and after an hour or two cut open and placed in more of the same solution. Observe the large flat superficial cells, and the pear-shaped cells of the second layer. Measure and sketch one or two of each kind. The cells will vary greatly in appearance according to the amount of distension of the organ.

Stain and preserve as in §§ 1 and 3.

All the above varieties of epithelium will afterwards be studied *in situ* when the organs where they occur come under consideration.

Columnar epithelium.—The cells of a columnar epithelium (fig. 48) are prismatic columns, which are set closely side by side, so that when seen from the surface a mosaic appearance is produced. They often taper somewhat towards their attached end, which is generally truncated, and set upon a basement membrane. Their free surface is

covered by a thick striated border (fig. 49, *str*) which may sometimes become detached in teased preparations. The protoplasm of the cell

Fig. 48.

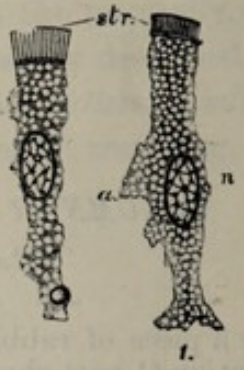


Fig. 49.

Fig. 48.—A row of columnar cells from the intestine of the rabbit. Smaller cells are seen between the epithelium-cells; these are leucocytes.

Fig. 49.—Columnar epithelium-cells of the rabbit's intestine. The cells have been isolated after maceration in very weak chromic acid. The cells are much vacuolated, and one of them has a fat-globule adhering to it near its attached end; the striated border (*str*) is well seen, and the bright disk separating it from the cell-protoplasm; *n*, nucleus with intranuclear network; *a*, a thinned-out wing-like projection of the cell which probably fitted between two adjacent cells.

is highly vacuolated and reticular, and fine longitudinal striæ may be seen in it, which appear continuous with the striæ of the free border.

Fig. 50.

Fig. 51.

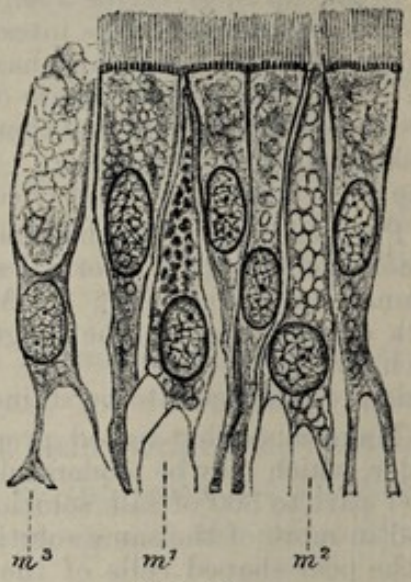


Fig. 52.

Fig. 50.—A columnar epithelium-cell, showing mass of fibrils (cytomitome) within the cell protoplasm. (M. Heidenhain.)

Fig. 51.—A goblet or mucus-secreting cell, from columnar epithelium. (M. Heidenhain.) An ordinary columnar cell is also shown.

Fig. 52.—Ciliated columnar epithelium, from the trachea of a rabbit. m^1, m^2, m^3, mucus-secreting cells in various stages of mucigen formation. The preparation was treated with dilute chromic acid in the manner recommended in the instructions for practical work.

Between the striated border and the protoplasm of the cell is a highly refracting disk which contains fine dumbbell shaped particles set

vertically, connected below with the fibrils or striæ which run through the cell protoplasm (fig. 50). It has been suggested that these particles are formed by multiplication of the centrosome, but the fact cannot be regarded as established. The nucleus is ovoid and reticular. The lateral borders of the cells are often somewhat irregular or jagged, the result of the presence of amœboid cells, which are generally found between the columnar cells, at least in the intestine. After a meal containing fat the epithelium-cells of the small intestine contain fat globules, which become stained black in the osmic preparation.

Columnar epithelium-cells are found lining the whole of the interior of the stomach and intestines: they are also present in the ducts of most glands, and sometimes also in their secreting tubes and saccules. The epithelium which covers the ovary also has a modified columnar shape, but cells having *all* the structural peculiarities indicated above are found only in the alimentary canal and in its diverticula.

Goblet-cells.—Some columnar cells, and also cells of glandular, ciliated, and transitional epithelia, contain mucigen, which is laid down within the cell in the form of granules (fig. 52, m^1, m^2). These granules eventually swell up to form globular masses which may run together and may greatly distend the part of the cell nearest the free border. When the mucigen is extruded as mucus the cell takes the form of an open cup or chalice (fig. 51 and fig. 52, m^3), hence the name.

These *goblet-cells*, or, as they may appropriately be termed, *mucus-secreting cells*, are probably not mere temporary modifications of the ordinary columnar and ciliated cells amongst which they are found, but permanently differentiated cells, which, after having got rid of their mucus by extrusion, again form a fresh supply in the same way as before.

Ciliated epithelium.—The cells of a ciliated epithelium are usually columnar in shape (figs. 52, 53), but in place of the striated border of the ordinary columnar cell the free surface is surmounted by a bunch of fine tapering filaments (*vibratile cilia*) which, during life, move spontaneously to and fro, and serve to produce a current in the fluid which covers them. The border upon which the cilia are set is bright, and appears formed of little juxtaposed *knobs* or *basal particles*, to each of which a cilium is attached.

In the large ciliated cells which line the alimentary canal of some molluscs (fig. 54), and with less distinctness in the ciliated cells of vertebrates, the knob may be observed to be prolonged into the protoplasm of the cell as a fine varicose filament, termed the *rootlet* of the cilium. Since the axial fibril in the tail (cilium) of the spermatozoon is developed in connection with and probably from the centrosome, it has been supposed that the cilia of an ordinary ciliated cell may also be outgrowths from the (multiplied) centrosome. But while it appears to be true that the basal particles are formed

by the division of the centrosome of the cell, in which case the rootlets may represent the fibrils of archoplasm which radiate from the centrosome of such a cell as the white corpuscle (fig. 4), it appears not to be the case that the cilia are developed from these basal particles, for the cilia sometimes appear before the basal particles. In plant spores, which have no centrosomes, the cilia have been described as becoming developed from amœboid processes of the ectoplasm of the cell (Strassburger). Similar basal particles and longitudinal fibrils have been described in columnar cells (see page 50),

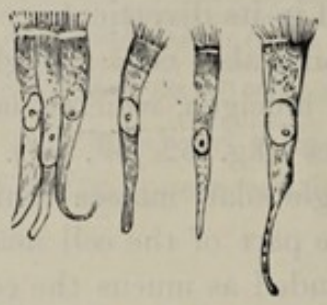


FIG. 53.—COLUMNAR CILIATED EPITHELIUM-CELLS FROM THE LOWER PART OF THE HUMAN NASAL PASSAGES. EXAMINED FRESH IN SERUM. (Sharpey.)

FIG. 54.—CILIATED CELL, FROM THE INTESTINE OF A MOLLUSC. (Engelmann.)

and these are probably homologous with the knobs and rootlets of the ciliated cell, while the bunch of cilia of the latter is represented by the striated border of the columnar cell.

Ciliated epithelium is found in man throughout the whole extent of the air-passages and their prolongations (but not in the part of the nostrils supplied by the olfactory nerves, nor in the lower part of the pharynx, nor in the terminal bronchioles and pulmonary alveoli); in the Fallopian tubes and the greater part of the uterus; in the efferent tubes of the testicle (where the cilia are longer than elsewhere in the body); in the ventricles of the brain, and the central canal of the spinal cord.

Transitional epithelium is a stratified epithelium consisting of only three or four layers of cells. It occurs in the urinary bladder, the ureter, and the pelvis of the kidney. The superficial cells (fig. 55, *a*) are large and flattened; they often have two nuclei. Their free sur-

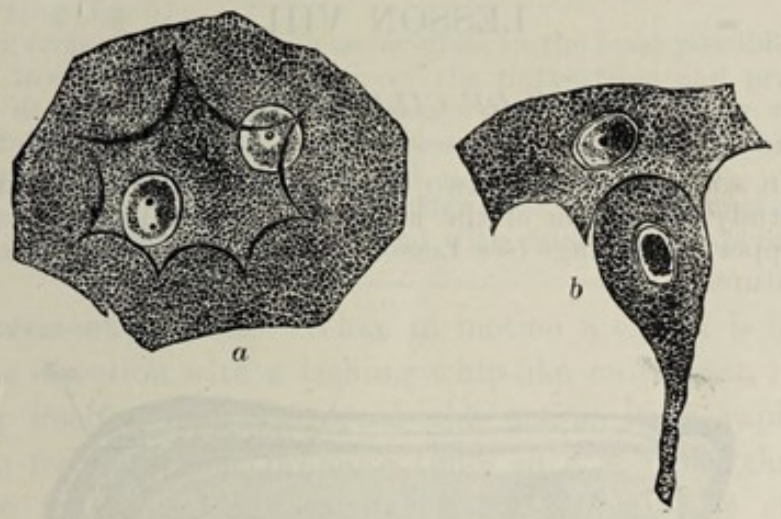


FIG. 55.—EPITHELIAL-CELLS FROM THE BLADDER OF THE RABBIT. (Klein.)
(Magnified 500 diameters.)

a, large flattened cell from the superficial layer, with two nuclei and with strongly marked ridges and intervening depressions on its under surface; *b*, pear-shaped cell of the second layer adapted to a depression on one of the superficial cells.

face is covered with a cuticular stratum, and on their under surface they exhibit depressions, into which fit the larger ends of pyriform cells, which form the next layer (fig. 55, *b*). Between the tapered ends of the pyriform cells one or two layers of smaller polyhedral cells are found. The epithelium seems to be renewed by division of these deeper cells, but it is not certain that the superficial cells do not also multiply.

LESSON VIII.

STUDY OF CILIA IN ACTION.

1. Mount in sea-water one or two bars of the gill of the marine mussel (fig. 56). Study the action of the large cilia. Now place the preparation upon the copper warm stage (see Lesson V.) and observe the effect of raising the temperature.

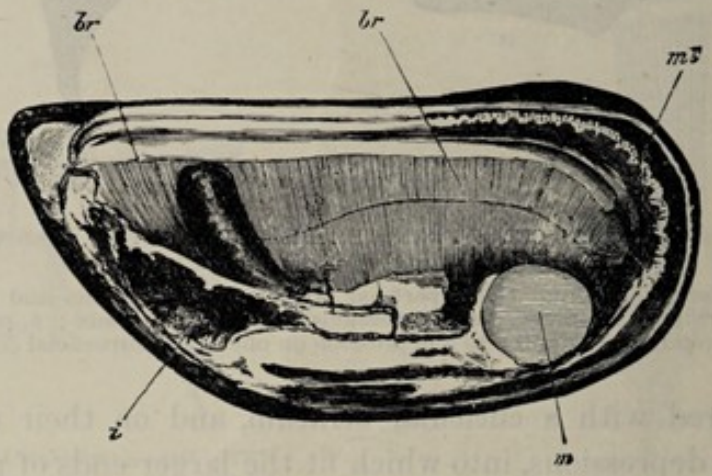


Fig. 56.—Valve of mussel (mytilus edulis) showing *br*, *br*, the expanded gills or branchiæ, which, owing to the little bars of which they are composed, present a striated aspect.

ml, mantle; *m*, cut adductor muscle; *i*, mass of viscera; the dark projection just above is the foot.

Keep this preparation until the end of the lesson, by which time many of the cilia will have become languid. When this is the case pass a drop of dilute potash solution (1 part KHO to 1000 of sea-water) under the cover-glass and observe the effect.

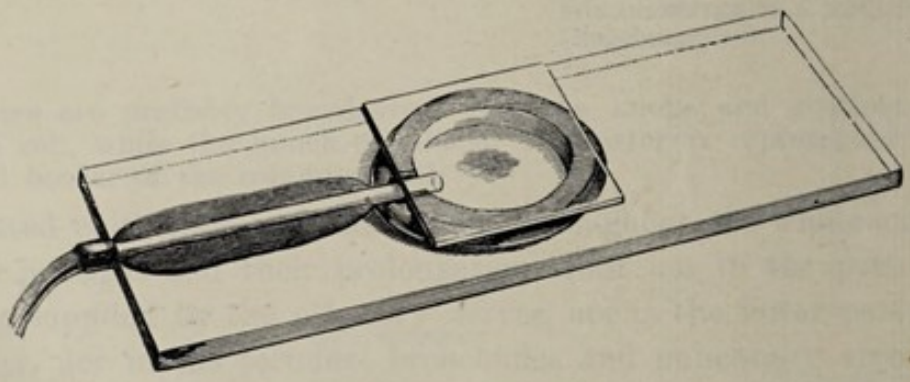


Fig. 57.—Moist chamber adapted for passing a gas or vapour to a preparation under the microscope.

2. Cement with sealing-wax a piece of small glass tubing to a slide so that one end of the tube comes nearly to the centre of the slide. To do this

effectually the slide must be heated and some sealing-wax melted on to it and allowed to cool. The glass tube is then made hot and applied to the slide, embedding itself as it does so in the sealing-wax. On this put a ring of putty or modelling wax (half an inch in diameter and rising above the glass tube) so as to include the end of the tube. Make a deep notch in the ring opposite the tube for the exit of the gas. Place a small drop of water within the ring (fig. 57).

Put a bar from the gill upon a cover-glass in the least possible quantity of sea-water; invert the cover-glass over the putty ring, and press it gently and evenly down. The preparation hangs in a *moist chamber* within which it can be studied through the cover-glass, and into which gases or vapours can be passed and their effects observed.

Pass CO_2 through the chamber, and after observing the effect replace it by air (see fig. 58). Repeat with ether and with chloroform vapour.

The movement of cilia.—When in motion a cilium is bent quickly over in one direction with a lashing whip-like movement, immediately recovering itself. When vigorous the action is so rapid, and the rhythm so frequent (ten or more times in a second), that it is impossible to follow the motion with the eye. All the cilia upon a ciliated surface are not in action at the same instant, but the move-

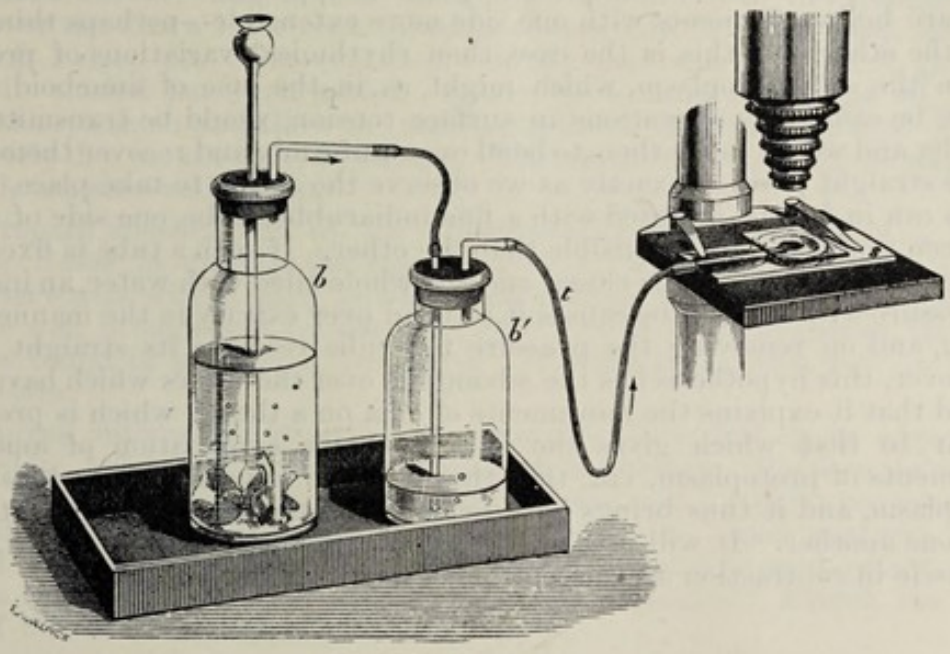


FIG. 58.—METHOD OF SUBJECTING A PREPARATION TO A STREAM OF CARBON DIOXIDE.

b, bottle containing marble and hydrochloric acid; *b'*, wash-bottle, connected by india-rubber tube, *t*, with the moist chamber, *s*.

ment travels in waves over the surface. If a cell is detached from the general surface, its cilia continue to act for a while, but their movement at once ceases if they are detached from the cell. If, however, a portion of the cell protoplasm is detached with them, they will continue to move for a time.

The rhythm is slowed by cold, quickened by warmth; but heat

beyond a certain point kills the cells. The movement will continue for some time in water deprived of oxygen. Both CO_2 gas and ether and chloroform vapour arrest the action, but it recommences on restoring air. Dilute alkaline solutions quicken the activity of cilia, or may even restore it shortly after it has ceased.

Theories of ciliary action.—Various attempts have been made to explain the manner in which cilia act. One hypothesis supposes that one side only of each cilium is contractile, the other side being elastic. This supposition is negatived by the fact that in heat rigor the cilia are not bent over as they would be by the contraction which always accompanies rigor, but stand up straight. It is moreover impossible to suppose that a soft structure like a cilium could be bent over in a uniform gentle curve by contraction along one side ; such contraction could only produce shortening and wrinkling of the cilium, effects which are never observed. By another hypothesis it has been assumed that the projecting cilia are set in action by rhythmic lateral contractions in the protoplasm ; which, by moving the rootlets, cause the cilia to bend over as a whip is bent over by movements of the wrist applied to its handle. But this again implies an amount of rigidity which cilia do not possess, for it must be borne in mind that they have to overcome the resistance of a fluid which is in many cases highly viscous.

If in our complete ignorance of the structure of the individual cilia we are to form any idea as to the cause of the rhythmical bending over of these minute cell processes, the simplest hypothesis appears to be to assume that they are hollow filaments with one side more extensible—perhaps thinner—than the other. If this is the case, then rhythmical variations of pressure within the cell-protoplasm, which might, as in the case of amœboid movements, be caused by alterations in surface tension, would be transmitted to the cilia and would cause them to bend over uniformly and recover themselves to the straight position exactly as we observe the action to take place. Such action can in fact be imitated with a fine indiarubber tube, one side of which has been rendered less extensible than the other. If such a tube is fixed to a syringe and the free end is closed and the whole filled with water, an increase of pressure within the tube causes it to bend over exactly in the manner of a cilium, and on removing the pressure the tube resumes its straight form. Moreover, this hypothesis has the advantage over the others which have been offered that it explains the movements of cilia on a theory which is precisely similar to that which gives the most probable explanation of amœboid movements of protoplasm, viz., that they are due to variations in tension of protoplasm, and it thus brings both forms of protoplasmic activity into line with one another. It will presently be shown that the changes which occur in muscle in contraction are susceptible of a similar explanation.

LESSON IX.

THE CONNECTIVE TISSUES.

AREOLAR AND ADIPOSE TISSUE, RETIFORM TISSUE.

1. Take a little of the subcutaneous tissue or of the intermuscular connective tissue of a rabbit or guinea-pig and spread it out with needles on a dry slide into a large thin film. Keep the centre moist by occasionally breathing on it, but allow the edges to dry to the slide. Before commencing put a drop of salt solution on a cover-glass, and now invert this over the film. Examine with a high power. Sketch one or two bundles of white fibres and also one or two elastic fibres, distinguishable from the former by their sharp outline, isolated course, and by their branching. Sketch also one or more connective-tissue corpuscles, if any such are visible in the clear interspaces. Look also for migratory cells (leucocytes). Next carefully remove the cover-glass and replace the salt solution by dilute acetic acid (1 per cent.). Watch its effect in swelling the white fibres and bringing more clearly into view the elastic fibres and corpuscles. Look for constricted bundles of white fibres.

2. Make another film in the same way, but allow to dry completely. Pour over the film a 1 per cent. solution of magenta in 50 per cent. alcohol, to which 1 drop per cubic centimetre of a 1 per cent. solution of gentian violet in alcohol has been added. After one minute drain this off, wipe round the specimen and allow the staining solution to dry on the film. When completely dry mount in xylol balsam. The elastic fibres are deeply stained; the cells are also well shown.

3. Prepare another film of the subcutaneous tissue, including a little adipose tissue in exactly the same way as 2. Examine first with a low and afterwards with a high power. The nucleus and envelope of the fat-cell are well brought out by the stain, and, if from a young animal, fat-cells will be found in process of formation. Measure and sketch two or three of the cells.

4. Spread out another large film of connective tissue, letting its edges dry to the slide, but keeping the centre moist by the breath. Place on its centre a large drop of nitrate of silver solution (0·75 per cent.). After ten minutes, wash this away with distilled water, and expose to direct sunlight until stained brown. Now allow the film to dry completely, and mount it in Canada balsam dissolved in xylol. Cover[1] and examine. Sketch the outlines of two or three of the cell-spaces.

5. To display retiform tissue the following method is recommended (Spalteholz). Place a piece of the organ (*e.g.* lymphatic gland) for twenty-four hours or more in alcohol, then overnight at 38° C. in a 1 per cent. solution of carbonate of soda to which a few drops of glycerine extract of pancreas have been added. Cautiously transfer the semi-digested structure to alcohol again, and leave it for a few hours. Embed in paraffin in the usual way and stain the sections with iron hæmatoxylin.[2] The fibrils of connective and retiform tissue are the only structures which have remained undigested and they are deeply coloured by the hæmatoxylin.

[1] Preparations which are mounted in Canada balsam solution will soon become fixed by the hardening of the Canada balsam at the edges of the cover-glass. They must on no account be cemented with gold size.

[2] See Appendix.

The **connective tissues** include *areolar* tissue, *adipose* tissue, *elastic* tissue, *fibrous* tissue, *retiform* and *lymphoid* tissue, *cartilage* and *bone*. All these tissues agree in certain microscopical and chemical characters. They, for the most part, have a large amount of intercellular substance in which fibres are developed, and these fibres are of two kinds—*white* and *yellow or elastic*. Moreover, there are many points of similarity between the cells which occur in these tissues; they are all developed from the same embryonic formation, and they tend to pass imperceptibly the one into the other. Besides this, the use of these several tissues is everywhere similar; they serve to connect and support the other tissues, performing thus a passive mechanical function. They may therefore be grouped together, although differing considerably in external characters. Of the connective tissues, however, there are three which are so intimately allied as to be naturally considered together, being composed of exactly the same elements, although differing in the relative development of those elements: these are the areolar, elastic, and fibrous tissues. Adipose tissue and retiform tissue may both be looked upon as special modifications of areolar tissue. Areolar tissue being the commonest and, in a sense, the most typical, its structure may be considered first.

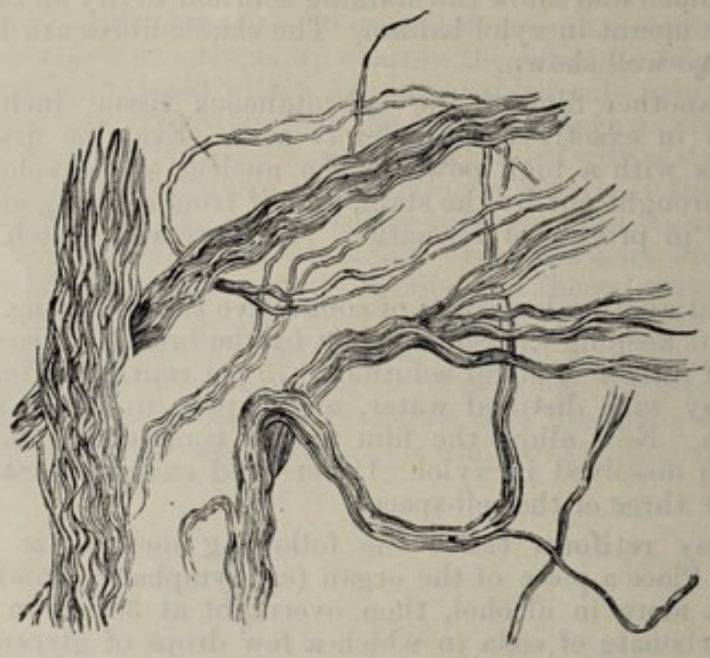


FIG. 59.—BUNDLES OF THE WHITE FIBRES OF AREOLAR TISSUE PARTLY UNRAVELLED. (Sharpey.)

Areolar tissue.—The areolar tissue presents to the naked eye an appearance of fine transparent threads and laminæ which intercross in every direction with one another, leaving intercommunicating meshes, or areolæ, between them. When examined with the microscope, these

threads and fibres are seen to be principally made up of wavy bundles of exquisitely fine transparent fibres (*white fibres*, fig. 59). The bundles run in different directions, and may branch and intercommunicate with one another; but the individual fibres, although they pass from one bundle to another, never branch or join other fibres. The fibres are cemented together into the bundles by a clear substance containing mucin, and the same clear material forms also the basis or *ground-substance* of the tissue, in which the bundles themselves course, and in which also the corpuscles of the tissue lie embedded. This ground-substance between the bundles can with difficulty be seen in the fresh tissue on account of its extreme transparency; but it can be brought to view by staining with nitrate of silver, as in § 4. The whole of the tissue is thereby stained of a brown colour, with the exception of the spaces which are occupied by the corpuscles (*cell-spaces*, fig. 60).

FIG. 60.—GROUND SUBSTANCE OF CONNECTIVE TISSUE STAINED BY SILVER. The cell-spaces are left white. From a photograph. (Magnified 250 diameters.)

Besides the white fibres of connective tissue here described, fibres of a different kind (fig. 61) may be made out in the preparations; these are the *elastic fibres*. They are especially well seen after treatment with acetic acid, and after staining with magenta, or, in sections, with orcein; but they can be detected also in the fresh preparation. They are characterised by their distinct outline, their straight course, the fact that they never run in bundles, but singly, and that they branch or join neighbouring fibres. If broken by the needles in making the preparation, the elastic recoil causes them to curl up, especially near the broken ends. Besides these histological differences, the two kinds of fibres differ also in their chemical characters. Thus the white fibres are dissolved by boiling in water, and yield

gelatin, but are not dissolved by tryptic digestion; whereas the substance of which the elastic fibres are composed (*elastin*) resists for a long time the action of boiling water, although it is dissolved

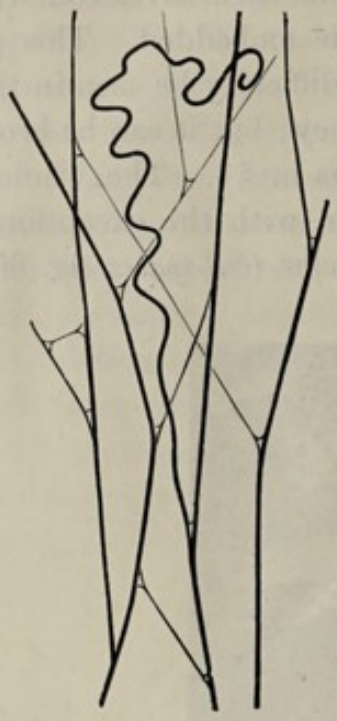


FIG. 61.—ELASTIC FIBRES OF AREOLAR TISSUE. FROM THE SUBCUTANEOUS TISSUE OF THE RABBIT.

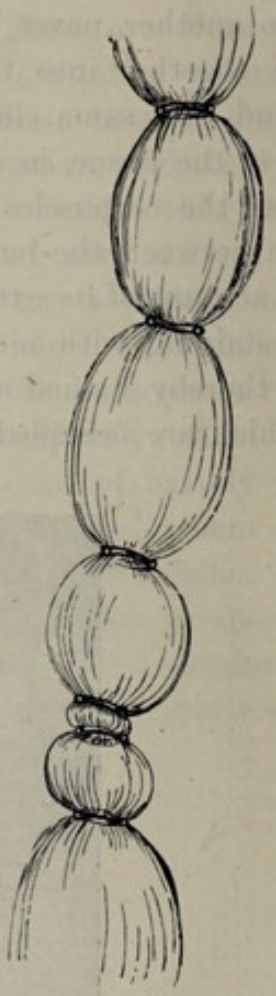


FIG. 62.—A WHITE BUNDLE SWOLLEN BY ACETIC ACID. FROM THE SUBARACHNOID TISSUE AT THE BASE OF THE BRAIN. (Toldt.)

by tryptic digestion. Moreover, the white fibres swell and become indistinct under the action of acetic acid; the elastic fibres are unaltered by this reagent. Elastic fibres appear to have a sheath which is more resistant to reagents than the middle of the fibre.

The bundles of white fibres which have been swollen out by acid sometimes exhibit constrictions at irregular intervals (fig. 62). These are in most instances due to elastic fibres coiling round the white bundles.

The cells of areolar tissue.—Several varieties of connective-tissue cells are distinguished, viz.: (1) *Lamellar cells*, which are flattened and often branched (fig. 63, *c*, *c'*) and may be united one to the other by their branches, as in the cornea, or are unbranched and

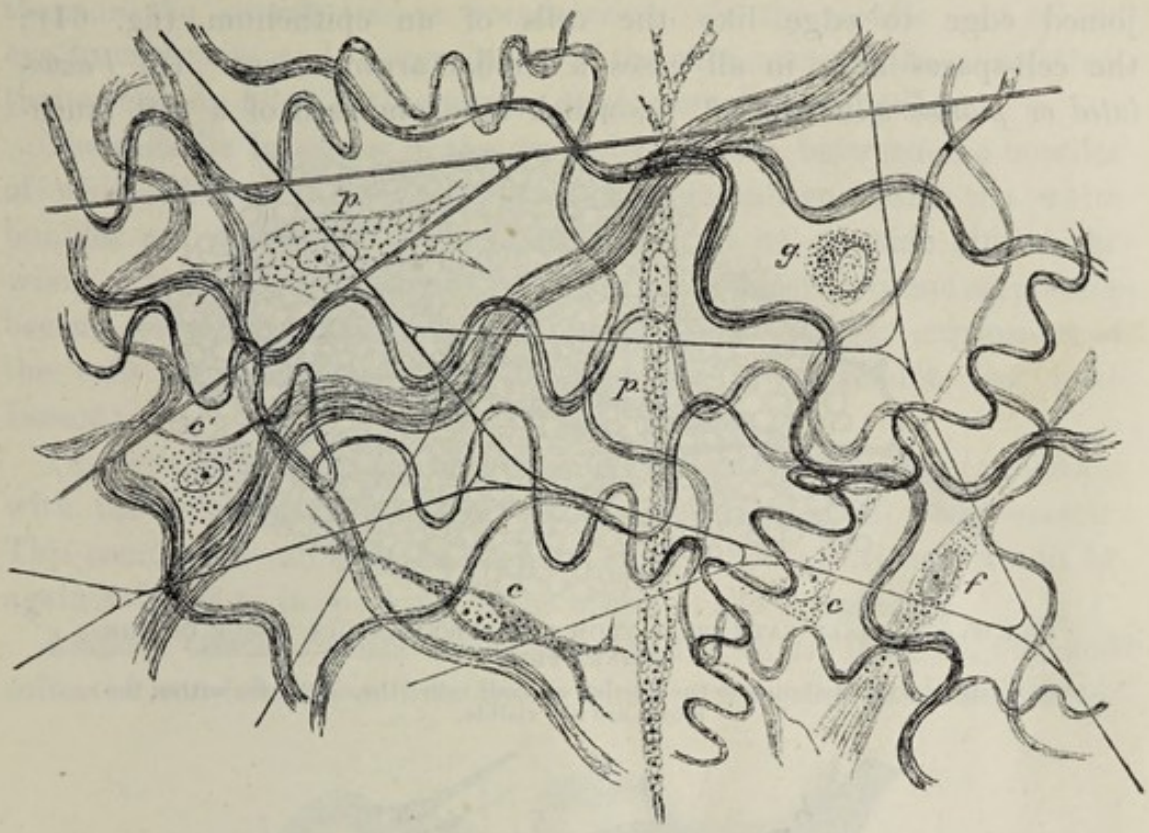


FIG. 63.—SUBCUTANEOUS TISSUE FROM A YOUNG RABBIT, PREPARED AS DIRECTED IN § 1. (Highly magnified.)

The white fibres are in wavy bundles; the elastic fibres form an open network. *p*, *p*, plasma-cells; *g*, granule-cell; *c*, *c'*, lamellar-cells; *f*, fibrillated-cell.

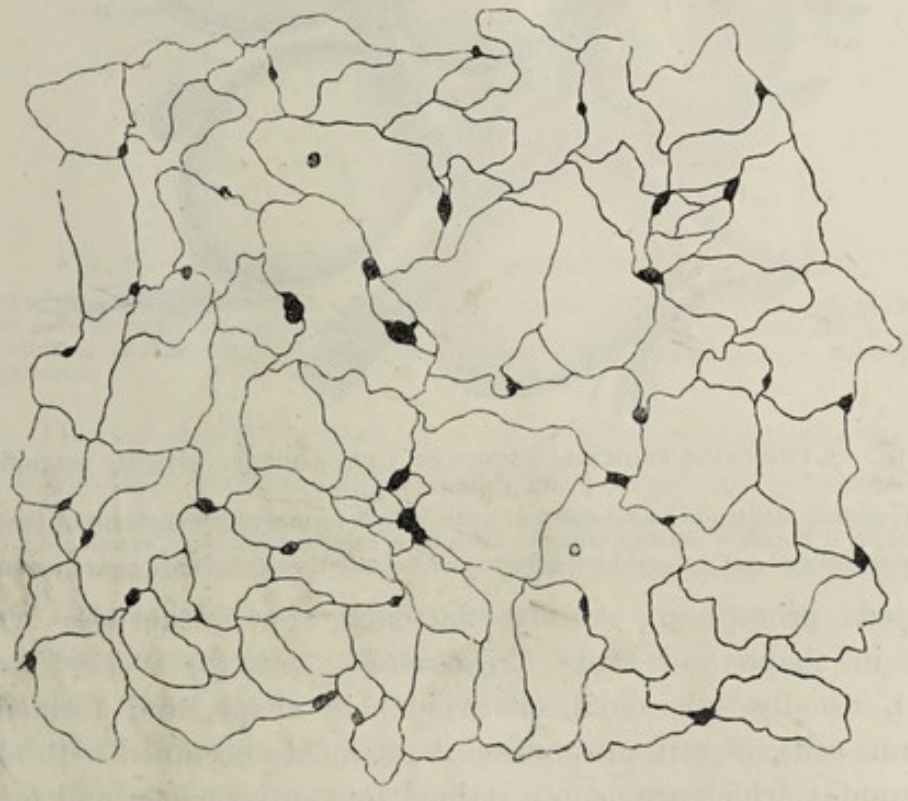


FIG. 64.—EPITHELIOID CELLS OF CONNECTIVE TISSUE FROM THE SURFACE OF AN APONEUROSIS. (Nitrate of silver preparation.)

joined edge to edge like the cells of an epithelium (fig. 64); the cell-spaces have in all cases a similar arrangement. (2) *Vacuolated or plasma cells* (fig. 63, *p*), which are composed of a soft much-

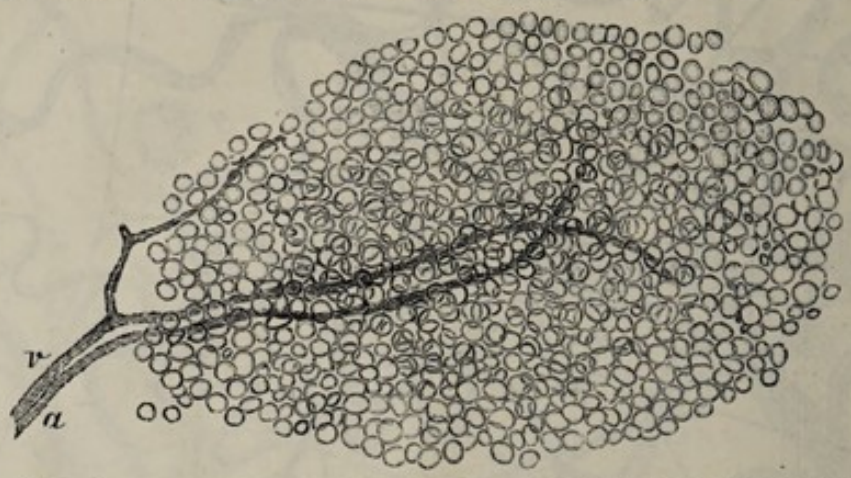


FIG. 65.—A SMALL FAT-LOBULE FROM THE SUBCUTANEOUS TISSUE OF THE GUINEA-PIG.

a, small artery distributed to the lobule; *v*, small vein; the capillaries within the lobule are not visible.

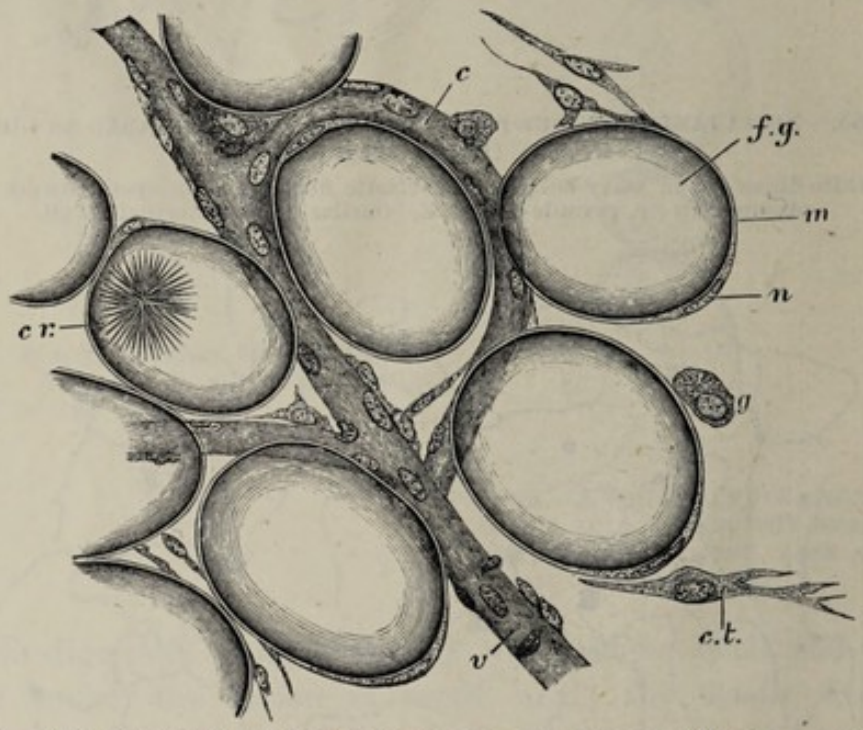


FIG. 66.—A FEW CELLS FROM THE MARGIN OF A FAT-LOBULE. (Highly magnified. From a photograph.)

f.g. fat-globule distending a fat-cell; *n*, nucleus; *m*, membranous envelope of the fat-cell; *c. r.* bunch of crystals within a fat-cell; *c*, capillary vessel; *v*, venule; *c. t.* connective-tissue cell; *g*, granular cell; the connective-tissue fibres are not represented.

vacuolated protoplasm, rarely flattened, but otherwise varying greatly in shape and size. (3) *Granular cells* (*g*) (*"Mast"-cells* of Ehrlich), usually spheroidal or ovoidal in shape, and formed, like the plasma-cells, of soft protoplasm, but thickly occupied with albuminous granules, which are deeply stained by gentian violet and by other basic aniline dyes. Migratory leucocytes may also be seen here and

there in the areolar tissues (*wander-cells*). In the middle coat of the eye in mammals, and in some parts of the skin, some of the connective-tissue cells are filled with granules of pigment (*pigment-cells*).

The cells lie in spaces in the ground substance, between the bundles of white fibres. In some parts of the connective tissue the white bundles are developed to such an extent as to pervade almost the whole of the ground-substance, and then the connective-tissue corpuscles become squeezed into the interstices, flattened lamellar expansions of the cells extending between the bundles, as in tendon (see next Lesson).

The cells and cell-spaces of areolar tissue come into intimate relation with the cells lining the lymphatic vessels and small blood-vessels. This connection can best be seen in silvered preparations; it will be again referred to in speaking of the origin of the lymphatics.

Adipose tissue consists of vesicles filled with fat (figs. 65, 66), and collected into lobules, or into tracts which accompany the small blood-

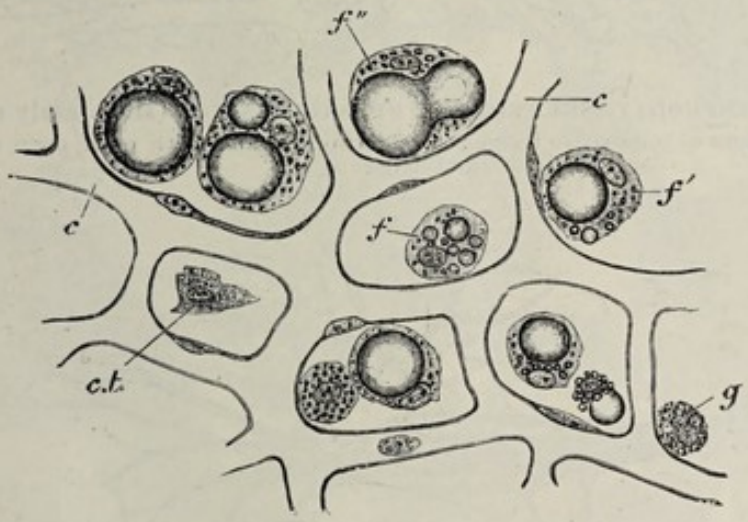


FIG. 67.—DEPOSITION OF FAT IN CONNECTIVE-TISSUE CELLS.

f, a cell with a few isolated fat-droplets in its protoplasm; *f'*, a cell with a single large and several minute drops; *f''*, fusion of two large drops; *g*, granular cell, not yet exhibiting any fat-deposition; *c.t.*, flat connective-tissue corpuscle; *c*, *c*, network of capillaries.

vessels. The vesicles are round or oval in shape, except where closely packed, when they become polyhedral from mutual compression. The fat-drop is contained within a delicate protoplasmic envelope (fig. 66, *m*) which is thickened at one part, and here includes an oval flattened nucleus. The fat is stained of an intense black by osmic acid. The vesicles are supported partly by filaments of areolar tissue, but chiefly by a fine network of capillary blood-vessels.

The fat when first formed is deposited within granular cells of areolar tissue (fig. 67) similar in general appearance to the "Mast"-cells of Ehrlich; some authorities regard them as of a specific nature. The

fat appears to be produced by a transformation of the albuminous granules into droplets of fat. As these droplets increase in size they run together into a larger drop, which gradually fills the cell more and more, swelling it out so that the cell-protoplasm eventually appears merely as the envelope of the fat-vesicle.

Fat is found most abundantly in subcutaneous areolar tissue, and under the serous membranes; especially in some parts, as at the

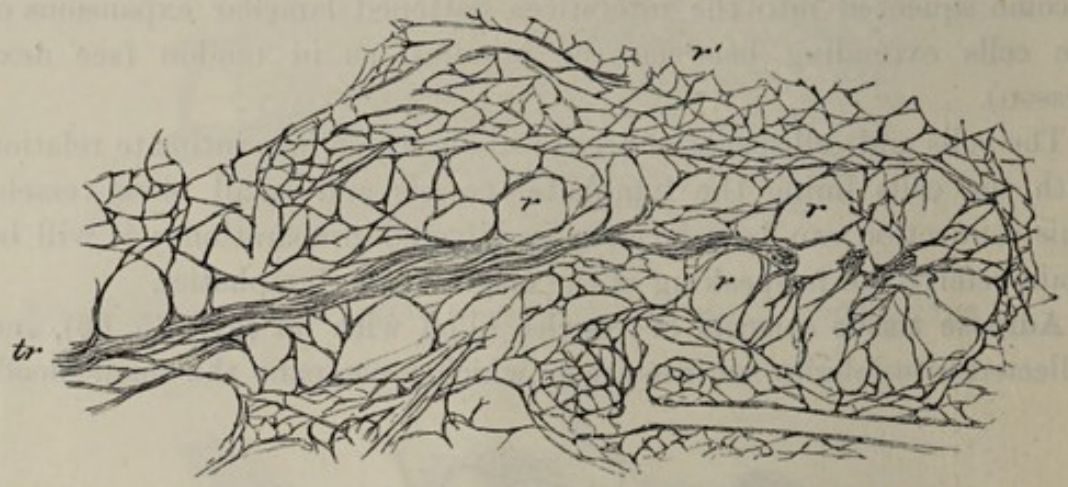


FIG. 68.—LYMPHOID TISSUE FROM A LYMPHATIC GLAND. (Moderately magnified.)
tr, a trabeculum of connective tissue; *r*, *r'*, retiform tissue, with more open meshes at *r* and denser at *r'*.

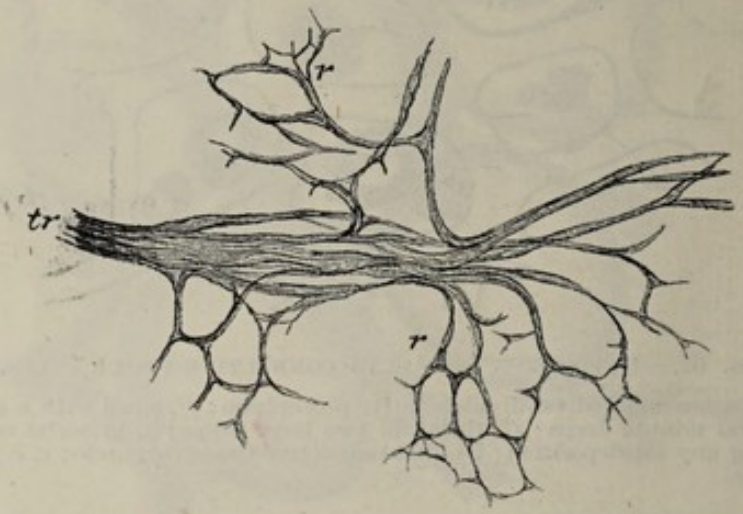


FIG. 68 A.—PORTION OF THE ABOVE, MORE HIGHLY MAGNIFIED,
showing the continuity of the retiform tissue, *r*, *r*, with the connective tissue of a trabeculum, *tr*.

back of the peritoneum around the kidneys, under the epicardium, and in the mesentery and omentum. The yellow marrow of the bones is also principally composed of fat. There is no adipose tissue within the cavity of the cranium.

Retiform or **reticular tissue** (figs. 68, 69) is a variety of connective tissue in which the intercellular or ground-substance has mostly disappeared or is replaced by fluid. There are very few or no elastic

fibres in it, and the white fibres and bundles of fibres form a dense network, the meshes of which vary in size, being very small and close in some parts; more open and like areolar tissue in other parts. In some places where the tissue occurs the fibres are almost everywhere enwrapped by flattened branched connective-tissue cells, and until these are removed it is not easy to see the fibres. Chemical differences have been stated to occur between the fibres of retiform tissue and those of ordinary areolar tissue, but these are doubtful, and it is certain that microscopically the fibres of the tissues are indistinguishable from and are found in continuity with one another (see figs. 68A, 69).

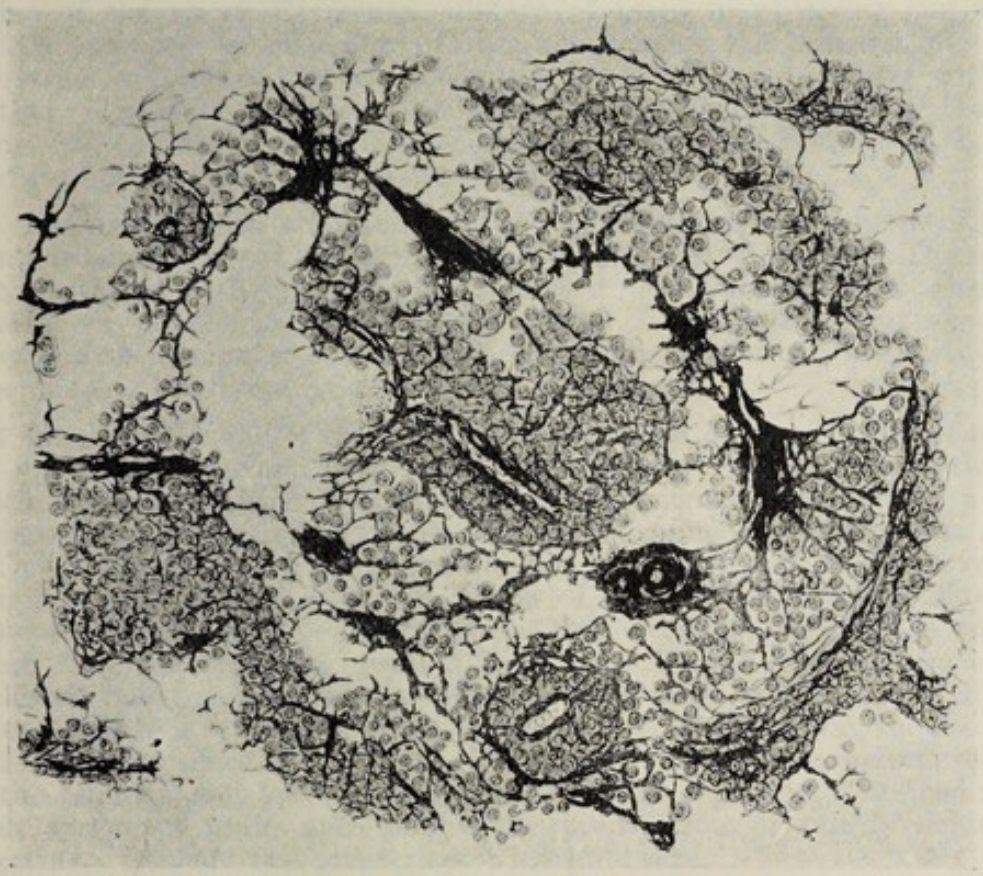


FIG. 69.—LYMPHOID TISSUE OF A LYMPHATIC GLAND.

Lymphoid or **adenoid tissue** is retiform tissue in which the meshes of the network are largely occupied by lymph-corpuscles. This is by far the most common condition of a retiform tissue, and is met with in the lymphatic glands and allied structures, and also in the tissue of the alimentary mucous membrane, and in some other situations.

Basement-membranes (*membranæ propriæ*) are homogeneous-looking membranes, which are found forming the surface-layers of connective-tissue expansions in many parts, especially where there is a covering of epithelium, as on mucous membranes, in secreting glands, and else-

where. They are generally formed of flattened connective-tissue cells joined together to form a membrane; but in some cases they are evidently formed not of cells, but of condensed ground-substance, and in yet other cases they are composed of elastic substance; the name basement-membrane is therefore used to denote structures of an entirely different nature.

Jelly-like connective tissue, although occurring largely in the embryo, is found only in one situation in the adult—viz. forming the vitreous humour of the eye. It is composed mainly of soft, perhaps fluid, ground-substance, with cells scattered here and there through it, and with very few fibres, or none at all.

LESSON X.

THE CONNECTIVE TISSUES (*continued*).

ELASTIC TISSUE, FIBROUS TISSUE, DEVELOPMENT OF CONNECTIVE TISSUE.

1. Tease out as finely as possible a small shred of elastic tissue (ligamentum nuchæ of the ox or ligamenta subflava of man) in glycerine and water, slightly coloured by magenta. Cover and cement the preparation. Note the large well-defined fibres constantly branching and uniting with one another. Look for transverse markings on the fibres. Measure three or four. Sketch a small part of the network. Note the existence of bundles of white fibres amongst the elastic fibres.

2. Examine a thin transverse section of ligamentum nuchæ which has been hardened in 2 per cent. solution of bichromate of potash. The section is to be stained with hæmalum and mounted in Canada balsam by the usual process,[1] or simply in glycerine and water. Observe the grouping of the fibres and their angular shape. Notice also the nuclei of connective-tissue cells amongst the fibres. Sketch one or two groups.

3. Pinch off the end of the tail of a dead mouse or rat, draw out the long silk-like tendons and put them into salt solution. Take two of the threads, which must be at least two inches long, and stretch them along a slide, letting the ends dry firmly to the slide but keeping the middle part moist. Put a piece of hair between them and cover in salt solution. Observe with a high power the fine wavy fibrillation of the tendon. Draw. Now run dilute acetic acid (0·75 per cent.) under the cover-glass, watch the tendons where they are becoming swollen by the acetic acid. Notice the oblong nucleated cells coming into view between the tendon-bundles. Sketch three or four cells in a row. Lastly, lift the cover-glass, wash away the acid with distilled water, place a drop of Ehrlich's hæmatoxylin or carmalum solution on the tendons, and leave the preparation until it is deeply stained; then wash away the stain and mount the preparation in faintly acidulated glycerine. Cement the cover-glass with gold size.

4. Take one or two other long pieces of tendon, and after washing them in distilled water, stretch them upon a slide as before, fixing the ends by allowing them to dry on to the slide. Put a drop of nitrate of silver solution (0·75 per cent.) on the middle of the tendons, and leave it on for five minutes, keeping the preparation in the dark. Then wash off the silver nitrate with distilled water, and expose the slide to direct sunlight. In a very few minutes the silvered part of the tendons will be brown. As soon as this is the case, dehydrate the tendons with alcohol *in situ* upon the slide, run off the alcohol, and at once put a drop of clove oil on the preparation. In a minute or two the clove oil can be replaced by xylol balsam and covered.

5. Stain with magenta solution a thin section of a tendon which has been hardened in 70 per cent. alcohol. Mount in dilute glycerine and cement the cover-glass at once. Sketch a portion of the section under a low power.

[1] See Appendix.

Elastic tissue is a variety of connective tissue in which the elastic fibres preponderate. It is found most characteristically in the ligamentum nuchæ of quadrupeds and the ligamenta subflava of the vertebræ, but the connective tissue of other parts may also have a considerable development of elastic fibres. It occurs in an almost pure form in the walls of the air-tubes, and uniting the cartilages of the larynx. It also enters largely into the formation of the lungs and of the walls of the blood-vessels, especially the arteries.

In the ligamentum nuchæ most of the fibres are very large (figs. 70, 71). They often exhibit cross-markings or even transverse clefts.

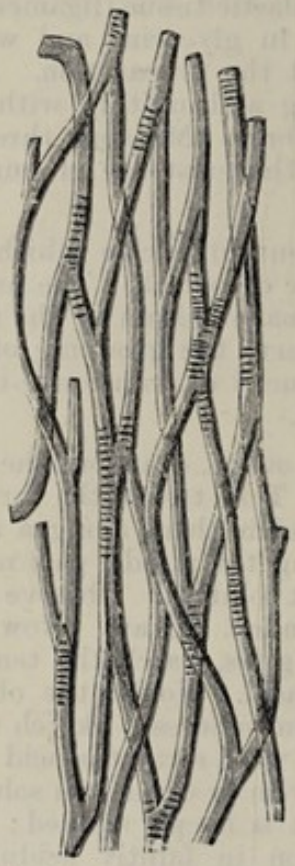


FIG. 70.—ELASTIC FIBRES FROM THE LIGAMENTUM NUCHÆ OF THE OX, SHOWING TRANSVERSE MARKINGS ON THE FIBRES.

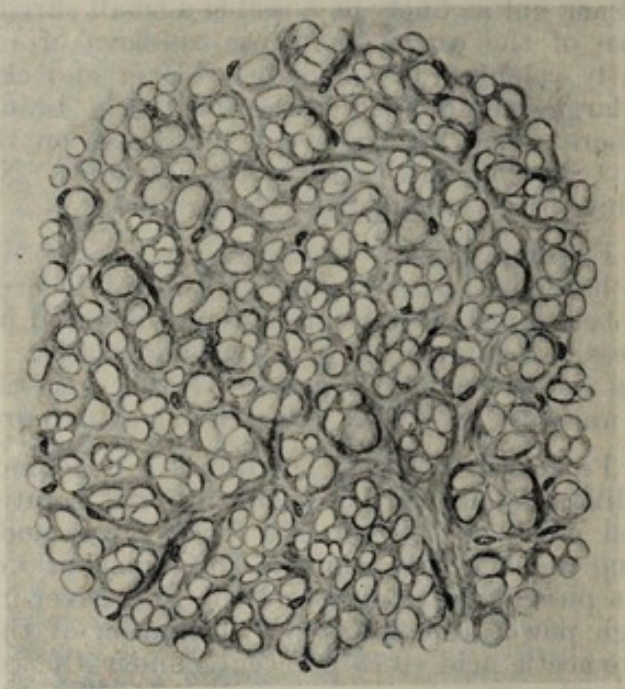


FIG. 71.—CROSS-SECTION OF ELASTIC FIBRES FROM THE LIGAMENTUM NUCHÆ OF THE OX.

When dragged asunder, they break sharply across. They constantly branch and unite, so as to form a close network. In transverse section they are seen to be separated into small groups or bundles (fig. 71) by intervening septa of areolar tissue.

Elastic tissue does not always take the form of fibres, but may occur as membranes (as in the blood-vessels). Sometimes the fibres are very small, but their microscopical and chemical characters are always very well marked (see p. 59).

Fibrous tissue is almost wholly made up of bundles of white fibres running in a determinate direction. These again are collected into

larger bundles, which give the fibrous appearance to the tissue. The bundles are constantly uniting with one another in their course, although their component fibres remain perfectly distinct.

The interspaces between the larger bundles are occupied by areolar tissue (fig. 72, *c*, *d*, *e*) in which the blood-vessels and lymphatics of the

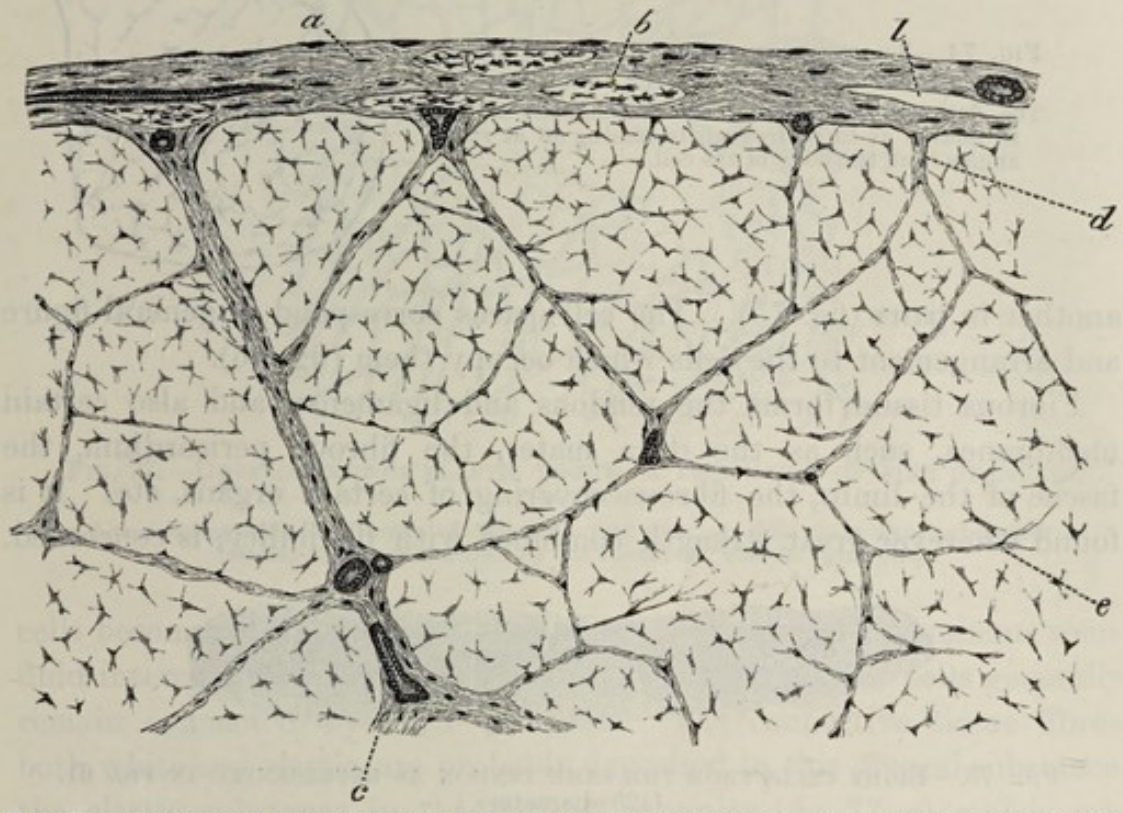


FIG. 72.—PART OF A LARGE TENDON IN TRANSVERSE SECTION. (Moderately magnified.)

a, areolar sheath of the tendon, with the fibres for the most part running transversely; but with two or three longitudinal bundles, *b*; *l*, lymphatic cleft in the sheath; immediately over it a blood-vessel is seen cut across, and on the other side of the figure a small artery is shown cut longitudinally; *c*, large septum of areolar tissue; *d*, smaller septum; *e*, still smaller septum. The irregularly stellate bodies are the tendon-cells in section.

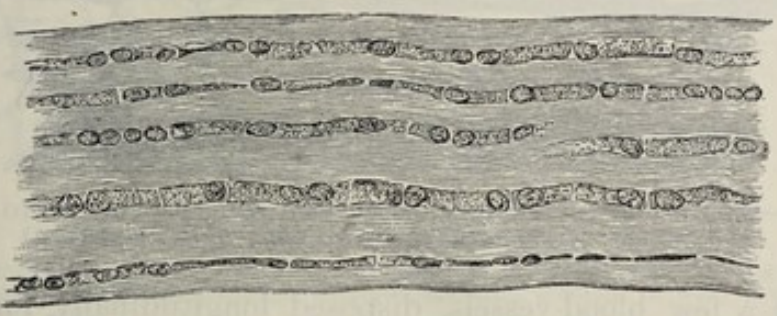


FIG. 73.—TENDON OF MOUSE'S TAIL; SHOWING CHAINS OF CELLS BETWEEN THE TENDON-BUNDLES. (175 diameters.)

fibrous tissue are conveyed. The interstices between the smallest bundles are occupied by rows of lamellar connective-tissue corpuscles (*tendon-cells*), which, from being squeezed up between three or more bundles, become flattened out in two or three directions. In transverse section the cells appear somewhat stellate (figs. 72, 74), but when seen on the flat

they appear lamellar (fig. 73), and from this aspect their general shape is square or oblong. They lie, as before said, in rows between the tendon-bundles, and the nuclei of adjacent cells are placed opposite one

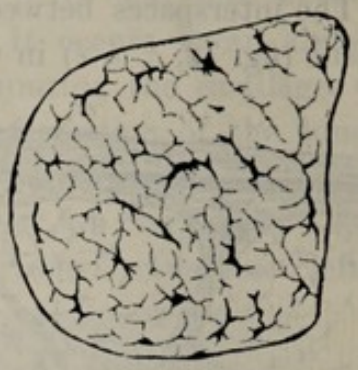


FIG. 74.—TRANSVERSE SECTION OF TENDON OF MOUSE'S TAIL, STAINED. (175 diameters.)
The flattened processes of the tendon-cells appear in section as lines, frequently coming off at right angles from the body of the cell.

another in pairs (fig. 75). The cell-spaces correspond in general figure and arrangement to the cells which occupy them (fig. 76).

Fibrous tissue forms the tendons and ligaments, and also certain membranes, such as the dura mater, the fibrous pericardium, the fasciæ of the limbs, the fibrous covering of certain organs, etc. It is found wherever great strength combined with flexibility, is concerned.

FIG. 75.—EIGHT CELLS FROM THE SAME TENDON AS REPRESENTED IN FIG. 61. (425 diameters.)
The dark lines on the surface of the cells are the optical sections of lamellar extensions directed towards or away from the observer.

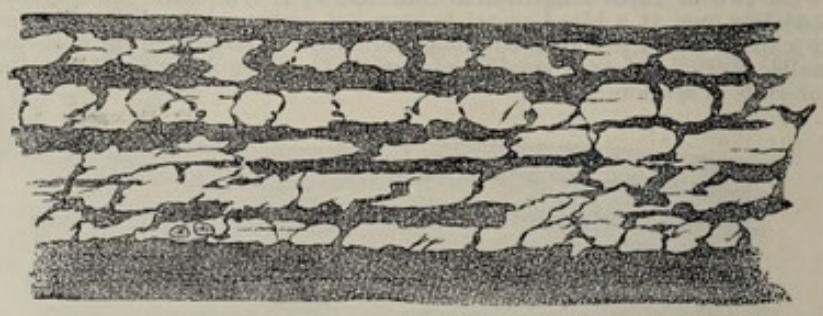


FIG. 76.—CELL-SPACES OF TENDON OF MOUSE'S TAIL, BROUGHT INTO VIEW BY TREATMENT WITH NITRATE OF SILVER. (175 diameters.)

It receives a few blood-vessels, disposed longitudinally for the most part, and contains many lymphatics. Both blood-vessels and lymphatics run in the areolar tissue which separates and surrounds the tendon-bundles. Tendons and ligaments also receive nerve-fibres, which, in some cases, end in localised ramifications within fusiform enlargements of the tendon-bundles (organs of Golgi), while others terminate in end-bulbs or in simple Pacinian corpuscles. These will be described along with the modes of ending of nerve-fibres.

Development of connective tissue.—Connective tissue is always developed in the mesoblast or mesoderm of the embryo. In those parts of this layer which are to form connective tissue, the embryonic

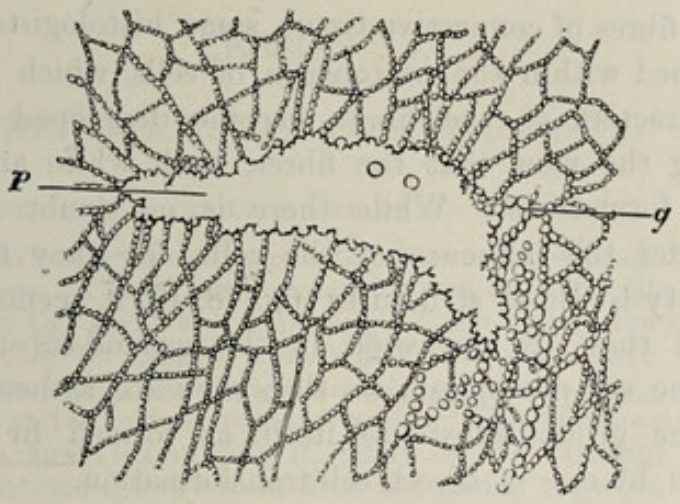


FIG. 77.—DEVELOPMENT OF ELASTIC TISSUE BY DEPOSITION OF FINE GRANULES. (Ranvier.)

g, fibres being formed of rows of 'elastin' granules; *p*, flat plate-like expansion of elastic substance formed by the fusion of 'elastin' granules.

cells become separated from one another by a muco-albuminous semi-fluid intercellular substance (ground-substance), but the cells generally remain connected by their processes. The connective tissue fibres, both white and elastic, are probably deposited in this ground-substance, the elastic substance in the form of granules (fig. 77, *g*), which sub-

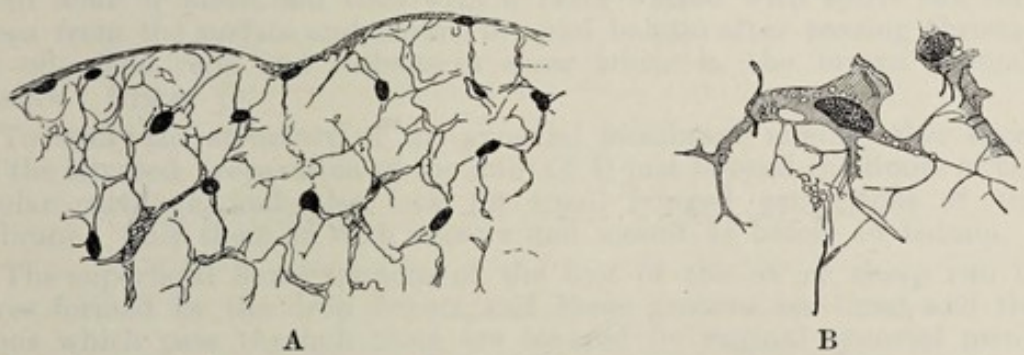


FIG. 78.—SECTION OF JELLY OF WHARTON. (Flemming.)

A, moderately magnified, showing ramified cells intercommunicating by their branches; B, two cells further enlarged, showing portions of wavy fibrils passing over the cells.

sequently become connected together into elastic fibres or laminæ, as the case may be, the white fibres appearing at first in the form of very fine bundles, which afterwards become gradually larger; so that in fibrous tissue the whole ground-substance is eventually pervaded by the bundles, and the cells of the tissue become squeezed up into the intervals between them. Before any considerable development

of fibres has taken place, the embryonic connective tissue has a jelly-like appearance; in this form it occurs in the umbilical cord, where it is known as the *jelly of Wharton* (fig. 78).

There has been always a considerable difference of opinion as to the origin of the fibres of connective tissue, some histologists holding that they are formed within the protoplasm of cells, which gradually lose their cell-characters as the fibres become developed within them; others taking the view that the fibres, both white and elastic, are extracellular formations. While there is no doubt that they are produced under the influence of the cells, for they first appear in close proximity to those structures (fig. 78, B), it seems on the whole probable that they are deposited in the ground-substance and not actually in the cell-protoplasm, so that they are rather to be looked upon, like the ground-substance itself, as formed by a process of secretion than by one of direct cell-transformation.

LESSON XI.

THE CONNECTIVE TISSUES (continued).

ARTICULAR CARTILAGE: SYNOVIAL MEMBRANES.

1. Cut two or three very thin tangential slices of the fresh cartilage of a joint, mount them in salt solution, and examine with the high power. Observe carefully the form and grouping of the cells. Look at the thin edge of the section for spaces from which the cells have dropped out. Measure two or three cells and their nuclei, and sketch one or two groups. Now replace the salt solution by water and set the preparation aside for a little while. On again examining it, many of the cartilage cells will be found to have contracted away from their containing capsules.

2. Make other sections of the cartilage (1) from near the middle, (2) from near the edge. Place the sections for two or three minutes in acetic acid (1 per cent.), wash them with water, and stain with dilute hæmalum or carmalum solution. When stained mount in dilute glycerine and cement the cover-glass. In (2) look for branched cartilage cells. Draw one or two.

3. Make vertical sections of articular cartilage from an end of bone which has been decalcified in 0·5 per cent. chromic acid solution, and mount the sections in glycerine and water, or, after staining with carmalum, in xylol balsam. Sketch the arrangement of the cells in the different layers.

4. Brush a fresh joint with distilled water; drop 0·75 per cent. nitrate of silver solution over it; after five minutes wash away the nitrate of silver and expose in water to direct sunlight. When browned, place in spirit for half an hour or more, and then with a razor wetted with spirit cut thin sections from the surface and mount in xylol balsam after passing through clove oil. The cells and cell-spaces show white in the brown ground-substance. Draw.

5. To study the structure of the synovial membrane mount other slices from the silvered preparation of the joint (§ 4) just beyond the limits of the articular cartilage, and also look for small fringed projections of the membrane. Snip them off with scissors and mount as before in balsam.

6. The superficial flexor tendons of the foot of the ox or sheep run in grooves formed by the deep flexors, and these grooves are lined, and the tendons which pass through them are covered by vaginal synovial membranes. To show the structure of these treat one of the superficial flexor tendons with silver nitrate in the same way as recommended for the joint, and after hardening in spirit cut sections from the surface and mount them in balsam.

Cartilage or *gristle* is a translucent bluish-white tissue, firm, and at the same time elastic, and for the most part found in connection with bones of the skeleton, most of which are in the embryo at first represented entirely by cartilage. Three chief varieties of cartilage are distinguished. In one, which is termed *hyaline*, the matrix or ground-substance is almost clear, and free from obvious fibres; in the other

two, which are termed *fibro-cartilage*, the matrix is everywhere pervaded by connective-tissue fibres. When these are of the white variety, the tissue is *white fibro-cartilage*; when they are elastic fibres, it is *yellow* or *elastic fibro-cartilage*.

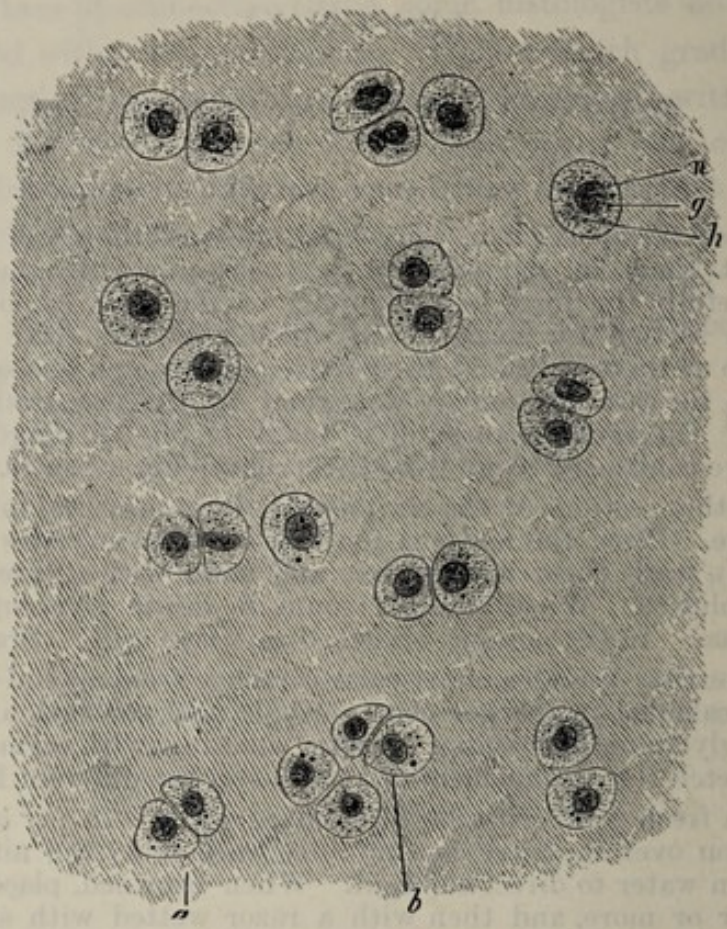


FIG. 79.—ARTICULAR CARTILAGE FROM HEAD OF METATARSAL BONE OF AMPUTATED FOOT, HUMAN (OSMIC ACID PREPARATION). THE CELL-BODIES ENTIRELY FILL THE SPACES IN THE MATRIX. (340 diameters.)

a, group of two cells; *b*, group of four cells; *h*, protoplasm of cell, with *g*, fatty granules; *n*, nucleus.

Hyaline cartilage occurs principally in two situations—namely (1) covering the ends of the bones in the joints, where it is known as *articular cartilage*; and (2) forming the rib-cartilages, where it is known as *costal cartilage*. It also forms the cartilages of the nose, of the external auditory meatus (but not the pinna), most of those of the larynx, and the cartilages of the windpipe; in these places it serves to maintain the shape and patency of the orifices and tubes.

Articular cartilage.—The cells of articular cartilage are generally scattered in groups of two or four throughout the matrix (fig. 79). The latter is free from obvious fibres, except at the extreme edge of the cartilage, where the connective-tissue fibres from the synovial membrane extend into it, and here also the cartilage-cells are often branched, and offer transitions to the branched connective-tissue

corpuscles of that membrane (*transitional cartilage*, fig. 80). By long maceration in brine, however, evidence of a fibrous structure may be obtained, even in the matrix of true hyaline cartilage. Some his-

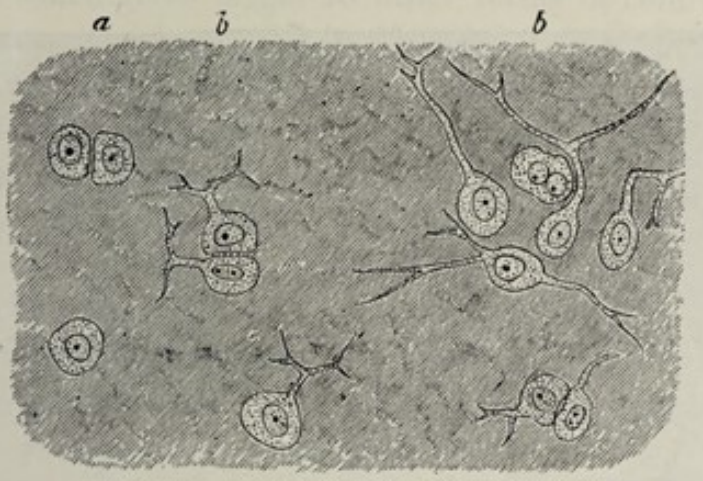


FIG. 80.—BORDER OF ARTICULAR CARTILAGE SHOWING TRANSITION OF CARTILAGE CELLS INTO CONNECTIVE-TISSUE CORPUSCLES OF SYNOVIAL MEMBRANE. FROM HEAD OF METATARSAL BONE, HUMAN. (About 340 diameters.)
a, ordinary cartilage-cells; *b*, *b*, with branching processes.

tologists also describe fine communications in the matrix uniting the cartilage-cells with one another, but these are of doubtful occurrence in vertebrate cartilage, although they unquestionably exist in the cartilage of cephalopods.

The matrix immediately around the cartilage-cells is often marked off from the rest by a concentric line or lines, this part of the matrix, which is the latest formed, being known as the *capsule* of the cell. The cells are bluntly angular in form, the sides opposite to one another in the groups being generally flattened. The protoplasm is very clear, but it may contain droplets of fat; and with a high power fine interlacing filaments and granules have been observed in it. During life the protoplasm entirely fills the cavity or cell-space which it occupies in the matrix; but after death, and in consequence of the action of water and other agents, it tends to shrink away from the capsule. The nucleus is round, and shows the usual intranuclear network.

In vertical section (fig. 81) the deeper cell groups (*c*) are seen to be arranged vertically to the surface, the more superficial ones (*a*) parallel to the surface; whilst in an intermediate zone the groups are irregularly disposed (*b*). In the deepest part of the cartilage, next to the bone, there is often a deposition of calcareous salts in the matrix (*calcified cartilage*, *d*).

The disposition of the cells of cartilage in groups of two, four, eight, etc., is apparently due to the fact that these groups have originated from the division of a single cell first into two, and these again into

two, and so on (fig. 82). It would seem that the matrix is formed of successive portions, which are deposited around each cartilage-cell as the so-called 'capsules,' each newly formed portion soon blending in its

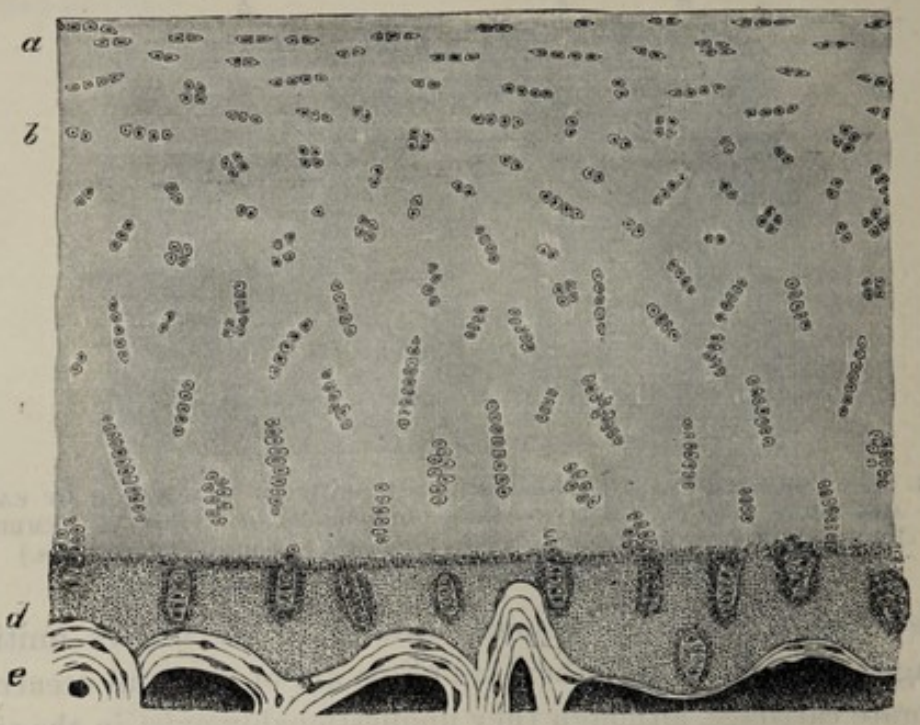


FIG. 81.—VERTICAL SECTION OF ARTICULAR CARTILAGE COVERING THE LOWER END OF THE TIBIA, HUMAN. (Magnified about 30 diameters.)

a, cells and cell-groups flattened conformably with the surface; *b*, cell-groups irregularly arranged; *c*, cell-groups disposed perpendicularly to the surface; *d*, layer of calcified cartilage; *e*, bone.

turn with the previously formed matrix, whilst a new capsule is formed within it. The division of the cartilage-cell, like that of other cells, is mitotic.

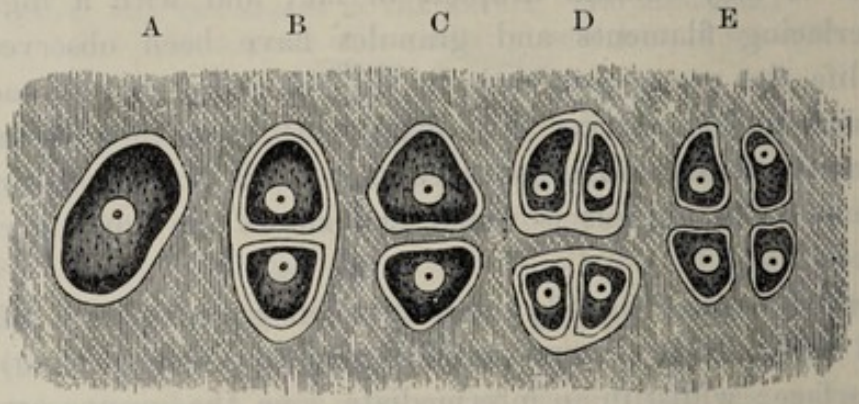


FIG. 82.—PLAN OF THE MULTIPLICATION OF CELLS OF CARTILAGE. (Sharpey.)

A, cell in its capsule; B, divided into two, each with a capsule; C, primary capsule disappeared, secondary capsules coherent with matrix; D, tertiary division; E, secondary capsules disappeared, tertiary coherent with matrix.

Embryonic cartilage is characterised by the cells being usually more sharply angular and irregular; they are even in some cases markedly branched, like those which occur at the junction of cartilage and

synovial membrane in the adult. The cells are also more closely packed, the matrix being in relatively less amount than in later life.

Development.—Cartilage is formed in the embryo from mesoblast similar to that which gives origin to other forms of connective-tissue. Each cell forms a capsule around itself, and the blended capsules compose the first matrix. Cartilage sometimes remains in this condition throughout life; it is then termed *parenchymatous cartilage*. This can be seen in the mouse's ear; where also the cartilage cells become filled with fat. Cartilage grows at first partly by interstitial expansion (accompanied by cell multiplication and by formation around and between the cells of intercellular substance), partly by apposition at the perichondrium, the connective-tissue becoming here transformed into cartilage. At a later period of growth the increase in size and change in shape of cartilages are due almost entirely to the agency of the perichondrium.

FIG. 83.—VILLUS OF SYNOVIAL MEMBRANE. (Hammar.)

The **synovial membranes** are often compared with the serous membranes. They are indeed, like the latter, connective-tissue membranes which bound closed cavities moistened with fluid, but they are not connected with the lymphatic system, nor is the fluid (synovia) which moistens them of the nature of lymph. Moreover, there is either no epithelial lining, or it occurs only in patches, in place of the continuous lining which we find in the serous membranes. Long villus-like projections occur in many parts; they are often covered by small rounded cells, and probably serve to extend the surface for the secretion of synovia. The blood-vessels of synovial membranes are numerous, and approach close to the inner surface of the membrane. They are well seen in preparations from an injected limb.

LESSON XII.

THE CONNECTIVE TISSUES (*continued*).

COSTAL CARTILAGE. FIBRO-CARTILAGE.

1. MAKE transverse and tangential sections of a rib-cartilage, which may either be fresh, or may have been preserved in spirit or formol. Stain them with hæmalum or carmalum (if fresh, after treatment with acetic acid as in Lesson XI., § 2, or they may be placed for an hour or two in ·5 p.c. osmic acid), and mount in glycerine. Sketch a part of a transverse section under a low power and a cell-group from one of the tangential sections under a high power. Notice especially the arrangement of the cells, somewhat concentric near the surface but radial near the centre. The costal cartilages tend to become ossified near the middle in most animals, but in man when ossification occurs it is the superficial layer which is invaded.

2. Make sections of the cartilage of the external ear (pinna), either fresh or after hardening in alcohol. Mount in dilute glycerine faintly coloured with magenta, or stain with orcein and mount in balsam. If from the ox, notice the very large reticulating elastic fibres in the matrix. Notice also the isolated granules of elastin, and around the cartilage-cells the area of clear ground-substance. If from the mouse or rat there is very little matrix and no elastic fibres, and the cells are almost in contact (parenchymatous cartilage). Draw a small portion of the section.

3. Mount a section of the epiglottis in the same way. Notice the closer network of much finer fibres in its cartilage.

4. Cut sections of white fibro-cartilage (intervertebral disk or semilunar cartilage of knee), which has been hardened in picric acid, followed by spirit, or in spirit only. Stain the sections with dilute hæmalum or carmalum. Mount in dilute glycerine. Observe the wavy fibres in the matrix and the cartilage-cells lying in clear areas often concentrically striated. Look for branched cartilage-cells. Sketch three or four cells and the adjoining fibrous matrix.

Costal cartilage.—In the costal cartilages the matrix is not always so clear as in the cartilage of the joints, for it more often happens that fibres become developed in it. The cells are generally larger and more angular than those of articular cartilage, and collected into larger groups (fig. 84). Near the circumference, and under the perichondrium or fibrous covering of the cartilage, they are flattened and parallel to the surface, but in the deeper parts they have a more irregular or a radiated arrangement. They frequently contain fat, staining with osmic acid. The cartilages of the larynx and windpipe and of the nose resemble on the whole the costal cartilages, but the study of them may be deferred until the organs where they occur are dealt with.

Elastic or **yellow fibro-cartilage** occurs in only a few situations.

These are, the cartilage of the external ear and that of the Eustachian tube, and the epiglottis and cartilages of Santorini of the larynx. The

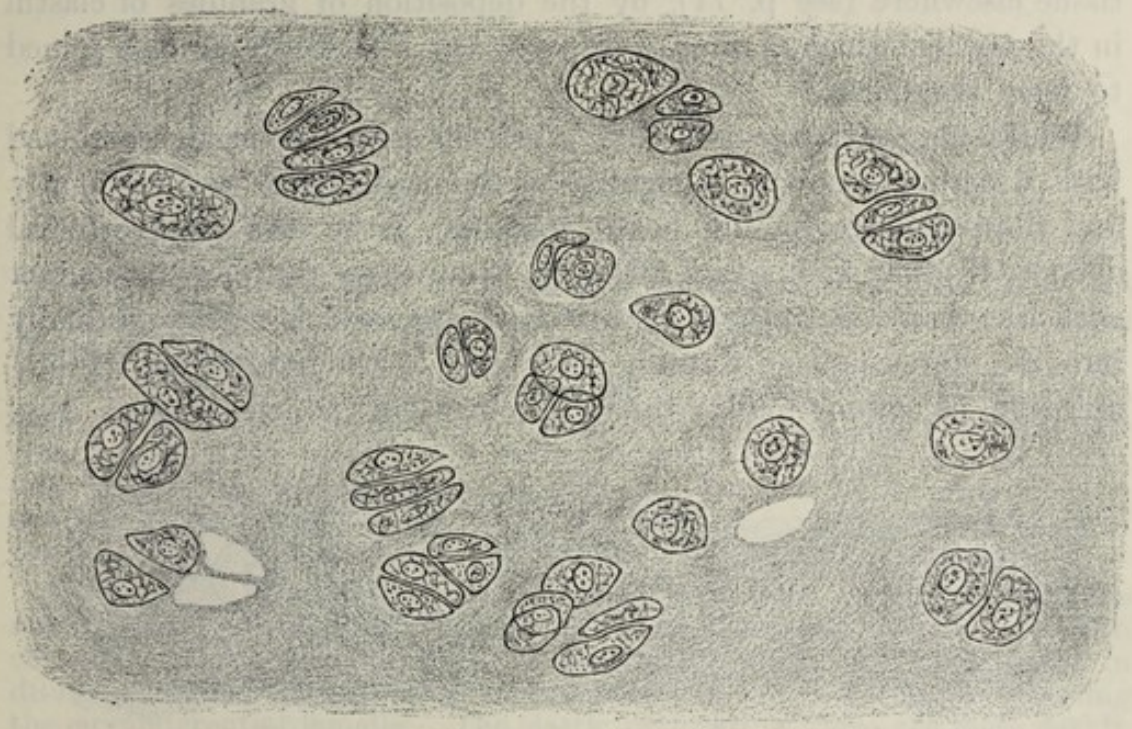


FIG. 84.—SECTION OF RIB-CARTILAGE, SHOWING CELLS AND CELL-GROUPS IN AN INDISTINCTLY FIBROUS MATRIX.

Two or three empty cell-spaces are seen from which the cells have dropped out in preparing the section.

matrix is everywhere pervaded with well-defined branching fibres, which unite with one another to form a close network (fig. 85).

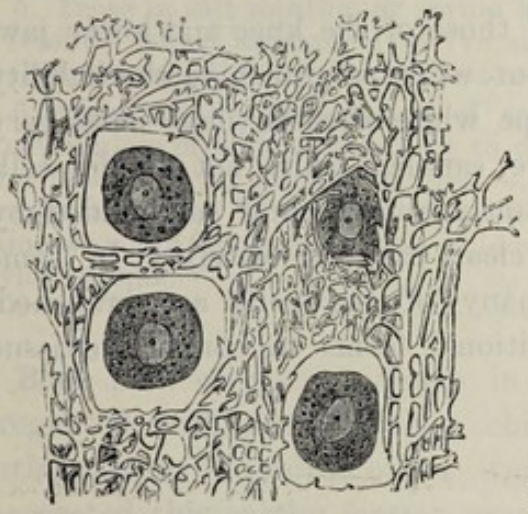


FIG. 85.—SECTION OF THE ELASTIC CARTILAGE OF THE EAR. (Hertwig.) (Highly magnified.)

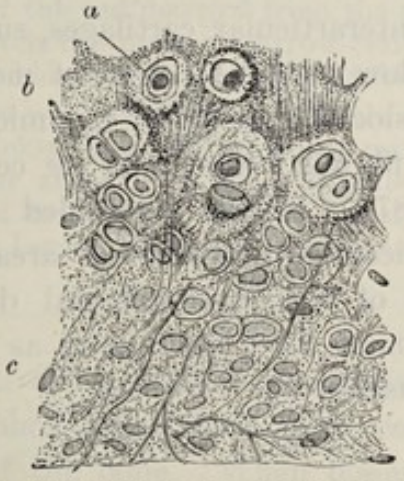


FIG. 86.—SECTION OF PART OF THE CARTILAGE OF THE EPIGLOTTIS. (Ranvier.)

a, cartilage cell in clear area; *b*, granular-looking matrix near the middle of the cartilage, the granular appearance being due partly to the fine reticulum of elastic fibres, partly to the presence of granules of elastic substance in the matrix; *c*, clearer matrix with longer fibres.

These fibres resist the action of acetic acid, and are stained deeply by magenta; they are evidently elastic fibres. In the ox they are

very large, but smaller in man, especially in the cartilage of the epiglottis (fig. 86). They appear to be developed, as with elastic tissue elsewhere (see p. 71), by the deposition of granules of elastin in the matrix, which at first lie singly, but afterwards become joined to form the fibres.

White fibro-cartilage is found wherever great strength combined with a certain amount of rigidity is required: thus we frequently find fibro-cartilage joining bones together, as in the intervertebral disks and other symphyses. But in these cases the part in contact with the bone is always hyaline cartilage, which passes gradually into the fibro-cartilage forming the bulk of the symphysis. Fibro-cartilage is often found lining grooves in which tendons run,

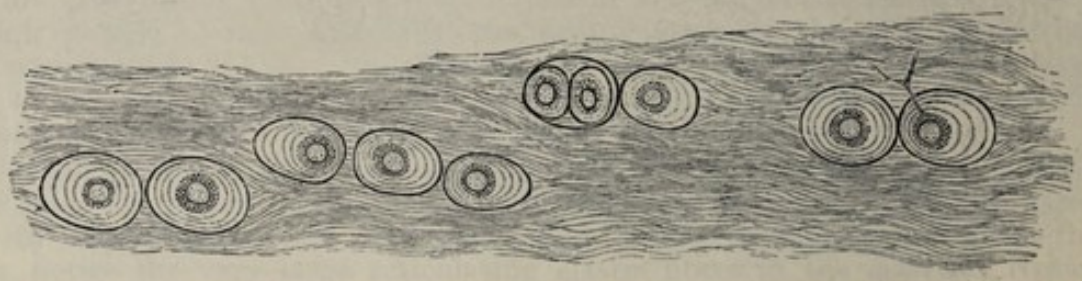


FIG. 87.—WHITE FIBRO-CARTILAGE FROM AN INTERVERTEBRAL DISK, HUMAN. (Highly magnified.)

The concentric lines around the cells indicate the limits of deposit of successive capsules. One of the cells has a forked process which extends beyond the hyaline area surrounding the cell, amongst the fibres of the general matrix.

and it may be found in the tendons themselves. It is also employed to deepen cup-shaped articular surfaces; and in the case of the interarticular cartilages, such as those of the knee and lower jaw, to allow greater freedom of movement whilst diminishing the liability to dislocation. Under the microscope white fibro-cartilage looks very like fibrous tissue, but its cells are cartilage-cells, not tendon-cells (fig. 87). They are rounded or bluntly angular and surrounded by a concentrically striated area of clear cartilage-matrix. In some parts of the intervertebral disk many of the cells are branched, and may be looked upon as transitional forms to connective-tissue corpuscles.

LESSON XIII.

BONE AND MARROW.

1. In thin sections of hard bone made by grinding, observe the Haversian canals, lamellæ, lacunæ, canaliculi, etc. Make a sketch first under a low and afterwards under a high power.

2. With fine forceps strip off a thin shred from the superficial layers of a bone which has been decalcified in dilute nitric acid and afterwards kept for some time in dilute alcohol repeatedly changed. Mount the shred in water. Observe the fibrous structure of the lamellæ. Look for perforating fibres or the holes from which they have been dragged out. Sketch a small piece of the thin edge of a lamella.

3. Stain with dilute magenta and hæmalum solution, or with methyl-blue and eosin, very thin sections of compact bone which has been decalcified in chromic or picric acid, or in phloroglucin and nitric acid, and mount in dilute glycerine, cementing at once. Look for fibres of Sharpey piercing the circumferential lamellæ. The elastic perforating fibres are more darkly stained than the others. Notice the stained nuclei of the bone-corpuscles in the lacunæ. In the thinnest parts of the sections try to make out the blood-vessels and other structures in the Haversian canals.

4. Mount in xylol balsam sections of marrow fixed with mercuric chloride and stained with eosin and methyl blue from a long bone of a rabbit. Observe the fat-cells, the supporting reticular tissue, the proper marrow-cells in this tissue, the myeloplaxes and the erythroblasts.

5. Tease in salt solution or serum some of the red marrow from the rib of a recently killed animal. Observe and sketch the proper marrow-cells and look for myeloplaxes and nucleated coloured blood-corpuscles (erythroblasts).

6. Make a film preparation of red marrow by smearing a little upon a cover-glass or slide, allowing it to dry quickly, and placing it in a mixture of equal parts of ether and alcohol. After an hour or more in this, the preparation may be stained with eosin and methylene blue in exactly the same way as a film preparation of blood (see Lesson II., § 5), and mounted in xylol balsam.

Bone is a connective tissue in which the ground-substance is impregnated with salts of lime, chiefly phosphate, these salts constituting about two-thirds of the weight of the bone. When bones are macerated this earthy matter prevents the putrefaction of the animal matter. When bones are calcined they lose one-third of their weight, owing to the destruction of the animal matter; when steeped in acid the earthy salts are dissolved and only the animal matter is left. This, like areolar and fibrous tissue, is converted into gelatine by boiling.

Bony tissue is either *compact* or *cancellated*. Compact bone is dense, like ivory; cancellated is spongy with obvious interstices. The outer

layers of all bones are compact, and the inner part is generally cancellated, but the shaft of a long bone is almost entirely made up of compact substance except along the centre, which is hollow and filled with marrow. The interstices of cancellated bone are also occupied by marrow. Externally bones are covered except at the joints by a vascular fibrous membrane, the *periosteum*.

True bone is always made up of *lamellæ*, and these again are composed of fine *fibres* lying in a *calcified ground-substance*. Between the lamellæ are branched cells, the *bone-corpuscles*, which lie in cell-spaces or *lacunæ*. The ramified passages which contain the cell-processes are termed *canaliculi*.

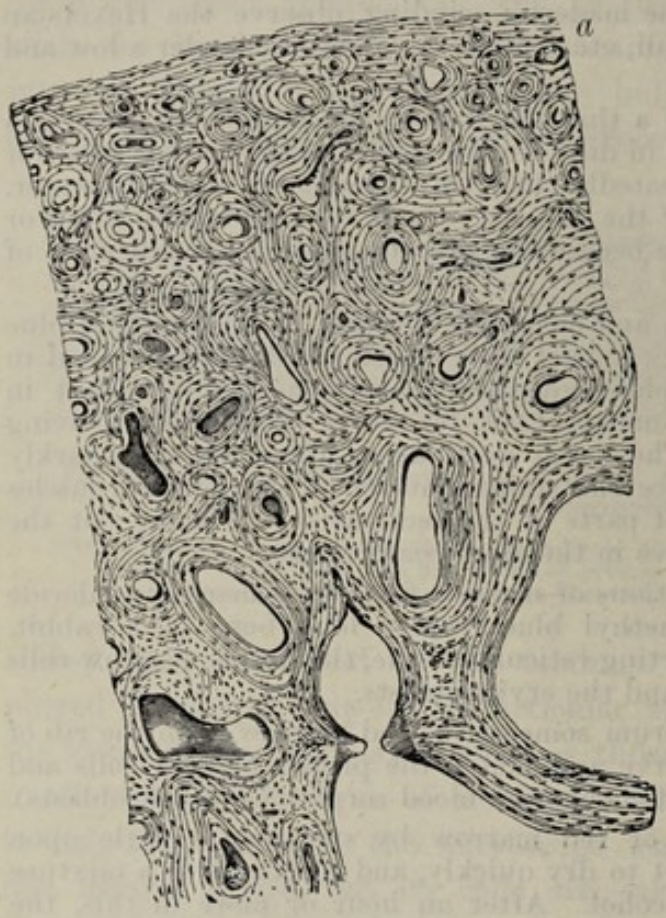


FIG. 88.—TRANSVERSE SECTION OF A BONE (ULNA). (Sharpey.) (Magnified 20 diameters.)

The openings of the Haversian canals are seen encircled by concentric lamellæ. Other lamellæ (*a*) run parallel with the surface.

In cancellated bone the blood-vessels run in the interstices supported by the marrow. In compact bone they are contained in little canals—the *Haversian canals*—which everywhere pervade the bone. These canals are about 0·05 mm. ($\frac{1}{500}$ inch) in diameter, but some are smaller, others larger than this. Their general direction is longitudinal, *i.e.* parallel to the long axis of the bone, but they are constantly united by transversely and obliquely running passages. In a section across the shaft of a long bone they are seen as small rounded or irregular holes (fig. 88). When the section has been made by grinding, the holes get filled up with air and debris, and they then look black by transmitted light, as do also the lacunæ and canaliculi (fig. 89). Most of the lamellæ in compact bone are disposed concentrically around the Haversian canals; they are known as the Haversian lamellæ, and with the included canal form what is known as a *Haversian system*. The lacunæ of a Haversian system communicate with one another and with the Haversian canal, but not as a rule with the lacunæ of other Haversian systems. The angular interstices between the Haversian

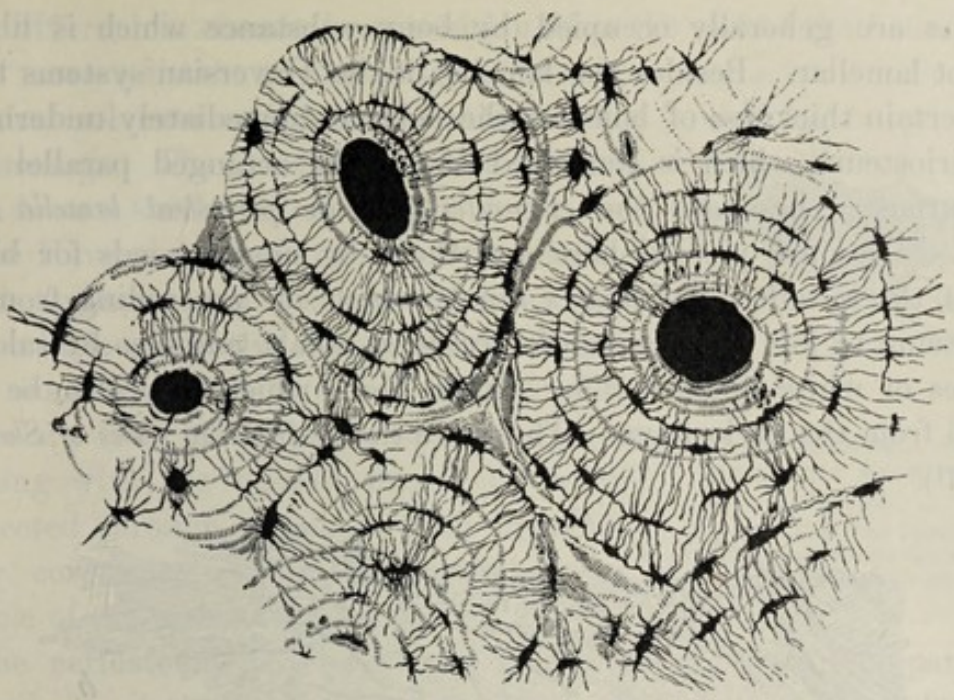


FIG. 89.—TRANSVERSE SECTION OF COMPACT TISSUE (OF HUMERUS). (Sharpey.) (Magnified about 150 diameters.)

Three of the Haversian canals are seen, with their concentric rings; also the lacunæ, with the canaliculi extending from them across the direction of the lamellæ. The Haversian apertures had become filled with air and debris in grinding down the section, and therefore appear black in the figure, which represents the object as viewed by transmitted light.

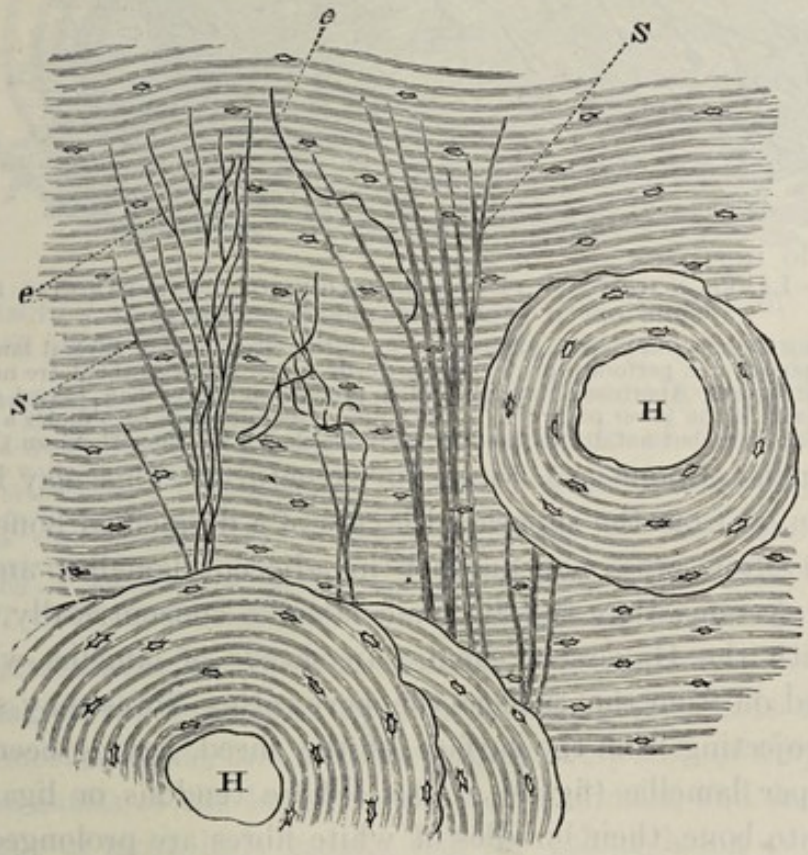


FIG. 90.—TRANSVERSE SECTION OF DECALCIFIED HUMAN TIBIA, FROM NEAR THE SURFACE OF THE SHAFT.

H, H, Haversian canals, with their systems of concentric lamellæ; in all the rest of the figure the lamellæ are circumferential; *s*, ordinary perforating fibres of Sharpey; *e*, *e*, elastic perforating fibres. Drawn under a power of about 150 diameters.

systems are generally occupied by bony substance which is fibrous but not lamellar. Besides the lamellæ of the Haversian systems there is a certain thickness of bone at the surface, immediately underneath the periosteum, which is composed of lamellæ arranged parallel with the surface; these are the *circumferential* or *periosteal lamellæ* (fig. 88, *a*). They are pierced here and there by simple canals for blood-vessels, the so-called *Volkmann's canals*, which are proceeding from the periosteum to join the system of Haversian canals, and also by calcified bundles of white fibres and by elastic fibres which may also be prolonged from the periosteum. These are the *perforating fibres of Sharpey* (fig. 90).

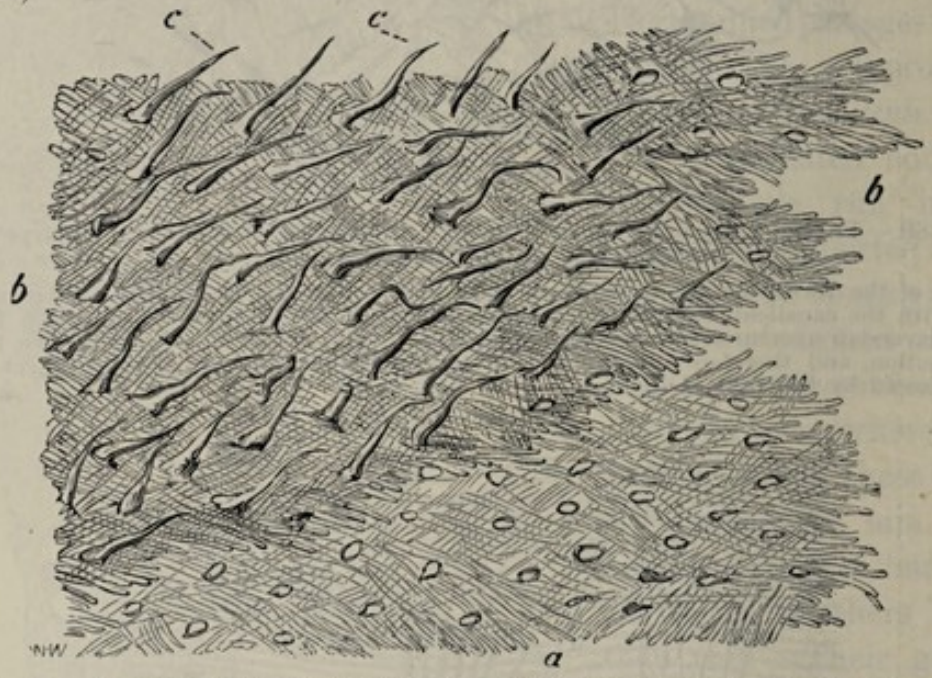


FIG. 91.—LAMELLÆ TORN OFF FROM A DECALCIFIED HUMAN PARIETAL BONE AT SOME DEPTH FROM THE SURFACE. (Sharpey.)

a, lamellæ, showing decussating fibres; *b*, *b*, thicker part, where several lamellæ are superposed; *c*, *c*, perforating fibres; the fibrils which compose them are not shown in the figure. Apertures through which perforating fibres had passed are seen, especially in the lower part, *a*, *a*, of the figure. Magnitude as seen under a power of 200 diameters, but not drawn to scale. (From a sketch by Allen Thomson.)

The lamellæ of bone are fibrous in structure. This may be seen in shreds torn off from the superficial layers of a decalcified bone (fig. 91). The fibres often cross one another in adjacent lamellæ, and in the Haversian systems they run in some lamellæ concentrically, in others parallel with the Haversian canal. In shreds of lamellæ which have been peeled off from the surface the perforating fibres may sometimes be seen projecting from the surface of the shred, having been torn out of the deeper lamellæ (fig. 91, *c*, *c*). Where tendons or ligaments are inserted into bone, their bundles of white fibres are prolonged into the bone as perforating fibres.

The lacunæ are occupied by nucleated corpuscles, which send branches along the canaliculi (fig. 92). They have a special lining

layer different in chemical composition from the rest of the bone, being much more resistant to the action of strong chemical solvents such as hydrochloric acid (Neumann). The dentinal tubules of the teeth have a similar lining layer.

The Haversian canals contain one or two blood-capillaries and nervous filaments, besides a little connective tissue; and the larger ones may also contain a few marrow-cells. There are also cleft-like lymphatic spaces running with the vessels, their cells being connected through canaliculi with branches from corpuscles within the neighbouring lacunæ of the osseous substance (fig. 93).

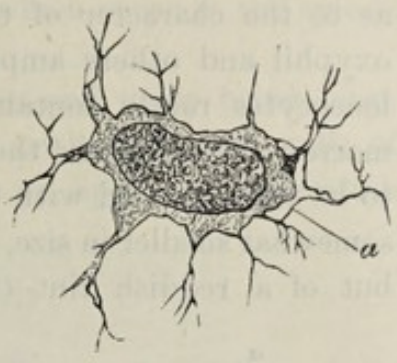


FIG. 92.—A BONE-CELL ISOLATED AND HIGHLY MAGNIFIED. (Joseph.)

a, proper wall of the lacuna (Neumann's layer), where the corpuscle has shrunken away from it.

The **periosteum** may be studied in torn-off shreds, in preparations stained *in situ* with silver nitrate, and in stained sections from an unmacerated bone which has been decalcified in nitric, chromic, or picric acid. It is a fibrous membrane composed of two layers, the inner of which contains many elastic fibres. In the outer layer numerous blood-vessels ramify and send from it branches to the Haversian canals of the bone. The periosteum ministers to the nutrition of the bone, partly on account of the blood-vessels and lymphatics it contains, partly, especially in young animals, on account of the existence between it and the bone of a layer of *osteoblasts* or *bone-forming cells*, a remainder of those which originally produced the bone. It also serves to give attachment to muscular fibres.

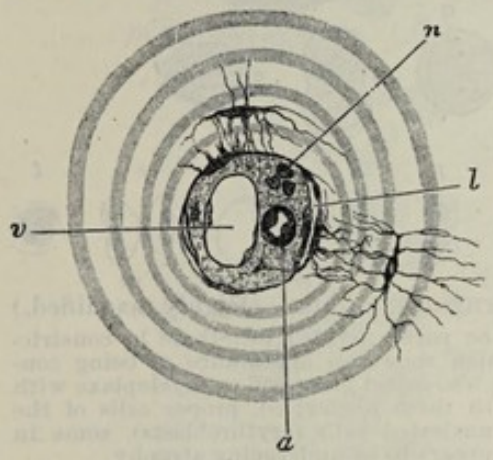


FIG. 93.—SECTION OF A HAVERSIAN CANAL, SHOWING ITS CONTENTS. (Highly magnified.)

a, small arterial capillary vessel; *v*, large venous capillary; *n*, pale nerve-fibres cut across; *l*, cleft-like lymphatic vessel; one of the cells forming its wall communicates by fine branches with the branches of a bone-corpuscle. The substance in which the vessels run is connective tissue with ramified cells; its finely granular appearance is probably due to the cross-section of fibrils. The canal is surrounded by several concentric lamellae.

The **marrow of bone** is of a yellow colour in the shafts of the long bones of most animals, and is there largely composed of adipose tissue, but in the shafts of the long bones of some animals, and in the cancellated tissue of most, it is usually red, the colour being partly due to the large amount of blood in its vessels. This red marrow is chiefly composed of round nucleated cells—the *marrow cells* or *marrow leucocytes* (fig. 94, *e-i*)—which resemble large blood leucocytes, and, like

these, are amœboid. They also exhibit the same kind of differences as to the character of the granules which they contain, some being oxyphil and others amphophil or neutrophil. But while the blood-leucocytes rarely contain any coarse basophil granules some of the marrow cells contain these in considerable numbers. There are also to be seen mingled with the marrow leucocytes a number of corpuscles somewhat smaller in size, nucleated, and some of them at least amœboid, but of a reddish tint (fig. 94, *j-t*). These cells, which are termed

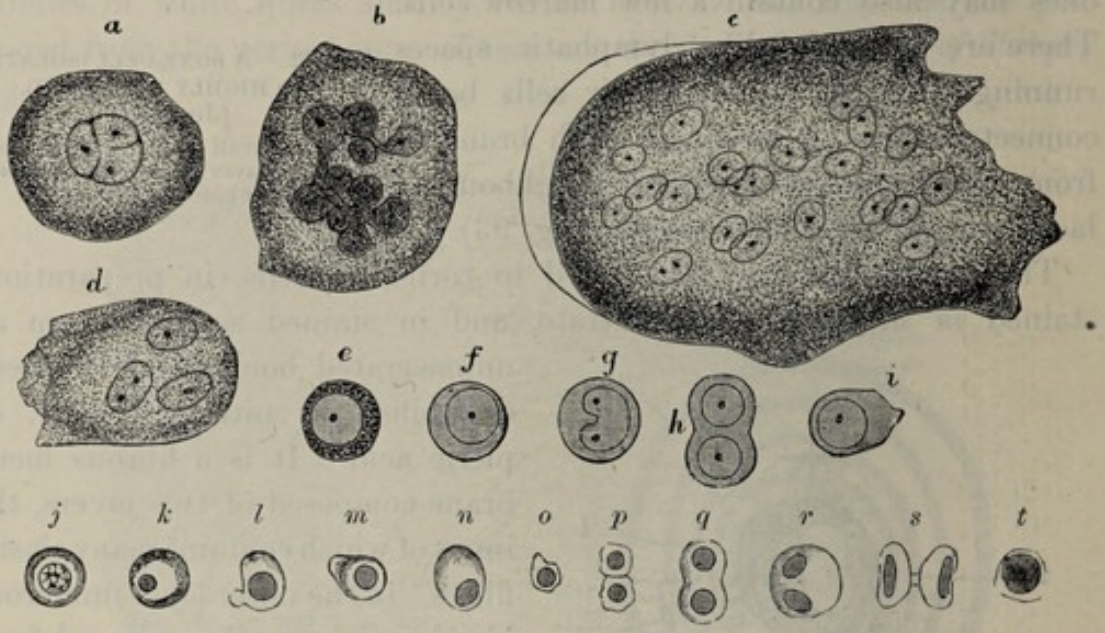


FIG. 94.—CELLS OF THE RED MARROW OF THE GUINEA-PIG. (Highly magnified.)
a, a large cell, the nucleus of which appears to be partly divided into three by constrictions; *b*, a cell, the enlarged nucleus of which shows an appearance of being constricted into a number of smaller nuclei; *c*, a so-called giant-cell or myeloplaxe with many nuclei; *d*, a smaller myeloplaxe with three nuclei; *e-i*, proper cells of the marrow; *j-t*, various forms of coloured nucleated cells (erythroblasts), some in process of division; in others the nucleus appears to be undergoing atrophy.

erythroblasts, resemble the nucleated coloured blood-corpuscles of the embryo, and they are believed to be cells from which the coloured blood-disks become developed. Many of them are in process of mitotic division and others are seen with the nucleus in a more or less atrophied condition; from this it may perhaps be inferred that the transformation into a discoid blood-corpuscle is accompanied by the disappearance of the nucleus (Bizzozero). Lastly, the marrow contains a certain number of very large cells, the *myeloplaxes* of Robin (fig. 94, *a*, *b*, *c*, *d*; fig. 95, *my*). These are especially numerous wherever bone is becoming absorbed, but are not confined to such situations, being indeed normal constituents of marrow. Sometimes the myeloplaxes possess several nuclei, but more often each contains but one large nucleus, which then usually shows an appearance as of budding. They are also characterised by possessing a number of centrosomes grouped together near the nucleus. Lastly, the existence of cells

within the marrow containing blood-corpuscles in various stages of transformation into pigment, similar to those which occur in the spleen pulp, has also been affirmed (Osler).

The marrow is very vascular, the capillaries and veins being large and thin-walled; indeed, according to some authorities, the walls of the capillaries are imperfect, so that there is an open communication

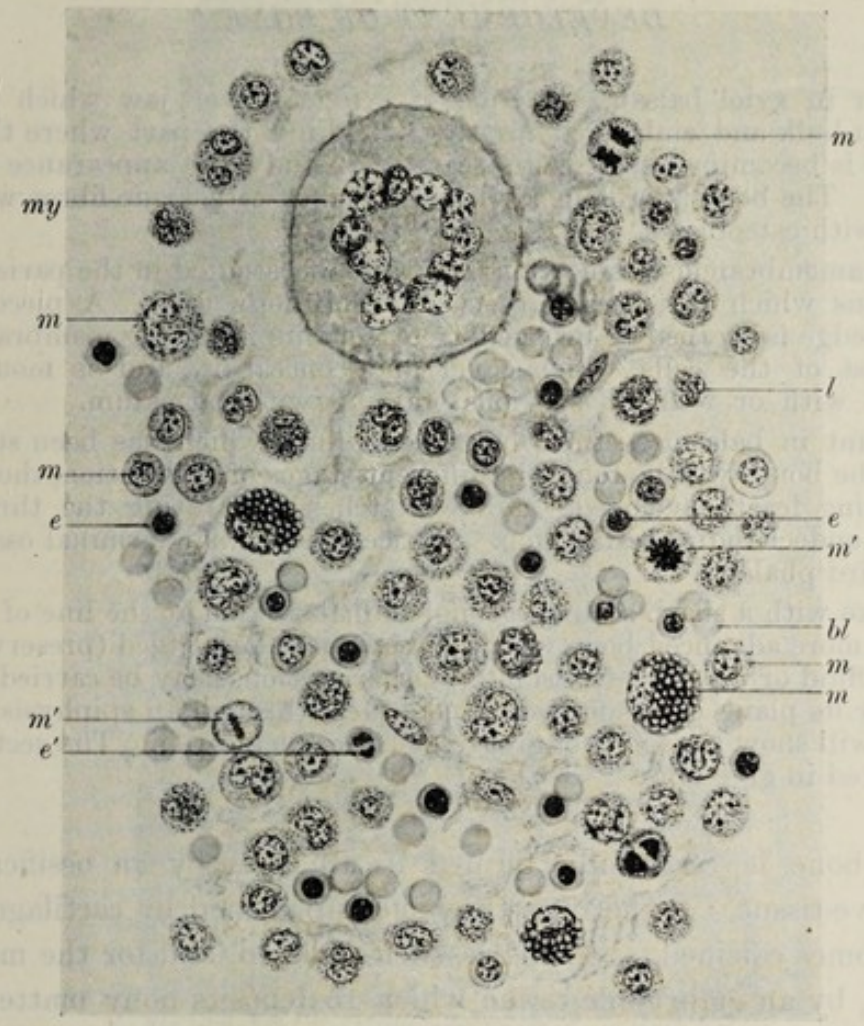


FIG. 95.—SECTION OF RED MARROW. (Magnified 800 diameters.)

e, erythroblasts; *e'*, an erythroblast dividing; *my*, myeloplaxe; *m*, *m*, proper marrow cells of different kinds, some of them, *m'*, *m'*, dividing; *bl*, red blood-corpuscles; *l*, a blood leucocyte.

between them and the interstices of the tissue, and in this way it is supposed that the coloured blood-disks, which are believed to be produced from the coloured nucleated cells (erythroblasts) of the marrow, may get into the circulation. There is not, however, an interstitial circulation of blood in the marrow such as is found in the spleen, nor does injection material such as carmine gelatine pass into the interstices of the tissue, but remains confined to the vessels, so that the existence of an open communication is improbable.

In birds the erythroblasts are confined to the large blood-channels of the marrow, and their transformation into erythrocytes occurs within these.

LESSON XIV.

DEVELOPMENT OF BONE.

1. Mount in xylol balsam a section of a fœtal lower jaw which has been stained in bulk and embedded in paraffin. Find the part where the lower jaw-bone is becoming ossified, and carefully study the appearance which it presents. The bone is prolonged in the form of osteogenic fibres which are covered with osteoblasts.

2. Intramembranous ossification may also be studied in the parietal bone of a fœtus which has been preserved in Müller's fluid. A piece of the growing edge is scraped or brushed free from its investing membranes, and from most of the cells which cover and conceal it, and is mounted in glycerine with or without previous staining with carmalum.

3. Mount in balsam sections of a fœtal limb which has been stained in bulk. The bones will be found in different stages of ossification, those of the digits being least developed. Make sketches illustrating the three chief stages of endochondral ossification. Notice the peculiar terminal ossification of the third phalanx.

4. Make with a sharp scalpel a longitudinal section at the line of ossification in a more advanced bone which has not been decalcified (preservation in Müller's fluid or 5 per cent. formol). Other sections may be carried across a bone near its plane of ossification, and others through an epiphysis. These sections will show the mode of progress of the calcification. The sections can be mounted in glycerine.

True bone is essentially formed in all cases by an ossification of connective-tissue. Sometimes the bone is preceded by cartilage, which first becomes calcified, and this is then invaded, and for the most part removed, by an embryonic tissue which re-deposits bony matter in the interior of the cartilage. This is *intracartilaginous* or *endochondral ossification*. At the same time layers of bone are being formed outside underneath the periosteum. The bone thus formed is termed a *cartilage bone*. Sometimes the bone is not preceded by cartilage, and then the only process which occurs is one corresponding to the subperiosteal ossification of the cartilage bone; the ossification is then known as *intramembranous*, and the bone formed is a *membrane bone*.

Ossification of cartilage.—This may be described as occurring in three stages. In the *first stage* the cells in the middle of the cartilage become enlarged and arranged in rows radiating from the centre (fig. 96), and fine granules of calcareous matter are deposited in the matrix. Simultaneously with this the osteoblasts underneath the periosteum deposit a layer or layers of fibrous lamellæ upon the

surface of the cartilage, and these lamellæ also become calcified (fig. 96, *im*). As they are formed, some of the osteoblasts (*o*) are included between them and become bone-corpuscles.

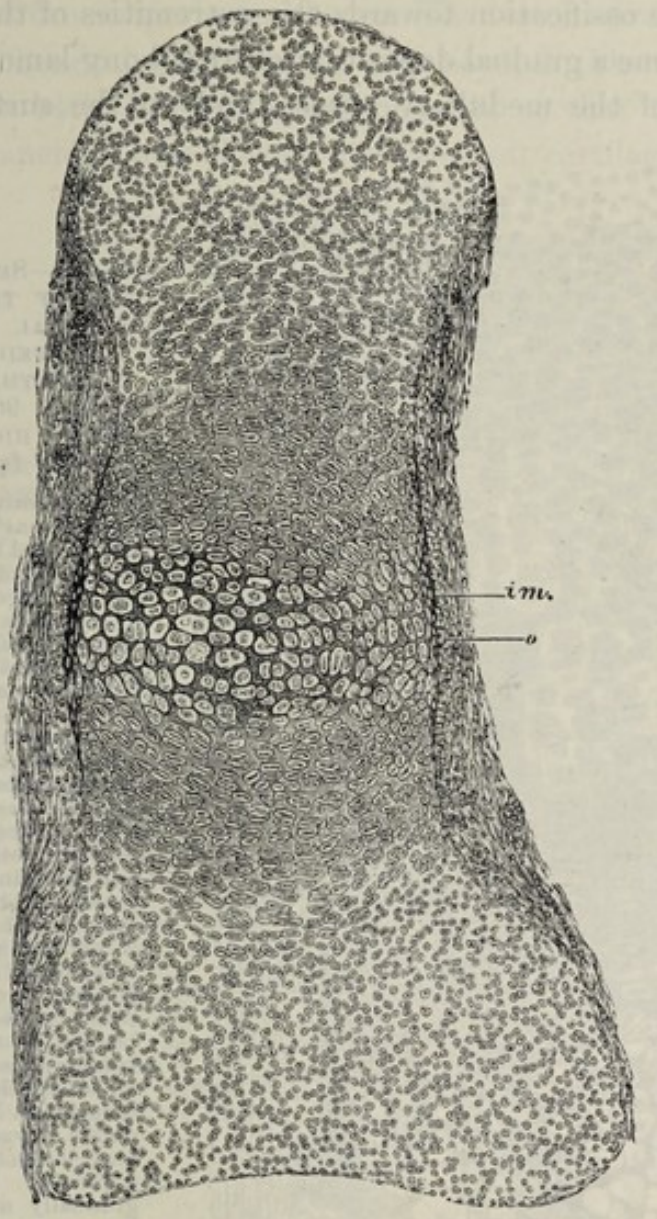


FIG. 96.—SECTION OF PHALANGEAL BONE OF HUMAN FŒTUS, AT THE TIME OF COMMENCING OSSIFICATION. (From a preparation by F. A. Dixey. The preparation was stained in bulk with magenta. The drawing is made from a photograph.) (Magnified about 75 diameters.)

The cartilage-cells in the centre are enlarged and separated from one another by stained calcified matrix ; *im*, layer of bone deposited underneath the periosteum ; *o*, layer of osteoblasts by which the layer has been formed. Some of the osteoblasts are already embedded in the new bone as lacunæ. The cartilage-cells are becoming enlarged and flattened and arranged in rows above and below the calcified centre. At the ends of the cartilage the cells are small, and the groups are irregularly arranged ; the fibrous periosteum is not sharply marked off from the cartilage.

In the *second stage* some of the subperiosteal tissue eats its way through the newly formed layer of bone and into the centre of the calcified cartilage (fig. 97, *ir*). This is freely absorbed before it (fig. 98), so that large spaces are produced which are filled with osteoblasts and contain numerous blood-vessels which have grown

in at the same time. The spaces are termed *medullary spaces*, and this second stage may be termed the *stage of irruption*.

In the *third stage* of endochondral ossification there is a gradual advance of the ossification towards the extremities of the cartilage, and at the same time a gradual deposition of fresh bony lamellæ and spicules on the walls of the medullary spaces, and on the surface of the new

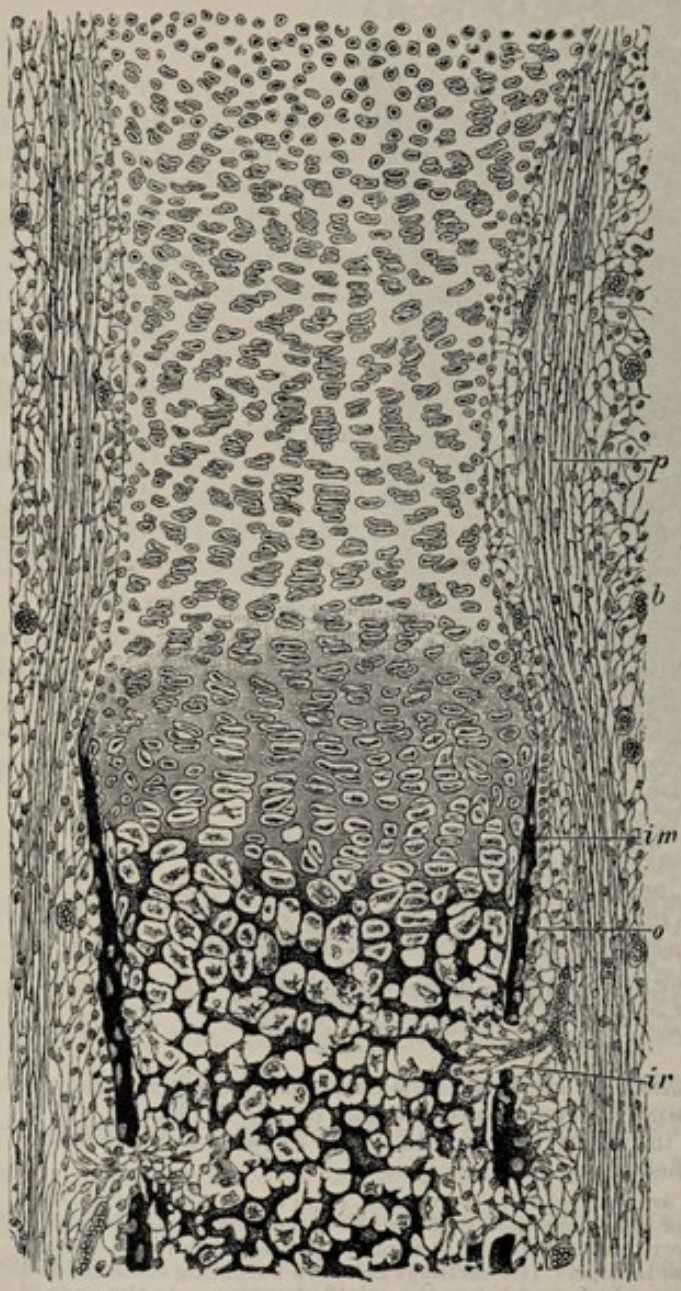


FIG. 97.—SECTION OF PART OF ONE OF THE LIMB-BONES OF A FŒTAL CAT, AT A MORE ADVANCED STAGE OF OSSIFICATION THAN IS REPRESENTED IN FIG. 96, AND SOMEWHAT MORE HIGHLY MAGNIFIED. (Drawn from a photograph.)

The calcification of the cartilage-matrix has advanced from the centre, and is extending between the groups of cartilage-cells, which are arranged in characteristic rows. The subperiosteal bony deposit (*im*) has extended *pari passu* with the calcification of the cartilage-matrix. The cartilage cells in the calcified part are mostly shrunken and stellate; in some cases they have dropped out of the spaces. At *ir* and in two other places an irruption of the subperiosteal tissue, composed of ramified cells with osteoblasts and growing blood-vessels, has penetrated the subperiosteal bony crust, and has begun to excavate secondary areolæ or medullary spaces; *p*, fibrous layer of the periosteum; *o*, layer of osteoblasts, some of them are embedded in the osseous layer as bone-corpuscles in lacunæ; *b*, blood-vessels occupied by blood-corpuscles. Beyond the line of ossific advance the periosteum may be noticed to be distinctly incurved. This incurvation is gradually moved on, the cartilage expanding behind it until the head of the bone is reached, when it forms the periosteal notch or groove represented in figs. 100 and 103.

bone under the periosteum. The advance into the cartilage always takes place by a repetition of the same changes, the cartilage-cells first enlarging and becoming arranged in rows, the matrix between the rows becoming calcified, and then the calcified cartilage becoming excavated from behind by the osteoblastic tissue so as to form new medullary spaces (fig. 98). The walls of these are at first formed only

by remains of the calcified cartilage-matrix (fig. 98 *c*), but they soon become thickened by lamellæ of fibrous bone (*b*) which are deposited by the osteoblasts, and between which bone-corpuscles become included, as in the case of the subperiosteal bone. The latter advances *pari passu* with the endochondral calcification, but beyond this the uncalcified cartilage grows both in length and breadth, so that the ossification is always advancing into larger portions of cartilage; hence the

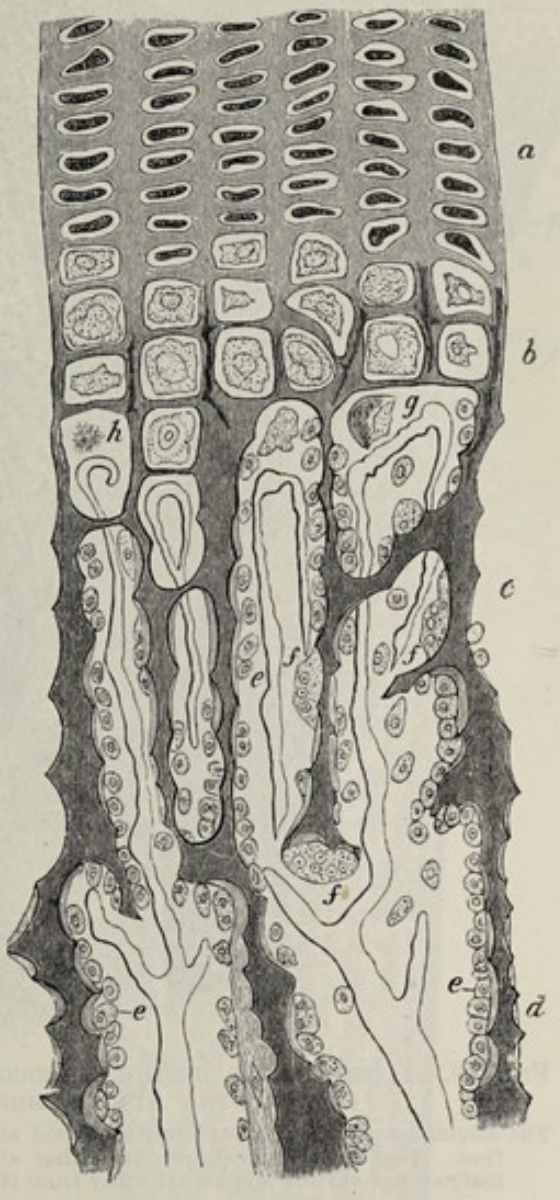


FIG. 98.—PART OF A LONGITUDINAL SECTION OF THE DEVELOPING FEMUR OF THE RABBIT. (Klein.) (Drawn under a magnifying power of 350 diameters.)

a, rows of flattened cartilage-cells; *b*, greatly enlarged cartilage-cells close to the advancing bone, the matrix between is partly calcified; *c*, *d*, already formed bone, the osseous trabeculæ being covered with osteoblasts (*e*), except here and there, where an osteoclast (*f*) is seen, eroding parts of the trabeculæ; *g*, *h*, cartilage-cells which have become shrunken and irregular in shape. From the middle of the figure downwards the dark trabeculæ, which are formed of calcified cartilage-matrix, are becoming covered with secondary osseous substance deposited by the osteoblasts. The vascular loops at the extreme limit of the bone are well shown, as well as the abrupt disappearance of the cartilage-cells.

endochondral bone as it forms assumes the shape of an hour-glass, the cylindrical shape of the whole bone being maintained by additions of periosteal bone to the outside (see fig. 100). The absorption of the calcified cartilage-matrix appears to be effected, as in the case with absorption of bony matter wherever it occurs, by large multi-nucleated cells (fig. 98, *f*, *f*) which are termed *osteoclasts*. They are cells of the same nature as the myeloplaxes of the marrow, and are found

on surfaces where absorption of bone is taking place, whereas the osteoblasts are always found covering surfaces where bony deposit is proceeding (fig. 101).

The bone which is first formed is more reticular and less regularly lamellar than that of the adult, and contains no Haversian systems. The regular lamellæ are not deposited until some little time after birth, and their deposition is generally preceded by a considerable

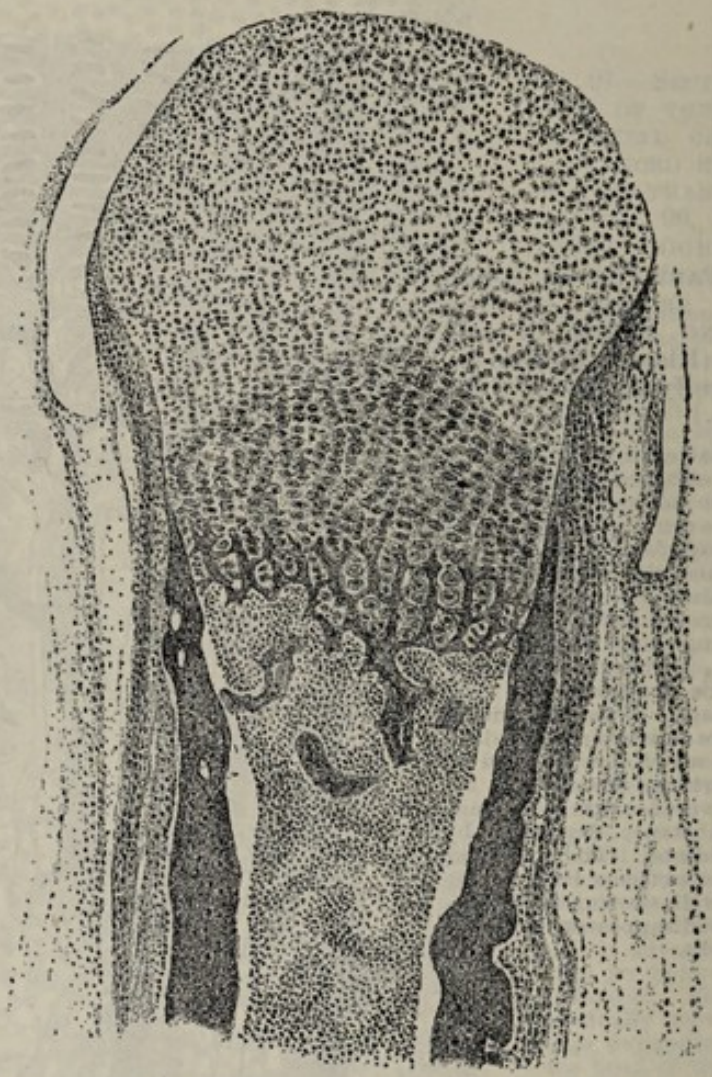


FIG. 99.—LONGITUDINAL SECTION THROUGH PART OF A PHALANX OF A SIX MONTHS' HUMAN EMBRYO. (Kölliker.)

The calcified cartilage is completely absorbed almost to the limit of advancing calcification. The darker substance on either side is periosteal bone. The embryonic marrow has shrunk somewhat away from it.

amount of absorption. It is about this time also that the medullary canal of the long bones is formed by the absorption of the bony tissue which originally occupies the centre of the shaft.

After a time the cartilage in one or both ends of the long bones begins to ossify independently, and the *epiphyses* are formed. These are not joined to the shaft until the growth of the bone is completed. Growth takes place *in length* by an expansion of the cartilage (*inter-*

mediate cartilage) which intervenes between the shaft and the epiphyses, and by the gradual extension of the ossification into it; *in width*

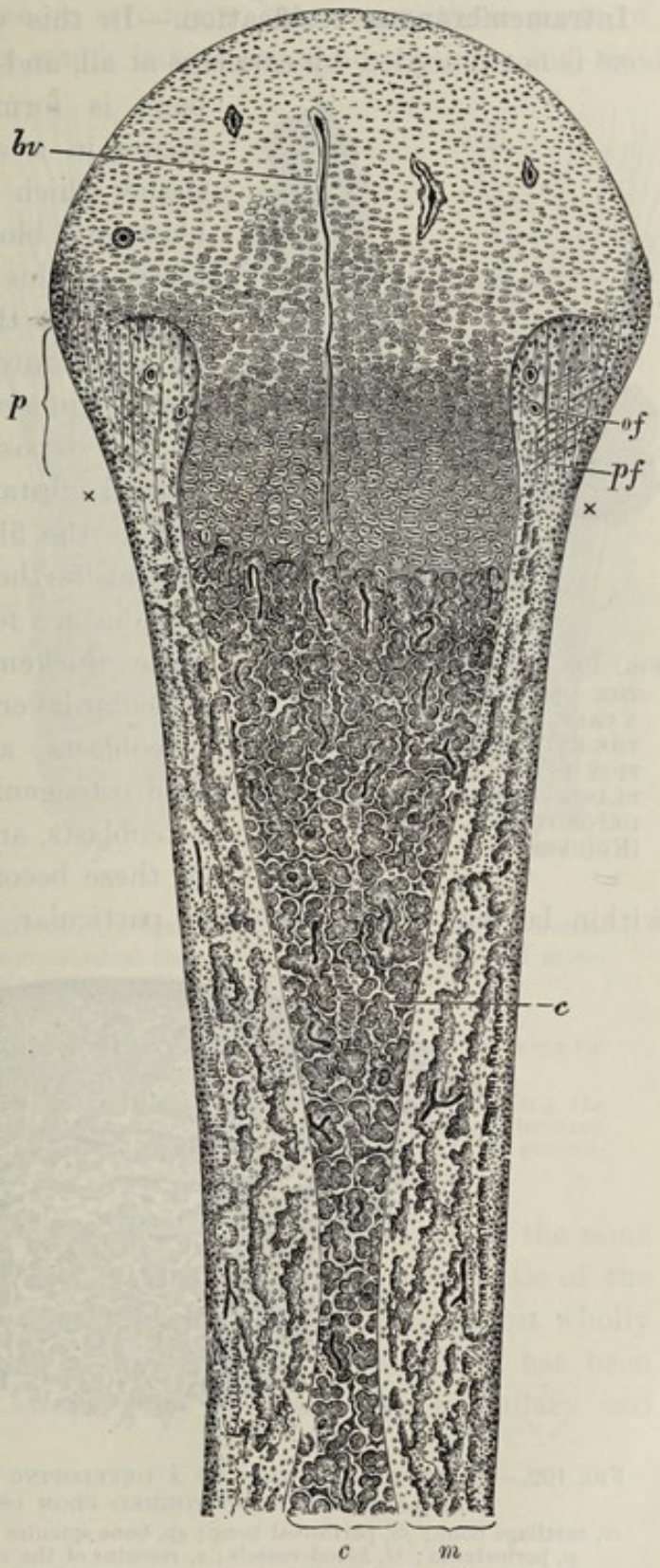


FIG. 100.—LONGITUDINAL SECTION THROUGH THE UPPER HALF OF THE DECALCIFED HUMERUS OF A FŒTAL SHEEP, AS SEEN UNDER A MAGNIFYING POWER OF ABOUT 30 DIAMETERS.

c, the part of the shaft which was primarily ossified in cartilage; what remains of the primary bone is represented dark, enveloped by the clear secondary deposit. The areolæ of the bone are occupied by embryonic marrow with osteoblasts, and blood-vessels variously cut, represented as dark lines. One long straight vessel (*bv*) passes in advance of the line of ossification far into the cartilaginous head, most of the others loop round close to the cartilage. At one or two places in the older parts of the bone elongated groups of cartilage-cells (*c*) may still be seen, which have hitherto escaped absorption. *m*, the part of the bone that has been ossified in membrane, that is to say, in the osteoblastic tissue under the periosteum. It is well marked off from the central portion, and is bounded, peripherally, by a jagged edge, the projections of which are indistinctly seen to be prolonged by bunches of osteogenic fibres. A row of osteoblasts covers the superficial layer of the bone. The subperiosteal layer is prolonged above into the thickening (*p*) which encroaches upon the cartilage of the head of the bone, and in which are seen amongst numerous osteoblasts and a few blood-vessels, the straight longitudinal osteogenic fibres (*of*), and some other fibres (*pf*) crossing them, and perhaps representing fibres of Sharpey. The calcareous salts having been removed by an acid, the granular ossific deposit passing up between the rows of cartilage-cells is not seen in this specimen; it would have extended as far as a line joining the marks ××. Observe the general tendency of the osseous trabeculæ and the vascular channels between them to radiate from the original centre of ossification. This is found to prevail more or less in all bones when they are first formed, although the direction of the trabeculæ may afterwards become modified in relation with varying physiological conditions, and especially as the result of pressure in different directions.

entirely by the deposition of fresh bony layers under the periosteum. In the terminal phalanges of the digits the ossification starts, not from the middle of the cartilage, but from its distal extremity.

For the regeneration of portions of bone which have been removed by disease or operation it is important that the periosteum be left.

Intramembranous ossification.—In this variety of ossification, the bone is not preceded by cartilage at all, and therefore no endochondral bone is formed, but the calcification occurs in a sort of embryonic fibrous tissue which contains numerous osteoblasts and blood-vessels (fig. 104). The fibres of this tissue (osteogenic fibres), which, like those of fibrous tissue, are collected into small bundles, become inclosed in a calcareous matrix, produced by the deposition of lime salts in the ground-substance of the connective tissue; and as the fibres grow, the calcification extends further and further, so that bony spicules are formed, which, as they become thickened, run together to form reticular layers, leaving spaces filled with osteoblasts around the blood-vessels. The osteogenic fibres are covered with osteoblasts, and as the bone forms, some of these become left as bone-corpuscles within lacunæ. Thus in every particular the development of these

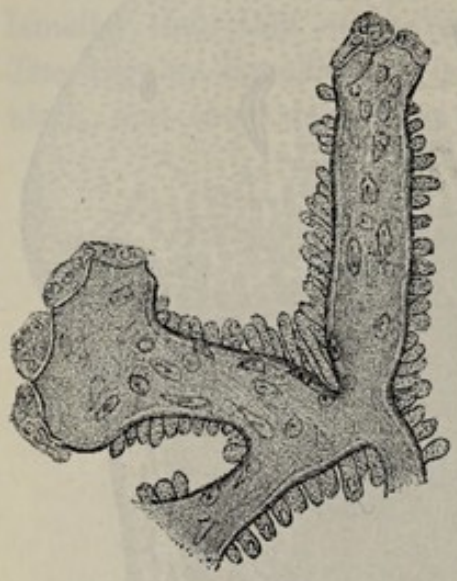


FIG. 101.—BONY TRABECULÆ FROM THE DEVELOPING LOWER JAW OF A CALF, SHOWING OSTEOCLASTS AT THE EXTREMITIES WHERE ABSORPTION IS PROCEEDING, AND OSTEOBLASTS COVERING THE SIDES WHERE DEPOSITION OF BONE IS GOING ON. (Kölliker.)

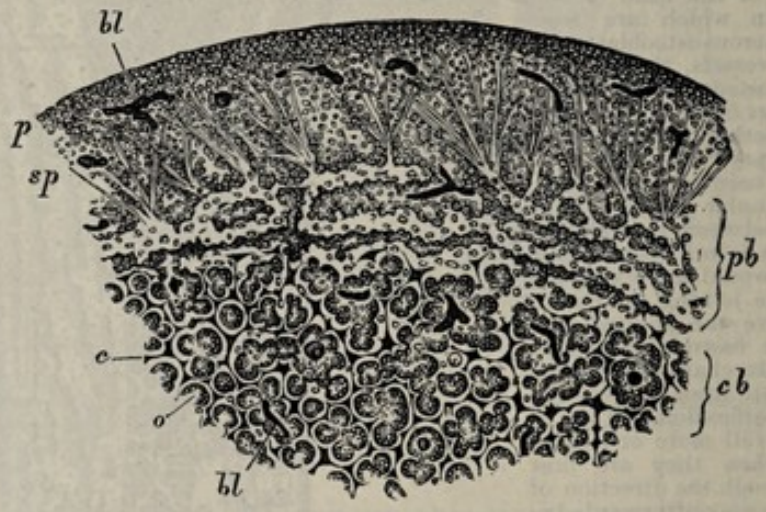


FIG. 102.—TRANSVERSE SECTION OF A DEVELOPING BONE, SHOWING THE PERIOSTEAL LAYER BECOMING FORMED FROM OSTEOGENIC FIBRES.

cb, cartilage bone; *fb*, periosteal bone; *sp*, bone spicules prolonged by osteogenic fibres; *p*, periosteum; *bl*, blood-vessels; *c*, remains of the calcified cartilage; *o*, osteoblasts forming bone upon this.

bones resembles that of the subperiosteal layer of endochondral bone; which is also to be considered as an instance of intramembranous

ossification, although taking place on the surface of cartilage. Moreover, it is the same subperiosteal tissue which, in endochondral ossification, deposits the true or secondary bone upon those parts of the calcified cartilage matrix which have escaped absorption; and this

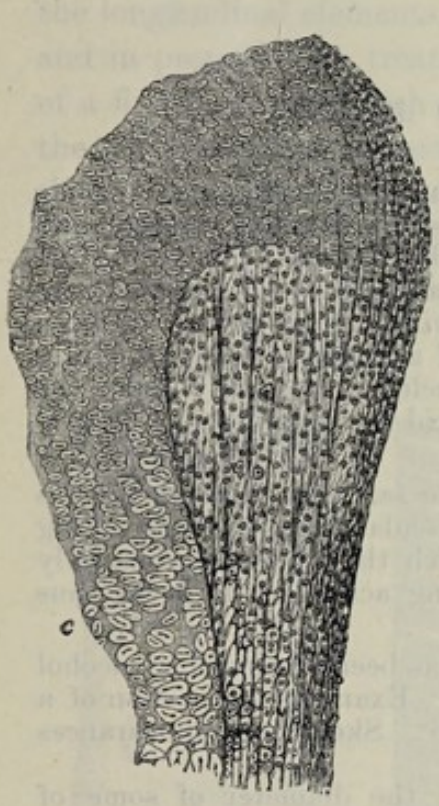


Fig. 103.

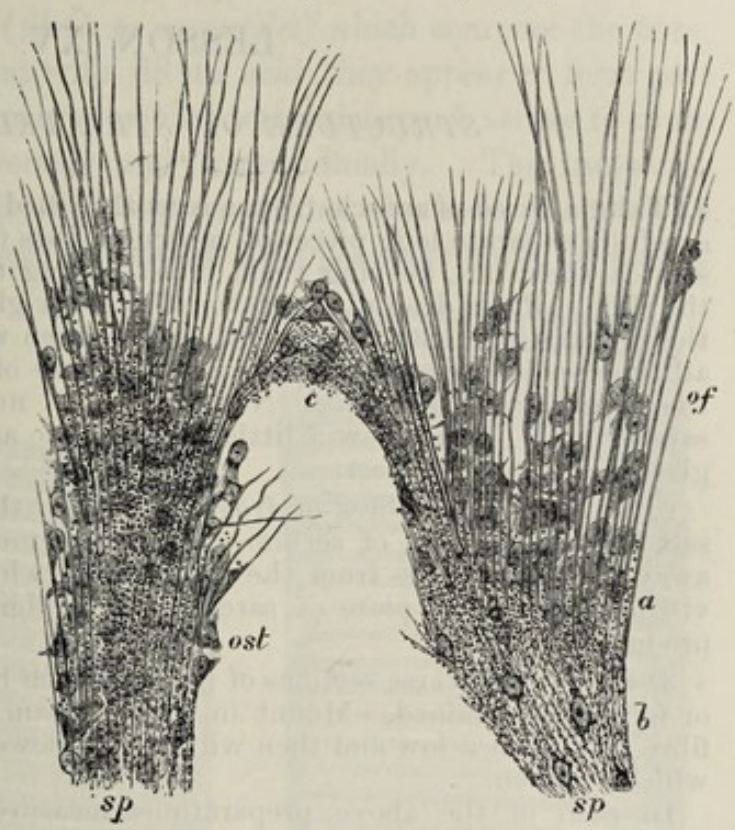


Fig. 104.

Fig. 103.—Section of the ossification groove in the head of a long bone.

c, cartilage; *p*, periosteum; *ip*, subperiosteal tissue with osteogenic fibres and osteoblasts. This tissue occupies the "groove."

Fig. 104.—Part of the growing edge of the developing parietal bone of a fœtal cat, 1½ inch long.

sp, bony spicules, with some of the osteoblasts embedded in them, producing the lacunæ; *of*, osteogenic fibres prolonging the spicules, with osteoblasts (*ost*) between them and applied to them; *a*, granular calcific deposit occurring in the ground-substance between the fibres; *c*, union of two adjacent spicules.

must also, therefore, be reckoned as developed according to the same type. In fact, even in intracartilaginous ossification, very little of the calcified cartilage matrix eventually remains; this being almost wholly absorbed and either replaced by true or fibrous bone which has been formed by osteoblasts, or swept away to form the medullary and other cavities.

LESSON XV.

STRUCTURE OF STRIATED MUSCLE.

1. Take a shred of muscle from a recently killed mammal, and on a dry slide carefully separate long pieces of muscular fibre (single fibres if possible) and stretch them out, keeping them moist during the process by breathing on the slide. Put a drop of serum on the cover-glass before placing this over the preparation. Study first with a low, then with a high power. Sketch all the appearances to be seen in a small piece of a fibre, focussing carefully the most superficial layers. Notice the oval nuclei immediately under the sarcolemma. Then allow a little dilute acetic acid to run under the cover-glass and watch its effect.

2. Prepare some fibres of frog's muscle in the same way, but mount in salt solution instead of serum. Notice the muscular substance shrinking away here and there from the sarcolemma, which then becomes distinctly visible. Sketch a piece of sarcolemma bridging across an interval thus produced.

3. Study transverse sections of muscle which has been hardened in alcohol or formol and stained. Mount in xylol balsam. Examine the section of a fibre first with a low and then with a high power. Sketch the appearances which are seen.

In each of the above preparations measure the diameter of some of the fibres.

Sections of muscle spindles may be searched for in the transverse sections of muscle.

4. Place in 1 per cent. osmic acid a small shred of mammalian muscular tissue which has been stretched upon a cork. After 24 hours, when it will be deeply stained, wash it in water and with needles break the fibres up in glycerine as finely as possible. Cover and examine with a high power.

Voluntary muscle is composed of long cylindrical fibres, measuring on an average about ·05 mm. in diameter ($\frac{1}{500}$ inch) in mammalian muscles, and often having a length of an inch or more. Each fibre has an elastic sheath, the *sarcolemma*, which incloses the contractile substance. The sarcolemma is seldom distinct, unless the contained substance becomes broken (fig. 105).

The contractile substance of the fibre is characterised by the alternate dark and light stripes which run across the length of the fibre; hence the name, *cross-striated* or *striped muscle*. On focussing, it can be seen that the stripes pass through the whole thickness of the fibre; they may therefore be looked upon as representing alternate disks of dark and light substance. If the fibre be very carefully focussed, rows of apparent granules are seen lying in or at the boundaries of

the light streaks, and very fine longitudinal lines may, with a good microscope, be detected uniting the apparent granules (fig. 106). These fine lines, with their enlarged extremities the granules, are more conspicuous in the muscles of insects. They indicate the divisions between the longitudinal elements (*fibrils* or *sarcostyles*) which compose the fibre, and in preparations treated with dilute acid they appear to form part of a fine network, which pervades that substance, and serves to unite the granules both transversely and longitudinally. This network, which is sometimes very distinct in preparations of muscle treated with chloride of gold, is, however, a network in appearance only: in reality

Fig. 105.

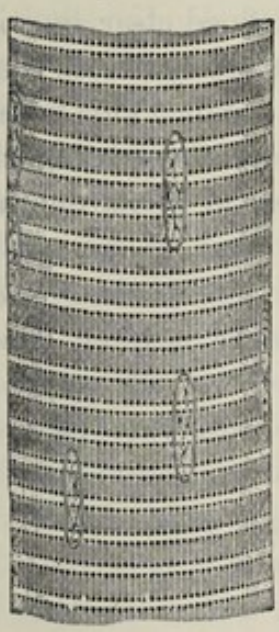


Fig. 106.

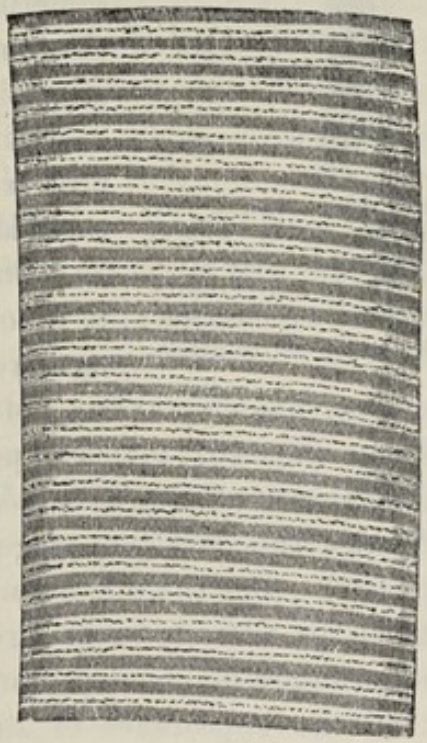


Fig. 107.

Fig. 105.—Sarcolemma of mammalian muscle highly magnified.
The fibre is represented at a place where the muscular substance has become ruptured and has shrunk away, leaving the sarcolemma (with a nucleus adhering to it) clear. The fibre had been treated with serum acidulated with acetic acid.

Fig. 106.—Muscular fibre of a mammal examined fresh in serum, highly magnified, the surface of the fibre being accurately focussed.
The nuclei are seen on the flat at the surface of the fibre, and in profile towards the edge.

Fig. 107.—Portion of a medium-sized human muscular fibre, showing the intermediate line mentioned in the text. (Sharpey.)

it is the optical expression of the interstitial substance which lies between the fibrils. This substance is termed *sarcoplasm*.

On examining the transverse section of a fibre with a high power, it is seen to be subdivided everywhere into small angular fields, *Cohnheim's areas* (fig. 109), which are themselves again divided up. The smallest divisions represent sections of the fibrils of which the fibres are

composed, and into which they may be split after death, especially after being hardened in certain reagents, *e.g.* chromic acid or osmic acid.

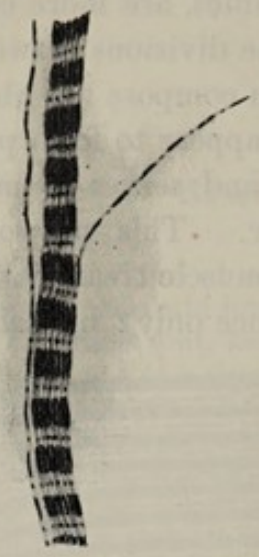


FIG. 108.—SMALL PORTION OF A MUSCLE FIBRE OF CRAB SPLITTING UP INTO FIBRILS. (From a photograph.) Magnified 600 diameters.

The larger areas represent groups of fibrils. These areas of Cohnheim are usually polyhedral, but they may be elongated and disposed either radially or concentrically with the circumference of the section. The interstitial substance or sarcoplasm lies between them and can be made visible by treatment with dilute acid or by staining with chloride of gold (figs. 111, 112 and 113). It is sometimes in relatively large amount, but in most muscular fibres is reduced to a very fine interstitium.

An ill-defined clear line is sometimes seen running transversely across the fibre in the middle of each dark band. This is termed *Hensen's line*.

If instead of focussing the surface of the fibre it be observed in its depth, an appearance different from that shown in fig. 106 is frequently visible, namely, a fine dotted line (*Dobie's line*), bisecting each clear stripe (fig. 107); this appearance is often considered to represent a membrane (*Krause's membrane*), which subdivides the fibrils at regular intervals (see p. 102). But the membrane of the individual fibrils or sarcostyles is rarely, if ever, visible in an intact mammalian fibre, and it is certain that the appearance of such a line in the middle of the clear stripe of an intact fibre is in most cases due to interference, caused by the light being transmitted between disks of different refrangibility.

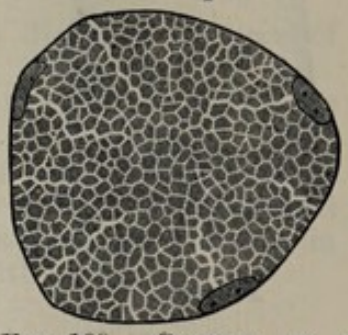


FIG. 109. — SECTION OF A MUSCULAR FIBRE, SHOWING AREAS OF COHNHEIM. Three nuclei are seen lying close to the sarcolemma.

Haycraft has suggested that the cross-striation of voluntary muscle is due to refractive effects produced by a varicosity of the component fibrils, basing his view upon the fact that in impressions of the fibres made in soft collodion all the cross-striations which are observed in the fibre itself are reproduced. There is no doubt that a well-marked cross-striated appearance can be produced in homogeneous fibrils by regularly-occurring varicosities, and many of the appearances observed in muscle may, as Haycraft contends, be referred to this cause. But even when a fibre or fibril is stretched so that it exhibits no varicosities, the cross-striations are still perfectly distinct. Moreover, in view of the entirely different manner in which the substance of the dark and clear stripes behave to many staining reagents, and especially to chloride of gold when applied as directed in Lesson XVI., § 3, the fact being that very definite structural appearances can under these circumstances be made out, the homogeneity of the muscle-fibril cannot be admitted.

Besides the sarcolemma and striated substance, a muscular fibre also exhibits a number of oval nuclei which have the usual structure of cell-nuclei: their chromoplasm often has a spiral arrangement. Sometimes there is a little granular substance (protoplasm) at each pole of the nucleus; each nucleus with the adjacent protoplasm has then been spoken of as a *muscle-corpuscle*. But the protoplasm which is adjacent to the nuclei is in all probability continuous with the sarcoplasm between the fibrils; both being the remains of the original undifferentiated protoplasm of the cell from which the muscular fibre was developed. In mammalian muscle the nuclei usually lie immediately under the sarcolemma (figs. 105, 106, 109), in frog's muscle they are scattered throughout the substance of the fibre; in insect muscle they occupy the middle of the fibre, embedded in undifferentiated protoplasm (fig. 112). Some animals, such as the rabbit, have, besides muscles of the ordinary type of structure which in this animal are pale in colour, others of a deep red colour. These *red muscles* were found by Ranvier to exhibit certain differences both in structure and function. One difference of structure is that the nuclei, which are numerous, are not confined to the surface, but are scattered throughout the substance of the fibres. The fibres in question also contain more sarcoplasm than the ordinary fibres, and their blood-vessels have a peculiarity of structure which will be afterwards noticed. Here and there, in all mammals, amongst the ordinary fibres are some in which the nuclei are distributed through the thickness of the fibres; this is the case also, as just remarked, with all the muscular fibres of the frog. In muscles which are in constant activity, such as the diaphragm and the dorsal fin muscles of Hippocampus, the protoplasm (sarcoplasm) of the fibres is present in relatively large proportion, and this is also the case with the wing muscles of insects.

The transverse section of a muscle shows the fibres to be nearly cylindrical in figure. Between the fibres there is a certain amount of areolar tissue, which serves to support the blood-vessels and also unites the fibres into fasciculi; the fasciculi are again united together by a larger amount of this intramuscular connective tissue (*endomysium*).

LESSON XVI.

STRUCTURE OF STRIATED MUSCLE (continued).

1. Cut off the head of a garden beetle or other insect (*e.g.* wasp), and bisect the trunk with scissors so as to expose the interior. Notice two kinds of muscular tissue, the one belonging to the legs greyish in colour, the other attached to the wings yellowish. Preparations of both kinds of muscle are to be made in the same way as living mammalian muscle (see previous Lesson), but it is better to mount them in a drop of white of egg. In both preparations the dark-looking air-tubes or tracheæ form prominent objects ramifying amongst the fibres. Observe the structure of the two kinds of muscle so far as it can be made out in the fresh preparation. If the preparation is made quickly, waves of contraction will probably be observed passing along the fibres.

2. Make another preparation of the leg-muscles, mounting the muscle in vinegar. (Alcohol-hardened muscle of insect or crab may be used for this purpose.) Notice that the muscular substance swells up somewhat and becomes clearer, whilst the sarcoplasm-network, with its lines and dots, comes more distinctly into view. In a well-teased preparation of alcohol-hardened muscle, the fibres will be frequently found breaking across into disks. Make careful drawings from this preparation.

3. Rollett's method. Cut off the head of an insect (wasp, small beetle), bisect the trunk and place in 90 per cent. alcohol for from 24 to 48 hours or more. Then take a small piece of each kind of muscle, and place in strong glycerine for some hours. Wash thoroughly with water and transfer to 1 per cent. chloride of gold solution: leave the pieces of muscle in this from 15 to 30 minutes according to their size. From the gold solution they are transferred to formic acid (1 part of the strong acid to 3 of water), and kept in the dark for 24 hours, but they may be kept longer without disadvantage. The muscle is then teased in glycerine. Some of the fibres will be found after this method to have their sarcoplasm darkly stained, and to show, therefore, the appearance of a network both in longitudinal and transverse view: others, on the other hand, have the sarcous elements of the fibrils or sarcostyles stained, whilst the sarcoplasm has remained colourless.

Ordinary or leg-muscles of insects.—In the muscles of insects the stripes are relatively broad, and their structure can be more readily seen than in mammals. In the living fibres from the muscles which move the legs, the sarcoplasm presents a striking appearance of fine longitudinal lines traversing the muscle, and enlarging within the light stripes into rows of dots (fig. 110). This is still better seen in fibres and portions of fibres which have been treated with dilute acid (fig. 111). In separated disks produced by the breaking across of muscle-fibres, the surfaces of the disks show a network with poly-

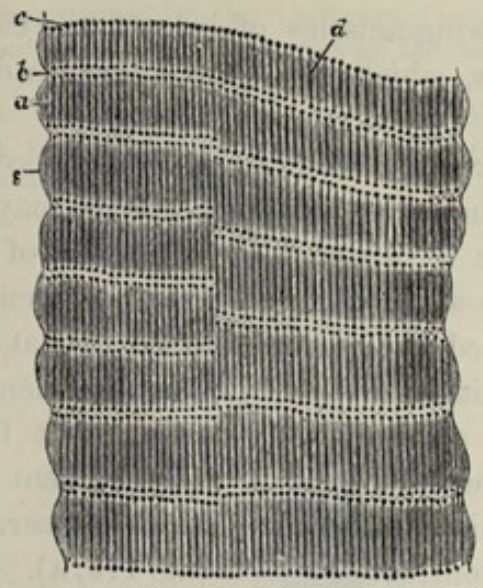


FIG. 110.—LIVING MUSCLE OF WATER-BEETLE (DYTISCUS MARGINALIS.) (Highly magnified.)

s, sarcolemma; *a*, dim stripe; *b*, bright stripe; *c*, row of dots in bright stripe, which seem to be the enlarged ends of rod-shaped particles, *d*, but are really expansions of the interstitial sarcoplasm which appear in the living muscles as fine dark lines with dot-like enlargements upon them.

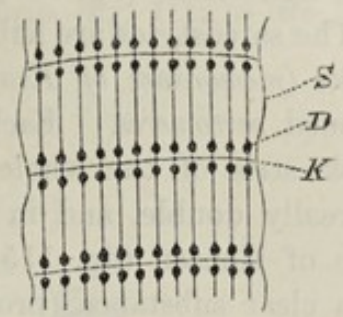


FIG. 111.—PORTION OF LEG-MUSCLE OF INSECT TREATED WITH DILUTE ACID.

S, sarcolemma; *D*, dot-like enlargement of sarcoplasm; *K*, Krause's membrane. The sarcous elements are dissolved or at least rendered invisible by the acid.

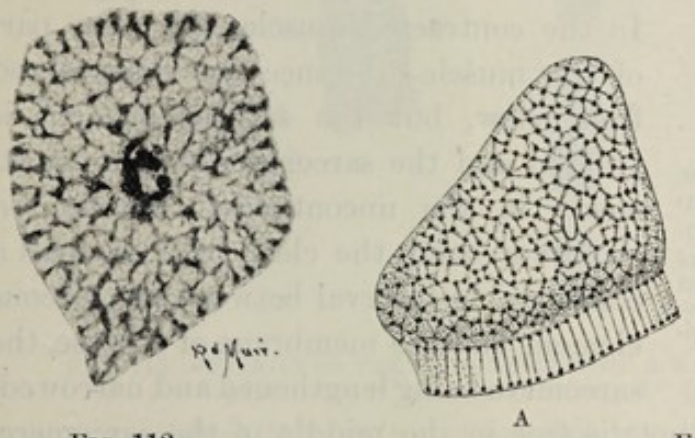
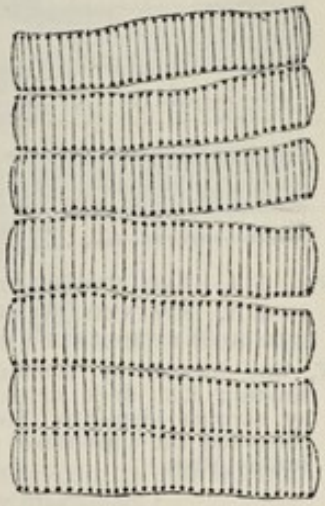


FIG. 112.



A B

FIG. 113.

FIG. 112.—TRANSVERSE SECTION OF LEG-MUSCLE FIBRE OF AN INSECT, STAINED WITH GOLD CHLORIDE.

The sarcoplasm is here stained, and appears in the form of a network, in the meshes of which lie the sections of the sarcostyles. Notice the mottled appearance of the sections of the sarcostyles or fibrils, indicating a porous structure, as in the wing fibrils (see fig. 116). The central protoplasm (with a nucleus) is also evident. (From a photograph.)

FIG. 113.—MUSCLE FIBRE OF INSECT LEG TREATED WITH DILUTE ACID, SHOWING A TENDENCY TO BREAK ACROSS INTO DISKS.

The sarcoplasm is in the form of fine lines. The ordinary dark stripes of the fibre have disappeared in the acid. A, a disk seen partly in section and exhibiting the reticular arrangement of the sarcoplasm.

hedral meshes in some insects (fig. 113, A), one formed of lines radiating from the centre of the fibre in others. The nuclei, with some inclosing protoplasm, usually lie in the middle of the fibre.

Wing-muscles of insects.—The wing-muscles of insects are easily broken up into fibrils or sarcostyles, which also show alternate dark and light striæ (fig. 115).

The sarcostyles are subdivided at regular intervals by thin transverse disks (*membranes of Krause*) into successive portions, which may be termed *sarcomeres*. Each sarcomere is occupied by a portion of the dark stria of the whole fibre (*sarcous element*): the sarcous element is really double, and in the stretched fibre separates into two at the line of Hensen (fig. 115, B). At either end of the sarcous element is a clear substance (probably fluid or semi-fluid) separating it from the membrane of Krause: this clear substance is more evident the more the fibril is extended, but diminishes to complete disappearance in the contracted muscle (fig. 115, A). The cause of this change is explained when we study more minutely the structure of the sarcous element. For each sarcous element is pervaded with longitudinal canals or pores, which are open in the direction of Krause's membranes, but closed at the middle of the sarcous element (fig. 116). In the contracted muscle, the clear part of the muscle-substance has disappeared from view, but the sarcous element is swollen and the sarcomere is thus shortened: in the uncontracted muscle, on the other hand, the clear part occupies a considerable interval between the sarcous element and the membrane of Krause, the sarcomere being lengthened and narrowed. The sarcous element does not lie free in the middle of the sarcomere, but is attached at either end to Krause's membrane by very fine lines, which may represent fine septa, running through the clear substance (fig. 117); on the other hand, Krause's membrane appears to be attached laterally to a fine membrane which limits the fibril externally.

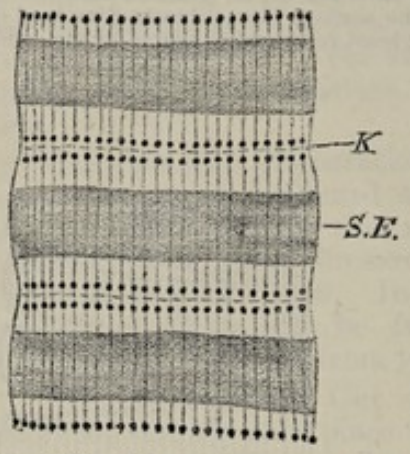


FIG. 114.—LEG MUSCLE-FIBRE OF INSECT, STAINED WITH GOLD CHLORIDE BY ROLLETT'S METHOD.

K, line formed by membranes of Krause; *S.E.*, dark stripe formed by sarcous elements. The sarcoplasm has the appearance of longitudinal lines.

The planes of sarcous elements set side by side in a muscle-fibre form the dark stripe (the so-called *principal disk*) of the muscle-substance of ordinary muscle-fibres (fig. 114). But in the wing-muscles of insects the sarcous elements of the fibrils less constantly lie in continuous planes, and the whole fibre is therefore very indistinctly and irregularly cross-striated, although each individual fibril is markedly so (fig. 115).

Sometimes in the ordinary (leg) muscles of arthropods what look like detached dot-like portions of the sarcous element are seen within the clear stripes, lying usually near Krause's membrane. The rows of such dots have been termed *accessory disks*. Most muscles show no accessory disks, but the sarcoplasmic enlargements between the fibrils (fig. 111, D) are often mistaken for them.

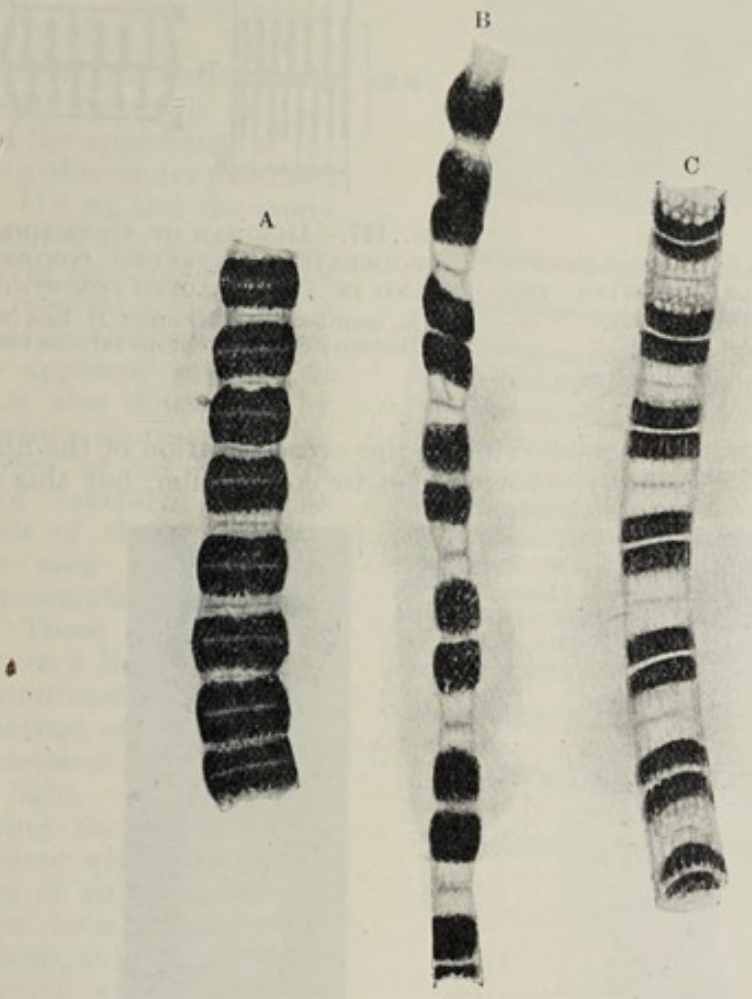


FIG. 115.—FIBRILS OF THE WING-MUSCLES OF A WASP, PREPARED IN THE MANNER DESCRIBED IN LESSON XVI., SEC. 3. (Highly magnified.)

A, a contracted fibril. B, a stretched fibril, with its sarcous elements separated at the line of Hensen. C, an uncontracted fibril, showing the porous structure of the sarcous elements.

Muscle in Polarised Light.—When muscle-fibres are examined with polarised light between crossed Nichol's prisms, the sarcous elements (which form the dark stripe) are seen to be doubly refracting (anisotropous), while the clear substance (forming the light stripe) is singly refracting (isotropous). In contracted parts of the muscle the (anisotropous) sarcous elements are seen to have increased in bulk, while the isotropous substance of the clear stripe has correspondingly diminished in amount (fig. 118, B).

F. Merkel described a reversal of the stripes during contraction, *i.e.* a transference of the anisotropous substance of the dark stripe from Hensen's line to Krause's membrane, the place of the dark stripes thus becoming occupied by clear material, that of the light stripes by dark. He further described this condition as being preceded by an intermediate stage in which the fibril shows homogeneity of shading. No doubt in the ordinary muscle-

fibres of arthropods, when we observe the so-called "fixed" waves of con-

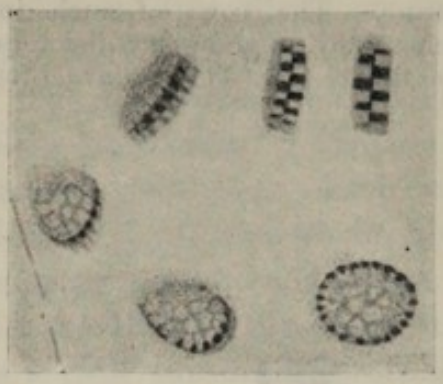


FIG. 116.—ISOLATED SARCOUS ELEMENTS OF A WING-MUSCLE, SHOWING THE TUBULAR OR POROUS STRUCTURE. (Magnified 2300 diameters.)

A, profile view; B, surface view, seen on the flat.

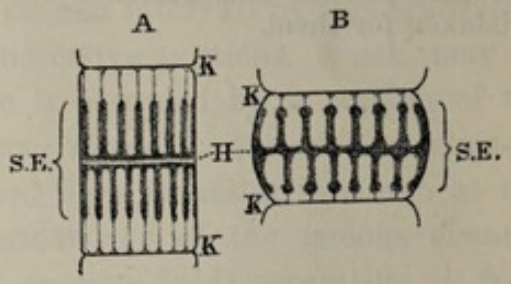
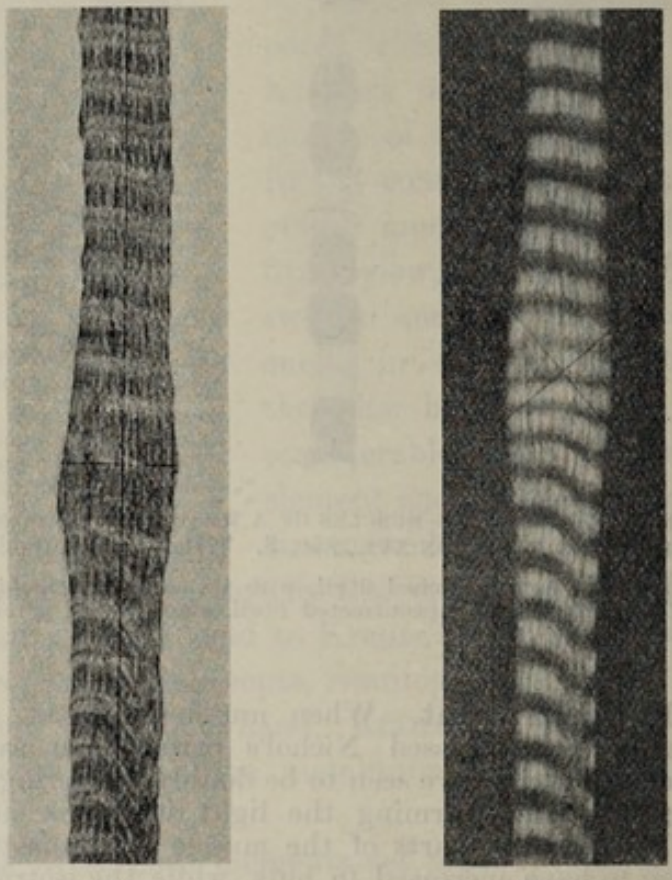


FIG. 117.—DIAGRAM OF A SARCOMERE IN A MODERATELY EXTENDED CONDITION, A, AND IN A CONTRACTED CONDITION, B.

K, K, membranes of Krause; H, line or plane of Hensen; S.E., poriferous sarcous element.

traction, there is an apparent blurring of the cross-striation of the fibre just where the muscle is passing from extension to contraction, but this appear-



A B

FIG. 118.—LEG-MUSCLE FIBRE OF CHRYSOMELA COERULEA WITH (FIXED) CONTRACTION WAVE PHOTOGRAPHED UNDER POLARISING MICROSCOPE.[1]

A, with uncrossed Nichols; B, with crossed Nichols.

ance is explicable by the unequal pull of the contracted parts of the fibrils upon those which are not yet contracted. The contraction in each fibre

[1] I am indebted to Professor Engelmann for these two photographs.

starts from the nerve ending, which is at one side of the fibre, and spreads first across the fibre and then tends to pass as a wave towards either end. But the one side always has a start in the progress of this wave, and the fibrils must thus receive an unequal pull, so that they are shifted along one another and the line of cross-striping is broken up. That no transference of anisotropous substance really occurs is at once clear from the appearance of the contracting fibre under polarised light (fig. 118, B), and the study of the isolated fibrils of wing-muscle gives no support to the theory of reversal, although it is widely held by German authors. That the apparent reversal is not real is also illustrated by fig. 119, which represents a leg muscle fibre of an insect in process of contraction. The dark bands of the contraction wave are seen to be really due to accumulations of sarcoplasm. These accumulations appear as dark lines which obscure the continuity of the fibrils, and by contrast cause the whole of the sarcomeres between them to appear light.

FIG. 119.—WAVE OF CONTRACTION PASSING OVER A LEG MUSCLE FIBRE OF DYTISCUS. Highly magnified.

Comparing the structure of the sarcomere with that of the protoplasm of an amœboid cell we find in both a framework (spongioplasm, substance of sarcous element), which tends to stain with hematoxylin and similar reagents, and which incloses in its meshes or pores a clear, probably semi-fluid substance (hyaloplasm, clear substance of sarcomere) which remains unstained by these reagents. In both instances also the clear substance or hyaloplasm, when the tissue is subjected to stimulation, passes into the pores of the porous substance or spongioplasm (contraction), whilst in the absence of such stimulation it tends to pass out from the spongioplasm (formation of pseudopodia, resting condition of muscle). Thus both the movements of cell-protoplasm and those of muscle seem brought about by similar means, although at first sight the structure of muscle is so dissimilar from that of protoplasm. We have already noticed that the movements of cilia are susceptible of a similar explanation (p. 56).

LESSON XVII.

CONNECTION OF MUSCLE WITH TENDON; BLOOD-VESSELS OF MUSCLE; CARDIAC MUSCULAR TISSUE; DEVELOPMENT OF MUSCLE; PLAIN MUSCULAR TISSUE.

1. To study the connection of muscle with tendon, a frog is killed by destruction of the brain and spinal cord, and placed in about a litre of water raised to a temperature of 55° C. It is left in this for 15 minutes, the water gradually cooling. It is then easy to dissociate the muscular fibres in large numbers. To observe their attachment to the tendon-bundles a fine longitudinal shred must be snipped off with scissors at the tendinous attachment, and dissociated upon a slide in a drop of water. It will usually be found that the muscular substance is retracted from the end of the sarcolemma tube, which is firmly cemented to the tendon-bundle. The structure may be brought more distinctly into view by adding to the dissociated fibres a drop of a weak solution of iodine in salt solution or in serum (iodised serum).[1]

2. The blood-vessels of muscle. These are studied in longitudinal and transverse sections of injected muscle. It will be noticed that the capillaries are very numerous, and form a network with oblong meshes. In the red muscles of the rabbit, small dilatations are seen on the transverse cords of the network.

3. The muscular tissue of the heart is studied in sections of that organ and also in teased preparations. To prepare the latter, place a small piece of heart-muscle in 33 per cent. alcohol for a few days; stain in picro-carmine solution for some hours or days; and tease in dilute glycerine.

4. Tear off a small shred of the muscular coat of a piece of intestine which has been for 48 hours or more in $\frac{1}{8}$ per cent. bichromate of potash solution or in 33 per cent. alcohol. Hold the shred with forceps in a drop of water and fray it out with a needle. In this process many cells will be set free and can be found with a low power. The preparation may then be covered and examined with a high power. Sketch one of the cells. Then allow dilute hæmatoxylin solution to pass under the cover-glass and lastly a drop of glycerine. Sketch another cell after staining. Measure two or three cells and their nuclei.

Ending of muscle in tendon.—A small tendon-bundle passes to each muscular fibre and becomes firmly united with the sarcolemma, which extends over the end of the fibre (fig. 120). Besides this immediate attachment, a further connection is established by the

[1] This method is the one given by Ranvier (*Traité Technique*, 2me édition, p. 395). The muscle-endings may also sometimes be well seen at the extremities of the tendons which are removed from the mouse's tail in the manner described in Lesson X.

fact that the areolar tissue between the tendon-bundles is continuous with that which lies between the muscular fibres.

Blood-vessels of muscle.—The capillaries of muscular tissue are very numerous. They run, for the most part, longitudinally, with transverse branches, so as to form long oblong meshes (fig. 121). No blood-vessels ever penetrate the sarcolemma. In the red muscles of the rabbit, the transverse capillaries have small dilatations upon

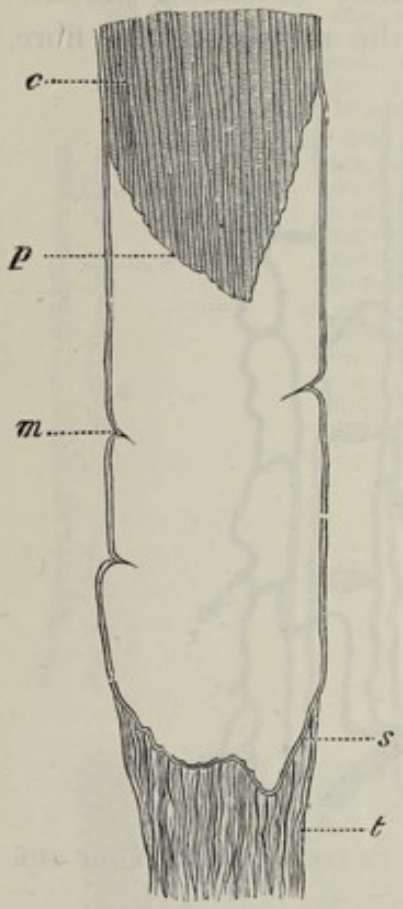


FIG. 120.—TERMINATION OF A MUSCULAR FIBRE IN TENDON. (Ranvier.)

m, sarcolemma, *s*, the same membrane passing over the end of the fibre; *p*, extremity of muscular substance, *c*, retracted from the lower end of the sarcolemma-tube; *t*, tendon-bundle passing to be fixed to the sarcolemma.

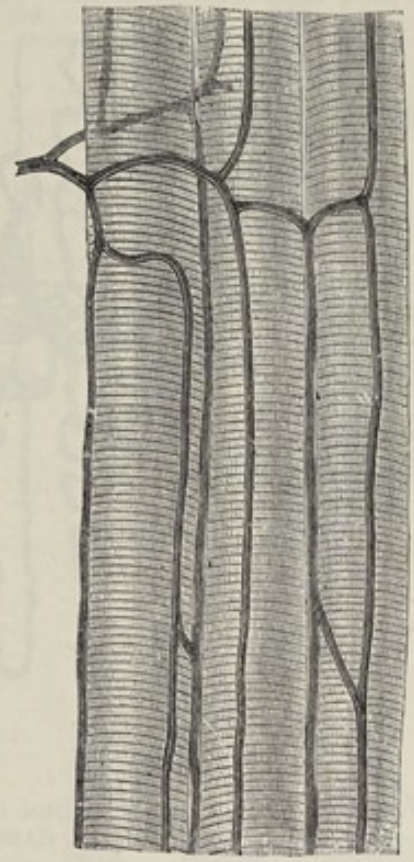


FIG. 121.—CAPILLARY VESSELS OF MUSCLE.

them (fig. 122). Associated with this and other peculiarities of structure (see p. 99), it is found that the red muscles have a much slower rate of contraction, and a much longer period of latency than the ordinary muscles.

Lymphatic vessels, although present in the connective-tissue sheath (perimysium) of a muscle, do not penetrate between the component fibres.

The **motor nerves** of voluntary muscles pierce the sarcolemma

and terminate in a ramified expansion known as an *end-plate* or *motor end-organ*; the *sensory nerves* end in groups of specially modified muscle fibres known as *muscle-spindles* (see Lesson XXI.).

Development. — Voluntary muscular fibres are developed from embryonic cells of the mesoderm, which become elongated, and the nuclei of which become multiplied, so as to produce long multinucleated fusiform or cylindrical fibres. These become cross-striated, at first along one side, the change gradually extending around the fibre and also towards the centre; but the middle of the fibre, to

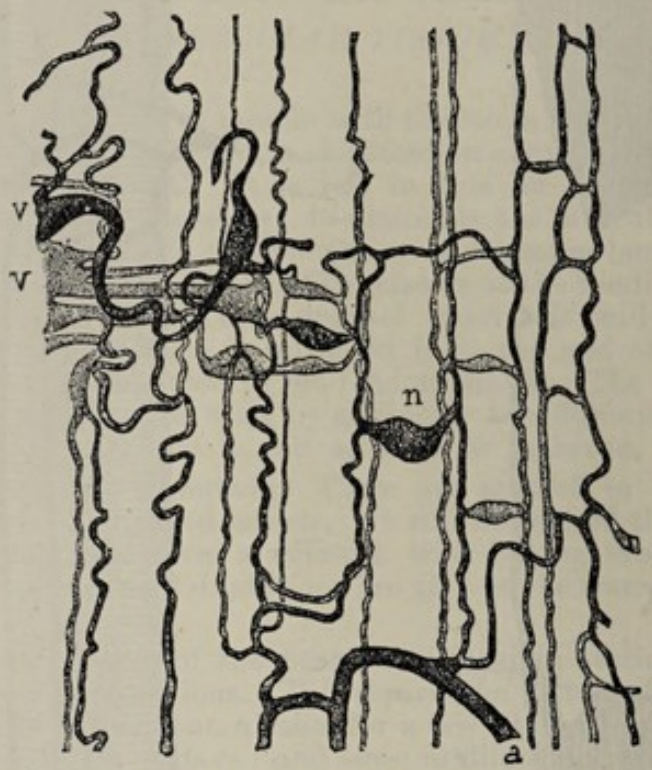


FIG. 122.—VASCULAR NETWORK OF A RED MUSCLE (SEMI-TENDINOUS) OF THE RABBIT. (Ranvier.)

a, arteriole; *v*, *v*, venules; *a*, dilatation on transverse branch of capillaries.

which the nuclei are at first confined, and the side opposite to that at which the differentiation began, remains for some time unaltered (fig. 123). Eventually the change in structure extends to this also, and the nuclei pass gradually to occupy their ordinary position under the sarcolemma, which has by this time become formed.

CARDIAC MUSCLE.

The muscular substance of the heart is composed of transversely striated muscular fibres, which differ from those of voluntary muscle in the following particulars, viz.:—their striations are less distinct; they have no sarcolemma; they branch and unite by their branches and also at the side with neighbouring fibres, and their nuclei lie in the substance and often near the centre of the fibres. Moreover, the fibres

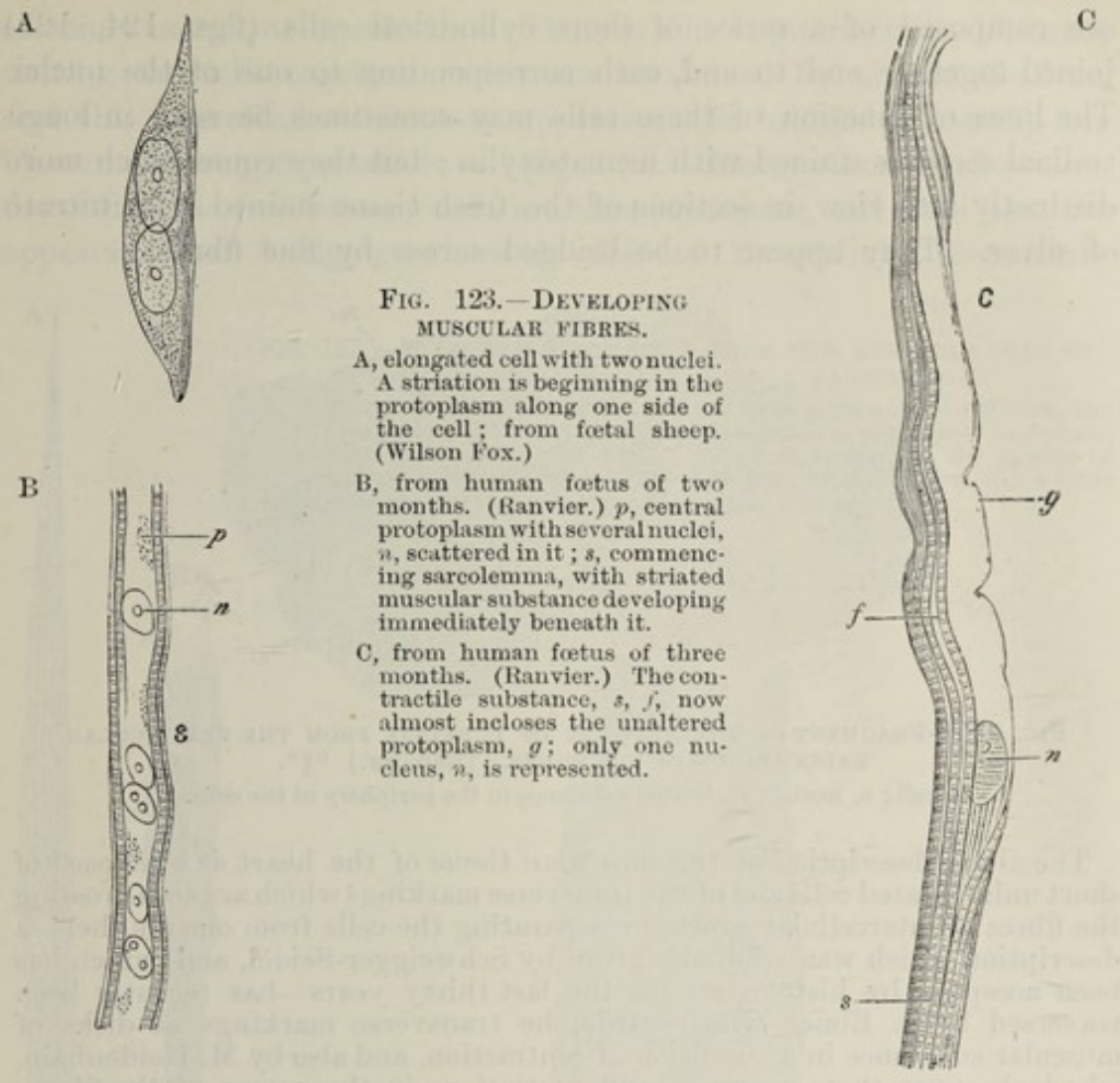


FIG. 123.—DEVELOPING MUSCULAR FIBRES.

A, elongated cell with two nuclei. A striation is beginning in the protoplasm along one side of the cell; from fœtal sheep. (Wilson Fox.)

B, from human fœtus of two months. (Ranvier.) *p*, central protoplasm with several nuclei, *n*, scattered in it; *s*, commencing sarcolemma, with striated muscular substance developing immediately beneath it.

C, from human fœtus of three months. (Ranvier.) The contractile substance, *s*, *f*, now almost incloses the unaltered protoplasm, *g*; only one nucleus, *n*, is represented.

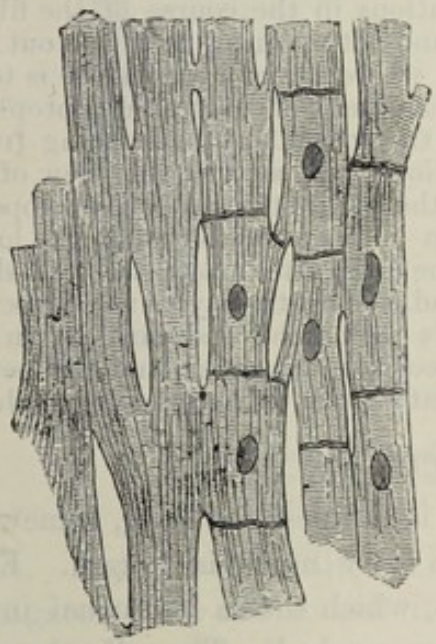


FIG. 124.—MUSCULAR FIBRES FROM THE HEART, MAGNIFIED, SHOWING THEIR CROSS-STRIÆ, DIVISIONS, AND JUNCTIONS. (Schweigger-Seidel.)

The nuclei and cell-junctions are only represented on the right-hand side of the figure.

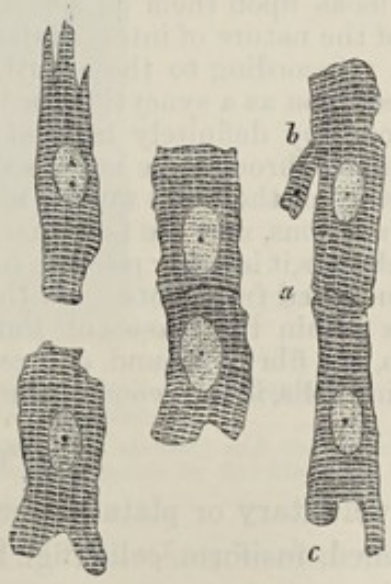


FIG. 125.—SIX MUSCULAR FIBRE-CELLS FROM THE HEART. (Magnified 425 diameters.)

a, line of junction between two cells; *b*, *c*, branching of cells. (From a drawing by J. E. Neale.)

are composed of a series of short cylindrical cells (figs. 124, 125) joined together end to end, each corresponding to one of the nuclei. The lines of junction of these cells may sometimes be seen in longitudinal sections stained with hæmatoxylin ; but they come much more distinctly into view in sections of the fresh tissue stained with nitrate of silver. They appear to be bridged across by fine fibrils.

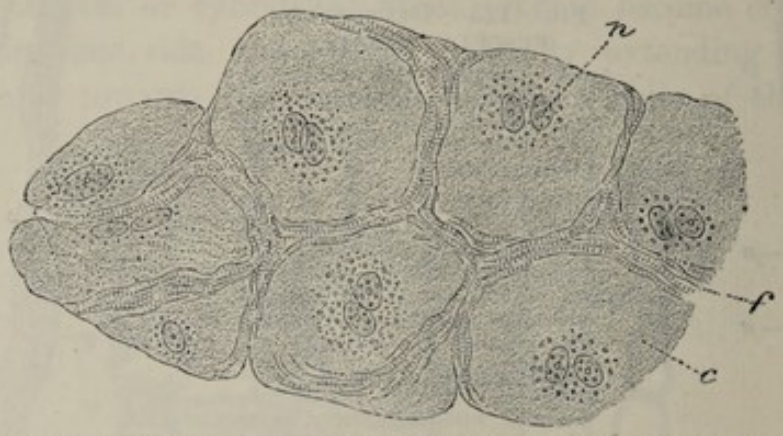


FIG. 126.—FRAGMENT OF THE NETWORK OF PURKINJE FROM THE VENTRICULAR ENDOCARDIUM OF THE SHEEP. (Ranvier.) $\frac{300}{1}$.

c, cell ; *n*, nuclei ; *f*, striated substance in the periphery of the cells.

The above description of the muscular tissue of the heart as composed of short uninucleated cells and of the transverse markings which are seen crossing the fibres as intercellular substance separating the cells from one another—a description which was originally given by Schweigger-Seidel, and which has been accepted by histologists for the last thirty years—has recently been traversed by v. Ebner, who regards the transverse markings as disks of muscular substance in a condition of contraction, and also by M. Heidenhain, who looks upon them as special differentiations in the course of the fibres, not of the nature of intercellular material, and not marking the fibres out into cells. According to these authorities the whole heart musculature is to be looked upon as a syncytium or ramified amassment of nucleated protoplasm without any definitely marked cell-areas, the muscular fibrils being freely continued through the supposed cell junctions. As against this view of the structure of the heart muscle must be set the silver-staining of the supposed cell-junctions, and the fact that, at least in young animals and in the lower vertebrates,it is easily possible to separate the fibres after maceration into short uninucleated fragments. On the other hand, the continuity of the muscular fibres within the masses of Purkinje's cells under the endocardium in the sheep, the fibrils around one cell being freely continued around the neighbouring cells, is in favour of the view advocated by v. Ebner and Heidenhain.

PLAIN MUSCLE.

Involuntary or **plain muscular tissue** is composed of long, somewhat flattened, fusiform cells (fig. 127), which vary much in length. Each cell has an oval or rod-shaped nucleus, which shows the usual intranuclear network and commonly one or two nucleoli. The cell-substance is longitudinally striated (fibrillated), but does not exhibit cross-striæ like those of voluntary muscle. There appears to be a delicate non-striated external layer,probably a stratum of undifferentiated protoplasm,

certainly not a true sarcolemma. There is a little intercellular substance uniting the cells together, which can be stained by nitrate of silver, and this intercellular substance appears to be bridged across by fine filaments passing from cell to cell (fig. 128). Some authorities, however, deny that the involuntary cells are thus connected, and hold that the appearance of bridging fibres is due to intercellular connective

Fig. 127.

Fig. 127.—Muscular fibre-cells from the muscular coat of the small intestine, highly magnified.

A, a complete cell, showing the nucleus with intra-nuclear network, and the longitudinal fibrillation of the cell-substance, with finely vacuolated protoplasm between the fibrils; B, a cell broken in the process of isolation; a delicate external layer projects at the broken end a little beyond the striated substance of the cell.

Fig. 128.—Muscle-cells of intestine. (Szymonowicz.) Magnified 530 diameters.

The fibres are represented in longitudinal section; and the interstices between them are seen to be bridged across by fine fibrils. *i*, interstice; *n*, nucleus.

tissue. It is however difficult to understand how the contractions are propagated from cell to cell if there is no sort of protoplasmic continuity in the tissue.

Plain muscular tissue is found chiefly in the walls of hollow viscera; thus it forms the muscular coat of the stomach and intestines, and occurs abundantly in the muscular coat of the gullet, although it is

here intermixed with cross-striated muscle; it is found also in the mucous membrane of the whole alimentary canal from the œsophagus downwards; in the trachea and its ramifications; in the urinary bladder and ureters; in the uterus, Fallopian tubes, and ovary; in the prostate; the spleen and lymphatic glands; the muscle of Müller in the orbit, and in the ciliary muscle and iris. The walls of gland ducts also contain it, and the middle coat of the arteries, veins and lymphatics is largely composed of this tissue. It occurs in the skin, both in the secreting part of the sweat glands, and in small bundles attached to the hair-follicles; in the scrotum it is found abundantly in the subcutaneous tissue (dartos), and it also occurs in the areola of the nipple.

LESSON XVIII.

STRUCTURE OF NERVE-FIBRES.

1. Tease a piece of fresh nerve rapidly in salt solution (or by the method of semidesiccation, afterwards mounting in salt solution), injuring the fibres as little and obtaining them as long and straight as possible. Study the medullated fibres, carefully noticing all the structures that are visible—viz., nodes of Ranvier, nucleus of primitive sheath, double contour of medullary sheath, medullary segments, etc. Measure the diameter of half a dozen fibres. Draw a short length of a fibre very exactly.

2. Prepare a piece of sympathetic nerve in the same way. The nerves passing to the spleen are the best for the study of non-medullated fibres. They may also be found amongst the medullated fibres of the ordinary nerves. Measure and sketch as before.

3. Separate (in dilute glycerine) into its fibres a small piece of nerve or nerve-root that has been twenty-four hours in 1 per cent. osmic acid. The nerve should have been moderately stretched on a piece of cork by means of glass pins before being placed in the acid. Keep the fibres as straight as possible and only touch them near their ends with the needles. Sketch two portions of a fibre under a high power, one showing a node of Ranvier and the other a nucleus of the primitive sheath. Look for fibres of Remak. Measure the length of the nerve-segments between the nodes of Ranvier.

4. Mount in xylol balsam sections of a nerve which has been hardened in picric acid or fixed with osmic acid and hardened in alcohol. Stain with picro-carmine or hæmatoxylin. The nerve should be straightened out before being placed in the hardening solution. Examine the sections first with a low and afterwards with a high power. Notice the lamellar structure of the perineurium, the varying size of the nerve-fibres, the axis cylinder in the centre of each fibre, etc. Measure the diameter of five or six fibres, and sketch a small portion of one of the sections.

5. Mount in glycerine sections of splenic nerve which was placed as soon as possible after death in 1 per cent. osmic acid.

Nerve-fibres are of two kinds, *medullated* and *non-medullated*. The cerebro-spinal nerves and the white matter of the nerve-centres are composed of medullated fibres; the sympathetic nerves near their peripheral distribution are largely made up of non-medullated fibres.

The **medullated** or **white fibres** are characterised, as their name implies, by the presence of the so-called *medullary sheath* or *white substance*. This is a layer of soft substance, physically of a fatty nature, which encircles the essential part of a nerve-fibre, viz., the *axis-cylinder*. Outside the medullary sheath is a delicate but tough homogeneous membrane, the *primitive sheath* or *nucleated sheath of Schwann*, but this is not present in all medullated fibres, being absent

in those which are within the nerve-centres. The primitive sheath is also known as the *neurolemma*.[1]

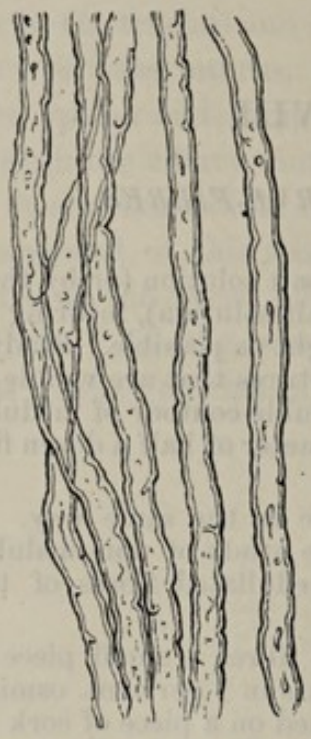


FIG. 129.—WHITE OR MEDULLATED NERVE-FIBRES, SHOWING THE SINUOUS OUTLINE AND DOUBLE CONTOURS.

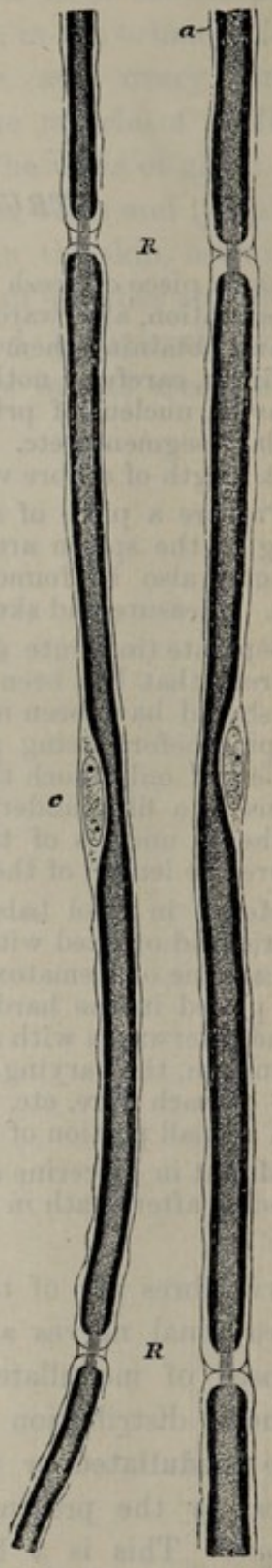


FIG. 130.—PORTIONS OF TWO NERVE-FIBRES STAINED WITH OSMIC ACID (FROM A YOUNG RABBIT). (425 diameters.)

R, *R*, nodes of Ranvier, with axis-cylinder passing through. *a*, primitive sheath of the nerve; *c*, opposite the middle of the segment, indicates the nucleus and protoplasm lying between the primitive sheath and the medullary sheath. In A the nodes are wider, and the intersegmental substance more apparent than in B. (Drawn by J. E. Neale.)

The *medullary sheath* is composed of a highly refracting fatty material, which gives a characteristic dark contour and tubular appearance

[1] Often termed "neurilemma," a name formerly applied to the sheath of Henle (see p. 120).

to the nerve-fibres (fig. 129). It affords a continuous investment to the axis-cylinder, except that, as was shown by Ranvier, it is interrupted at regular intervals in the peripheral nerve-fibres. Here the

FIG. 131.—A SMALL PART OF A MEDULLATED FIBRE, HIGHLY MAGNIFIED.

The fibre looks in optical section like a tube—hence the term tubular, formerly applied to these fibres. Two partial breaches of continuity (medullary clefts) are seen in the medullary sheath, which at these places exhibits a tendency to split into laminæ. The primitive sheath is here and there apparent outside the medullary sheath, and the delicate striæ which are visible in the middle of the fibre indicate the fibrillations of the axis cylinder.

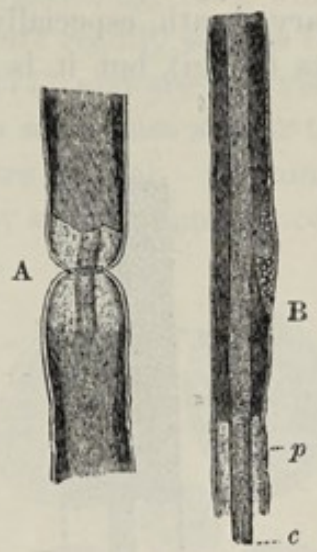


FIG. 132.—TWO PORTIONS OF MEDULLATED NERVE-FIBRES, AFTER TREATMENT WITH OSMIC ACID, SHOWING THE AXIS-CYLINDER AND THE MEDULLARY AND PRIMITIVE SHEATHS. (Key and Retzius.)

A, node of Ranvier. B, middle of an internode with nucleus. *c*, axis-cylinder projecting; *p*, primitive sheath, within which the medullary sheath, which is stained dark by the osmic acid, is broken away for a short distance.

primitive sheath appears to produce a constriction in the nerve-fibre, and the interruptions of the medullary sheath are accordingly known as the *constrictions* or *nodes of Ranvier* (figs. 130, 132, 133), the

FIG. 133.—NERVE-FIBRE PREPARED WITH OSMIC ACID. (Szymonowicz.)

b, node of Ranvier. The intervals between the medullary segments appear as clear oblique lines, *a*, *a*.

term nodes being applied from the resemblance which they bear to the nodes of a bamboo. It is however uncertain whether the constriction is entirely occupied by the neurolemma itself or largely by a special band (*constricting band of Ranvier*) of a material which resembles intercellular substance in its reaction to nitrate of silver (see fig. 142). The length of nerve between two successive nodes is termed an inter-

node; in the middle of each internode is one of the nuclei of Schwann's sheath. Besides these interruptions the medullary sheath shows a variable number of oblique clefts (figs. 131, 133), which subdivide it into irregular portions, which have been termed *medullary segments*; but there is some reason to believe that the clefts are artificially produced. At the clefts there is an appearance of spiral fibres in the medullary sheath, especially after treatment of the nerve with certain reagents (Golgi), but it is also doubtful if these fibres are present in

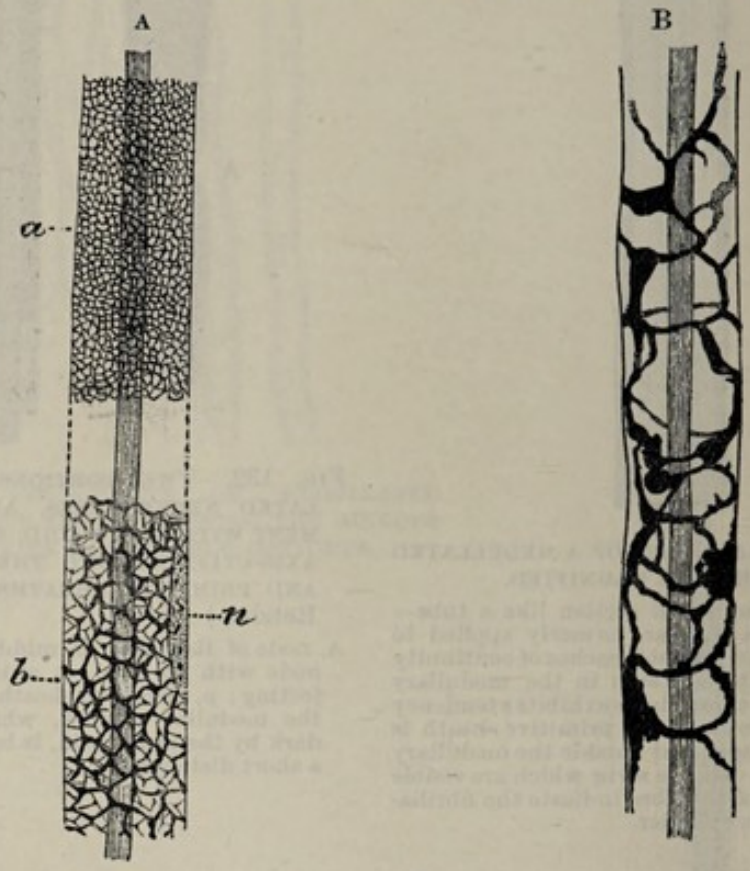


FIG. 134.—RETICULAR APPEARANCES IN THE MEDULLARY SHEATH OF NERVE-FIBRES. (Gedoelst.)

A, from the toad; B, from the guinea-pig. The reticulum is finer at *a*, coarser at *b*; still coarser in the fibre shown at B: *n*, nucleus of fibre.

the fresh nerve. A reticular structure has also been described in the medullary sheath (*neurokeratin network* of Kühne), and can be readily seen in nerve fibres fixed in alcohol and treated with ether, but it varies greatly in appearance, and is perhaps produced by the action of the reagents employed to show it (fig. 134). By other modes of fixation (*e g.* picric acid) the medullary sheath appears to have a rod-like structure (fig. 136), but this again may be due to the manner in which certain of its constituents are coagulated by the reagent. Osmic acid stains the medullary sheath black (fig. 137).

The *axis-cylinder*, which runs along the middle of the nerve-fibre, is a soft transparent thread which is continuous from end to end of the

nerve. On account of the peculiar refractive nature of the medullary sheath it is difficult to see the axis-cylinder in the fresh nerve except at the nodes, where it may be observed stretching across the interruptions in the medullary sheath; it may also sometimes be seen projecting from a broken end of a nerve-fibre. It is longitudinally striated, being made up of exceedingly fine fibrils (*ultimate fibrils*, fig. 135), which are stained darkly by chloride of gold. They are readily seen at the termination of a nerve, as in the cornea (fig. 177), and are also visible in the section of a nerve-fibre as fine dots which sometimes appear to have a clear centre (fig. 136), as if the fibrils were tubular. Staining with nitrate of silver produces a curious transversely striated appearance in the

FIG. 135.—AXIS-CYLINDER, HIGHLY MAGNIFIED, SHOWING THE FIBRILS COMPOSING IT. (M. Schultze.)

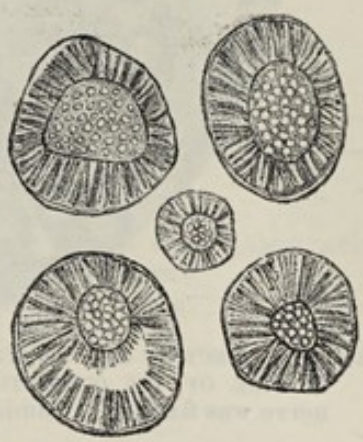


FIG. 136.—SECTION ACROSS FIVE NERVE-FIBRES. (Magnified 1000 diameters.)

The nerve was hardened in picric acid and stained with picro-carmine. The radial striation of the medullary sheath is very apparent. In one fibre the rays are broken by shrinkage of the axis-cylinder. The fibrils of the axis-cylinder appear tubular. (From a photograph.)

axis-cylinder, but it is doubtful if this indicates a pre-existent structure.

Medullated nerve-fibres vary greatly in size (fig. 137), but may be classified as *large*, *intermediate*, and *small*. The largest are those which are passing to the skin and to the voluntary muscles; the smallest are those which are distributed to the viscera and blood-vessels by way of the sympathetic ganglia. As shown by Gaskell, the anterior roots of all the thoracic, of the first and second lumbar, and of the second and third sacral nerves contain besides the ordinary large medullated fibres a bundle of very small medullated fibres which are destined for the viscera and blood-vessels, and which for the most part pass to the sympathetic. The roots of one or two of the cranial nerves (*e.g.* the spinal accessory and the seventh) contain similar fine medullated fibres.

Non-medullated fibres.—Intermingled with the medullated fibres there may always, even in the cerebro-spinal nerves, be found a certain

number of pale fibres devoid of the dark double contour which is

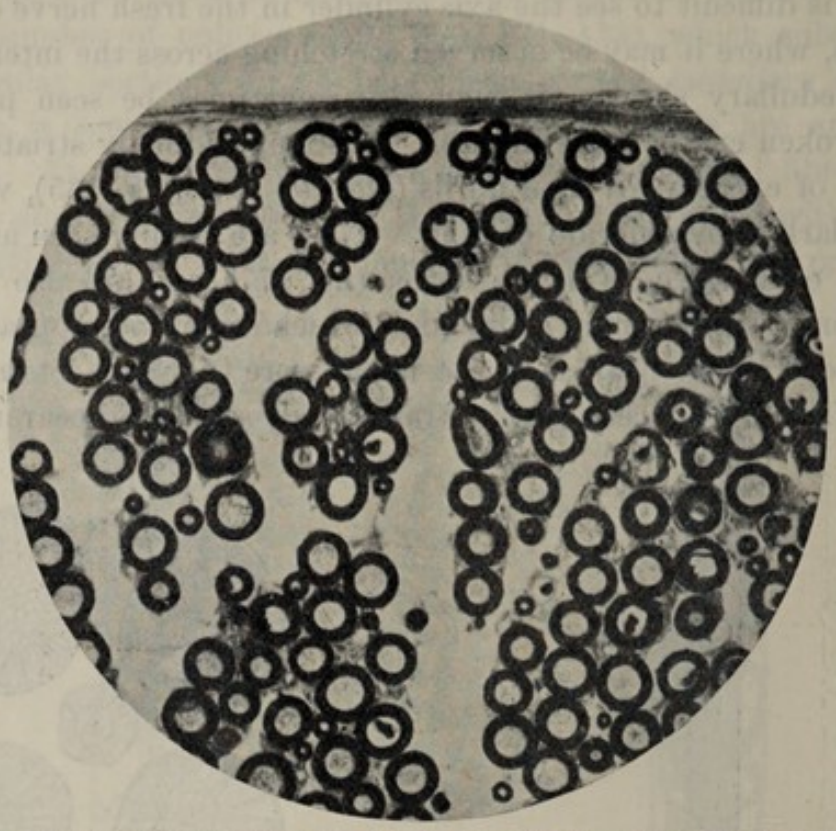


FIG. 137.—SECTION OF THE SCIATIC NERVE OF A CAT, SHOWING THE VARIATIONS IN SIZE OF ITS CONSTITUENT FIBRES. (Magnified 300 diameters.) The nerve was fixed with osmic acid.

characteristic of the presence of a medullary sheath. These are the *grey* or *non-medullated fibres*, also called, after their discoverer, *fibres of*

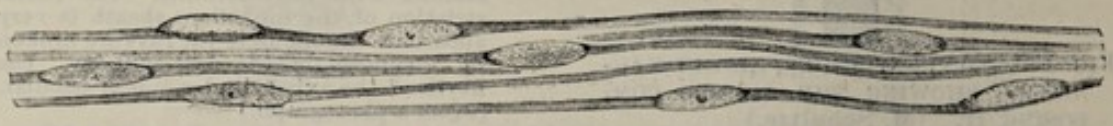


FIG. 138.—NON-MEDULLATED NERVE-FIBRES. (Magnified 400 diameters.)

Remak (fig. 138). They frequently branch, which the medullated fibres rarely do except near their termination, and they are beset with numerous nuclei which perhaps belong to a delicate sheath. The sympathetic nerves, as they approach their peripheral distribution, are largely made up of fibres of this nature, but, on the other hand, many of the fibres of the sympathetic nerves possess a thin medullary sheath.

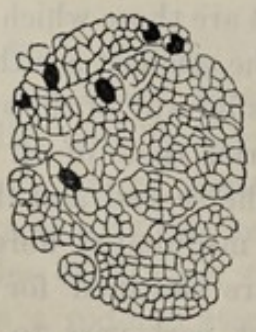


FIG. 139.—SECTION ACROSS NON-MEDULLATED FIBRES FROM THE SPLENIC NERVE OF THE OX. (Tuckett.)

Structure of the nerve-trunks.—In their course through the body the nerve-fibres are gathered up into bundles or *funiculi*, and the funiculi may again be united together to form the nerves which we

meet with in dissection. The connective tissue which unites the funiculi and invests the whole nerve, connecting it to neighbouring

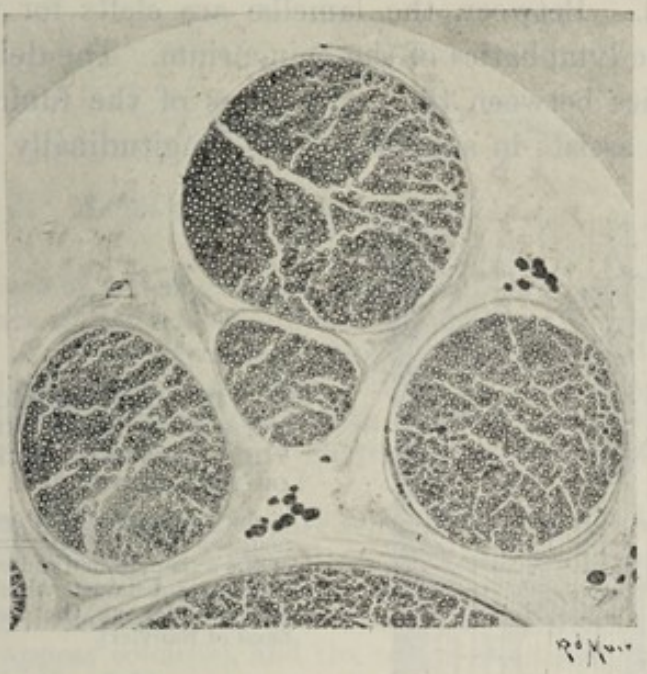


FIG. 140.—SECTION OF PART OF A NERVE-TRUNK FIXED WITH OSMIC ACID. (From a photograph.) (Magnified 40 diameters.)

Three small funiculi and a small part of a larger funiculus are shown. The fat-cells in the epineurium are stained black by the osmic acid.

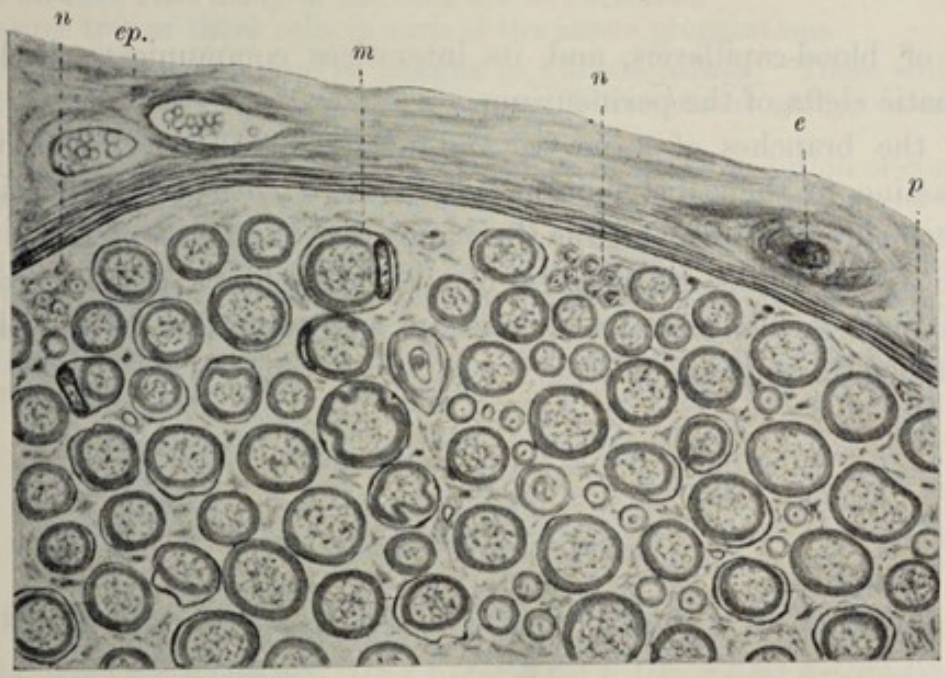


FIG. 141.—SECTION OF PART OF A FUNICULUS OF THE SCIATIC NERVE OF A CAT FIXED WITH FLEMMING'S SOLUTION. (Magnified 400 diameters.)

ep, epineurium with blood-vessels; *e*, section of an end-bulb; *p*, perineurium; *m*, medullated fibre cut at the level of a nucleus; *n*, *n*, bundles of non-medullated fibres.

parts and conveying to it blood-vessels, lymphatics, and even nerve-fibres destined for its coats, is termed the *epineurium*. That which ensheaths the funiculi is known as the *perineurium* (figs. 140, 141). It

has a distinctly lamellar structure (fig. 141), the lamellæ being composed of connective tissue and covered on both surfaces by flattened epithelioid cells (fig. 142). Between the lamellæ are clefts for the conveyance of lymph to the lymphatics of the epineurium. The delicate connective tissue which lies between the nerve-fibres of the funiculus is the *endoneurium*. It assists in supporting the longitudinally arranged mesh-

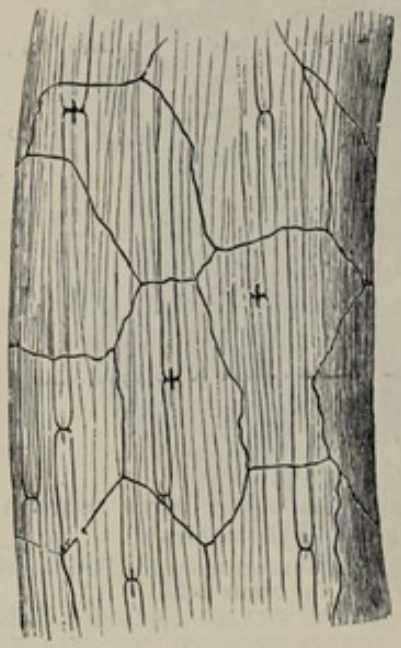


FIG. 142.—NERVE-FUNICULUS STAINED WITH NITRATE OF SILVER SHOWING THE OUTLINES OF EPITHELIOID-CELLS OF THE PERINEURIUM. (Ranvier.)

The dark crosses on the nerve-fibres at the nodes of Ranvier are due to the staining of the axis-cylinder and of a band of intercellular substance which encircles the axis-cylinder at the node (constriction band of Ranvier).

work of blood-capillaries, and its interstices communicate with the lymphatic clefts of the perineurium.

All the branches of a nerve, and even single nerve-fibres which are passing to their distribution, are invested with a prolongation of the perineural sheath, which is then known as the *sheath of Henle*.

The nerve-trunks themselves receive nerve-fibres (*nervi nervorum*) which ramify chiefly in the epineurium and terminate within this in end-bulbs (Horsley) (fig. 141, *e*).

LESSON XIX.

STRUCTURE OF GANGLIA.

1. Put a small piece of spinal ganglion into 1 per cent. osmic acid for two or three hours. Place in water containing a fragment of thymol for two days or more. Tease in dilute glycerine. Notice the spheroidal ganglion-cells; their large nuclei and distinct nucleoli. Many of the cells may still be seen within their nucleated membranous sheath. Look for cells which still retain the axis-cylinder process and for T-shaped junctions of nerve-fibres with this.

2. Place a spinal ganglion of a freshly killed animal in salt solution containing 1 part in 100 of methylene blue. In an hour's time transfer it to fresh salt solution, and tease a small piece carefully, with the aid of a dissecting microscope in order to isolate some of the cells. The ganglion cells with their processes should appear coloured, and the rest of the tissue nearly colourless. The colour may be fixed by treatment for an hour or more with picrate of ammonia (saturated solution), and the preparation may then be mounted in glycerine containing picrate of ammonia.

3. Prepare a piece of sympathetic ganglion as in §§ 1 and 2. If from a rabbit observe that many of the cells are bi-nucleated.

Measure two or three cells in each of the above preparations.

4. Mount stained sections of ganglia in Canada balsam. These will serve to show the arrangement of the cells and fibres in the ganglion and the nucleated sheaths around the nerve-cells.

The ganglia may be fixed and hardened in saturated solution of corrosive sublimate or of picric acid or a mixture of the two in equal parts. They may either be stained in bulk or sections cut from paraffin and stained on the slide. Or the fresh ganglia may be stained by prolonged immersion in 1 per cent. methylene blue in salt solution; rinsed with salt solution; fixed with picrate of ammonia for 15 minutes, then placed for 15 minutes more in Bethe's fixative for methylene blue,[1] and finally hardened in alcohol and prepared for sections in the usual way.

LESSON XX.

NERVE-CELLS OF SPINAL CORD AND BRAIN; DEGENERATION OF NERVE-FIBRES; DEVELOPMENT OF NERVE-CELLS AND FIBRES.

1. Place a portion of the grey matter from a piece of spinal cord in 33 per cent. alcohol. After macerating for two days or longer in this fluid, a little of the grey matter may be shaken up in a test-tube with water so as to break it up into fine fragments. Allow these to subside, decant off the water and

[1] See Appendix.

substitute a dilute solution (1 to 500) of toluidin blue or of methylene blue. After standing a few minutes this may also be decanted off and water again substituted. Some of the debris is now to be pipetted off and examined under a low power of the microscope, at first without a cover-glass so that the cells may, if necessary, be separated from the rest of the tissue. Mount in water with a thick hair under the cover-glass. Notice the large branching cells, some with a mass of pigment near the nucleus. Observe the fibrillation of the cell-processes. Many axis-cylinders will be seen in this preparation deprived wholly or partially of their medullary sheath, and their fibrillar structure can then also be well seen. Carefully sketch these appearances. To keep this preparation the stain must be fixed with picrate of ammonia, after which a mixture of glycerine and picrate of ammonia may be used for mounting. Similar preparations may be made from the grey matter of the cerebral cortex and cerebellar cortex.

2. Examine the nerve-cells and neuroglia-cells in sections from the spinal cord, cerebrum, and cerebellum of a small animal, *e.g.* young rat or kitten, prepared by Golgi's method. The sections must be mounted in thick xylol balsam without a cover-glass, and the balsam dried rapidly on a warm plate.

3. Make teased preparations from a nerve which, some days previously, has been cut nearer the spinal cord. The nerve should have been prepared with osmic acid, as in Lesson XVIII., § 3. Notice the breaking up of the myelin of the medullary sheath, varying in degree according to the length of time the section has been made previously. In preparations from the central cut end of the nerve new fibres may be seen budding from near the extremities of the undegenerated fibres of the stump. Sections of the part of the spinal cord of the ganglia from which the cut nerve-fibres arose will exhibit Nissl's degeneration of the nerve-cells.

Nerve-cells only occur in the grey matter of the nerve-centres, and in little groups on the course of certain of the peripheral nerves, these groups often causing nodular enlargements of the nerves, which are known as *ganglia*. The most important ganglia are those which are found upon the posterior roots of the spinal nerves, upon the roots of some of the cranial nerves, and upon the trunk and principal branches of the sympathetic nerve. Minute ganglia are also found very numerously in connection with the nerves which are supplied to involuntary muscular tissue, as in the heart, alimentary canal, bladder, uterus, etc.

Nerve-cells vary much in size and shape; many are large (fig. 143), some being amongst the largest cells met with in the body, but others are quite small. The nucleus is generally large, clear, and spherical, with a single large and distinct nucleolus; there may also be a network of chromoplasm, but this is not always to be seen. The protoplasm is fibrillated, the fibrils passing into the processes. It also contains peculiar angular granules (*Nissl granules*) staining darkly with methylene blue (fig. 144), but the size, number, and arrangement of these in different cells vary greatly. The granules are also found to vary in number and in size with the physiological condition of the cells; thus it

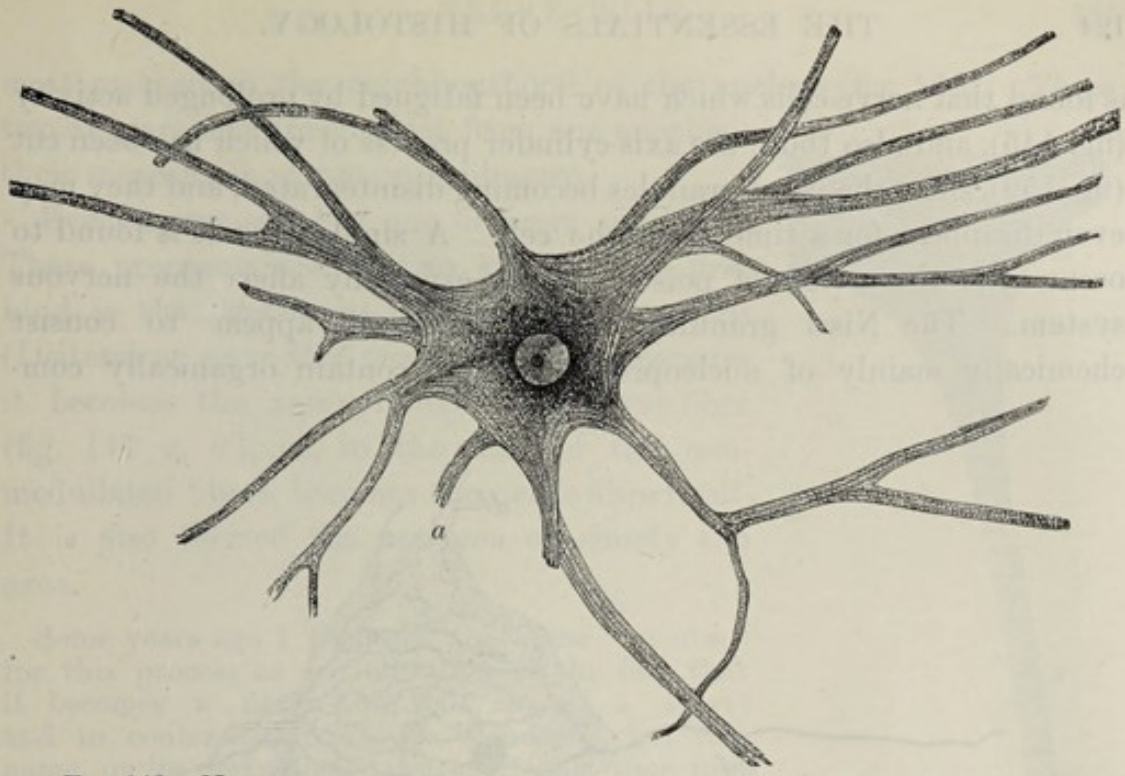


FIG. 143.—NERVE-CELL FROM SPINAL CORD OF OX, ISOLATED AFTER MACERATION IN VERY DILUTE CHROMIC ACID. (Magnified 175 diameters.)

The cell has a well-defined, clear, round nucleus, and a large nucleolus. The cell-processes are seen to be finely fibrillated, the fibrils passing from one process into another through the body of the cell. *a*, axis-cylinder process broken a short distance from the cell.

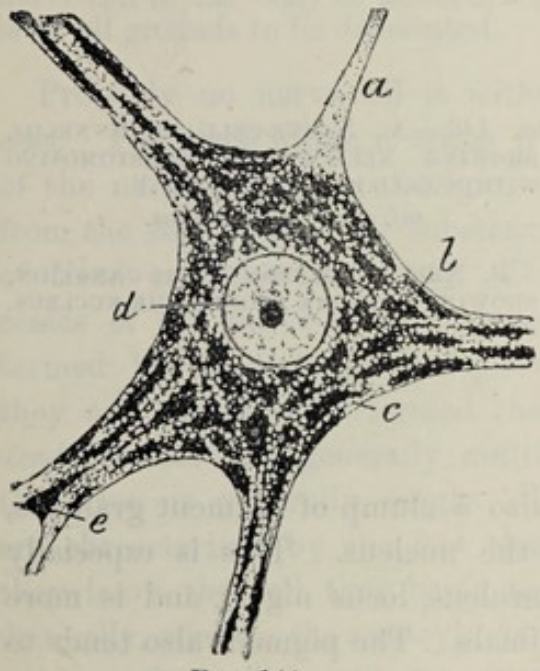


FIG. 144.

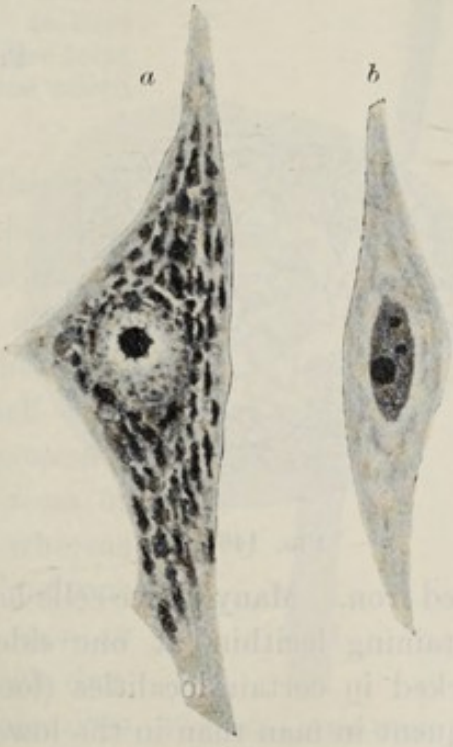


FIG. 145.

FIG. 144.—BODY OF A NERVE-CELL FROM THE SPINAL CORD, STAINED BY NISSL'S METHOD. (S. Ramón y Cajal.)

a, axis-cylinder process or axon; *b*, angular granules (Nissl granules) in the protoplasm: they are stained darkly by methylene blue; *c*, intergranular substance; *d*, nucleus; *e*, a Nissl granule at the point of division of one of the dendrons.

FIG. 145.—TWO MOTOR NERVE-CELLS FROM THE DOG.

a, normal; *b*, after a period of prolonged activity. (Photographed from preparations by Dr. Gustav Mann.)

is found that nerve-cells which have been fatigued by prolonged activity (fig. 145), and also those the axis-cylinder process of which has been cut (fig. 159), show the Nissl granules becoming disintegrated, and they may even disappear for a time from the cell. A similar result is found to occur after the action of poisons which especially affect the nervous system. The Nissl granules of the nerve-cell appear to consist chemically mainly of nucleoproteid and to contain organically com-

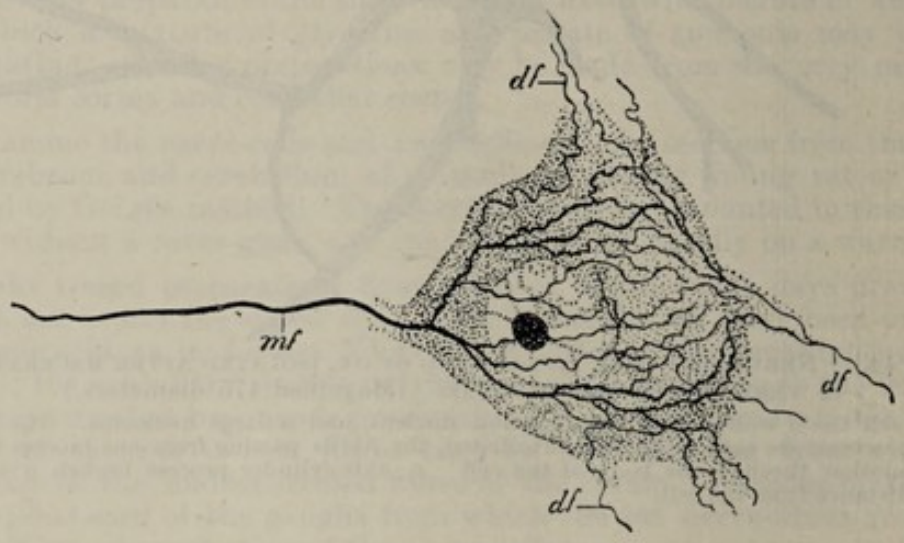


FIG. 146 A.

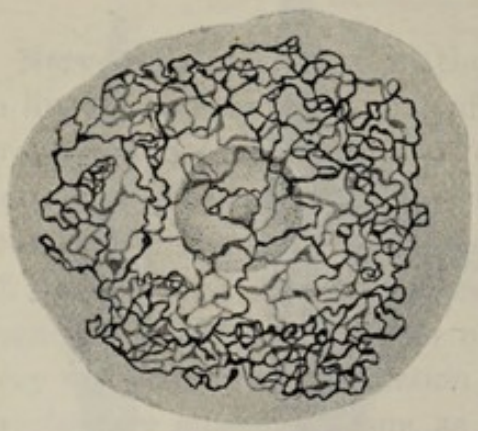


FIG. 146 B.

FIG. 146.—A. NERVE-CELL OF ANNELID, SHOWING NEUROFIBRILS ANASTOMOSING WITHIN CELL-BODY. (Apáthy.)
mf, axon; *df*, dendrons.

B. NERVE-CELL FROM SPINAL GANGLION, SHOWING NETWORK AROUND THE NUCLEUS. (Golgi.)

bined iron. Many nerve-cells have also a clump of pigment granules, containing lecithin, at one side of the nucleus. This is especially marked in certain localities (locus cœruleus, locus niger), and is more frequent in man than in the lower animals. The pigment also tends to increase in amount as age advances. Certain other points of structure in nerve-cells have recently attracted attention. One of these is the presence on the surface of most, if not of all, nerve-cells of a delicate investment which has a reticular character (*reticulum of Golgi*) (fig. 150). Besides this an appearance as of fine fibrils has been described in some nerve-cells, forming a network in the protoplasm,

most marked in the neighbourhood of the nucleus (fig. 146). These two appearances are distinct from one another; their meaning is at present unknown.

Every nerve-cell has one or more processes. These processes are of two kinds. The first kind is that known as the *axis-cylinder process* (Deiters) or *nerve-fibre process*, so called because it becomes the axis-cylinder of a nerve-fibre (fig. 147 *a*, *a'*), or, in the case of the non-medullated fibres, becomes the nerve-fibre itself. It is also termed the *neuraxon* or simply the *axon*.

Some years ago I proposed the name "neuron" for this process as an indication of the fact that it becomes a nerve-fibre (Gr. νευρον, a nerve) and in contradistinction to "dendron," but this name, or its derivative "neurone," has come into use in quite a different sense, viz.: to denote the nerve-cell itself, including all its processes, and its employment in this latter sense has become too deeply rooted in recent neurological literature to be eradicated. Suffice it to say that it is exactly synonymous with "nerve-cell" as here employed, although some authors restrict the term nerve-cell to the body of the cell, a practice which is on all grounds to be deprecated.

Probably no nerve-cell is without this process. The place where it arises from the body of the nerve-cell (cone of origin) is marked off from the rest of the cell substance by absence of Nissl granules (fig. 144). The other processes of the nerve-cell are those which were termed by Deiters the *protoplasmic processes*; they are now usually termed the *dendrons* or *dendrites* and are generally multiple, whereas the axon is generally single. The dendrons are characterised by the fact that as soon as they leave the cell they begin to branch dendritically, whereas the axis-cylinder process does not branch until near its termination, with the exception of a few fine lateral offshoots, which are sometimes given off in its course. Dendrons may be absent; the cell is then said to be adendric, *e.g.* most of the cells of the spinal ganglia. Most nerve-cells have only one nerve-

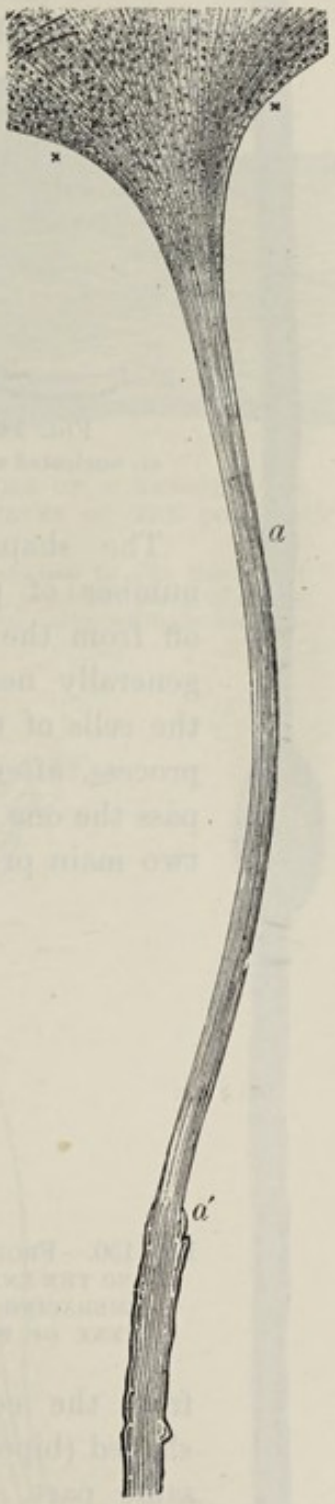


FIG. 147.—AXIS-CYLINDER PROCESS OF A NERVE-CELL FROM THE SPINAL CORD. (M. Schultze.)

× ×, portion of the cell-body, out of which the fibrils of the axis-cylinder process, *a*, are seen to emerge. At *a'*, this process acquires a medullary sheath. (Highly magnified.)

fibre process (*mononeuric* or *unipolar*), but some have two or more (*dineuric* or *bipolar*, *trineuric*, etc.). The dendrons contain Nissl's granules, but the axons do not (fig. 144).

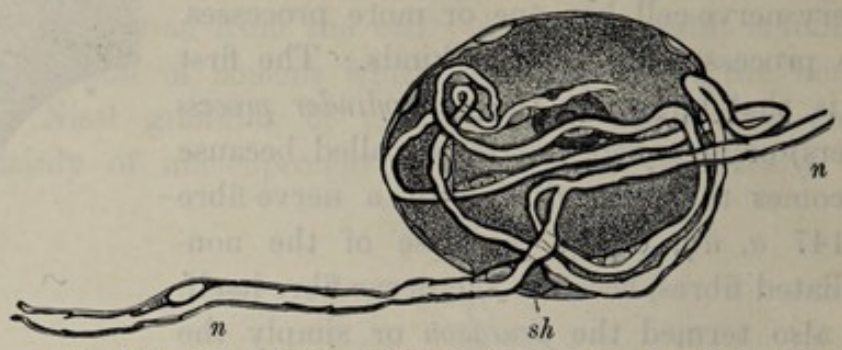


FIG. 148.—CELL FROM A SPINAL GANGLION. (G. Retzius.)
sh, nucleated sheath of the cell; *n*, *n'*, the nerve fibre which the single process of the cell, after a number of coils, joins.

The shape of the cell depends a good deal on the number of processes, and the manner in which they come off from the cell. If there is but one process the cell is generally nearly spherical. This is the case with most of the cells of the spinal ganglia (fig. 148); in these the single process, after a short course, divides into two fibres, which pass the one centrally the other peripherally. When there are two main processes, they often go off in opposite directions

FIG. 150.—FROM THE TRAPEZOID NUCLEUS IN THE PONS VAROLII, SHOWING THE ENDING OF AN AXON EXPANDED INTO A CALIX, AND CLOSELY EMBRACING THE BODY OF ANOTHER CELL, THE RETICULAR INVESTMENT OF WHICH IS ALSO APPARENT. (Vincenzi.)

from the cell, which is thus rendered somewhat spindle-shaped (bipolar, fig. 149), but occasionally they emerge at the same part. In some cases where there appear to be two fibres connected with a cell, one of them is really derived from another nerve-cell elsewhere, and is passing to end in a ramification which envelops the cell-body; in certain situa-

FIG. 149.

FIG. 149.—A BIPOLAR CELL WITH TWO AXONS, WHICH BECOME INVESTED WITH MEDULLARY SHEATH IMMEDIATELY ON LEAVING THE CELL. (Key and Retzius.)
The neurolemma of the nerve-fibres is continued over the cell-body.

tions the ramification is so intimately united to the body of the second cell that it appears to be rooted in the external layer (fig. 150)

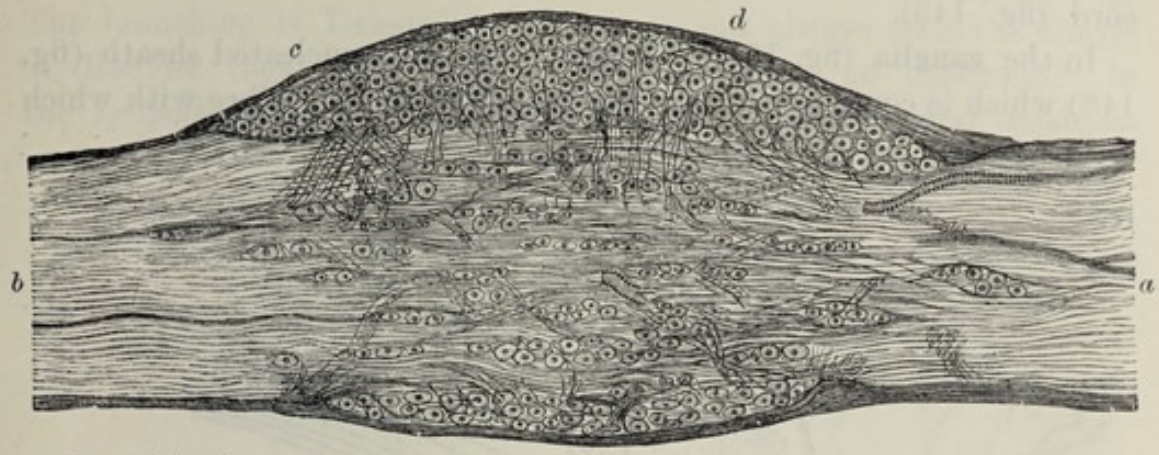


FIG. 151.—LONGITUDINAL SECTION THROUGH THE MIDDLE OF A GANGLION ON THE POSTERIOR ROOT OF ONE OF THE SACRAL NERVES OF THE DOG, AS SEEN UNDER A LOW MAGNIFYING POWER.

a, nerve-root entering the ganglion; *b*, fibres leaving the ganglion to join the mixed spinal nerve; *c*, connective-tissue coat of the ganglion; *d*, principal group of nerve-cells, with fibres passing down from amongst the cells, to unite with the longitudinally coursing nerve-fibres by T-shaped junctions.

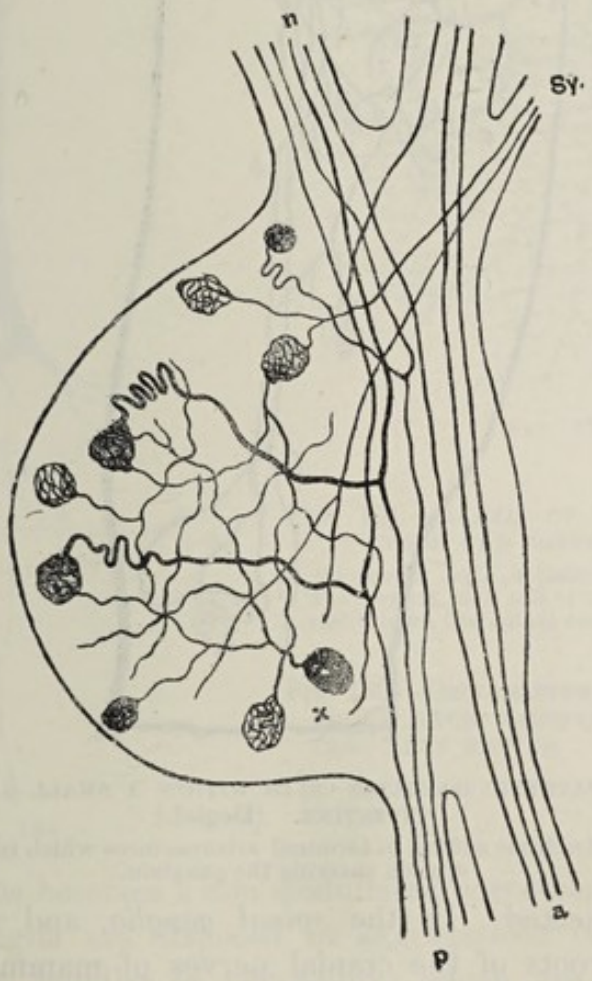


FIG. 152.—DIAGRAM SHOWING SOME OF THE CELLS OF A SPINAL GANGLION AND THEIR CONNECTION WITH NERVE-FIBRES. (Dogiel.)

a, *p*, anterior and posterior root of spinal nerve; *n*, an issuing nerve bundle; *sy*, fibres from sympathetic; ×, a cell, the axon of which ends in ramifications around the cell-bodies of the ordinary ganglion-cells.

(concrescence of Held). When there are three or more processes, the cell becomes irregularly angular, as in the motor-cells of the spinal cord (fig. 143).

In the **ganglia** (fig. 151) each nerve-cell has a nucleated sheath (fig. 148) which is continuous with the sheath of the nerve-fibre with which

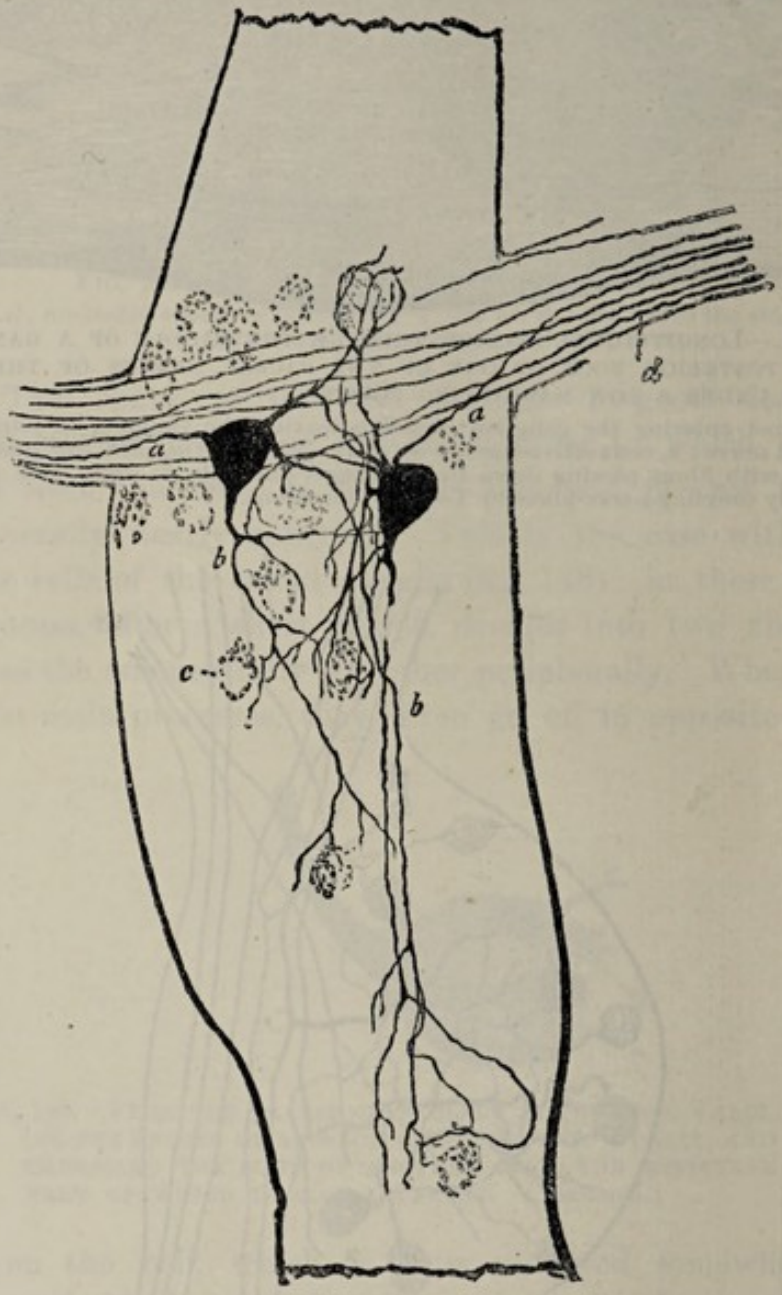


FIG. 153.—SYMPATHETIC GANGLION-CELLS WITHIN A SMALL GANGLION OF THE INTESTINE. (Dogiel.)

a, *a*, axons; *b*, *b*, dendrons ending in terminal arborescences which invest other cells, *c*; *d*, axon entering the ganglion.

the cell is connected. In the *spinal ganglia*, and in many of the ganglia at the roots of the cranial nerves of mammals and of most other vertebrates, the cells have only one process, the axis-cylinder process, which soon acquires a medullary sheath and then passes with a somewhat convoluted course to some little distance from the cell-

body, where, still within the ganglion, it divides into two, one fibre passing to the nerve-centre, and the other towards the periphery. The branching is T-shaped or Y-shaped, and always occurs at a node of Ranvier (figs. 148, 152). These cells have no dendrons. In the *sympathetic ganglia* the nerve-cells usually have several dendrons

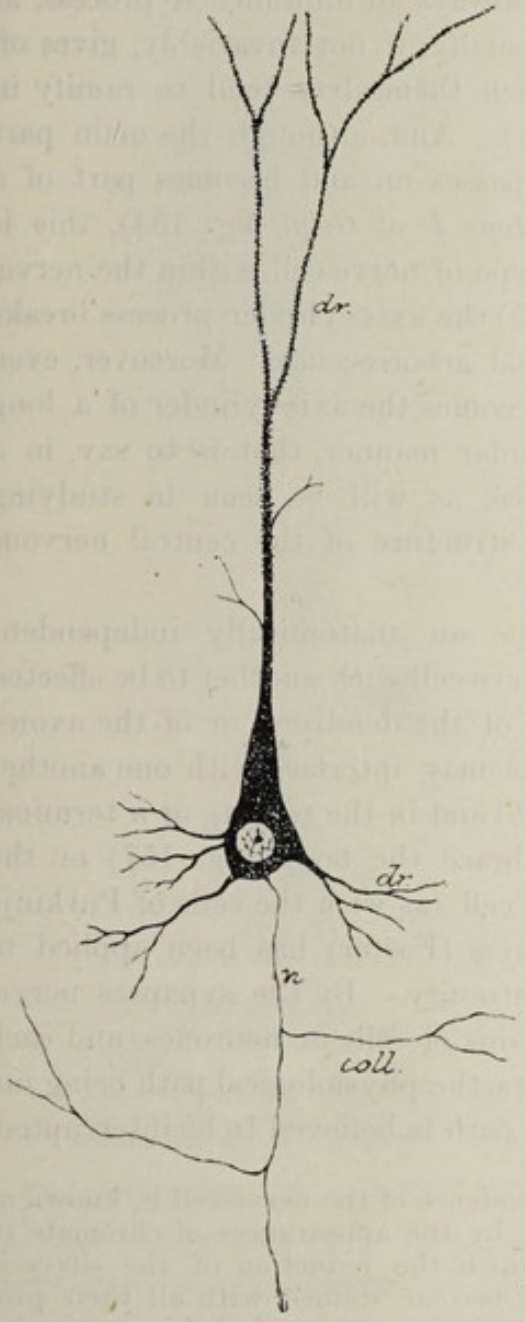


FIG. 154.

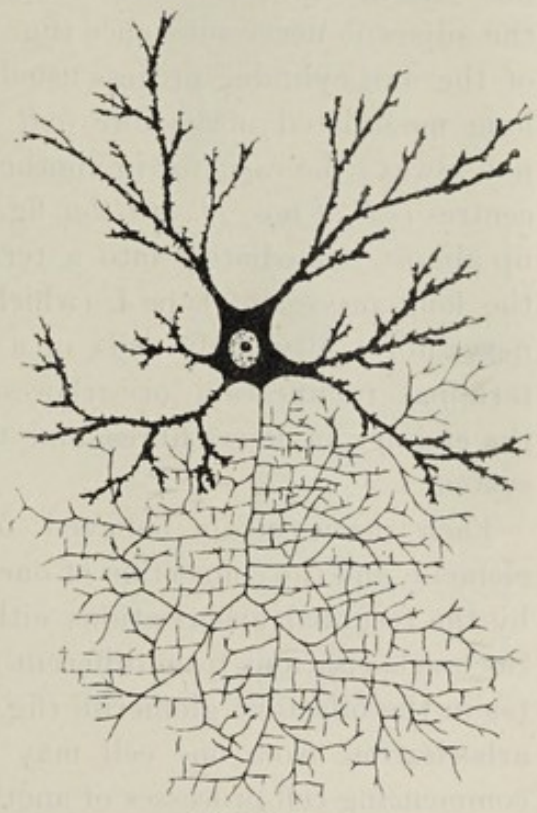


FIG. 155.

FIG. 154.—A CELL OF TYPE I. OF GOLGI FROM THE CORTEX CEREBRI.

n, its neuron; *coll.*, collaterals; *dr*, *dr*, dendrons. The neuron of a cell of this type may extend right down the spinal cord.

FIG. 155.—CELL OF TYPE II. OF GOLGI, WITH SHORT AXON RAMIFYING IN THE ADJACENT GREY MATTER.

and one axon; this becomes a non-medullated nerve-fibre (fig. 153, *a*, *a*). The cells of ganglia are disposed in aggregations of different size, separated by the bundles of nerve-fibres which are traversing the ganglion (fig. 151). The ganglion if large is inclosed by an investing capsule of connective tissue which is continuous with the epineurium and perineurium of the entering and issuing nerve-trunks.

In preparations made by Golgi's chromate of silver method the nerve-cells and their processes are coloured black by a deposit of reduced silver, so that the processes can be traced for a considerable distance from the body of the cell, in fact in many instances as far as their remotest ramifications. It is found by the employment of this method that the axis-cylinder process is not always an unbranched process, as was formerly supposed, but that it usually, if not invariably, gives off fine lateral branches (*collaterals*), which themselves tend to ramify in the adjacent nerve-substance (fig. 154). And, although the main part of the axis-cylinder process usually passes on and becomes part of a long medullated nerve-fibre (*cell of type I. of Golgi*, fig. 154), this is not always the case, for in another type of nerve-cell within the nerve-centres (*cell of type II. of Golgi*, fig. 155) the axis-cylinder process breaks up almost immediately into a terminal arborescence. Moreover, even the long process of type I. (which becomes the axis-cylinder of a long nerve-fibre) ultimately ends in a similar manner, that is to say, in a terminal ramification or arborescence, as will be seen in studying the endings of nerve-fibres, and the structure of the central nervous system.

Each nerve-cell is believed to be an anatomically independent element, and the connection of one nerve-cell with another to be effected by the terminal arborisations either of the dendrons or of the axons. Such arborisations from different cells may interlace with one another (as in the olfactory glomeruli (fig. 156) and in the retina), or a terminal arborisation from one cell may embrace the body (fig. 157) or the commencing cell-processes of another cell (as with the cells of Purkinje in the cerebellum). The term *synapse* (Foster) has been applied to these modes of junction without continuity. By the synapses nerve-cells are linked together into long chains of cells or neurones, and each physiological tract follows these chains, the physiological path being uninterrupted, although the anatomical path is believed to be interrupted.

The doctrine of the anatomical independence of the nerve-cell is known as the "neurone-theory." It is supported by the appearances of chromate of silver preparations of nerve-cells in which the reduction of the silver is strictly confined to single cells which become stained with all their processes, which, as demonstrated by this method, are never found in continuity either with the processes or with the bodies of other nerve-cells. Moreover many of the facts relating to nerve-degeneration can be more readily interpreted by this theory than by one which assumes the existence of direct continuity between the nerve units. But it has been shown by Apáthy that in annelids (the nervous system of which was formerly supposed to offer a typical example of isolated linked "neurones"), the fibrils are in fact continuous from cell to cell and are not interrupted at the synapses; it is therefore possible that the same may prove true for vertebrates also, in which case the doctrine of independent units would require modification.

We may at any rate assume the truth of the hypothesis so far as the *nutrition* of all the processes of the nerve-cell to their remotest terminations is concerned, independently of the question whether there is or is not anatomical continuity of nerve-fibrils from one unit to the other, for there are many examples of such continuity by means of fibrils combined with trophic independence, in both animal and plant cells.

Fig. 156.

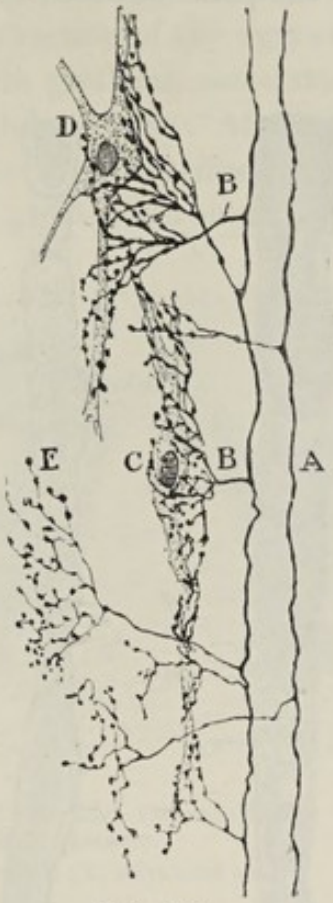


Fig. 157.

Fig. 156.—Synapse of olfactory nerve fibre, *n*, with dendron of a mitral cell in olfactory glomerulus, *gl*.

Fig. 157.—Arborisation of collaterals from the posterior root-fibres around cells in the posterior horn of grey matter. (S. Ramón y Cajal.)

A, fibres of posterior column derived from posterior root; B, collaterals; C, D, nerve-cells in grey matter surrounded by the arborisations of the collaterals; E, an arborisation shown separately.

Degeneration of nerve fibres and nerve-cells.—Since each nerve-fibre is the process of a nerve-cell, when a nerve is cut, the separated part dies, its axis-cylinder becomes broken up, the nuclei of the neurolemma multiply, and its medullary sheath undergoes a gradual process of disintegration into droplets of fatty substance which stain intensely like fat itself in a mixture of bichromate of potash and osmic acid which does not stain the medullary sheath of normal fibres.[1] The change which results in the fibres was described by Waller in 1850 and

[1] It has been shown by Halliburton and Mott that the histological breaking up into fatty droplets is accompanied by a chemical decomposition of the lecithin of the medullary sheath, cholin being set free.

is known as *Wallerian degeneration* (fig. 158, A to C). In man and mammals these changes begin 24 to 48 hours after section of the nerve, and proceed rapidly, so that by the third day the nerve-fibres cease to conduct impulses. When a peripheral nerve is cut, all the nerve-fibres distal to the point of section must degenerate, because all have grown

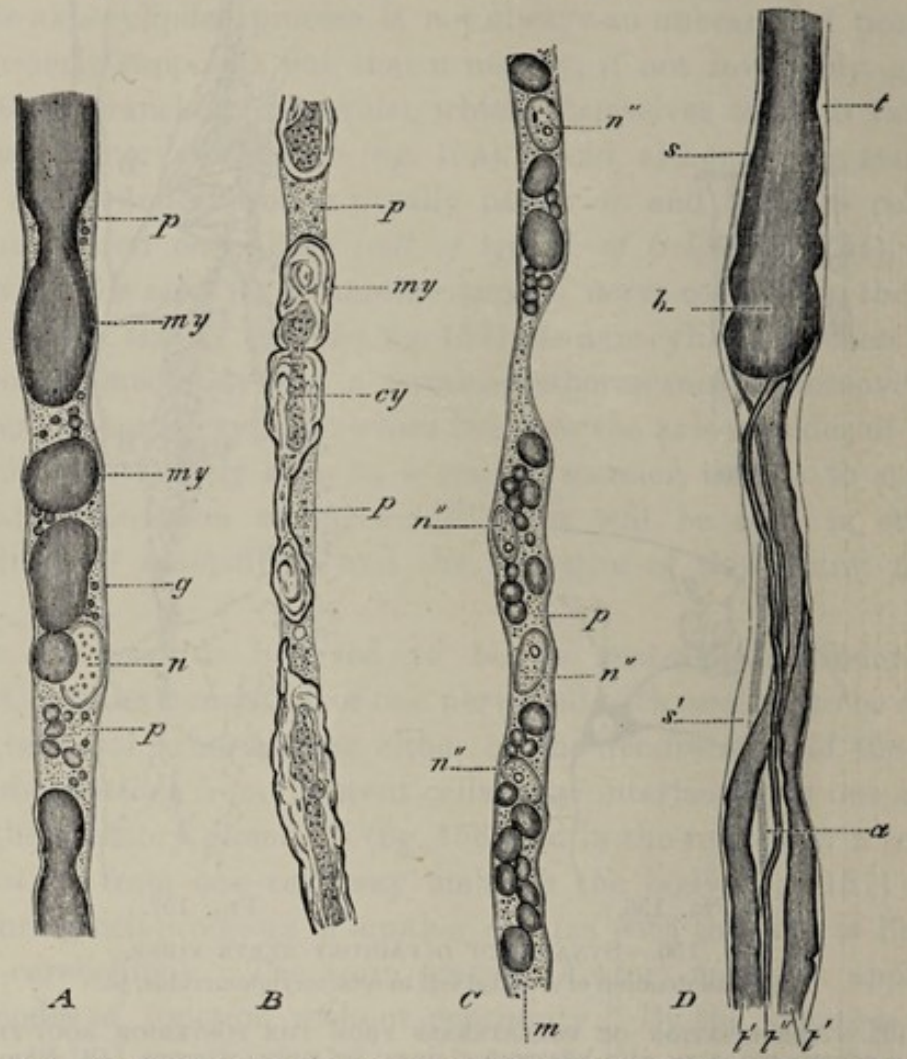


FIG. 158.—DEGENERATION AND REGENERATION OF NERVE-FIBRES IN THE RABBIT. (Ranvier.)

A, part of a nerve-fibre in which degeneration has commenced in consequence of the section, fifty hours previously, of the trunk of the nerve higher up; *my*, medullary sheath becoming broken up into drops of myelin; *p*, granular protoplasmic substance which is replacing the myelin; *n*, nucleus; *g*, neurolemma. *B*, another fibre in which degeneration is proceeding, the nerve having been cut four days previously; *p*, as before; *cy*, axis-cylinder partly broken up, and the pieces inclosed in portions of myelin, *my*. *C*, more advanced stage of degeneration, the medullary sheath having almost disappeared, and being replaced by protoplasm, *p*, in which, besides drops of fatty substance, *m*, are numerous nuclei, *n''*, which have resulted from the division of the single nucleus of the internode. *D*, commencing regeneration of a nerve-fibre. Several small fibres, *t'*, *t''*, have sprouted from the somewhat bulbous cut end, *b*, of the original fibre, *t*; *a*, an axis-cylinder which has not yet acquired its medullary sheath; *s*, *s'*, neurolemma of the original fibre. *A*, *C*, and *D* are from osmic preparations; *B*, from an alcohol and carmine preparation.

from and are processes of nerve-cells in or near the nerve-centre—the afferent fibres from the cells of the ganglion on the posterior root, the efferent fibres from the cells of the anterior horn of the spinal cord.

Waller supposed that no changes are produced centrally to the

injury when a nerve is cut, nor indeed is there any obvious alteration in the nerve-fibre itself between the injury and the cell-body, although it is stated that the fibrils of the axis-cylinder disappear for a time. But it was found by Nissl that marked changes occur in the cell-body of every cell the axis-cylinder of which has been severed. These changes become apparent a few days after section of the nerve-fibre and consist in a disintegration of the chromatin granules, associated at first with a general swelling of the cell-body and nucleus. After a time the disintegrated chromatic substance becomes in great measure removed and the cell-body and nucleus become greatly shrunken in volume.

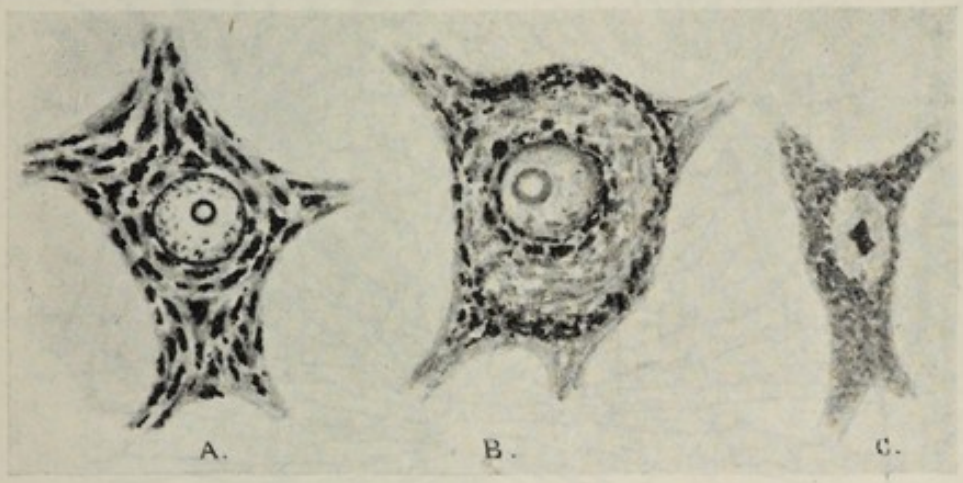


FIG. 159.—STAGES OF CHROMATOLYSIS IN NERVE-CELLS, THE AXONS OF WHICH HAVE BEEN SEVERED. (Diagrammatic.)
A, normal cell; B, early stage of chromatolysis; C, advanced stage.

This process of disintegration and disappearance of chromatin may be termed *Nissl's degeneration*: it is also known as *chromatolysis*. It is brought about not only by section of the axon, but also as the result of excessive fatigue of the intact cell (fig. 145), and of the action of a large number of drugs and poisons.

Regeneration.—After a certain lapse of time, especially if the cut ends of the nerve are in apposition, continuity between them may become re-established. But when such regeneration takes place in the cut nerve, it is effected not by a re-establishment of connection between the degenerated fibres and the fibres of the central stump, but by an outgrowth of new fibres from the stump (fig. 158, D); these may find their way to the periphery along the course of the degenerated fibres. If they succeed in doing so, the continuity and conducting power of the nerve become restored. Some authorities have attempted to show that regeneration may take place independently in the peripheral part of the cut nerve, but the evidence offered is not conclusive, and although changes no doubt occur in the peripheral

part preparatory to the down-growth of new fibres into it from the central stump, it is difficult to conceive how there can be union of the down-growing fibres with fibres in the periphery. If regeneration fail to establish itself, the central end of the cut fibre and the cell-body from which it takes origin undergo slow atrophic changes resulting from disuse. These atrophic changes may ultimately extend to adjoining links in the cell-chains, so that even remote cells in the same physiological path may eventually become atrophied (*Gudden's atrophy*).

No regeneration of cut nerve-fibres ever occurs in the brain or spinal cord, but the process of degeneration of the fibres which

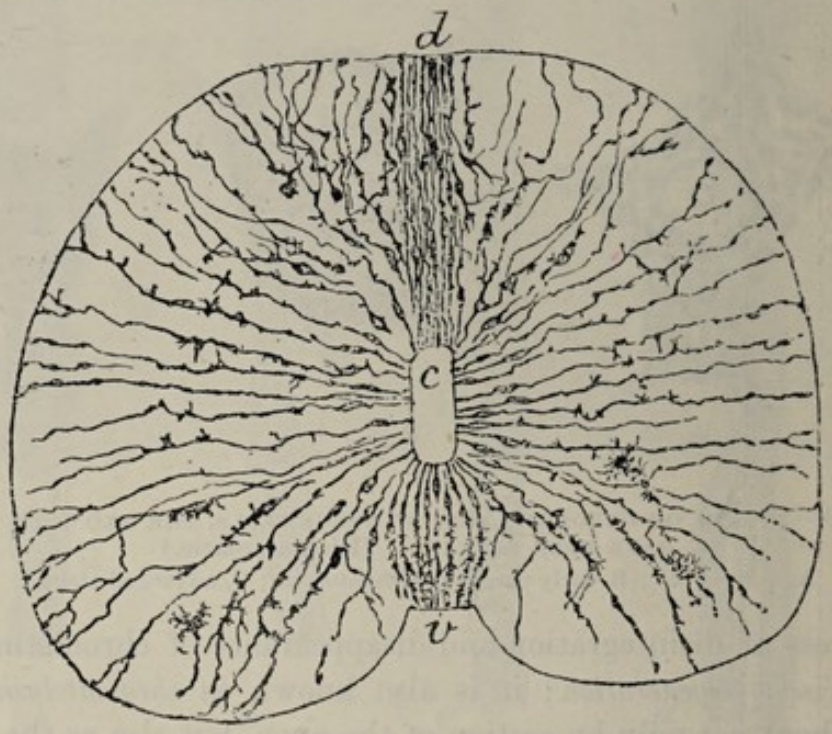


FIG. 160.—SECTION OF SPINAL CORD OF EMBRYO CHICK, SHOWING NEUROGLIA FIBRES PROLONGED FROM THE EPITHELIUM OF THE CENTRAL CANAL. (S. Ramón y Cajal.)

d, dorsal; *v*, ventral surface; *c*, central canal from which the neuroglia cells and fibres are seen to radiate to the periphery of the cord. Some detached neuroglia cells are also represented.

are cut off from their cell-bodies takes place in the same manner as at the periphery, and the Nissl degeneration also takes place in the cell-bodies. Both in the nerve-centres and in the peripheral nerves (if regeneration fail to occur), the place of the degenerated nerves becomes eventually occupied by strands of fine fibres, somewhat similar to the fibres of cicatricial tissue, and probably allied to connective-tissue fibres. These strands stain deeply with carmine and remain unstained by osmic acid and by the Weigert-Pal method,[1] and are thus differentiated from the surrounding normal medullated nerves.

[1] See Appendix.

Neuroglia cells.—In the brain and spinal cord the nerve-cells and nerve-fibres are supported by a peculiar tissue which has been termed the *neuroglia*. It is composed of cells and fibres, the

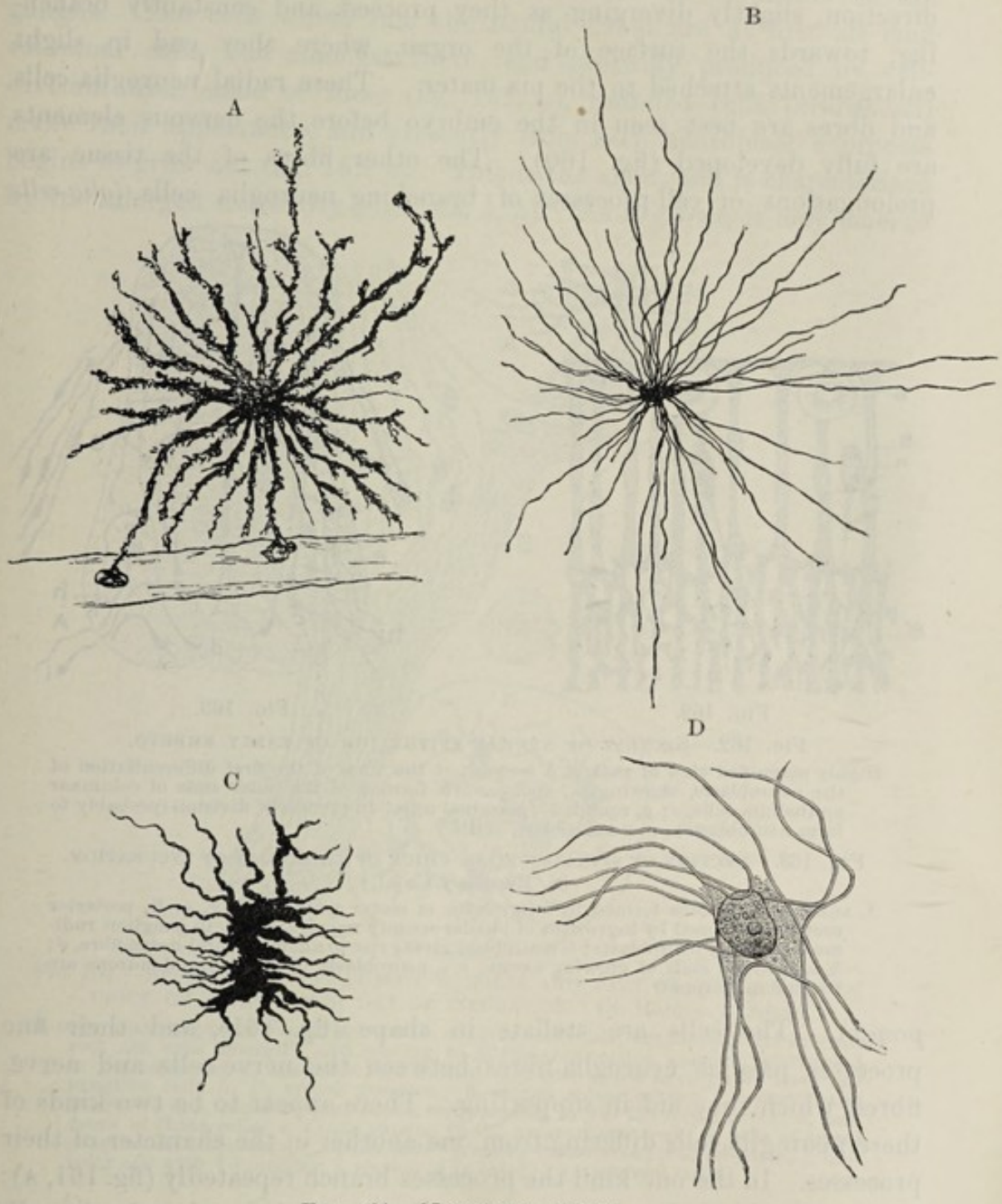


FIG. 161.—NEUROGLIA CELLS.

A. From brain, with dendritic processes attached to the sheath of a vessel. (Andriezen.)
B. From brain, with unbranched processes (spider cell). (Andriezen.)
C. From white substance of spinal cord.
D. From spinal cord. (Ranvier.)
A, B, and C shown by Golgi method; D, isolated after maceration in 33 per cent. alcohol.

latter being prolonged from the cells. Of the fibres some are radially disposed. These start partly from the lining layer of the central canal of the spinal cord and the ventricles of

the brain, where they are usually stated to be continuous with the ciliated epithelium cells lining these cavities, although according to Johnstone they pass between those cells. They course in a radial direction, slightly diverging as they proceed, and constantly branching, towards the surface of the organ, where they end in slight enlargements attached to the pia mater. These radial neuroglia cells and fibres are best seen in the embryo before the nervous elements are fully developed (fig. 160). The other fibres of the tissue are prolongations or cell-processes of branching neuroglia cells (*glia-cells*

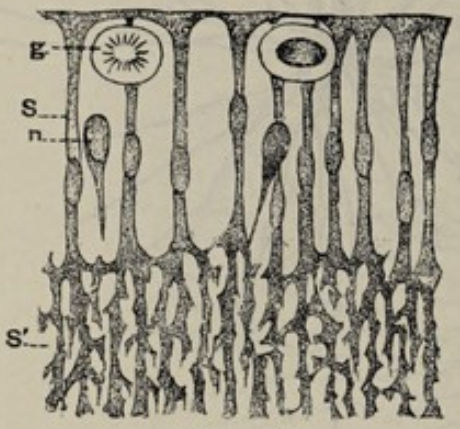


Fig. 162.

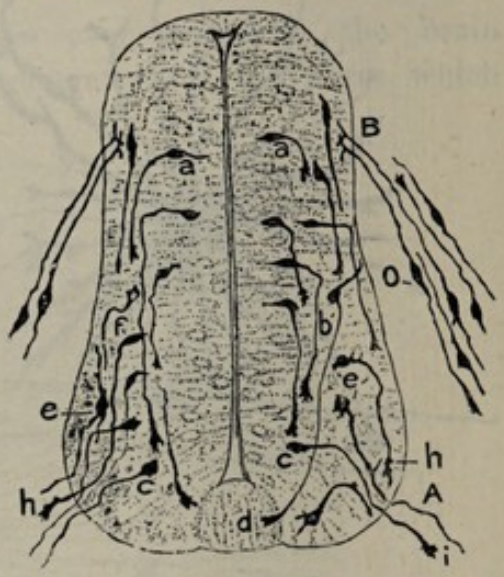


Fig. 163.

Fig. 162.—Section of neural epithelium of early embryo.

Highly magnified view of part of a section, at the time of the first differentiation of the neuroblasts, showing, *s'*, spongework formed of the outer ends of columnar epithelium cells, *s*; *g*, rounded "germinal cells" in process of division (probably to form neuroblasts); *n*, a neuroblast. (His.)

Fig. 163.—Section of spinal cord of chick of third day of incubation. (S. Ramón y Cajal.)

A, anterior root-fibres formed by outgrowths of motor neuroblasts, *c*, *e*; B, posterior root-fibres formed by ingrowths of bipolar sensory neuroblasts, o, in ganglion rudiment; *a*, early neuroblasts; *b*, neuroblast giving rise to a commissural nerve-fibre, *d*; *h*, *i*, enlarged ends of growing axons; *e*, *e*, neuroblasts of which the dendrons are beginning to appear.

proper). The cells are stellate in shape (fig. 161), and their fine processes pass as neuroglia-fibres between the nerve-cells and nerve-fibres, which they aid in supporting. There appear to be two kinds of these neuroglia-cells differing from one another in the character of their processes. In the one kind the processes branch repeatedly (fig. 161, A); in the other kind they remain unbranched from their origin in the cell-body to their termination (*spider-cells*) (fig. 161, B).

Some authorities consider that the fibres of the neuroglia are inter- not intra-cellular, although it is admitted by all that they are formed originally by the neuroglia cells.

Development of nerve-cells and fibres.—All nerve-cells in the body are developed from the cells of the neural groove and neural crest of

the early embryo ; the neural groove closing to form the neural canal, the cells of which form the spinal cord and brain, and the neural crest giving off at intervals sprouts which become the rudiments of the ganglia. The cells which line the neural canal are at first all long columnar cells, but amongst these, and probably produced by cell-division from some of these (fig. 162, *g*), rounded cells (*neuroblasts*) make their appearance, and presently from each neuroblast a process begins to grow out (fig. 162, *n*). This is the axon, and is characterised by its enlarged extremity (fig. 163, *h*, *h*). As it grows, it may emerge

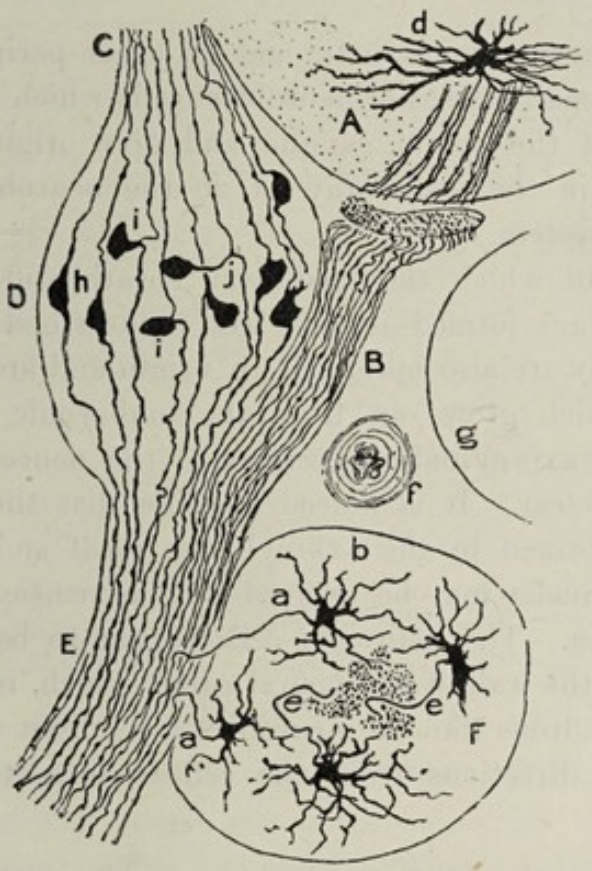


FIG 164.—SPINAL AND SYMPATHETIC GANGLIA AND PART OF SPINAL CORD OF CHICK OF SEVENTEENTH DAY OF INCUBATION. (S. Ramón y Cajal.)

A, antero-lateral part of spinal cord with *d*, a motor nerve-cell; the fibres of the anterior root are seen emerging and passing to B (the connection appears interrupted in the section); C, posterior root formed of fibres which have grown from the ganglion cells in D, spinal ganglion; E, mixed spinal nerve; F, sympathetic ganglion; *a*, *a*, axons of sympathetic cells, passing to join the spinal nerve; *b*, dendrons of these cells; *e*, axons passing to the sympathetic cord; *h*, cells of spinal ganglion still bipolar; *i*, *i*, bipolar cells becoming transformed into unipolar; *j*, unipolar cell with T-junction; *f*, section of an artery; *g*, vertebral body.

from the antero-lateral region of the canal and become the axis-cylinder of a *motor nerve* or *anterior root-fibre*. The dendrons of the cell appear somewhat later than the axon. The axis-cylinder processes of some of the neuroblasts remain within the nerve-centre, and are developed into commissural, association, or intra-central fibres.

The sprouts from the neural crest contain the neuroblasts from which the posterior root-fibres are developed. Axons grow out from

these neuroblasts in two directions, so that the cells become bipolar (fig. 163, o). One set, forming the posterior root-fibres, grow into the postero-lateral portion of the spinal cord and ramify in the developing grey matter; the other set, containing the afferent fibres of the spinal nerves, grow towards the developing anterior roots, and eventually mingle with them to form the mixed nerves. As development proceeds, the bipolar ganglion cells become gradually transformed in most vertebrates, by a shifting of the two axons, into unipolar cells (fig. 164, *h*, *i*, *j*); but in cartilaginous fishes the cells remain permanently bipolar (fig. 149).

The ganglia on the sympathetic and on other peripheral nerves are developed from small masses of neuroblast-cells which separate off from the rudiments of the spinal ganglia and give origin to axons and dendrons much in the same way as do the neuroblasts within the central nervous system.

The manner in which the medullary sheath and neurolemma of the nerve-fibres are formed is not well understood. It is usually assumed that they are also epiblastic in origin and are developed from epiblast cells which grow out from the embryonic central nervous system along the axis-cylinder processes of the neuroblasts. But this is by no means clear. It is indeed possible that the medullary substance may be formed by the axis-cylinder itself and that the neurolemma with its nuclei may be derived from extrinsic cells, perhaps of mesoblastic origin. The neuroglia cells appear to be developed from epiblast cells of the wall of the neural canal, which, in place of giving off axon and dendrons like the neuroblasts, send out a number of fine processes in all directions from the cell to form the fibres of the neuroglia.

It is held by some that the neuroglia has a double origin, some of the cells being developed from epiblast and others from mesoblast.

LESSON XXI.

MODES OF TERMINATION OF NERVE-FIBRES.

1. SHELL out a Pacinian corpuscle from a piece of cat's mesentery either fresh or after having been kept for two or three days in $\frac{1}{20}$ per cent. chromic acid. Clear it as much as possible of adhering fat, but be careful not to prick or otherwise injure the corpuscle itself. Mount in water or saline with a thick hair to prevent crushing with the cover-glass. Sketch the corpuscle under a low power, and afterwards draw under a high power the part of the core where the nerve enters and the part where it terminates. Notice the fibrous structure of the lamellar tunics of the corpuscle and the oval nuclei belonging to flattened epithelioid cells which cover the tunics. The distinct lines which when seen in the fresh corpuscles are generally taken for the tunics, are really the optical sections of these flattened cells.

2. Mount in dilute glycerine sections of a rabbit's cornea which has been stained with chloride of gold by Klein's method. Notice the arrangement in plexuses of the darkly-stained nerve-fibres and fibrils, (1) in the connective-tissue substance, (2) under the epithelium, and (3) between the epithelial cells. Make one or two sketches showing the arrangement of the fibrils.

3. Spread out a small piece of muscle which has been stained with chloride of gold by Löwit's method, or with hæmatoxylin by Sihler's method, and examine it with a low power to find the nerve-fibres crossing the muscular fibres and distributed to them.

The pieces of muscle may advantageously be thinned out for observation by pressure upon the cover-glass. Search thoroughly for the close terminal ramifications (end-plates) of the axis-cylinders immediately within the sarcolemma.

Modes of ending of sensory nerve-fibres.—Nerve-fibres which are distributed to sensory parts end either in *special organs* or in free *terminal ramifications*, these last being usually in epithelia. Within the special organs the actual nerve-ending is also generally ramified.

Nerve-endings in special connective-tissue organs.—Three chief kinds of these special organs are usually described, represented in man by *Pacinian corpuscles*, *tactile corpuscles*, and *end-bulbs*. The type is the same in all: a lamellated connective-tissue *capsule* enclosing a *core* of a soft material which appears to be composed of nucleated protoplasm, within which the axis-cylinder ramifies and its branches terminate. The variations which occur are chiefly due to the complexity of the capsule, which is simplest in the end-bulbs and most complex in the Pacinian corpuscles. In the **tactile corpuscles** and **end-bulbs** the connective-tissue sheath of a medullated fibre expands to form a bulbous enlargement, which is cylindrical or spheroidal in the end-bulbs and ellipsoidal in the tactile corpuscles. In both kinds of

end-organ there is a capsule of connective tissue within which is

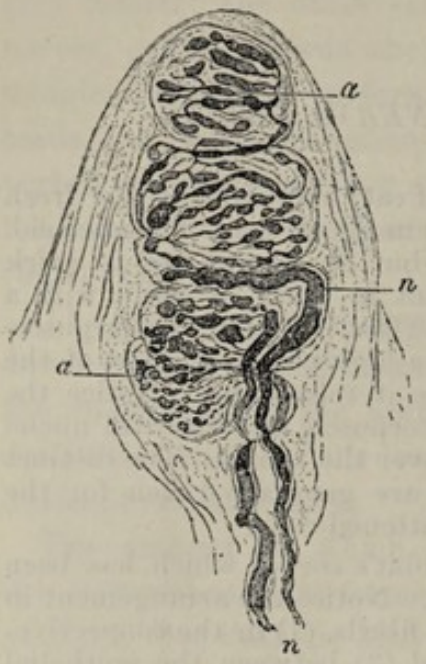


FIG. 165.

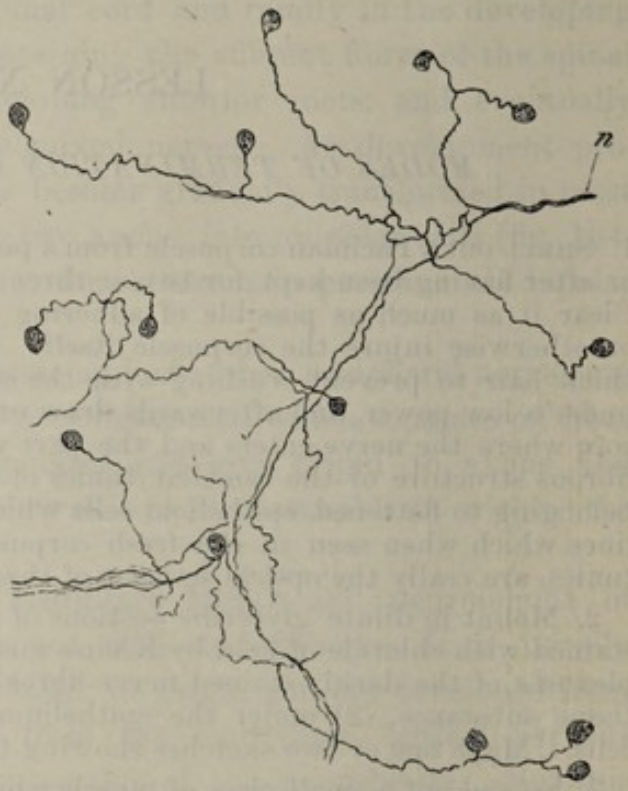


FIG. 166.

FIG. 165.—TACTILE CORPUSCLE WITHIN A PAPILLA OF THE SKIN OF THE HAND. STAINED WITH CHLORIDE OF GOLD. (Ranvier.)

n, two nerve-fibres passing to the corpuscle; *a*, *a*, varicose ramifications of the axis-cylinders within the corpuscle.

FIG. 166.—END-BULBS AT THE TERMINATIONS OF NERVES IN THE HUMAN CONJUNCTIVA, AS SEEN WITH A LENS. (Longworth.)

n, small nerve-trunk.

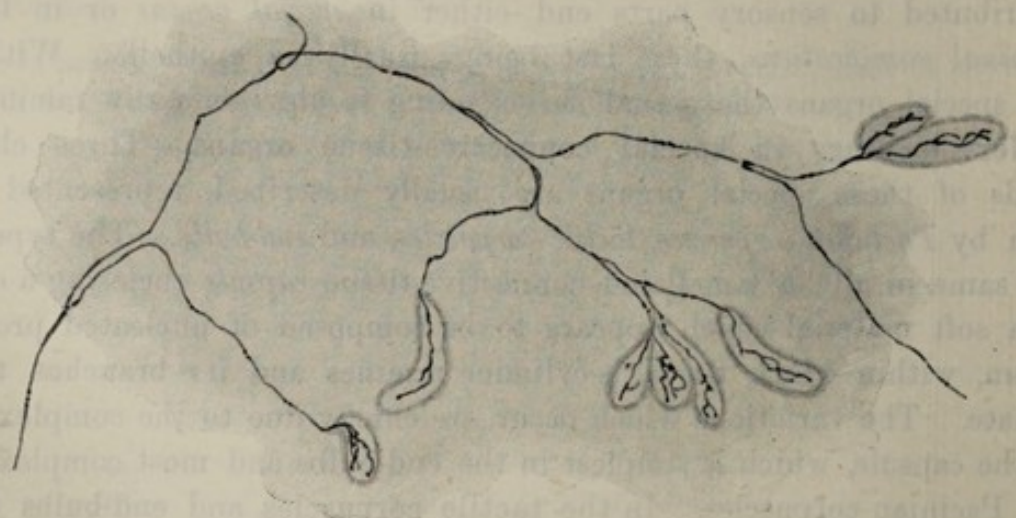


FIG. 167.—A MEDULLATED FIBRE TERMINATING IN SEVERAL END-BULBS IN THE HUMAN PERITONEUM. (Dogiel.) Methylene blue preparation. Low power.

generally a sort of core containing numerous nucleated cells. As the

nerve-fibre enters the corpuscle (which in the tactile corpuscle only happens when it has reached the distal part of the corpuscle, after having wound spirally once or twice round it) it loses its sheaths and is prolonged as the axis-cylinder only; this generally ramifies and its branches terminate after either a straight or a convoluted course within the organ, but it sometimes remains straight and unbranched (see figs. 165 to 169). Tactile corpuscles occur in some of the papillæ of the

FIG. 167A.—END-BULBS FROM THE HUMAN PERITONEUM. (Dogiel.) More highly magnified. Methylene blue preparation.

a, medullated fibre; *b*, nucleated lamellated capsule of end-bulb; *c*, non-medullated fibres, probably destined for the capillaries which surround the end-bulbs.

FIG. 168.—END-BULB FROM THE CENTRAL TENDON OF THE DIAPHRAGM OF THE DOG. (Dogiel.) Showing besides the main medullated fibre terminating by an arborescence within the core, a second very fine medullated fibre, forming a more delicate arborescence around the ending of the main fibre in the outer part of the core. Methylene blue preparation.

skin of the hand and foot, in sections of which they will be afterwards studied (see fig. 225). End-bulbs are found in the conjunctiva of the eye, where in most animals they have a cylindrical or oblong shape, but in man they are spheroidal (fig. 166). They have also been found in papillæ of the lips and tongue, in serous membranes, in tendons and aponeuroses, and in the epineurium of the nerve-trunks; and

somewhat similar sensory end-organs also occur in the integument of the external genital organs of both sexes (fig. 169). Similar bodies of larger size are also met with in the neighbourhood of the joints. In the skin covering the bills of certain birds (*e.g.* duck), a simple form of end-organ occurs, consisting of two or more cells arranged in rows within a capsule, with the axis-cylinder terminating in flattened expansions (*tactile disks*) between the cells (*corpuscles of Grandry*, fig. 170).

The **Pacinian corpuscles** are larger, and have a more complex structure, than the tactile corpuscles and end-bulbs (fig. 171). They

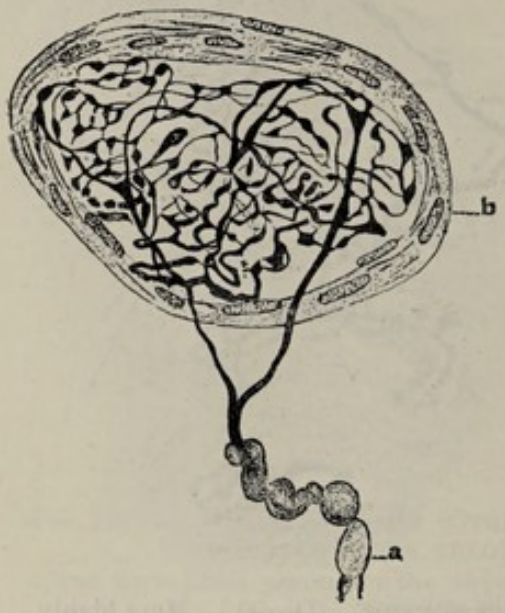


FIG. 169.—END-BULB FROM THE GLANS PENIS SHOWING ENDING OF AXIS-CYLINDER. Methylene blue preparation. (Dogiel.)

a, medullated nerve-fibre; *b*, sheath of end-bulb.

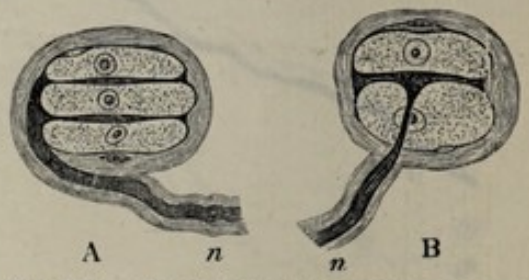


FIG. 170.—TACTILE CORPUSCLES FROM THE DUCK'S TONGUE. (Izquierdo.)

A, composed of three cells, with two interposed disks, into which the axis-cylinder of the nerve, *n*, is observed to pass; in B there is but one tactile disk inclosed between two tactile cells.

are composed of a number of concentric coats arranged like the layers of an onion, and inclosing the prolonged end of a nerve-fibre. A single medullated nerve-fibre goes to each Pacinian corpuscle, encircled by a prolongation of perineurium (sheath of Henle), and within this by endoneurium; when it reaches the corpuscle, of which it appears to form the stalk, the lamellæ of the perineurium expand into the tunics of the capsule. The nerve passes on, piercing the tunics, surrounded by endoneurium, and still provided with medullary sheath, to reach the central part of the corpuscle. Here the endoneurium is prolonged to form a core of cylindrical shape, along the middle of which the nerve-fibre, now deprived of its medullary and primitive sheaths, passes in a straight course as a simple axis-cylinder (figs. 171, *n'*; 172, *c.f*) to terminate at the farther end of the core, either in an arborisation or in a bulbous enlargement. In its course through

the core it may give off lateral ramifications, which penetrate to all parts of the core, and themselves end in fine branches.

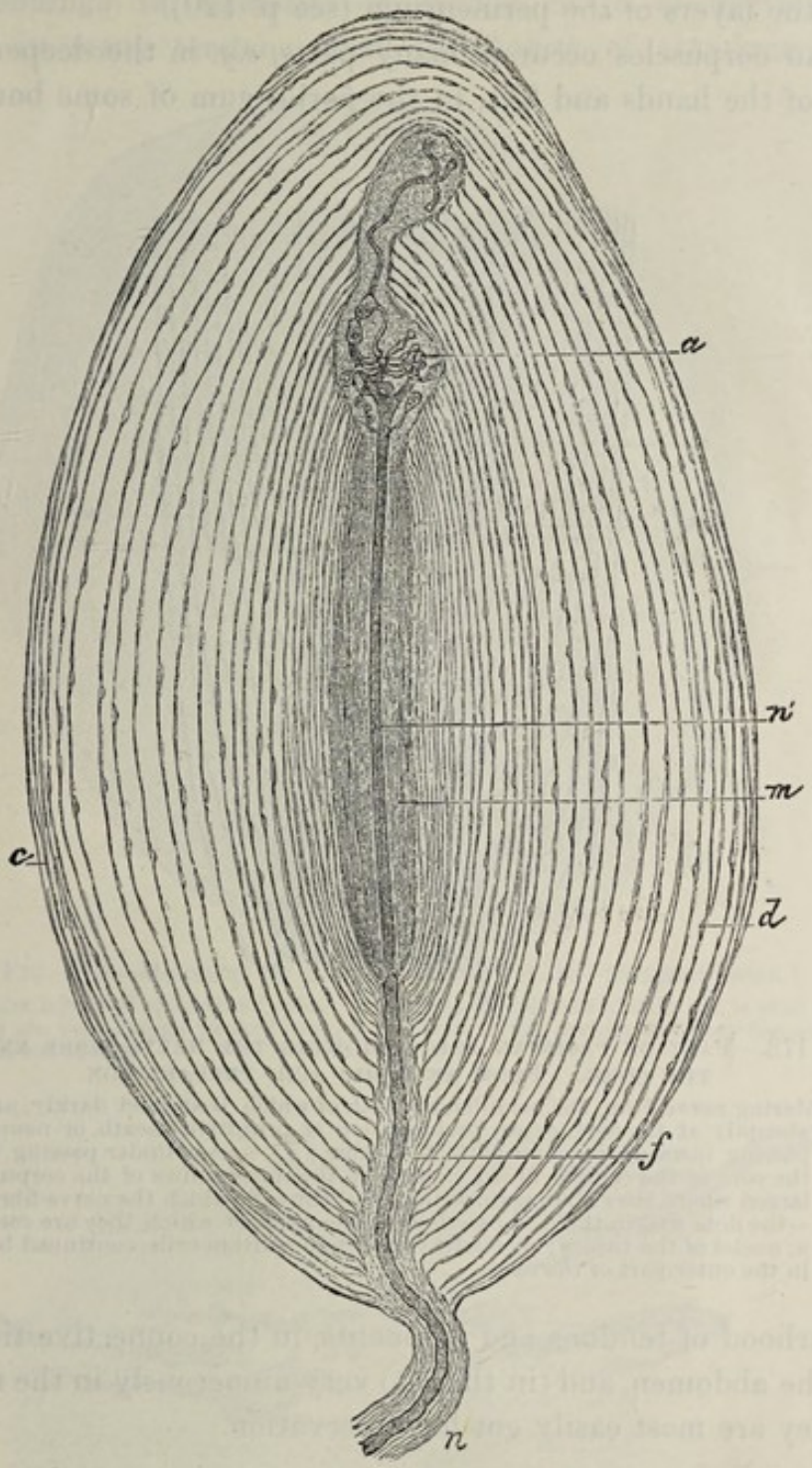


FIG. 171.—MAGNIFIED VIEW OF A PACINIAN BODY FROM THE CAT'S MESENTERY. (Ranvier.)

n, stalk of corpuscle with nerve-fibre, inclosed in sheath of Henle, passing to the corpuscle; *n'*, its continuation through the core, *m*, as axis-cylinder only; *a*, its terminal arborisation; *c*, *d*, sections of epithelioid cells of tunics, often mistaken for the tunics themselves; *f*, channel through the tunics which expands into the core of the corpuscle.

The tunics of the capsule are composed of connective tissue, the fibres of which for the most part run circularly. They are covered

on both surfaces with a layer of flattened epithelioid cells, and here and there cleft-like lymph-spaces can be seen between them like those between the layers of the perineurium (see p. 120).

Pacinian corpuscles occur in many parts, *e.g.* in the deeper layers of the skin of the hands and feet, in the periosteum of some bones, in the

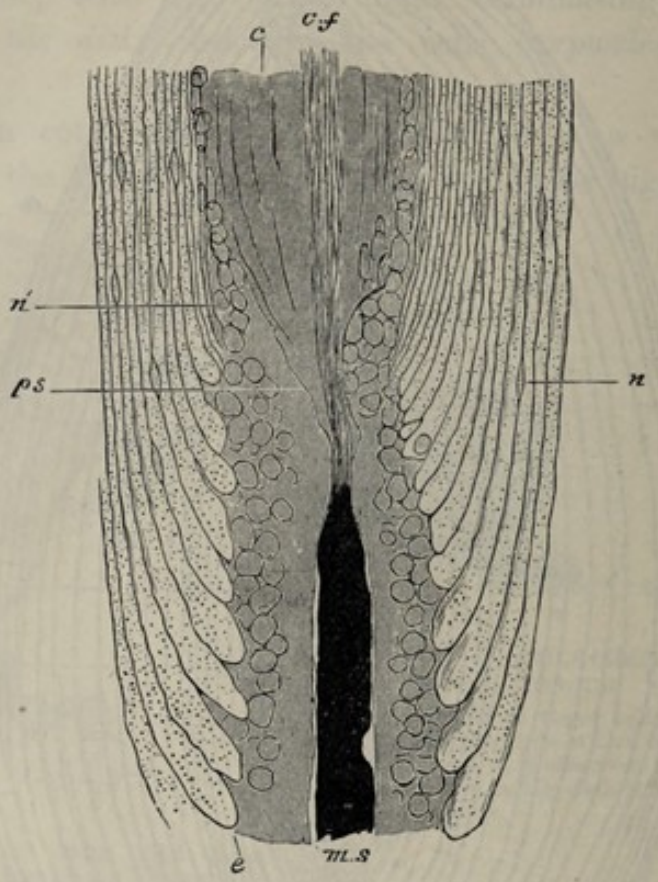


FIG. 172.—PART OF PACINIAN BODY, SHOWING THE NERVE-FIBRE ENTERING THE CORE. FROM AN OSMIC ACID PREPARATION.

ms, entering nerve-fibre, the medullary sheath of which is stained darkly, and ends abruptly at the core, *c*; *ps*, prolongation of primitive sheath or neurolemma passing towards the outer part of the core; *c.f*, axis-cylinder passing through the core as the central fibre; *e*, some of the inner tunics of the corpuscle, enlarged where they abut against the canal through which the nerve-fibre passes —the dots within them are sections of the fibres of which they are composed; *n*, nuclei of the tunics; *n'*, nuclei of the endoneurium-cells, continued by others in the outer part of the core.

neighbourhood of tendons and ligaments, in the connective tissue at the back of the abdomen, and (in the cat) very numerously in the mesentery, where they are most easily got for observation.

A simple form of Pacinian corpuscle with fewer tunics and a core formed of regularly arranged cells occurs in birds (*corpuscles of Herbst*).

Although most of the nerve endings in connective tissue structures are inclosed within lamellated capsules, nerves are found to end in some situations in the form of arborisations between the bundles of connective-tissue fibres. This has been shown by Dogiel to occur in intermuscular connective-tissue septa (fig. 174); and in serous membranes (fig. 175);

in the latter such arborisations may be quite superficial and placed just below the endothelium.

Nerve-endings in tendons.—A special mode of nerve-ending is met with in many tendons, near the points of attachment of the

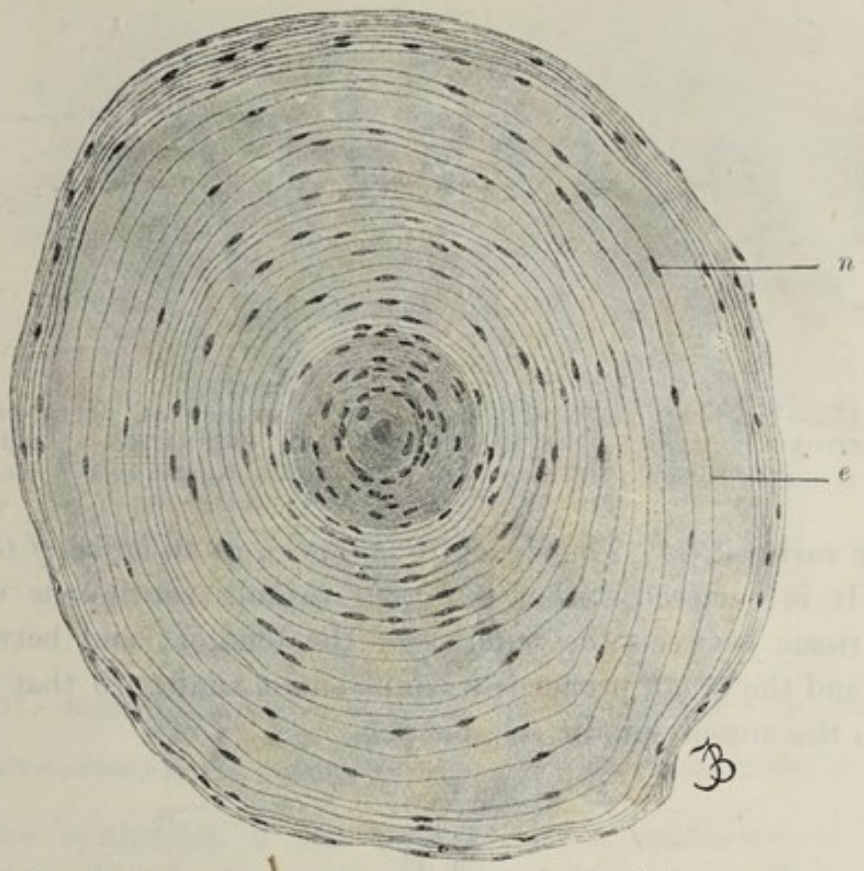


FIG. 173.—SECTION OF PACINIAN CORPUSCLE. (Szymonowicz.)
e, one of the layers of epithelioid cells; *n*, nucleus of epithelioid cell. It is seen that the tunics are very closely packed around the core, in the middle of which the axial-fibre is seen cut across.

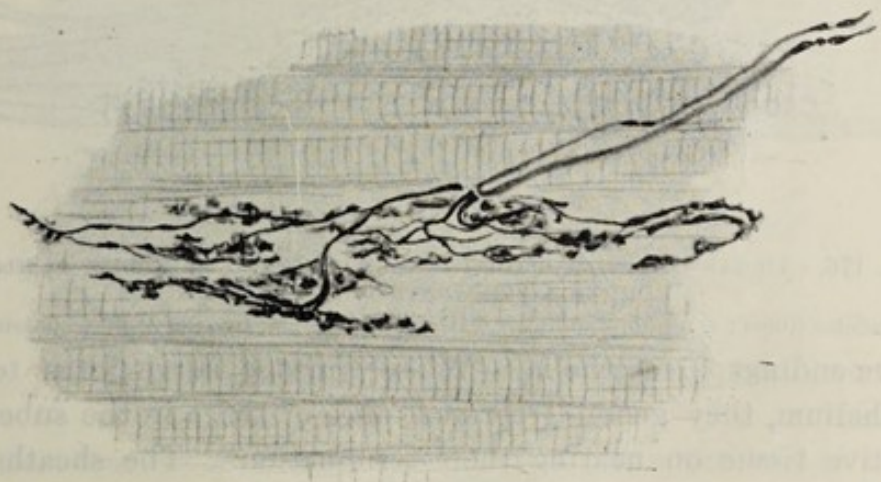


FIG. 174.—TERMINAL ARBORISATION FROM THE INTERMUSCULAR CONNECTIVE TISSUE OF THE RECTUS ABDOMINIS OF THE RABBIT. METHYLENE BLUE PREPARATION. (Dogiel.)

muscular fibres. The tendon-bundles become here somewhat enlarged

and split into a number of smaller fasciculi, and the nerve-fibres—one, two, or even more in number—pass to the enlarged part, and penetrating between the fasciculi of the tendon lose their medullary sheaths, while the axis-cylinders end in a terminal arborisation, beset with

FIG. 175.—TERMINAL ARBORISATION FROM THE SUPERFICIAL LAYER OF THE PERITONEUM OF THE RABBIT. METHYLENE BLUE PREPARATION. (Dogiel.)
a, medullated fibre ; *b*, fibre connecting the arborisation with another one not here represented.

irregular varicosities. The structure is known as an *organ of Golgi* (fig. 176). It is enclosed within a fibrous capsule continuous with the areolar tissue between the bundles of the tendon ; and between the capsule and the organ proper is a lymph-space, similar to that which is found in the muscle-spindle (see below).

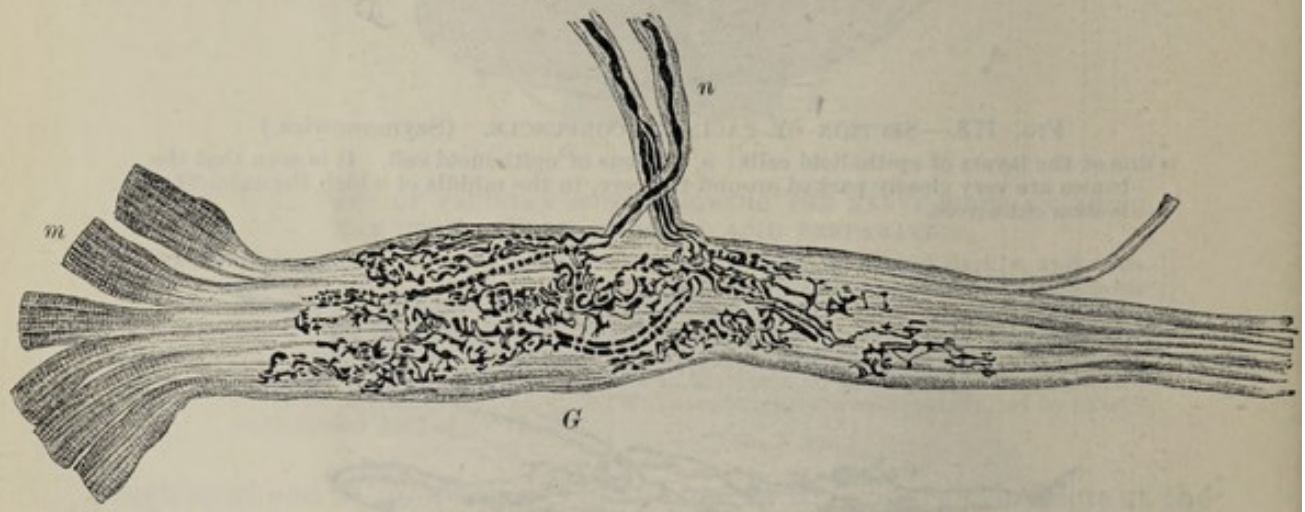


FIG. 176.—ORGAN OF GOLGI FROM THE HUMAN TENDO ACHILLIS. CHLORIDE OF GOLD PREPARATION. (Ciaccio.)
m, muscular fibres ; *t*, tendon-bundles ; *G*, Golgi's organ ; *n*, two nerve-fibres passing to it.

Nerve-endings in epithelia.—When sensory nerve-fibres terminate in **epithelium**, they generally branch once or twice in the subepithelial connective tissue on nearing their termination. The sheaths of the fibres then successively become lost, first the connective tissue or perineural sheath, then the medullary sheath, and lastly the neurolemma, the axis-cylinder being alone continued as a bundle of primitive fibrils (fig. 177, *n*). This branches and with the ramifications of the

axis-cylinders of neighbouring nerve-fibres forms a primary plexus. From the primary plexus smaller branches (*a*) come off, and these form a secondary plexus (*e*) nearer the surface, generally immediately

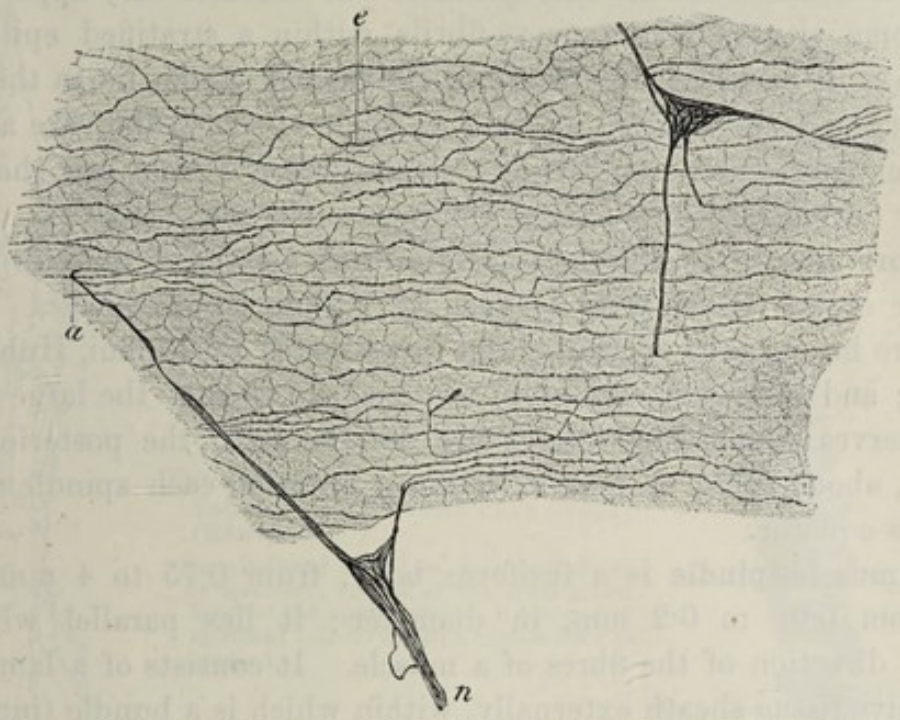


FIG. 177.—SUBEPITHELIAL PLEXUS OF THE CORNEA TREATED WITH CHLORIDE OF GOLD. (Ranvier.)

n, branch of primary plexus; *a*, small branch passing to join the subepithelial plexus, *e*.

under the epithelium if the ending is in a membrane covered by that tissue. Finally, from the secondary plexus nerve-fibrils proceed

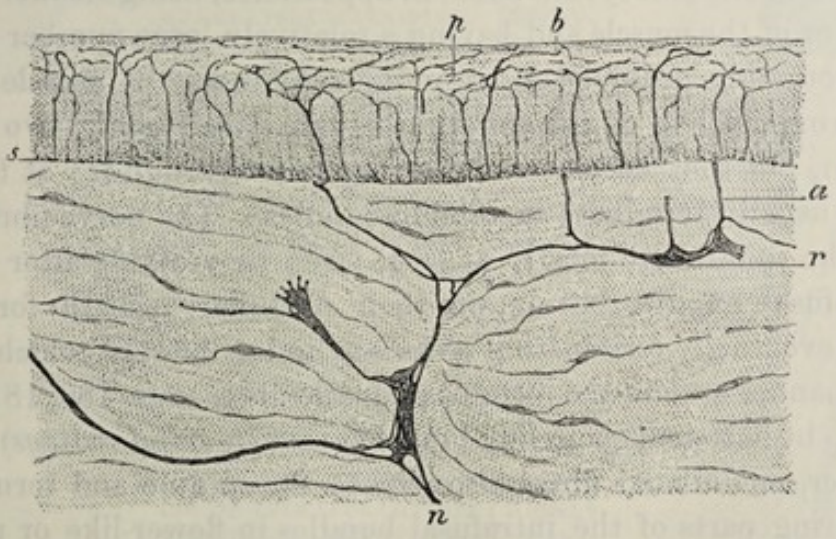


FIG. 178.—VERTICAL SECTION OF CORNEA STAINED WITH CHLORIDE OF GOLD. (Ranvier.)

n, *r*, primary plexus in connective tissue of cornea; *a*, branch passing to subepithelial plexus, *s*; *p*, intra-epithelial plexus; *b*, terminations of fibrils.

and form a terminal ramification amongst the epithelium cells (fig. 178, *p*), the actual ending being generally in free varicose fibrils (*b*).

The mode of ending in epithelium is most characteristically seen in the cornea of the eye. The nerve-fibrils may be brought distinctly into view by staining with chloride of gold, and then the fibrillar structure of the ramifications of the axis-cylinders also becomes very apparent.

In some situations the nerve-fibrils within a stratified epithelium terminate in flattened or crescentic expansions which lie in the interstices of the deeper epithelium cells to some of which they are applied. These expansions are known as "tactile disks"; they are characteristically developed in the skin of the pig's snout (fig. 179).

Sensory nerves of muscles.—The sensory nerves of muscles end in peculiar organs which were termed by Kühne *muscle-spindles*. Their structure has recently specially been investigated by Ruffini, Huber, and Dogiel; and also by Sherrington, who has shown that the large medullated nerves which they receive are derived from the posterior root-ganglia, about three or four such fibres entering each spindle not far from its equator.

The **muscle-spindle** is a fusiform body, from 0·75 to 4 mm. long, and from 0·08 to 0·2 mm. in diameter; it lies parallel with the general direction of the fibres of a muscle. It consists of a lamellated connective-tissue sheath externally, within which is a bundle (intrafusal bundle) of from two to twelve peculiar muscle-fibres. These form an axial mass with some connective tissue and the nerve-fibres; between this axial bundle and the sheath is a lymphatic periaxial space, bridged across by filaments of connective tissue. The intrafusal muscle-fibres are somewhat like embryonic fibres in appearance, being smaller than the other fibres of the muscle and having a relatively large number of nuclei with surrounding protoplasm, as in the red variety of muscle (p. 99). At the proximal end of the spindle they are usually only two or three in number, but they become cleft as they pass through it; at the distal end they usually terminate in tendon-bundles. The nerve-fibres which pass to the spindle are mostly of large size; they divide after reaching the intrafusal bundle, but retain their medullary sheath for a time, although eventually terminating as axis-cylinders merely, which wind in a spiral manner around the intrafusal muscle fibres (figs. 180, 181), which they clasp by flattened encircling branches (*annulo-spiral endings*). Other, much finer, medullated fibres also pass to the spindle and terminate in neighbouring parts of the intrafusal bundles in flower-like or plate-like expansions (fig. 180). According to some observers these fine fibres are prolonged from the annulo-spiral endings of the coarser fibres; but Dogiel states that they may run independently to the intrafusal bundle. No motor nerve-fibres appear to pass into the spindles, unless the fine fibres above mentioned are to be so regarded, nor do the muscle-

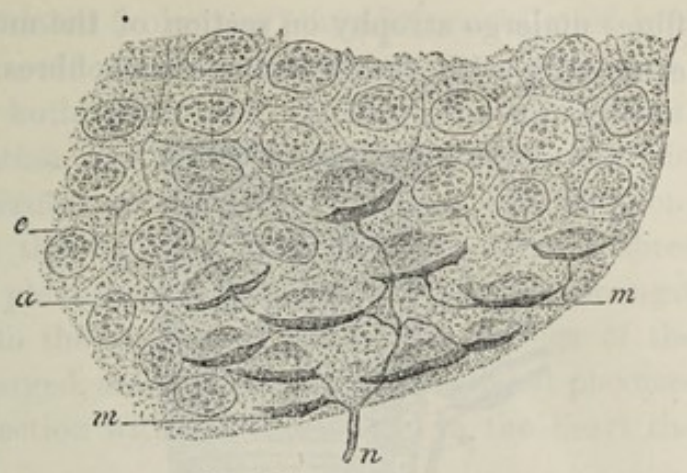


FIG. 179.

FIG. 179.—ENDING OF NERVE IN TACTILE DISKS IN THE PIG'S SNOUT. (Ranvier.)

n, medullated fibre; *m*, terminal disks or menisci; *e*, cells of the Malpighian layer of the epidermis; *a*, a somewhat modified cell to which a tactile disk is applied.

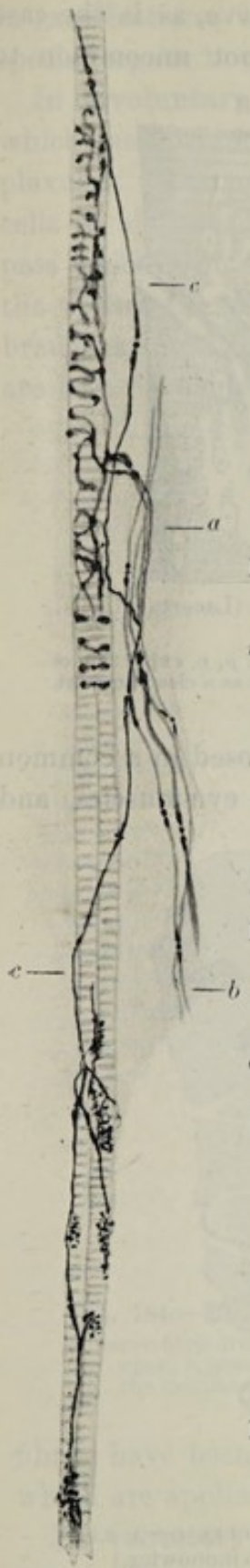


FIG. 180.

FIG. 180.—NERVE-ENDINGS UPON THE INTRAFUSAL MUSCLE-FIBRES OF A MUSCLE-SPINDLE OF THE RABBIT; MODERATELY MAGNIFIED. METHYLENE BLUE PREPARATION. (Dogiel.)

a, large medullated fibre coming off from "spindle" nerve and passing to end in an annulo-spiral termination on and between the intrafusal fibres; *b*, a fine medullated fibre coming off from the same stem and dividing. Its branches, *c*, pass towards the ends of the muscle fibres and terminate in a number of small localised arborisations.

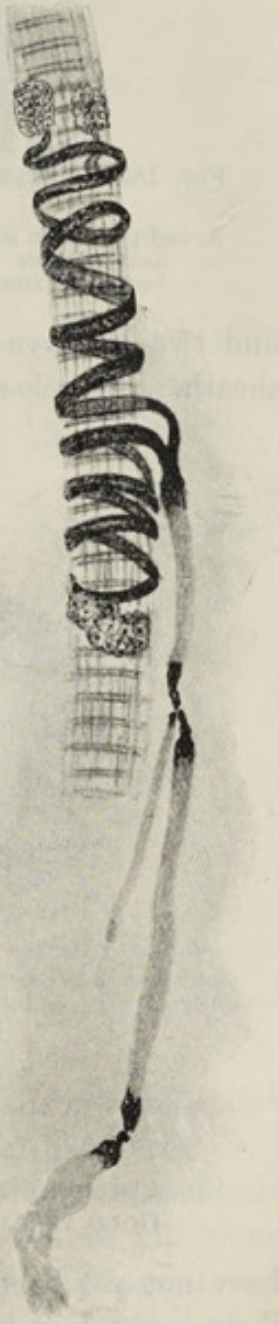


FIG. 181.

FIG. 181.—AN ANNULO-SPIRAL ENDING OF INTRAFUSAL FIBRE; HIGHLY MAGNIFIED. METHYLENE BLUE PREPARATION. (Dogiel.)

fibres undergo atrophy on section of the muscular nerve, as is the case eventually with the ordinary muscle-fibres. It is not uncommon to

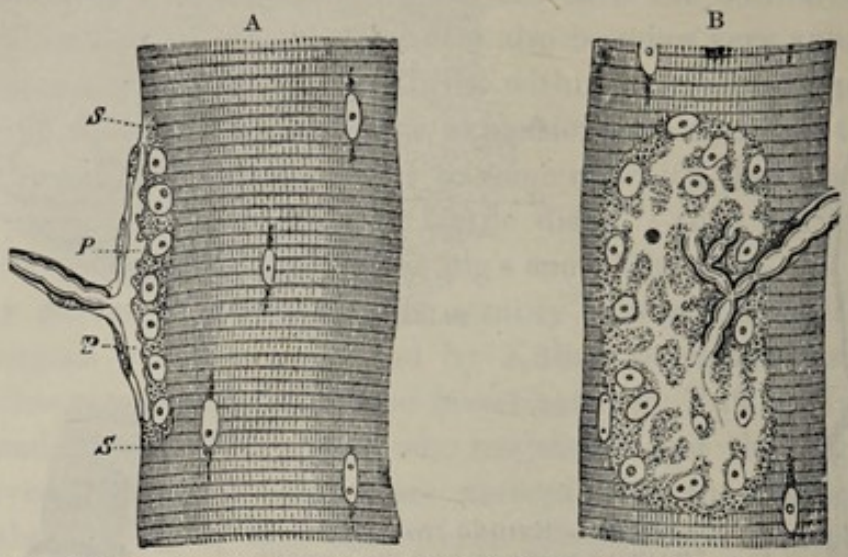


FIG. 182.—NERVE-ENDING IN MUSCULAR FIBRE OF A LIZARD (Lacerta viridis). (Kühne.)

A, end-plate seen edgeways; B, from the surface; *s*, *s*, sarcolemma; *p*, *p*, expansion of axis-cylinder. In B the expansion of the axis-cylinder appears as a clear network branching from the divisions of the medullated fibres.

find two or three spindles close together or even inclosed in a common sheath. Muscle-spindles are few in number in the eye-muscles, and

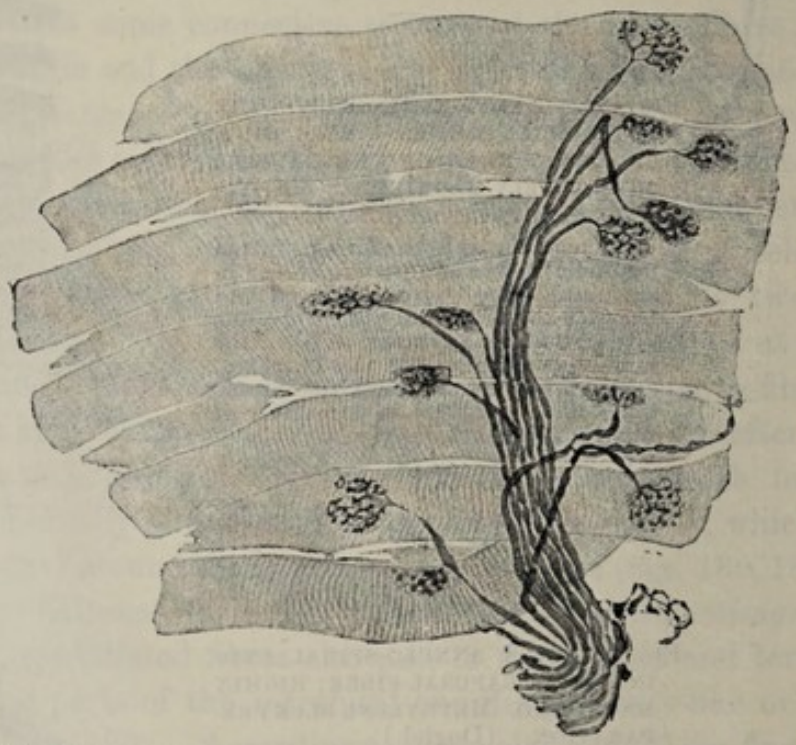


FIG. 183.—MOTOR NERVE-ENDINGS IN THE ABDOMINAL MUSCLES OF A RAT. GOLD PREPARATION. MAGNIFIED 170 DIAMETERS. (Szymonowicz.)

have not yet been found in the muscles of the tongue, but otherwise their occurrence is general.

Ending of motor nerves.—The motor nerves to muscles terminate

in ramifications, which in striated (voluntary) muscles are collected into special organs termed *motor end-organs*, or, less correctly, *end-plates*.

In **involuntary muscle**, both plain and cardiac, the nerve-fibres, which near their termination are entirely non-medullated, end in plexuses. The primary plexuses are generally furnished with ganglion-cells in abundance. From these plexuses and cells other nerve-fibres pass which form secondary plexuses and terminal ramifications amongst the contractile fibre-cells, to the surface of which the endings of the branches, often slightly enlarged, are applied. Such gangliated plexuses are best developed in connection with the intestine. In the heart the

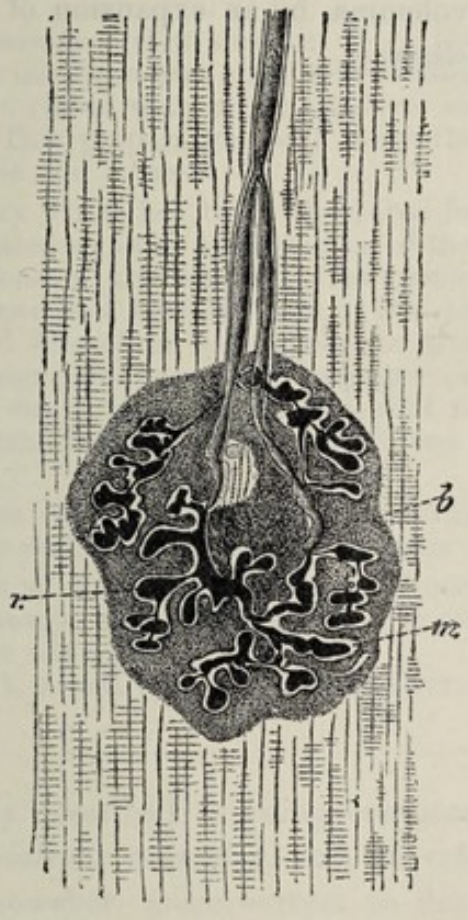


FIG. 184.—MOTOR END-ORGAN OF A LIZARD, GOLD PREPARATION. (Kühne.)
a, nerve-fibre dividing as it approaches the end-organ; *r*, ramification of axis-cylinder upon, *b*, granular bed or sole of the end-organ; *m*, clear substance surrounding the ramifications of the axis-cylinder.

fibrils have been described as ending by minute localized ramifications which are applied to the cells which constitute the cardiac fibres.

In **voluntary muscle**, the nerves, which are always medullated, terminate in special motor end-organs. A medullated fibre will branch two or three times before ending, and then each branch passes straight to a muscular fibre. Having reached this, the neurolemma of the nerve-fibre is continued into the sarcolemma of the muscle, the medul-

lary sheath stops short, and the axis-cylinder ends in a close terminal ramification with varicosities upon its branches (figs. 182 to 184). This ramification is embedded in a layer of granular nucleated protoplasm (fig. 184, *b*), probably a development of the sarcoplasm of the muscle. In some cases the ramification is restricted to a small portion of the muscular fibre, and forms with the granular bed a slight prominence (*eminence of Doyère*). This is the case in insects and mammals. In the lizard the ramification is rather more extended than in mammals, whilst in the frog it is spread over a considerable length of the fibre. In mammals there appears to be only one end-plate to each fibre, while in reptiles there may be several. The end-plate is covered, externally to the sarcolemma, by an expansion of the sheath of Henle of the nerve-fibre (*telolemma*).

LESSON XXII.

STRUCTURE OF THE LARGER BLOOD-VESSELS.

1. Sections of a medium-sized peripheral artery and vein, *e.g.* popliteal or radial. In this preparation the limits of the vascular coats can be well seen and also the differences which they present in the arteries and veins respectively. The sections may be stained with hæmalum and mounted in xylol balsam.

2. Mount in xylol balsam a thin slice cut from the inner surface of an artery which, after having been cut open longitudinally and washed with distilled water, has been rinsed with nitrate of silver solution and exposed to the light in spirit. This preparation will show the outlines of the epithelium cells which line the vessel.

3. A piece of an artery which has been macerated for some days in 33 per cent. alcohol is to be teased so as to isolate some of the muscular cells of the middle coat and portions of the elastic layers (networks and fenestrated membranes) of the inner and middle coats. The tissue may be stained cautiously with diluted hæmalum, and glycerine afterwards added. The muscular cells are recognisable by their irregular outline and long rod-shaped nuclei. Sketch one or two and also a piece of fenestrated membrane. The fenestrated membrane is best obtained from one of the arteries of the base of the brain.

4. Transverse sections of aorta and carotid. Notice the differences in structure between these and the section of the smaller artery.

5. Transverse section of vena cava inferior. Notice the comparatively thin layer of circular muscle, and outside this the thick layer of longitudinal muscular bundles in the adventitia.

Make sketches from 1, 4, and 5 under a low power, from 2 and 3 under a high power.

An **artery** is usually described as being composed of three coats, an *inner* or elastic, a *middle* or muscular, and an *external* or areolar (fig. 185, *b*, *c*, *d*). It is, however, more correct to describe the wall of an artery as being composed of muscular and elastic tissue lined internally by a pavement epithelium (endothelium) and strengthened externally by a layer of connective tissue (*adventitia*).

The *inner coat* (*tunica intima*) is lined by a thin layer of *pavement epithelium*, the cells of which are somewhat elongated in the direction of the axis of the vessel (fig. 186), and form a smooth lining to the tube. After death they become easily detached.

The *epithelium* (or endothelium) is the essential layer in all blood-vessels. It is always the first part to be developed, and in some it remains as the only layer of the vessel. This is the case with all

true capillaries and with certain veins, and also with the lacunar spaces, which, as Minot has pointed out, take the place of capillaries in certain parts (*e.g.* in the medulla of the suprarenal capsules and in the marrow of bones); it is also true of the sinuses of erectile

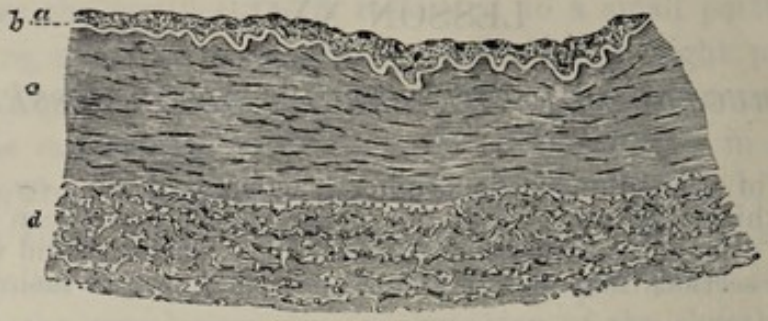


FIG. 185.—TRANSVERSE SECTION OF PART OF THE WALL OF THE POSTERIOR TIBIAL ARTERY. (75 diameters.)

a, epithelial and subepithelial layers of inner coat; *b*, elastic layer (fenestrated membrane) of inner coat, appearing as a bright line in section; *c*, muscular layer (middle coat); *d*, outer coat, consisting of connective-tissue bundles. In the interstices of the bundles are some connective-tissue nuclei, and, especially near the muscular coat, a number of elastic fibres cut across.

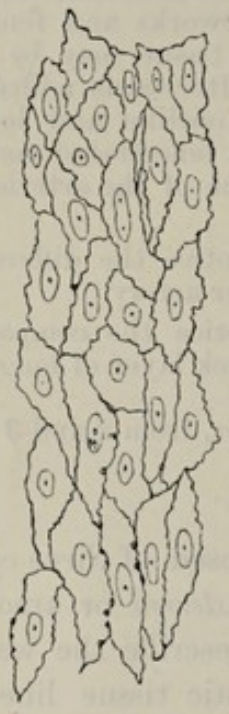


FIG. 186.—EPITHELIAL LAYER LINING THE POSTERIOR TIBIAL ARTERY. (250 diameters.)

FIG. 187.—PORTION OF FENESTRATED MEMBRANE OF HENLE FROM AN ARTERY. (Toldt.)

tissue, as well as the sinus-like blood-vessels which are met with in most invertebrates. Only in two structures is the epithelial layer imperfect, viz.: the capillaries and blood sinuses of the spleen, and the placental mucous membrane of the pregnant uterus; in these places the blood finds its way into the interstices of the connective tissue of the organ.

FIG. 188.—ELASTIC NETWORK of ARTERY. (Toldt.)

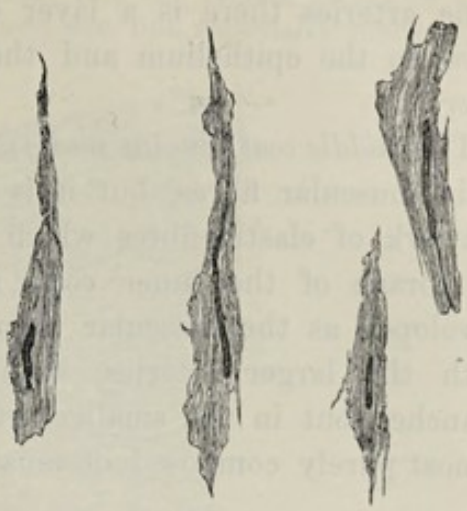


FIG. 189.—MUSCULAR FIBRE-CELLS FROM SUPERIOR THYROID ARTERY. (340 diameters.)

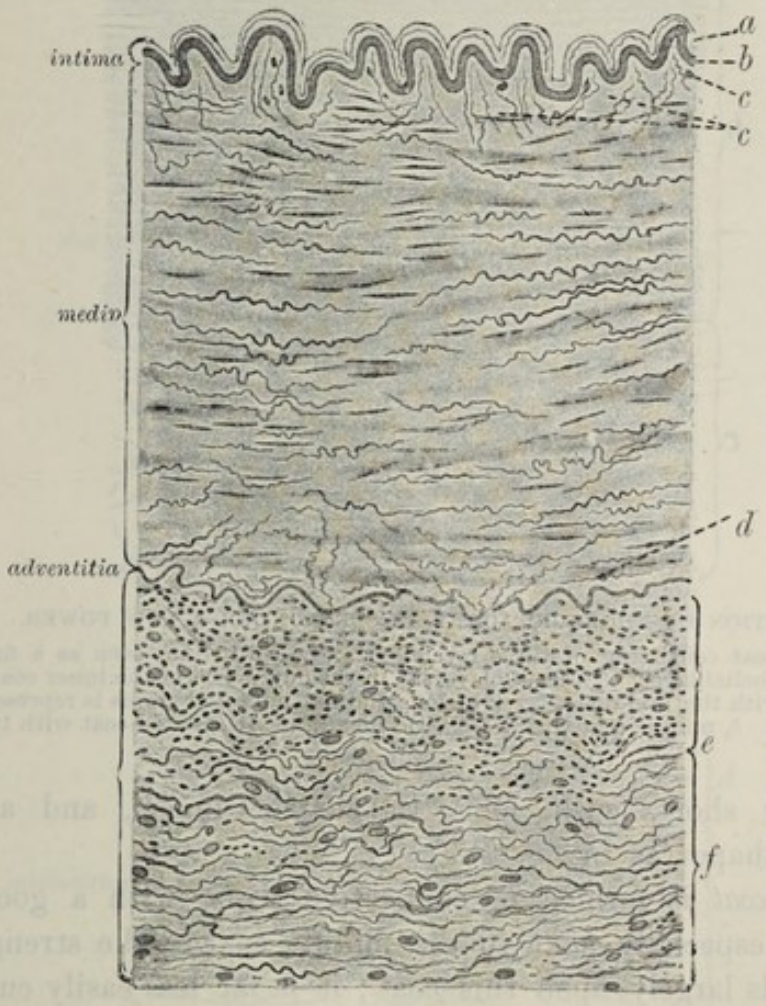


FIG. 190.—SECTION OF THE LINGUAL ARTERY. (Grünstein.)

a, epithelium and subepithelial layer of inner coat; *b*, its elastic layer; *c*, *c*, *d*, innermost and outermost layers of middle coat, with elastic fibres passing obliquely to join the elastic layers which bound that coat; *e*, innermost part of outer coat or adventitia, showing many elastic fibres cut across; *f*, outer part of adventitia.

Next to the epithelium comes an elastic layer in the form either of *elastic networks* (fig. 188) or of a *fenestrated membrane* (fig. 187). In

some arteries there is a layer of fine connective tissue intervening between the epithelium and the fenestrated membrane (*subepithelial layer*).

The *middle coat* (*tunica media*) consists mainly of circularly disposed plain muscular fibres, but it is also pervaded in most arteries by a network of elastic fibres which are connected with the fenestrated membrane of the inner coat and are sometimes almost as much developed as the muscular tissue itself. This is especially the case with the larger arteries, such as the carotid and its immediate branches, but in the smaller arteries of the limbs the middle coat is almost purely composed of muscular tissue. The muscular fibres are

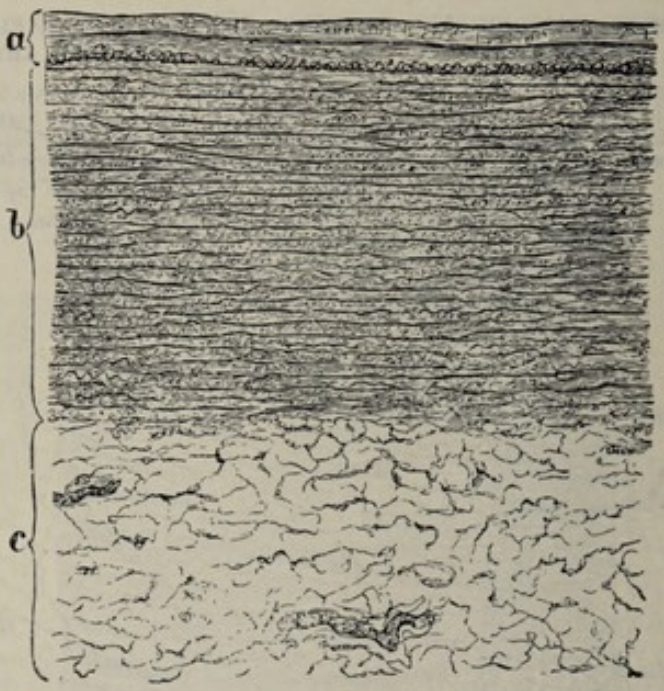


FIG. 191.—SECTION OF THORACIC AORTA AS SEEN UNDER A LOW POWER. (Toldt.)

a, the inner coat consisting of three layers, viz.: 1. Epithelium seen as a fine line. 2. Subepithelial layer. 3. Elastic layers. In the outer part of the inner coat, at its junction with the middle, a layer of longitudinal muscular fibres is represented as cut across. *b*, middle coat with its elastic membranes; *c*, outer coat with two vasa vasorum.

comparatively short, with long rod-shaped nuclei, and are often irregular in shape (as in fig. 189).

The *outer coat* is formed of connective tissue with a good many elastic fibres, especially next to the middle coat. The strength of an artery depends largely upon this coat; it is far less easily cut or torn than the other coats, and it serves to resist undue expansion of the vessel. Its outer limit is not sharply marked, for it tends to blend with the surrounding connective tissue; hence it has been termed *tunica adventitia*.

Variations in structure.—The *aorta* (figs. 191, 192) differs in some respects in structure from an ordinary artery. Its inner coat contains a considerable

thickness of subepithelial connective tissue, but the elastic layers of this coat are chiefly composed of fine fibres, and are not especially marked off

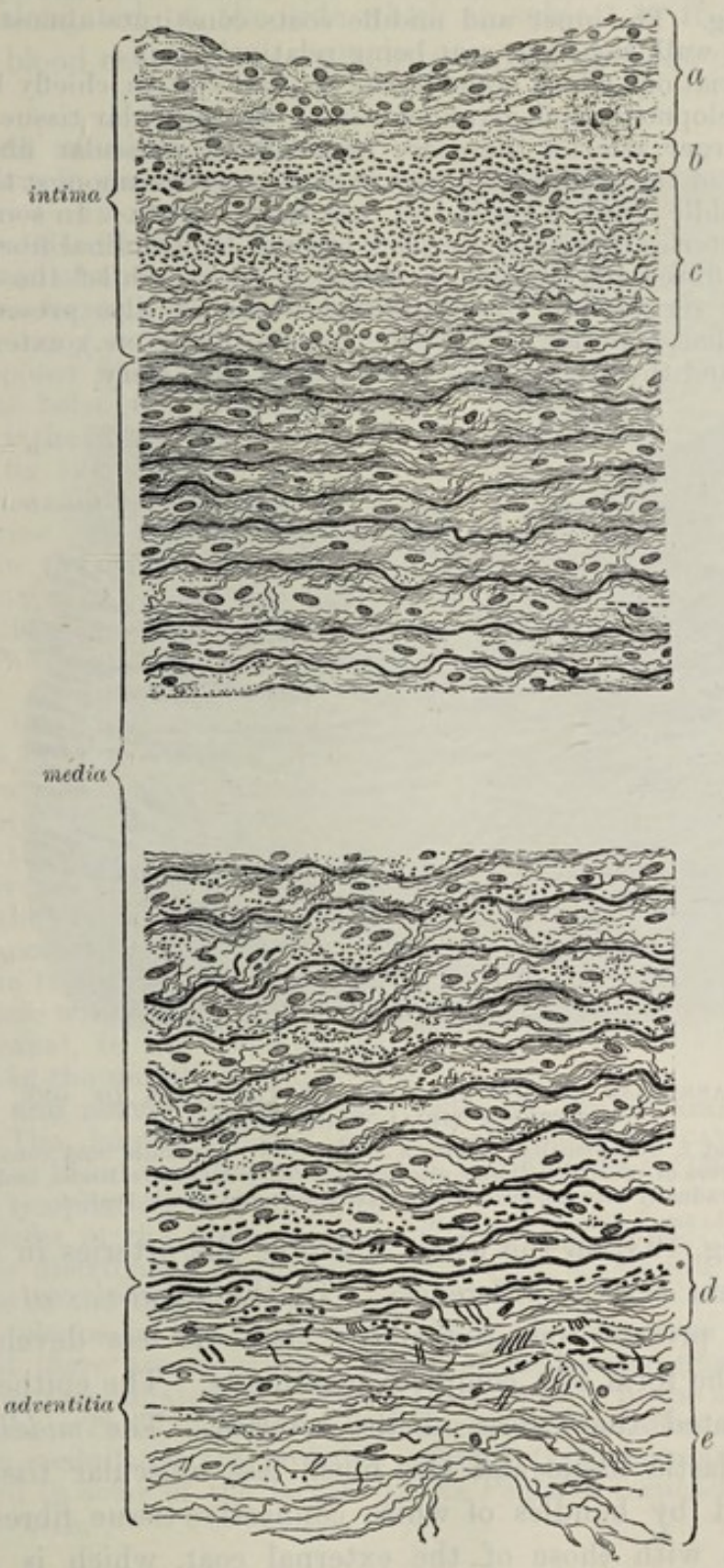


FIG. 192.—SECTION OF AORTA MORE MAGNIFIED. (Grünstein.)
a, epithelial and subepithelial layers of inner coat; *b*, *c*, outer layers of inner coat containing many fine elastic fibres; *d*, *e*, parts of outer coat.

from those of the middle coat, so that the inner and middle coats appear blended with one another. On the other hand, there is a very great develop-

ment of elastic tissue in the middle coat, forming membranous layers which alternate with layers of the muscular tissue. A good deal of connective tissue also takes part in the formation of the middle coat, making this coat unusually strong. The inner and middle coats constitute almost the entire thickness of the wall, the outer coat being relatively thin.

The other variations which occur in the arterial system chiefly have reference to the development and arrangement of the muscular tissue. Thus in many of the larger arteries there are longitudinal muscular fibres at the inner boundary of the middle coat, and in some arteries amongst the circular fibres of the middle coat. This is the case in the aorta. In some parts of the umbilical arteries there is a complete layer of longitudinal fibres internal to the circular fibres and another external to them, whilst the amount of elastic tissue is very small. Longitudinal fibres are also present in some other arteries (iliac, superior mesenteric, splenic, renal, etc.), external to the circular fibres, and therefore in the outer coat of the artery.

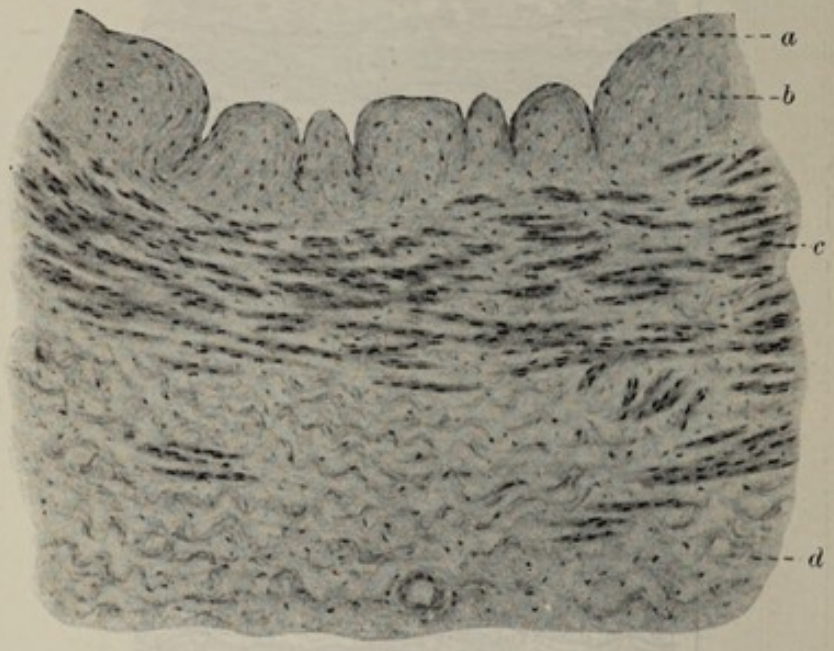


FIG. 193.—TRANSVERSE SECTION OF PART OF THE WALL OF ONE OF THE POSTERIOR TIBIAL VEINS (MAN).

a, epithelial, and *b*, subepithelial layers of inner coat; *c*, middle coat consisting of irregular layers of muscular tissue, alternating with connective tissue, and passing somewhat gradually into the outer connective tissue and elastic coat, *d*.

The **veins** (fig. 193) on the whole resemble the arteries in structure, but they present certain differences. In the *internal coat* the same layers may be present, but the elastic tissue is less developed and seldom takes the form of a complete membrane. The epithelium-cells are less elongated than those of the arteries. The *middle coat* (*c*) contains less elastic tissue and also much less muscular tissue, being partly occupied by bundles of white connective-tissue fibres. These are continuous with those of the external coat, which is relatively better developed in the veins than in the arteries, so that, although thinner, their walls are often stronger.

Many of the veins are provided with *valves*, which are semilunar folds of the internal coat strengthened by a little fibrous tissue:

a few muscular fibres may be found in the valve near its attachment. The layer of the inner coat is rather thicker and the epithelium-cells are more elongated on the side which is subject to friction from the current of blood than on that which is turned towards the wall of the vessel.

Variations in different veins.—The veins vary in structure more than do the arteries. In many veins longitudinal muscular fibres are found in the inner part of the middle coat, as in the iliac, femoral, umbilical; in others they occur external to the circularly disposed fibres, and may be described as belonging to the outer coat. This is the case with the inferior vena cava (fig. 194), and also with the hepatic veins and the portal vein and its tributaries. In the superior vena cava and in the upper part of the inferior vena cava the circular fibres of the middle coat are almost entirely absent. The veins of the following parts have no muscular tissue, viz. pia mater, brain and spinal cord, retina, bones, and the venous sinuses of the dura mater and placenta.

It is only the larger veins, and especially those of the limbs, that possess valves. They are wanting in most of the veins of the viscera (although occurring abundantly in some of the tributaries of the portal vein), in those within the cranium and vertebral canal, in the veins of the bones, and in the umbilical vein.

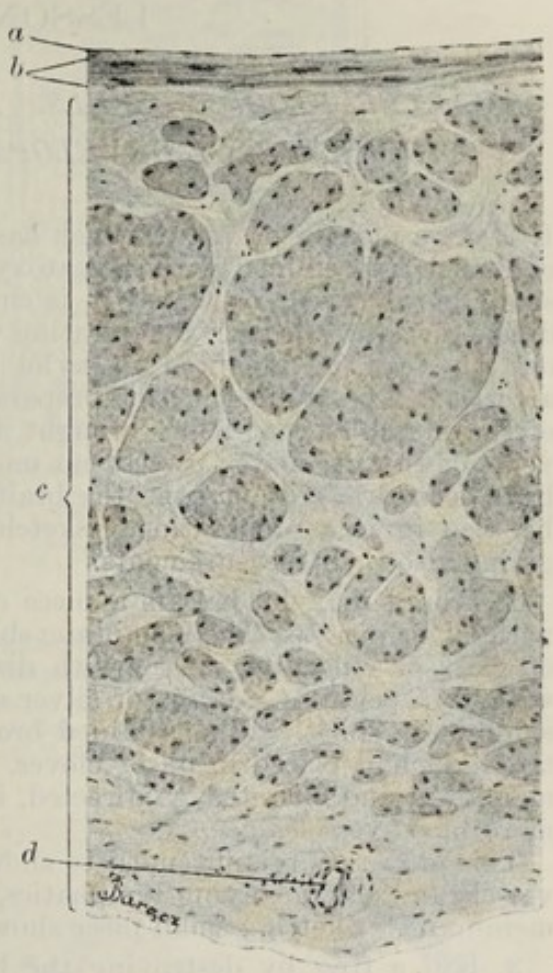


FIG. 194.—TRANSVERSE SECTION OF THE INFERIOR VENA CAVA OF THE DOG. (Szymonowicz.) (Magnified 150 diameters.)

a, intima; *b*, thin layer of circular muscle; *c*, thick adventitia with longitudinal muscular bundles; *d*, a vas vasis.

Vessels and nerves of the blood-vessels.—The larger arteries and veins possess blood-vessels (*vasa vasorum*) and lymphatics, both of which ramify chiefly in the external coat. Nerves are distributed to the muscular tissue of the middle coat, after forming a plexus in the outer coat. Most of the nerves are non-medullated. But there are a certain number of medullated fibres intermingled with the non-medullated and passing to end partly in the adventitia partly in the intima. These medullated fibres are doubtless afferent; the majority of the non-medullated are probably efferent (vaso-motors). In the aorta of man and in some of the larger trunks Pacinian corpuscles are here and there met with.

LESSON XXIII.

SMALLER BLOOD-VESSELS. MICROSCOPIC STUDY OF THE CIRCULATION; DEVELOPMENT OF BLOOD-VESSELS.

1. Take a piece of pia mater which has been fixed with 2 per cent. bichromate of potash and stained with hæmatoxylin, and separate from it some of the small blood-vessels of which it is chiefly composed. Mount the shreds in dilute glycerine, or after dehydrating with alcohol and passing through clove oil they can be mounted in xylol balsam. The structure of the small arteries can be studied in this preparation, the nuclei of the epithelium and of the muscular coat being brought distinctly into view by the stain. The veins of the pia mater possess no muscular tissue. Capillary vessels which have been dragged out from the brain in removing the pia mater may also be seen in this preparation. Sketch two small arteries of different sizes, giving also their measurements.

2. Mount in xylol balsam a piece of the omentum of the rabbit, stained with silver nitrate. The membrane should be stretched over a cork or a ring of glass or vulcanite, rinsed with distilled water, treated for five minutes with 0·75 per cent. nitrate of silver solution, again washed and exposed to sunlight in spirit. When stained brown, the preparation is removed from the light and placed in oil of cloves. Pieces may now be cut off from the membrane and mounted, as directed, in balsam; they should include one or more blood-vessels.

This preparation is intended to show the epithelium of the smaller blood-vessels and accompanying lymphatics, and also the epithelium of the serous membrane. Sketch a small piece showing the epithelium of the vessels.

3. Kill a frog by destroying the brain and study the circulation of the blood in the mesentery. It can also be studied in the web of the frog's foot, and in the tongue of the frog or toad, or in the tail of the tadpole or of any small fish. But for observing the phenomena attending commencing inflammation and the emigration of leucocytes from the vessels, the mesentery is the most convenient object. The frog can be immobilised with curari or by placing it in water in which chloroform or ether has been shaken up: a lateral incision is made in the abdominal wall, a loop of intestine drawn out, and laid over a ring of cork which is fixed to a glass plate and covered with a thin piece of glass. The membrane must be kept wet with salt solution.[1]

The coats of the **small arteries and veins** are much simpler in structure than those of the larger vessels, but they contain at first all the same elements. Thus there is a lining epithelium (endothelium) and an elastic layer forming an *inner coat*, a *middle coat* of circularly disposed plain muscular tissue, and a thin adventitia. The same

[1] For details of the methods of studying the circulation and of injecting the blood-vessels, see *A Course of Practical Histology*.

differences also are found between the arteries and veins, the walls of the veins being thinner and containing far less muscular tissue

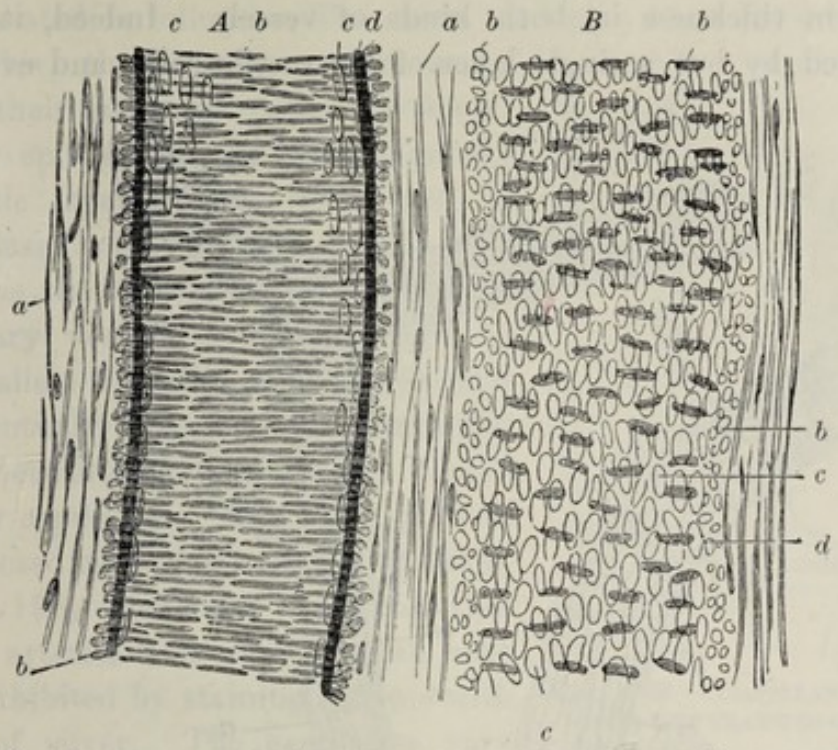


FIG. 195.—SMALL ARTERY, *A*, WITH CORRESPONDING VEIN, *B*, TREATED WITH ACETIC ACID. (Kölliker.) (Magnified 350 diameters.)

a, external coat with elongated nuclei; *b*, nuclei of the transverse muscular tissue of the middle coat (when seen endwise, as at the sides of the vessel, their outline is circular); *c*, nuclei of the epithelium-cells; *d*, elastic layer of the inner coat.

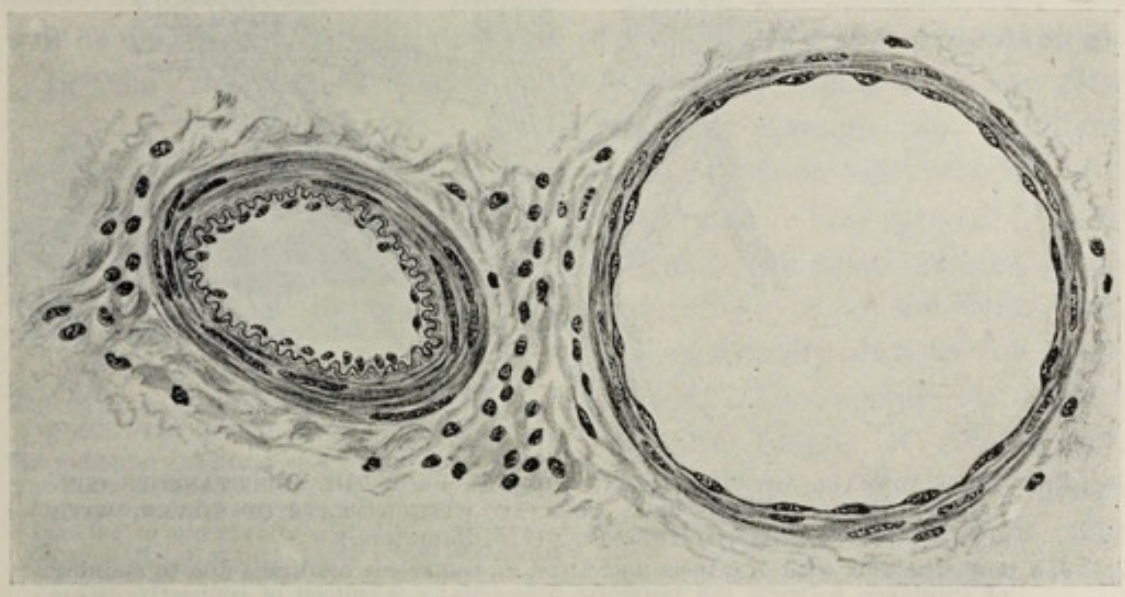


FIG. 196.—TRANSVERSE SECTION OF A SMALL ARTERY AND VEIN. (Magnified 250 diameters.)

(fig. 195), and the lining epithelium-cells, much elongated in both vessels, are far longer and narrower in the small arteries than in the corresponding veins (fig. 197).

In the smallest vessels it will be found that the elastic layer has disappeared in the veins, and the muscular tissue is considerably reduced in thickness in both kinds of vessels. Indeed, it is soon represented by but a single layer of contractile cells, and even these

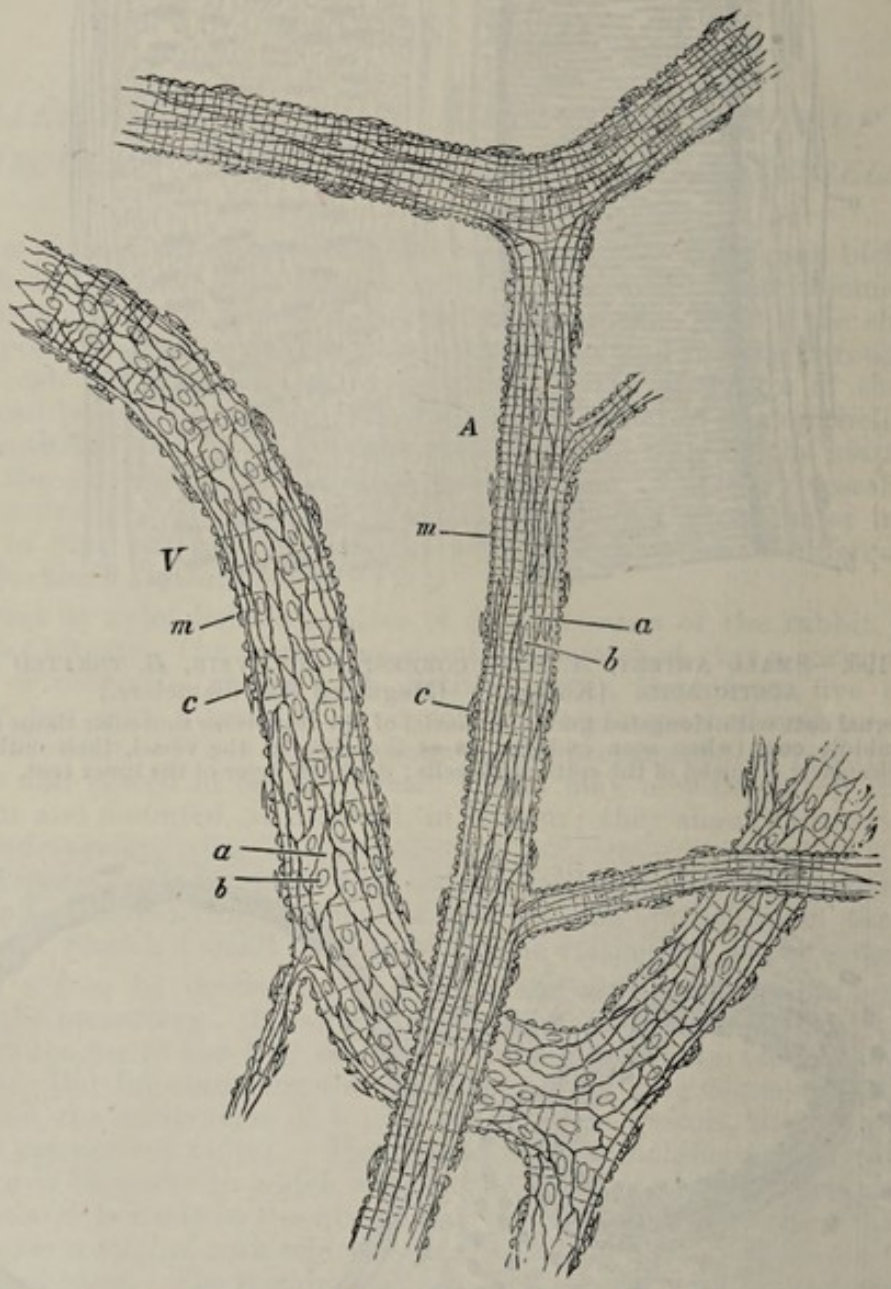


FIG. 197.—A SMALL ARTERY, *A*, AND VEIN, *V*, FROM THE SUBCUTANEOUS CONNECTIVE TISSUE OF THE RAT, TREATED WITH NITRATE OF SILVER, WITH SUBSEQUENT STAINING OF NUCLEI. (175 diameters.)

a, *a*, epithelial cells with *b*, *b* their nuclei; *m*, *m*, transverse markings due to staining of substance between the muscular fibre-cells; *c*, *c*, nuclei of connective-tissue corpuscles attached to exterior of vessel.

no longer form a complete layer. By this time also, the outer coat and the elastic layer of the inner coat have entirely disappeared both from arteries and veins. The vessels are reduced, therefore, to the condition of a tube formed of pavement-epithelium cells, with a partial covering of circularly disposed muscular cells.

Even in the smallest vessels, which are not capillaries, the differences between arteries and veins are still manifested. These differences may be enumerated as follows:—The veins are larger than the corresponding arteries; they branch at less acute angles; their muscular cells are fewer, and their epithelium-cells less elongated; the elastic layer of the inner coat is always less marked, and sooner disappears as the vessels become smaller.

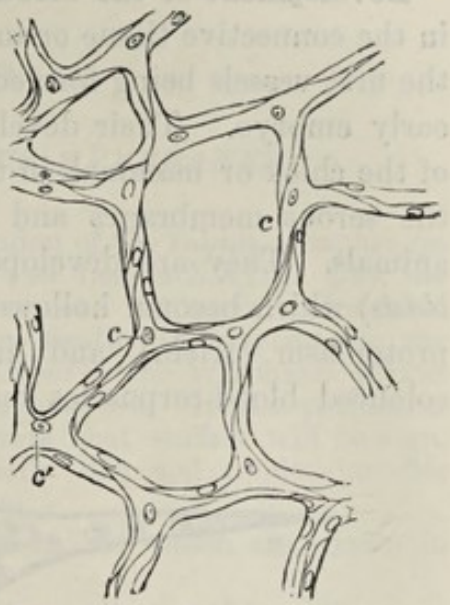


FIG. 198. — CAPILLARY VESSELS FROM THE BLADDER OF THE CAT, MAGNIFIED.

The outlines of the cells are stained by nitrate of silver.

Capillary vessels. — When traced to their smallest branches the arteries and veins eventually are seen to be continued into a network of the smallest blood-vessels or capillaries. The walls of these are composed only of flattened epithelium-cells (fig. 198) continuous with those that line the arteries and veins; these cells can be exhibited by staining a tissue with nitrate of silver. The capillaries vary somewhat in size and in the closeness of their meshes; their arrangement in different parts, which is mainly determined by the disposition of the tissue elements, may best be studied in injected preparations, and will be described when the structure of the several organs is considered.

In the transparent parts of animals, the blood may be seen flowing through the capillary network from the arteries into the veins. The current is very rapid in the small arteries, somewhat less so in the veins, and comparatively slow in the capillaries. The current is fastest in the centre of the vessel, slowest near the wall (inert layer), and with care it may be observed—especially where there is a commencing inflammation of the part, as in the mesentery in consequence of exposure—that the white blood-corpuscles, which always tend to pass into the inert layer, and to adhere occasionally to the inner surface of the blood-vessels, here and there pass through the coats of the small vessels, and appear as *migratory cells* in the surrounding

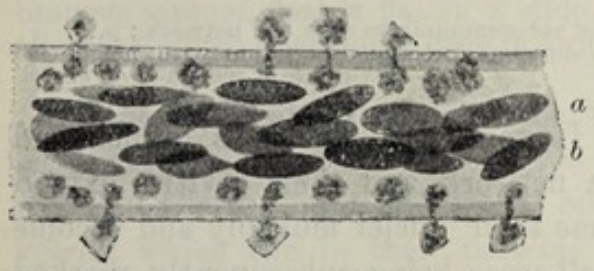


FIG. 199. — BLOOD FLOWING THROUGH A SMALL VEIN OF THE FROG'S MESENTERY.

The mesentery had been exposed for a short time, so that there was commencing inflammation and many of the white corpuscles are observed sticking to and even passing through the vascular wall. *a*, central rapid layer containing the coloured corpuscles; *b*, outer slower layer (inert layer) containing the white corpuscles.

connective tissue (fig. 199). The blood-platelets are also seen in the inert layer, and they also show a tendency to adhere to the wall and to one another in commencing inflammation.

Development of the blood-vessels.—The blood-vessels are developed in the connective tissue or in the mesoblastic tissue which precedes it, the first vessels being formed in the vascular area which surrounds the early embryo. Their development may be studied in the mesoblast of the chick or mammal, in the omentum of the new-born rabbit, or in the serous membranes and subcutaneous connective tissue of fœtal animals. They are developed from cells (*vaso-formative cells* or *angioblasts*) which become hollowed out by an accumulation of fluid in their protoplasm (Klein), and in the case of developing blood-vessels coloured blood-corpuscles may also be formed within these cells (see

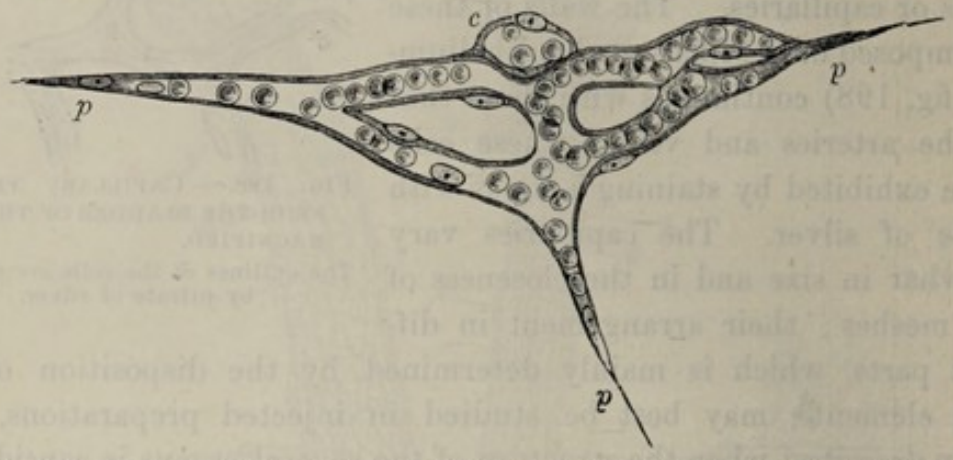


FIG. 200.—ISOLATED CAPILLARY NETWORK FORMED BY THE JUNCTION OF SEVERAL HOLLOWED-OUT CELLS, AND CONTAINING COLOURED BLOOD-CORPUSCLES IN A CLEAR FLUID.

c, a hollow cell the cavity of which does not yet communicate with the network; *p*, *p*, pointed cell-processes, extending in different directions for union with neighbouring capillaries.

Development of Blood-corpuscles, Lesson II.). The cells branch and unite with one another to form a network, and their cavities extend into the branches. In the meantime their nuclei multiply and become distributed along the branches, cell-areas being subsequently marked out around them. In this way intercommunicating vessels—capillaries containing blood—are produced (fig. 200). These presently become connected with previously formed vessels, which extend themselves by sending out sprouts, at first solid, and afterwards hollowed-out. Even the larger blood-vessels appear first to be developed in the same way as the capillaries, in so far that the epithelium is first formed and the muscular and other tissues are subsequently added; but whether they are formed as clefts in the mesoblastic tissue, which become bounded by flattened cells, or whether as hollowed-out cells, which join to form a continuous tube, has not been definitely ascertained.

LESSON XXIV.

LYMPHATIC VESSELS; SEROUS MEMBRANES.

1. Mount in balsam a piece of the central tendon of the rabbit's diaphragm which has been prepared with silver nitrate (see Lesson XXIII., § 2), the pleural surface having been first brushed to remove the superficial epithelium so as to enable the nitrate of silver more readily to penetrate to the network of underlying lymphatic vessels. Observe the lymphatic plexus under a low power; sketch a portion of the network. If the peritoneal surface is focussed, the epithelium which covers that surface will be seen, and opposite the clefts between the radially disposed tendon-bundles stomata may be looked for in this epithelium.

2. Study the lymphatics and the serous epithelium which are shown in preparation 2, Lesson XXIII.

3. Prepare sections of the thoracic duct. These may be made in the same way as sections of the blood-vessels (see Lesson XXII.).

4. Open the abdomen of a freshly killed frog, preferably a male, and remove the abdominal viscera, taking care not to injure the membrane or septum at the back of the abdomen, which lies over and between the kidneys and separates the peritoneal cavity from the *cisterna lymphatica magna*, a large lymphatic space in which the aorta and vena cava are contained. Cut out the kidneys along with as much as possible of the above septum; rinse with distilled water; and place in a watch-glass of 0·75 per cent. silver nitrate for 5 minutes. Rinse again in distilled water and expose in tap water to the light. When slightly browned snip off a portion of the membranous septum, float it flat on a slide, drain off the superfluous water and allow it to dry; then add a drop of xylol balsam and cover the preparation.

To the lymphatic system belong not only the *lymphatic vessels* and *lymphatic glands*, but also the *cavities of the serous membranes*, which are moistened with lymph and are in open communication with lymphatic vessels which run in their parietes.

The larger **lymphatic vessels** somewhat resemble the veins in structure, except that their coats are much thinner and their valves much more numerous. In lymphatics of somewhat smaller size, the wall of the vessel is formed, first, by a lining of pavement-epithelium cells (lymphatic endothelium), which are elongated in the direction of the axis of the vessel; and, secondly, by a layer of circularly and obliquely disposed muscular fibres. In the smallest vessels (so-called *lymphatic capillaries*, which, however, are generally considerably larger than the blood-capillaries), there is nothing but the epithelium remaining, and the cells of this are frequently not more elongated in one direction than in another, but have a characteristic wavy outline (fig. 201).

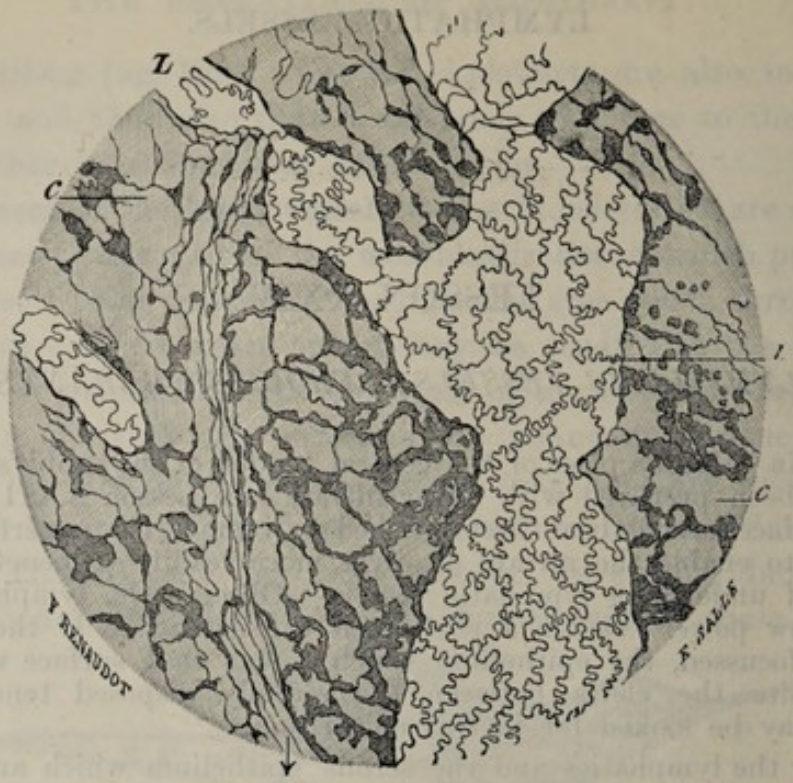


FIG. 201.—A SMALL PART OF THE LYMPHATIC PLEXUS OF THE PLEURAL LAYER OF THE DIAPHRAGM. (Magnified 110 diameters.) (Ranvier.)

L, lymphatic vessel with characteristic epithelium; *c*, cell-spaces of the connective tissue here and there abutting against the lymphatic.

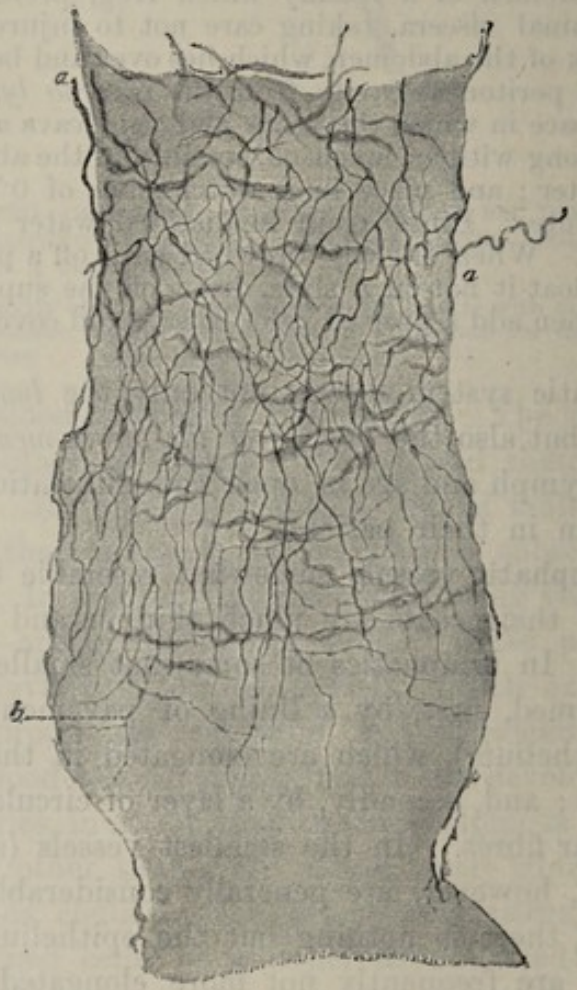


FIG. 202.—NERVES OF A LYMPHATIC VESSEL, SHOWN BY METHYLENE BLUE. (Dogiel.)

a, *a*, non-medullated fibres passing to the vessel; *b*, part of their terminal ramification.

The lymphatics receive numerous nerve-fibres, which are non-medullated, and end in a ramification of the finest fibrils, which are distributed to the coats of the vessel (fig. 202).

FIG. 203.—LYMPHATIC PLEXUS OF CENTRAL TENDON OF DIAPHRAGM OF RABBIT, PLEURAL SIDE. (Klein.)

a, larger vessels with lanceolate cells and numerous valves; *b*, *c*, lymphatic capillaries with wavy-bordered cells.

Lymphatics begin either in the form of *plexuses*, as in membranes (fig. 203), or of *lacunar interstices*, as in some of the viscera.

In order to show the structure of lymphatic vessels, it is usual to

stain a tissue with nitrate of silver; but they may easily be injected by sticking the nozzle of an injecting cannula into any tissue which contains them, and forcing coloured fluid under gentle pressure into the interstices of the tissue.

In silver preparations it may be observed that the lymphatics always appear in the form of clear channels in the stained ground-substance of the connective tissue, and that their walls are in close connection with the cells and cell-spaces of that tissue (fig. 201). But,

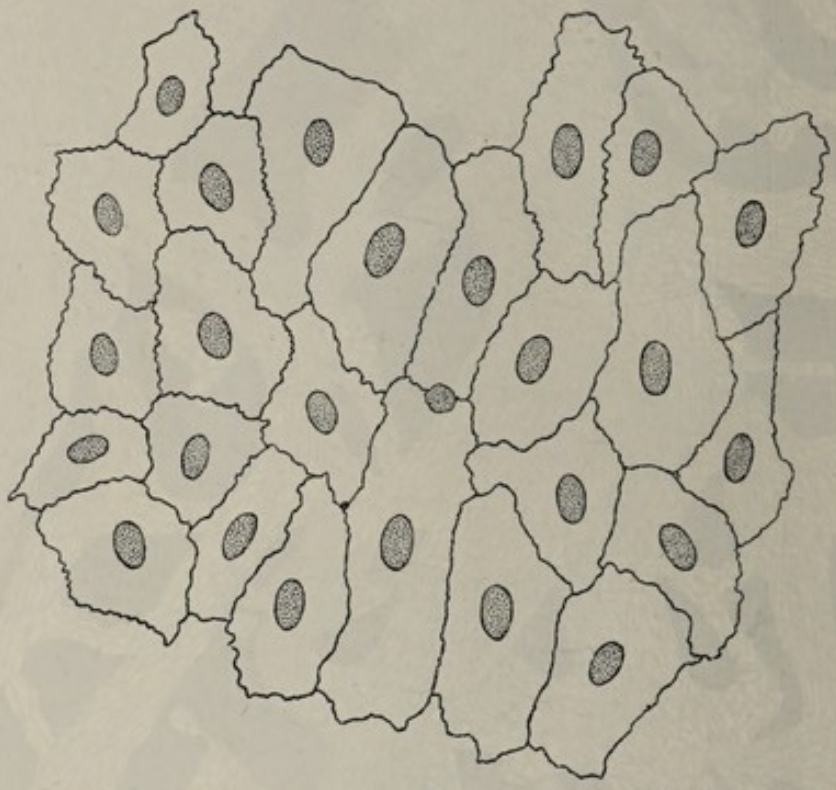


FIG. 204.—EPITHELIUM OF A SEROUS MEMBRANE. OMENTUM OF THE RABBIT. NITRATE OF SILVER PREPARATION. (Highly magnified.)

except in the case of the serous membranes, there is no open communication between the lymphatic vessels and the interstices of the connective tissue. The lymphatic vessels are developed from hollowed-out cells in the same manner as the blood-vessels (Klein).

SEROUS MEMBRANES.

The **serous membranes**, which may be conveniently studied in connection with the lymphatic system, are delicate membranes of connective tissue which surround and line the internal cavities of the body, and are reflected over many of the thoracic and abdominal viscera; in passing to which they form folds (such as the mesentery), within which blood-vessels, lymphatics, and nerves are conducted to the viscera.

The inner surface is lined by a continuous layer of *pavement-*

epithelium (*endothelium*) (fig. 204), which is very distinct in nitrate of silver preparations. In some places there are apertures in the epithelium which lead directly into subjacent lymphatic vessels. These apertures are called *stomata*, and are surrounded by small protoplasmic cells (fig. 205, *s*, *s*). They are numerous upon the peritoneal surface of the diaphragm, but are present in most serous membranes. They are nowhere better studied or more easily seen than in the peritoneal membrane at the back of the abdominal cavity in the frog. This membrane lies between and at the sides of the kidneys,

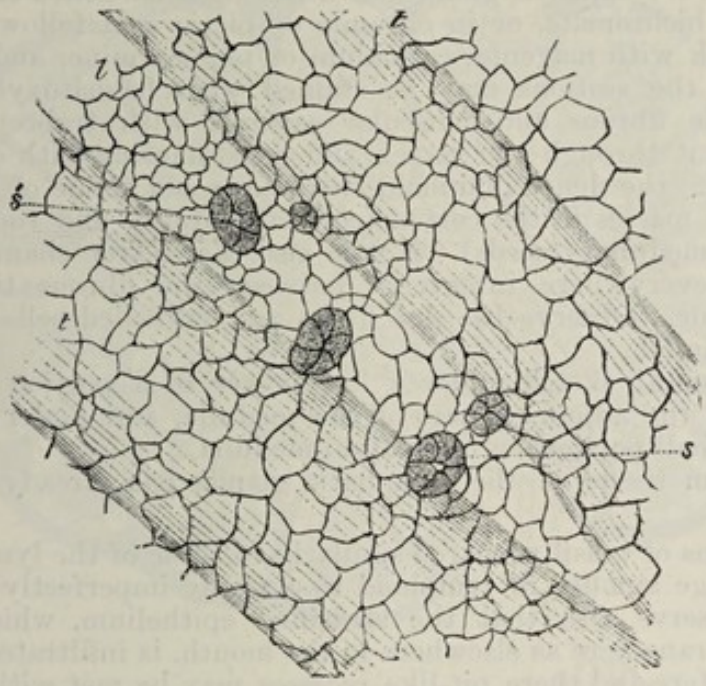


FIG. 205.—SMALL PORTION OF PERITONEAL SURFACE OF DIAPHRAGM OF RABBIT, STAINED WITH NITRATE OF SILVER TO SHOW THE SEROUS EPITHELIUM. (Klein.)

l, lymph-channel below the surface, lying between tendon bundles, *t*, *t*, and over which the surface-cells are seen to be relatively smaller, and to exhibit five stomata, *s*, *s*, leading into the lymphatic. The epithelium of the lymphatic channel is not represented.

and serves to separate the peritoneal cavity from the large lymphatic space just behind it. If the membrane is prepared by the nitrate of silver method the stomata and the cells which surround them on either side of the membrane are well shown.

The pavement-epithelium of the serous membrane rests upon a homogeneous basement-membrane, which is especially well marked in the serous membranes of man. The rest of the thickness of the membrane is composed of connective tissue, with a network of fine elastic fibres near the inner surface.

The cavities of the serous membranes are originally formed in the embryo as a cleft in the mesoderm (pleuro-peritoneal split, cœlom) which becomes lined with epithelium, and its wall eventually becomes differentiated into the serous membrane.

LESSON XXV.

LYMPHATIC GLANDS, TONSIL, THYMUS.

1. Sections of a lymphatic gland which has been hardened either in formol or potassium bichromate, or in chromic or picric acid followed by alcohol, stained in bulk with magenta, carmalum or picrocarmine, and embedded in paraffin. Or the sections may be stained with hæmatoxylin and eosin. Notice (1) the fibrous and muscular capsule, with trabeculæ extending inwards from it through the cortex and anastomosing with one another in the medulla, (2) the dense lymphoid tissue (adenoid tissue of some authors) forming large masses in the cortex (cortical nodules) and rounded cords in the medulla (medullary cords). Notice also the clearer channel or lymph-sinus which everywhere intervenes between the fibrous tissue and the lymphoid tissue. Observe the fine fibres and branched cells which bridge across this channel.

Make a general sketch under a low power of a portion of the cortex together with the adjoining part of the medulla, and under a high power drawings of small portions of cortex and medulla.

The retiform tissue of the lymphatic glands has already been studied (Lesson IX.).

2. In sections of tonsil prepared similarly to those of the lymphatic gland, notice the large amount of lymphoid tissue only imperfectly collected into nodules. Observe also that the stratified epithelium, which covers the mucous membrane here as elsewhere in the mouth, is infiltrated with lymph-corpuscles. Here and there pit-like recesses may be met with, with mucus-secreting glands opening into the pits.

3. A similar preparation of the thymus gland of an infant or young animal. Notice that the masses of lymphoid tissue which form the lobules of the gland are separated by septa of connective tissue, and that they show a distinction into two parts, cortical and medullary. Observe the differences of structure of these two parts, and especially notice the concentric corpuscles in the medullary part.

Make a sketch of one of the lobules under a low power and of a small part of the medulla under a high power, including one or two concentric corpuscles. Measure the latter.

Lymphatic Glands.

Structure of a lymphatic gland.—A lymphatic gland is composed of a *framework of fibrous and plain muscular tissue*, which incloses and supports the proper glandular substance, but is everywhere separated from it by a narrow channel, bridged across by cells and fibres, which is known as the *lymph-channel*. The *framework* consists of an envelope or *capsule* (fig. 206, *c*), and of *trabeculæ* (*tr*), which pass at intervals inwards from the capsule, and after traversing the cortex of the gland, divide and reunite with one another so as to form a network of fibrous

bands. At one part of the gland there is usually a depression (*hilum*), and at the bottom of this the medulla comes to the surface and its fibrous bands are directly continuous with the capsule.

The proper *glandular substance* (*l.h.*) is composed of lymphoid tissue, *i.e.* a fine reticulum with the meshes thickly occupied by lymph-corpuscles. It occupies all the interstices of the gland, forming com-

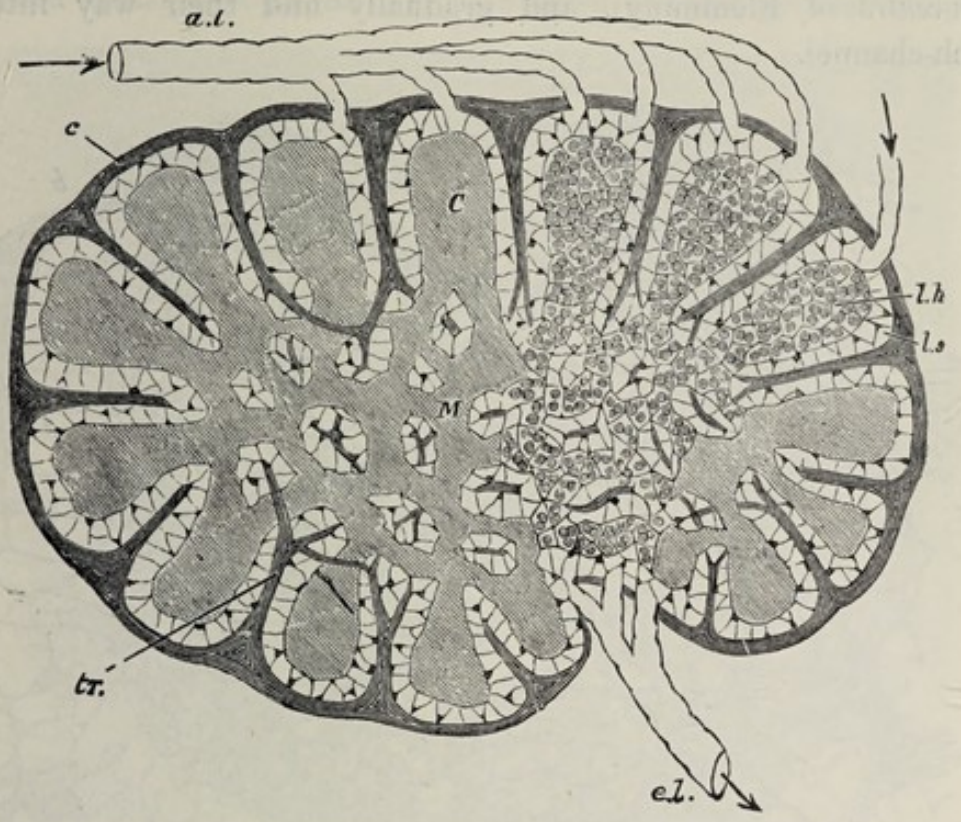


FIG. 206.—DIAGRAMMATIC SECTION OF LYMPHATIC GLAND. (Sharpey.)
a.l. afferent, *e.l.* efferent lymphatics; *C*, cortical substance; *M*, reticulating cords of medullary substance; *l.h.* lymphoid tissue; *l.s.* lymph-sinus; *c*, fibrous coat sending trabeculæ, *tr*, into the substance of the gland.

paratively large rounded masses in the cortex (lymphoid nodules, *C*), between the trabeculæ, and smaller reticulating cord-like masses (lymphoid cords, *M*) in the medulla.

The cells which bridge across the lymph-channel in the medulla (fig. 207, *c*) are branching nucleated cells which often contain pigment, so that this part of the gland has a dark colour. The lymph-channel is bridged across not only by these cells, but also by fibres derived from the capsule and trabeculæ, which pass to the lymphoid tissue and become lost in its reticulum. But the fibres are often covered and concealed by the branched cells.

Lymphatic vessels (fig. 206, *a.l.*) enter the lymph-channels after ramifying in the capsule, and the lymph is conveyed slowly along the channels of the cortical and medullary part towards the hilum, taking up many lymph-corpuscles in its passage. At the hilum it

is gathered up by an efferent vessel or vessels (*e.l.*) taking origin in the lymph-sinuses of the medulla.

The efferent lymphatics always contain many more lymph-corpuscles than those which enter the gland, for lymph-corpuscles are constantly being formed by indirect division of the pre-existing cells in the glandular substance, and especially in the centre of each cortical nodule (*germ-centre* of Flemming), and gradually find their way into the lymph-channel.

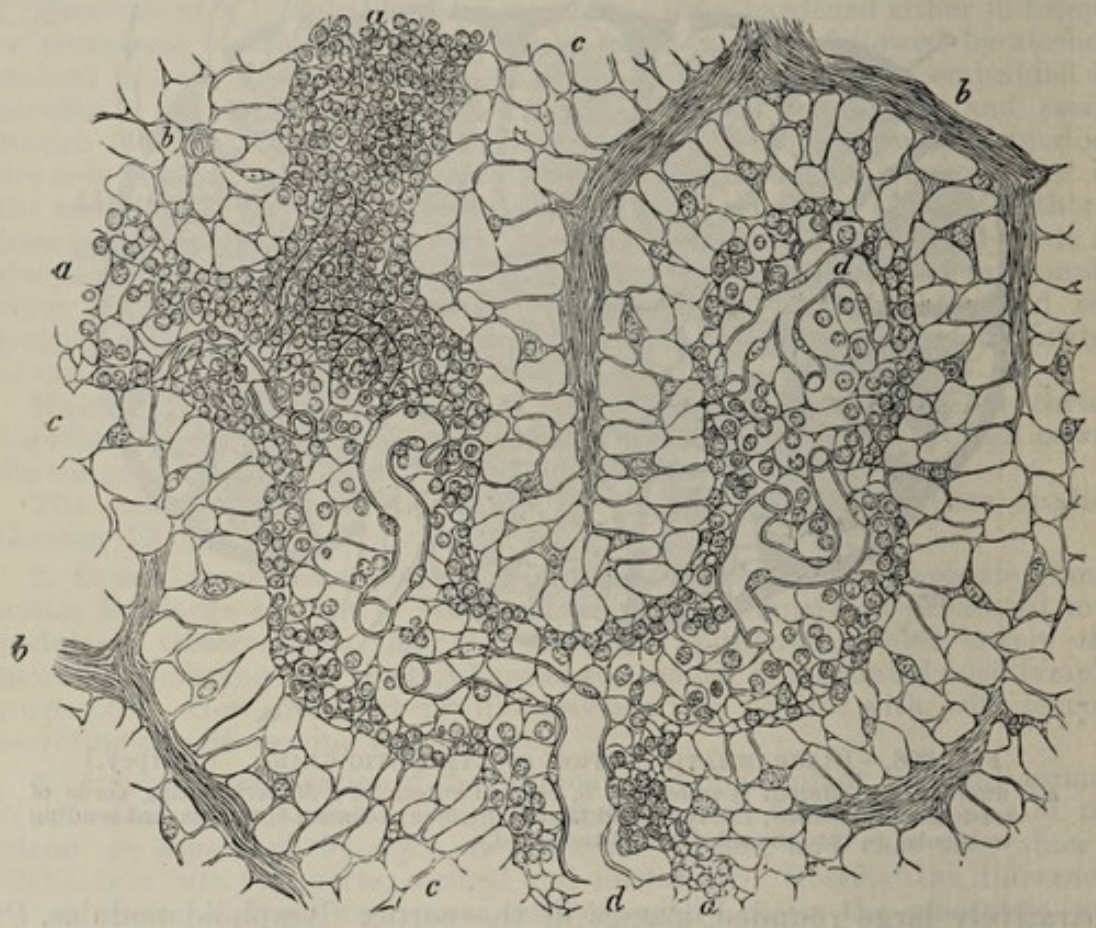


FIG. 207.—SECTION OF THE MEDULLARY SUBSTANCE OF A LYMPHATIC GLAND. (300 diameters.) (Recklinghausen.)

a, *a*, *a*, lymphoid cords; *c*, lymph-sinus; *b*, *b*, trabeculæ; *d*, *d*, capillary blood-vessels.

An artery passes into each gland at the hilum; its branches are conveyed at first along the fibrous cords, but soon pass into the lymphoid tissue, where they break up into capillaries (fig. 207, *d*). The blood is returned by small veins, which are conducted along the fibrous trabeculæ to the hilum again.

In some lymphatic glands the fibrous trabeculæ are very slightly developed, so that the gland seems in section to be an almost uniform mass of lymphoid tissue. This is the case with most, if not all, of the lymphatic glands of some animals. In others, on the other hand, the trabeculæ are very well developed and contain much muscular tissue.

Nerve fibres pass to lymphatic glands and appear to be distributed chiefly

as non-medullated fibres to the plain muscular tissue of the blood-vessels and trabeculæ.

Hæmal lymphatic glands.—In many animals a certain number of lymphatic glands are observable which have a red colour. Some of these on section show that what corresponds to the lymph-channel in ordinary lymphatic glands is in them occupied by blood. Others have the greater part of the interior occupied by large sinuses filled with blood ; in addition to which there are a number of cords of lymphoid tissue. The names *hæmal glands* and *hæmolymph glands* have been given to these peculiar lymphatic

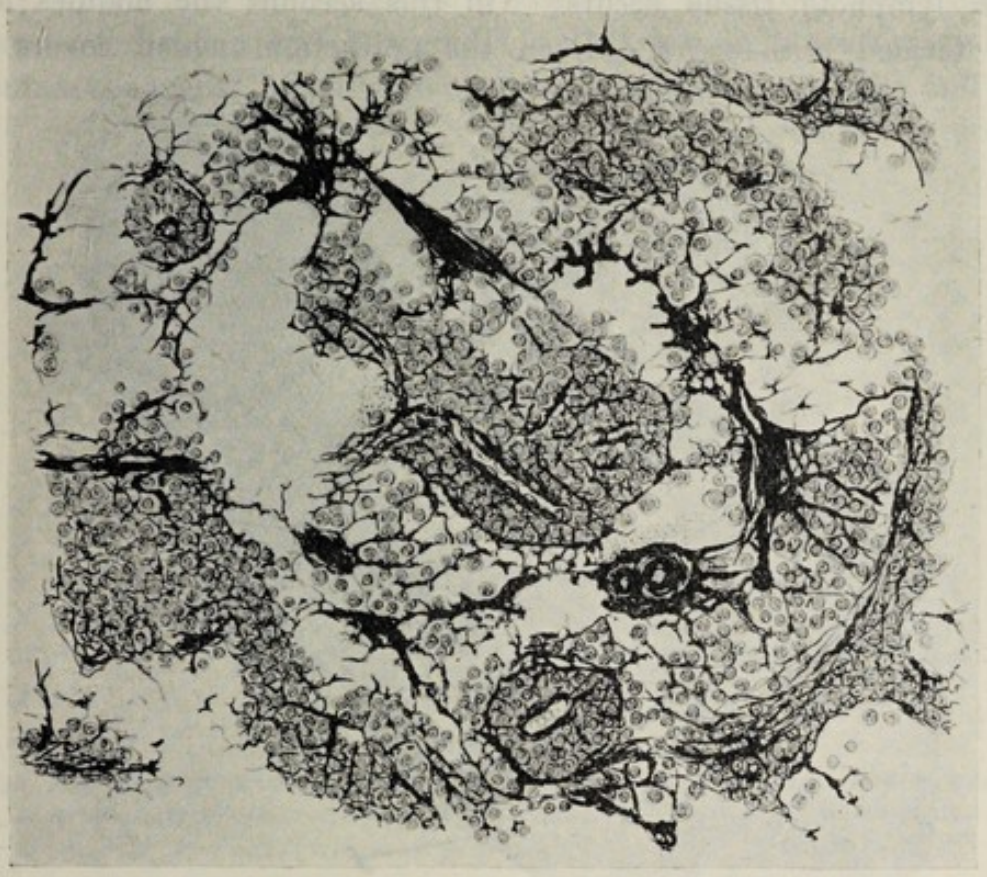


FIG. 208.—A SMALL PORTION OF THE MEDULLA OF A LYMPHATIC GLAND OF THE DOG SHOWING THE CONNECTION OF THE RETICULUM WITH THE FIBROUS TRABECULÆ.

glands, and it has been conjectured that they are connected with the production of blood-corpuscles, but we possess as yet no exact information as to the manner in which the blood passes into the sinuses, nor what relation the lymphatic vessels bear to them. Like the spleen the hæmal glands show cells (phagocytes ?) which contain red blood corpuscles in various stages of transformation into pigment.

THE TONSILS.

The **tonsils** are two masses of lymphoid tissue placed one on each side of the pharynx, into which they project. They are covered on the free surface with the stratified epithelium of the mucous membrane, and this surface is pitted with apertures which lead into recesses or crypts in the substance of the organ (fig. 209). These recesses are all lined by a prolongation of the stratified epithelium, and into them

the ducts of numerous small mucous glands open. The tonsils are composed almost entirely of lymphoid tissue, which, besides being diffused over the whole organ, is at intervals aggregated into small nodules, in which the lymph-cells are more closely arranged than elsewhere. In these nodules active multiplication of the lymph-cells by mitosis is constantly proceeding. This is, in fact, the cause of the formation of nodules in the tissue, as in most other organs in which lymphoid tissue occurs. On this account the nodules have been termed *germ-centres*. Even the epithelium which covers the

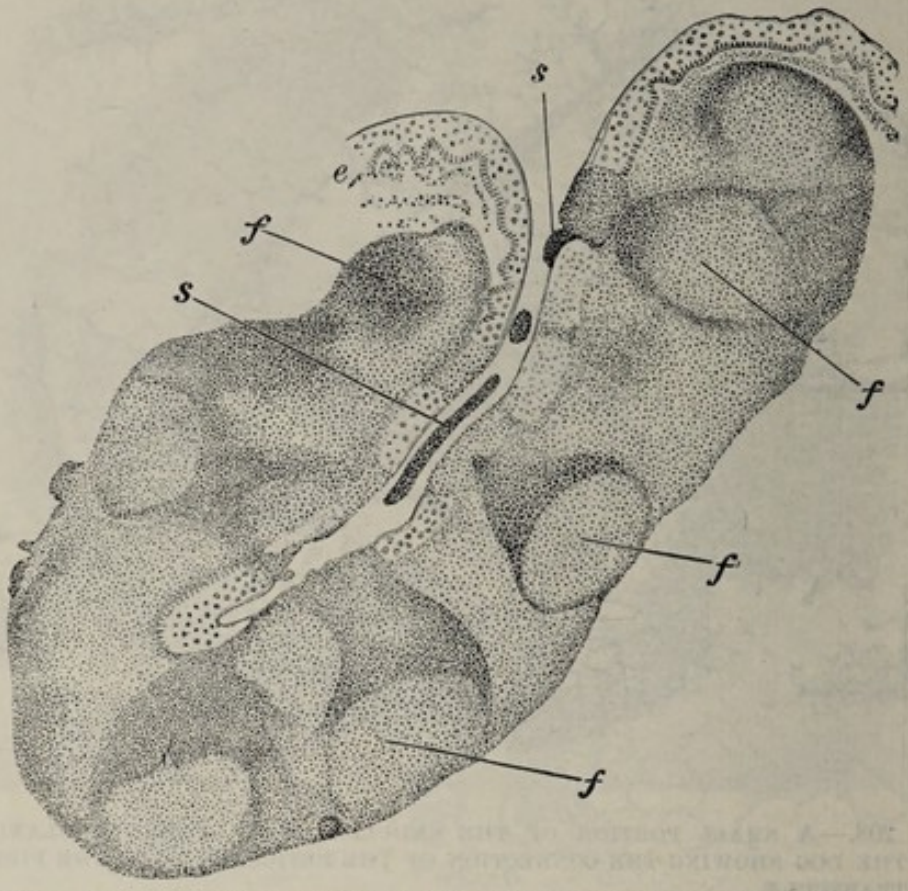


FIG. 209.—SECTION THROUGH ONE OF THE CRYPTS OF THE TONSIL. (Stöhr.)

e, *e*, stratified epithelium of surface of mucous membrane, continued into crypt; *f*, *f*, follicles or nodules of the lymphoid tissue, which is elsewhere diffuse; opposite each nodule numbers of lymph-cells are passing through the epithelium; *s*, masses of cells which have thus escaped from the organ to mix with the saliva as salivary corpuscles.

tonsils is infiltrated with lymph-corpuscles (Stöhr), and these may also wander out on to the free surface, and become mingled with the saliva as salivary corpuscles (see Lesson VI., § 1).

The mucous membrane of the neighbouring part of the pharynx and of the back of the tongue is similar in structure to the tonsils.

THYMUS.

The **thymus gland** is a lymphoid organ which is found only in the embryo and during infancy. It is composed of a number of lobules

(fig. 210) varying in size, which are separated from one another by septa of connective tissue, along which the blood-vessels and lymphatics pass to and from the lobules. Each lobule shows plainly, when examined with a low power, a distinction into an outer cortical and an inner medullary portion. The cortical part of the lobule is imperfectly divided into nodules by trabeculæ of connective tissue, and is very similar in structure to the lymphoid tissue of the lymphatic glands and tonsils, with which it also agrees in exhibiting numerous indications of indirect cell-division; but the medulla is more open in its texture, and the reticulum is covered by larger, more transparent, flattened cells, and con-

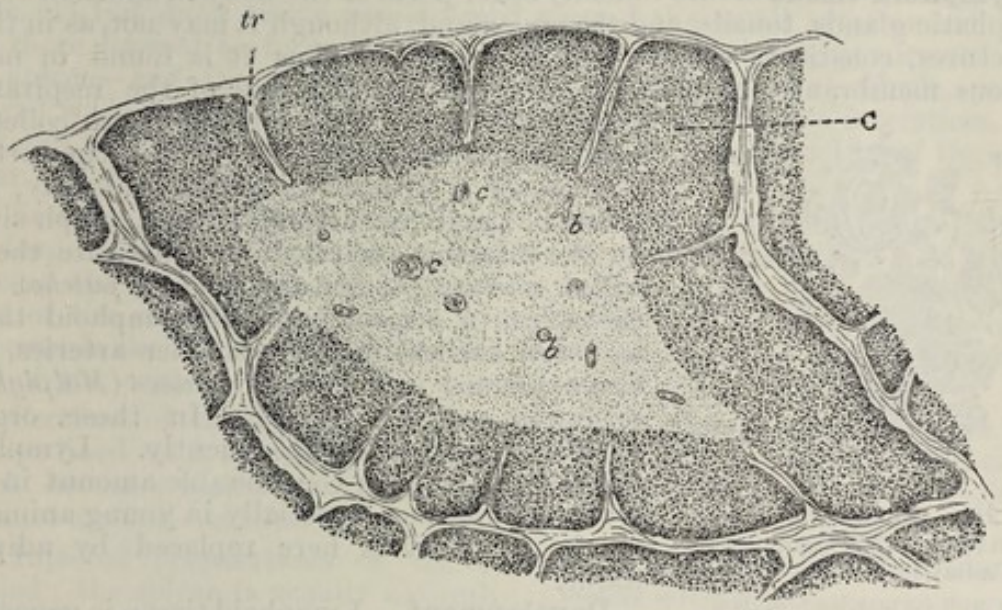


FIG. 210.—A LOBULE OF THE THYMUS OF A CHILD, AS SEEN UNDER A LOW POWER. c, cortex; *c*, concentric corpuscles within medulla; *b*, blood-vessels; *tr*, trabeculæ.

tains fewer lymph-corpuscles. Moreover, there are found in the medulla peculiar concentrically striated bodies (the *concentric corpuscles* of Hassal, figs. 210, 211), which are "nests" of flattened epithelial cells arranged concentrically around one or more central cells. Sometimes these corpuscles are compound, two or three being grouped together and similarly inclosed by flattened cells. They appear to represent the remains of an epithelial tube, which forms the thymus rudiment of the early embryo and is derived from certain of the branchial clefts. Around this tube the lymphoid tissue of the organ becomes formed; indeed, according to the observations of J. Beard in elasmobranchs (which have been confirmed by Nussbaum and Prymak in teleosts) the thymus is the original seat of appearance of leucocytes in the embryo; none being apparent until this organ begins to develop. The leucocytes are said, by Beard, to be produced by proliferation from some of the hypoblast cells of the thymus rudiment, and they are believed to pass from this organ to

other parts, where they are eventually found collected into masses of lymphoid tissue.

Nucleated red blood corpuscles (erythroblasts), similar to those found in red marrow, have also been described in the thymus, which is therefore probably a blood-forming organ.

The lymphoid tissue is abundantly supplied with capillary blood-vessels, and large lymphatic vessels issue from the thymus, but in what way they are connected with the lobules has not been ascertained.

Other Lymphoid Structures.

Lymphoid tissue occurs in many other parts of the body in addition to the lymphatic glands, tonsils, and thymus gland, although it may not, as in these structures, constitute the bulk of the organ. Thus it is found in many mucous membranes, such as those of the intestine and of the respiratory tract, both in a diffuse form and also collected into nodular masses which are like the cortical nodules of a lymphatic gland, and may, like those, be partially surrounded by a lymph-sinus. In the intestine such nodules constitute the so-called *solitary glands* and *Peyer's patches*. In the spleen a large amount of lymphoid tissue is found ensheathing the smaller arteries, and also expanded into nodular masses (*Malpighian corpuscles of the spleen*). In these organs it will be studied subsequently. Lymphoid tissue also occurs in considerable amount in the serous membranes, especially in young animals; in the adult it is here replaced by adipose tissue.

Fig. 211.—Elements of the thymus. (300 diameters.) (Cadiat.)

a, lymph-corpuscles; *b*, concentric corpuscle.

Development.—Lymphoid tissue is generally developed in connection with lymphatic vessels (Klein), an accumulation of retiform tissue and lymph-cells taking place either external to and around the lymphatic (*perilymphatic formation*); or the lymphatic is dilated into a sinus and the formation of lymphoid tissue occurs within it (*endolymphatic formation*).

LESSON XXVI.

STRUCTURE OF THE SPLEEN, SUPRARENAL CAPSULE, AND THYROID BODY.

1. Sections of the spleen hardened in Müller's fluid and stained with hæmatoxylin and eosin. Notice the trabeculæ extending into the substance of the organ from the capsule. Notice also that the glandular substance is of two kinds, (1) lymphoid tissue accumulated around the small arteries and here and there massed to form *lymphoid nodules*—the Malpighian corpuscles of the spleen—and (2) a tissue consisting of a reticulum of fibrils, partly covered with branched cells: this tissue contains blood in its interstices.

Sketch part of a section under a low power and a small portion of the pulp under a high power.

2. Sections across a suprarenal capsule hardened in Müller's fluid. Notice the deep brown staining of the medulla. Examine first with a low power, noticing the general arrangement and extent of the cortical and medullary parts of the organ, and making a general sketch which shall include both. Afterwards sketch carefully under the high power a group of cells from each part of the organ.

3. Sections of the thyroid body stained with hæmatoxylin. Notice the vesicles lined with cubical epithelium and filled with a "colloid" substance which becomes stained with hæmatoxylin. Sketch one or two vesicles. Measure several vesicles.

4. Injected preparations of the suprarenal and thyroid may also be studied: the spleen is usually naturally injected with blood.

The Spleen.

The **spleen** is the largest of the so-called ductless glands. It appears to be functionally connected with the blood, white blood corpuscles being certainly formed and coloured blood-corpuscles being submitted to destruction within it.

Like the lymphatic glands, the spleen is invested with a fibrous and muscular *capsule* (fig. 212), which is however stronger and has far more plain muscular tissue; outside the capsule is a covering derived from the serous membrane. The capsule sends bands of trabeculæ into the organ, and these join with a network of similar trabeculæ which pass into the gland at the hilum along with the blood-vessels. In the interstices of the framework thus constituted lies a soft pulpy substance containing a large amount of blood, and therefore of a deep red colour, dotted within which are here and there to be seen small round bodies, whiter than the pulp in the fresh organ but darker in stained sections, the *Malpighian corpuscles* of the spleen. These

are composed of lymphoid tissue which is gathered up into masses which envelop the smaller arteries, whilst the red pulp which everywhere surrounds them and which forms the bulk of the organ is composed of a close network of retiform tissue fibrils, partly covered by flattened and branched cells. Passing into the pulp and com-

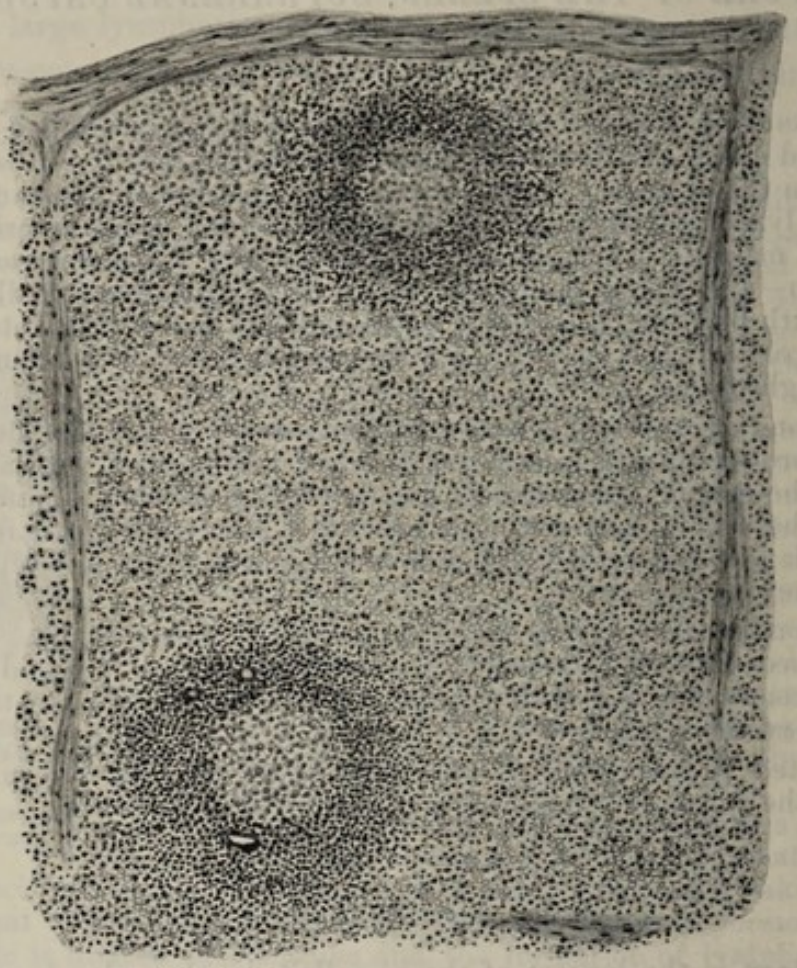


FIG. 212.—VERTICAL SECTION OF A PORTION OF THE MONKEY'S SPLEEN, AS SEEN WITH A LOW POWER.

municating with its interstices are capillary blood-vessels which are connected with the terminations of the arteries; whilst in other parts venous channels, characterised in the human spleen by an encirclement of elastic fibres, course through the pulp, and bring the blood which has passed into its interstices from the arterial capillaries towards the larger veins of the organ, which run in the trabeculæ, and are by them conducted to the hilum. The arteries, which are also at first conducted from the hilum along the trabeculæ into the interior of the organ, presently leave the trabeculæ, and their external coat becomes converted into a thick sheath of lymphoid tissue which invests them in the remainder of their course, and in places becomes swollen into the Malpighian corpuscles already mentioned.

The small arteries distribute a few capillaries to the Malpighian corpuscles, and then break up into pencils of capillary vessels which open into the interstices of the pulp.

The special cellular elements of the spleen-pulp are of three kinds, viz. (1) peculiar, large, amœboid cells, called *splenic cells*, (2) *multi-nucleated giant cells*, and (3) the *branched, flattened cells* which assist in forming

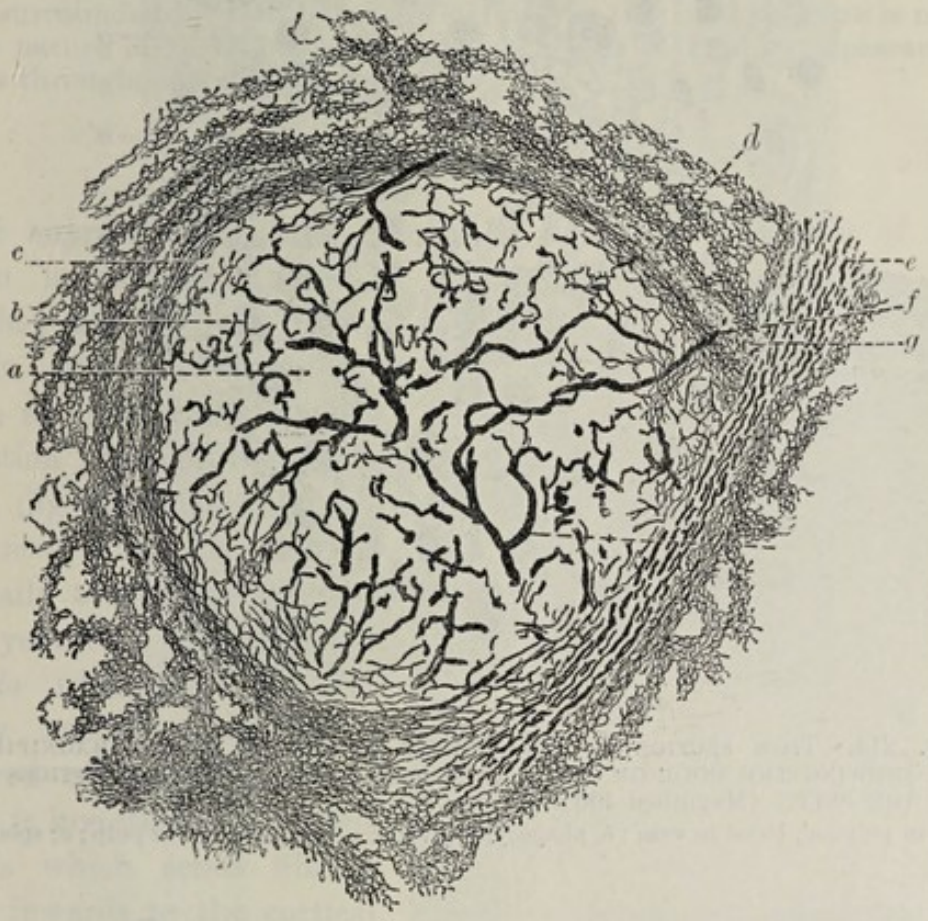


FIG. 213.—RETICULUM OF SPLEEN, GOLGI METHOD. (Oppel.)

a, Malpighian corpuscle; *b*, part of its reticulum; *c*, condensed reticulum at its margin; *d*, more open tissue next to this; *e*, wall of arteriole; *f*, capillaries of Malpighian corpuscle; *g*, reticulum of arteriole expanding into that of the Malpighian corpuscle.

the spongework. The splenic cells are phagocytic and are frequently found to contain coloured blood-corpuscles in their interior in various stages of transformation into pigment. They occur both in the interstices of the pulp and in the venous sinuses and veins, where they are often filled with erythrocytes (fig. 214). The giant cells are most frequent in young animals (fig. 215): their function has not been ascertained. The branched cells of the spongework are probably of the same nature as the epithelium cells of the terminal capillaries and veins of the pulp. They resemble one another in their tendency to branch and they are connected by their branches. The phagocytic spleen cells are perhaps derived from them.

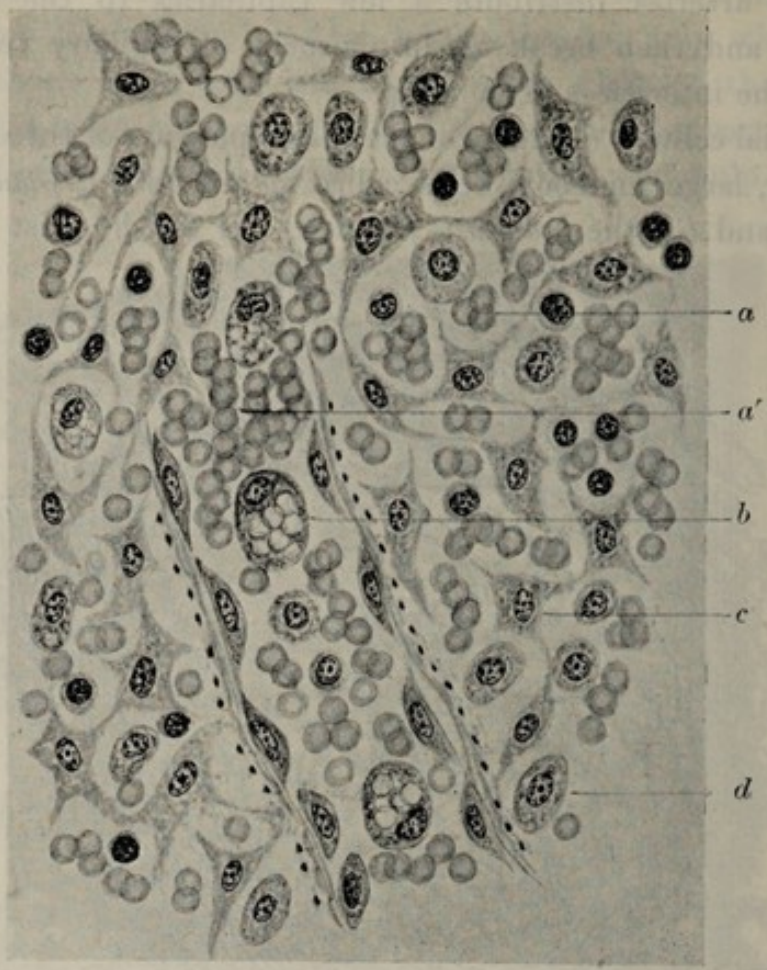


FIG. 214.—THIN SECTION OF SPLEEN-PULP OF CHILD, HIGHLY MAGNIFIED, SHOWING THE MODE OF ORIGIN OF A SMALL VEIN IN THE INTERSTICES OF THE PULP. (Magnified 400 diameters.)

a, blood in pulp; *a'*, blood in vein; *b*, phagocyte in vein; *c*, branched cell of pulp; *d*, splenic cell.

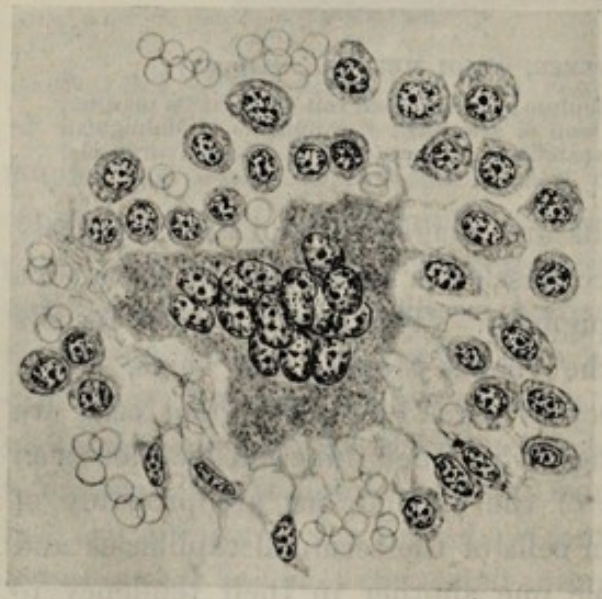


FIG. 215.—A GIANT CELL FROM THE SPLEEN OF A KITTEN. (Magnified 400 diameters.)

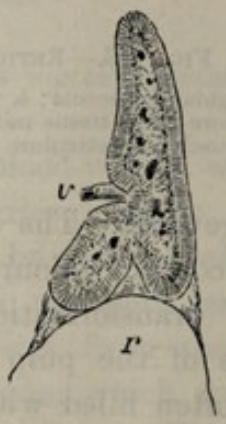


FIG. 216.—A VERTICAL SECTION OF THE SUPRARENAL BODY OF A FŒTUS, TWICE THE NATURAL SIZE, SHOWING THE DISTINCTION BETWEEN THE MEDULLARY AND CORTICAL SUBSTANCE. (A. Thomson.)

v, issuing vein; *r*, summit of kidney.

The *lymphatics* of the spleen run partly in the trabeculæ and capsule, and partly in the lymphoid tissue ensheathing the arteries. They join to form larger vessels which emerge together at the hilum.

Mall states that the distribution of the trabeculæ and of the blood-vessels within the spleen is such as to indicate a differentiation of the pulp into minute divisions, which he terms "spleen lobules," each of which has its own arteriole and venule, and in which the pulp appears arranged in columns or cords surrounded by venous spaces. However this may be there is nothing of the nature of partitions separating such lobules: to all appearance the pulp is throughout in continuity.

The Suprarenal Capsules.

The **suprarenal capsules** (adrenals) belong to the class of bodies known as ductless glands, but they are entirely different in structure from the spleen and lymphatic glands. A section through the fresh organ (fig. 216) shows a *cortical zone* which is striated vertically to the surface, and of a yellowish colour, and a *medulla* which is soft and highly vascular, and of a dark-red colour. The whole organ is invested by a fibrous *capsule* which sends fibrous septa inwards to the cortical substance (fig. 217, *a*), subdividing this for the most part into columnar groups of cells (zona fasciculata, *c*). Immediately underneath the capsule, however, the groups are more rounded, and the cells tend to assume a columnar form (zona glomerulosa, *b*), whilst next to the medulla they have a reticular arrangement (zona reticularis, *d*).

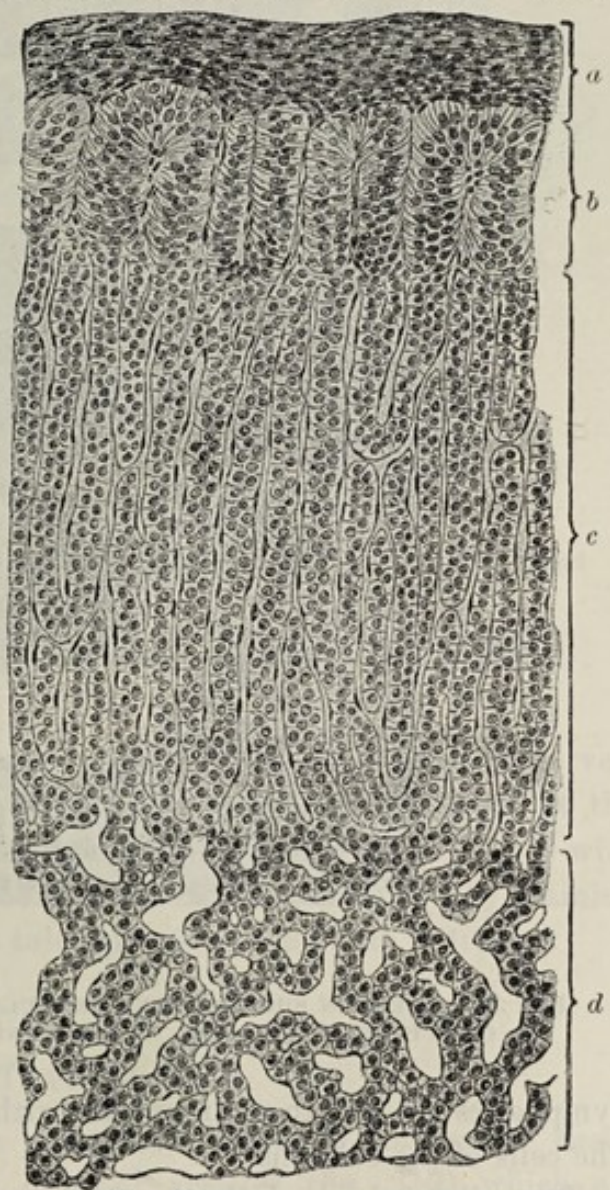


Fig. 217.—Vertical section of cortex of suprarenal of dog. (Böhm and v. Davidoff.) (Magnified about 150 diameters.)

a, capsule; *b*, zona glomerulosa; *c*, zona fasciculata; *d*, zona reticularis.

The cells which form the cortical substance are, for the most part, polyhedral in

form; each contains a clear round nucleus, and there are often yellowish oil-globules in their protoplasm. No blood-vessels penetrate between these cells, both the blood-vessels and lymphatics of the cortex running in the fibrous septa between the columns; the

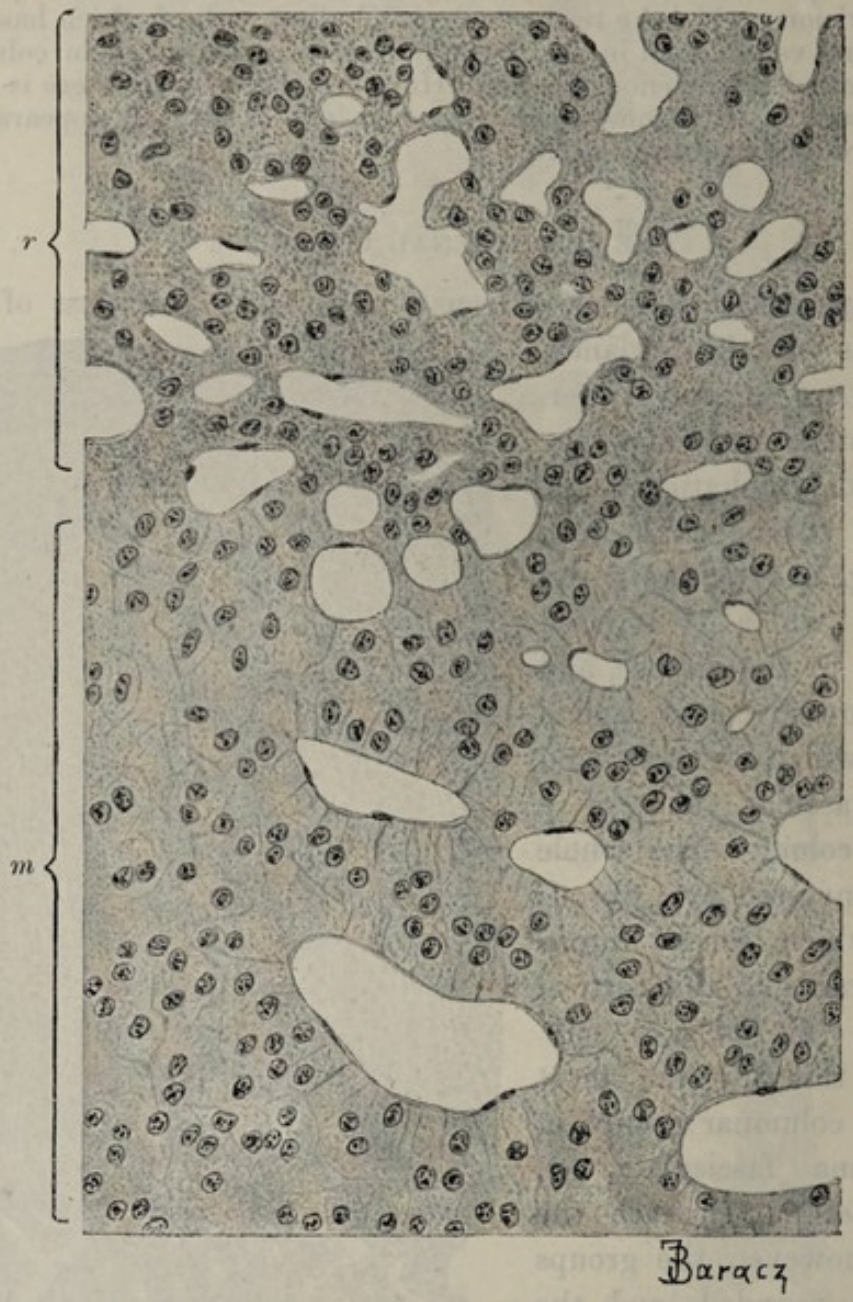


FIG. 218.—SECTION SHOWING ZONA RETICULARIS OF CORTEX, *r*, AND MEDULLA, *m*, OF SUPRARENAL OF DOG. (Szymonowicz.) (Magnified 384 diameters.)

lymphatics are said to communicate with fine spaces which run between the cells of the columns.

The cells of the medulla (fig. 218) are more irregularly disposed, and are often branched. Their protoplasm is granular, and in some animals it contains a brownish pigment, but in man the dark red colour of the medulla is due to the blood contained in the large venous spaces by

which it is pervaded, and which receive the blood after it has traversed the capillaries of the cortex. In addition there are a few arterioles which pass straight to the medulla through the cortex. One large vein usually passes out at a hilum in the anterior surface of the gland. Investing the larger veins are longitudinal bundles of plain muscular

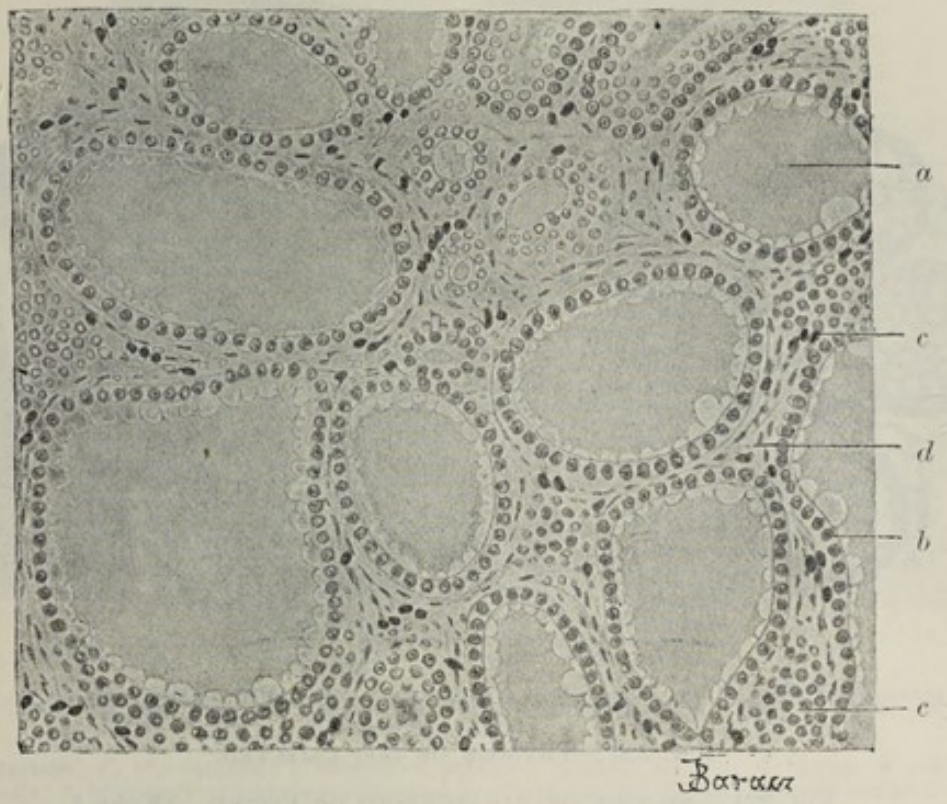


FIG. 219.—SECTION OF HUMAN THYROID. (Szymonowicz.) (Magnified about 180 diameters.)

a, vesicle occupied by colloid, which has partly shrunk away from the epithelium; *b*, epithelium of a large vesicle; *c*, *c*, epithelium of vesicles which are cut tangentially; *d*, interstitial connective tissue.

fibres; but most of the veins have only an intima. Numerous nerves, after traversing the cortical substance, are distributed throughout the medulla, where they form a close plexus provided here and there with ganglion-cells. The cells of the medulla are characterised by staining brown by chromic acid and its salts, provided the organ is fresh.

THE THYROID BODY.

The **thyroid body** consists of a framework of connective tissue inclosing numerous spherical or oval vesicles (fig. 219) which are lined with cubical epithelium. The cavities of the vesicles are filled with a peculiar viscid liquid (colloid) which is coagulated by alcohol and which then becomes stained with hæmatoxylin. A

similar material has been found in the lymphatics of the gland, and may often be detected also in the interstices of the connective tissue.

The blood-vessels of the thyroid are exceedingly numerous, and the capillaries form close plexuses round the vesicles (fig. 220).

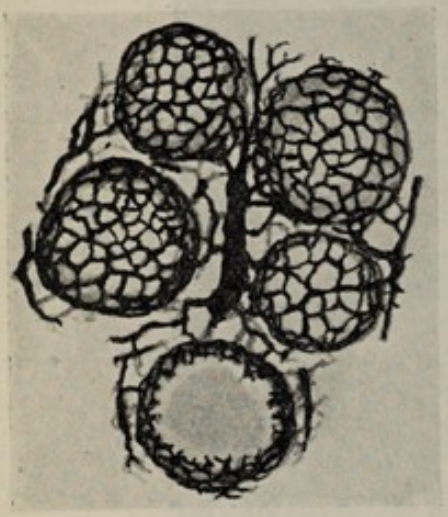


Fig. 220.

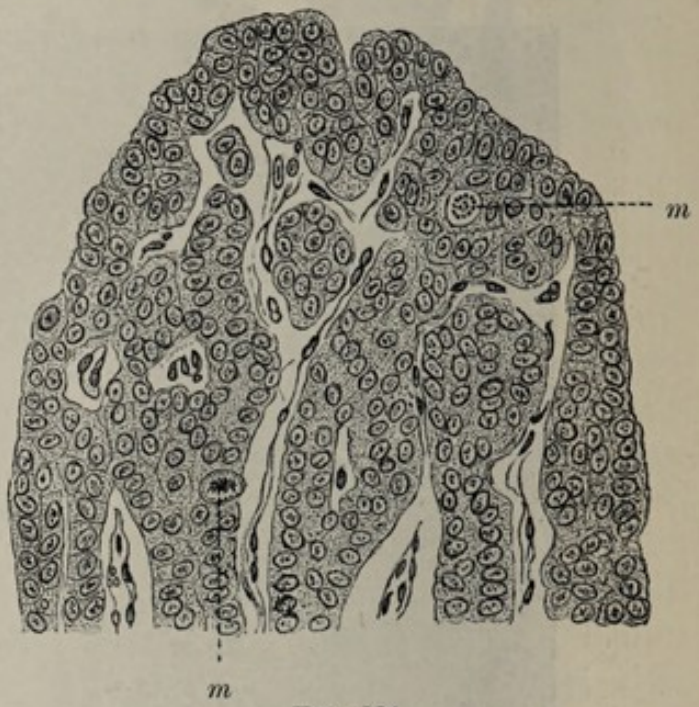


Fig. 221.

Fig. 220.—Thyroid of dog injected.

Fig. 221.—Section of parathyroid of kitten. (Kohn.)

The figure shows columns of epithelium cells, with intervening vascular septa; *m*, *m*, cells undergoing mitotic division.

Parathyroids.—In close proximity to the thyroid are always to be found four small glandular organs of different structure from the thyroid proper, although somewhat resembling it in its embryonic condition. These bodies, one of which usually lies on the lateral and one on the mesial surface of each lateral lobe, are formed of columns of granular epithelium-cells, with a very vascular connective tissue between the columns. If left after removal of the thyroid, they are stated to undergo hypertrophy and to supply its function. Besides these bodies, there is also frequently to be found in connection with the thyroid a small mass of lymphoid tissue which resembles the thymus tissue in structure, and, like it, contains concentric corpuscles.

Carotid and coccygeal glands.—These are minute glandular organs without ducts, lying respectively at the bifurcation of the carotid artery and in front of the apex of the coccyx. They are composed of polyhedral cells, with numerous blood-capillaries between them.

In the carotid gland the cells are collected into spheroidal clumps, in the coccygeal gland into irregular nodules. Some of the cells of

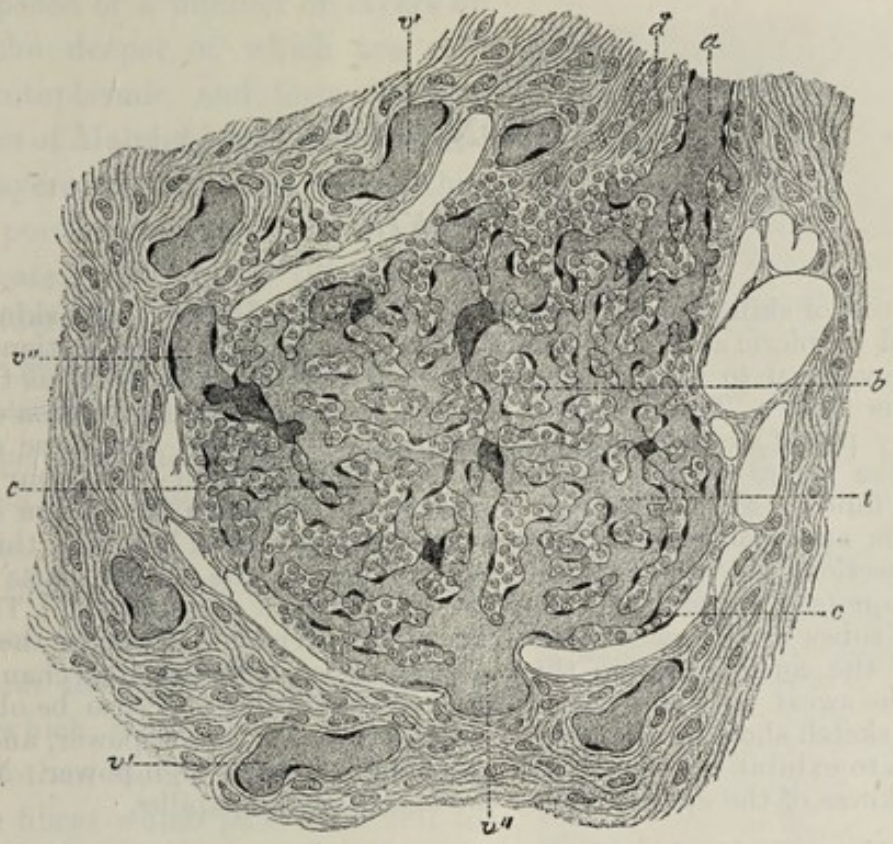


FIG. 222.—A CLUMP OR CELL-BALL FROM THE CAROTID GLAND, INJECTED. (Schaper.)

a, arteriole; *v'*, *v''*, venules; *t*, sinus-like capillary within nodule; *b*, group of gland cells; *c*, boundary of nodule surrounded by lymph space; *d*, inter-nodular connective tissue of gland.

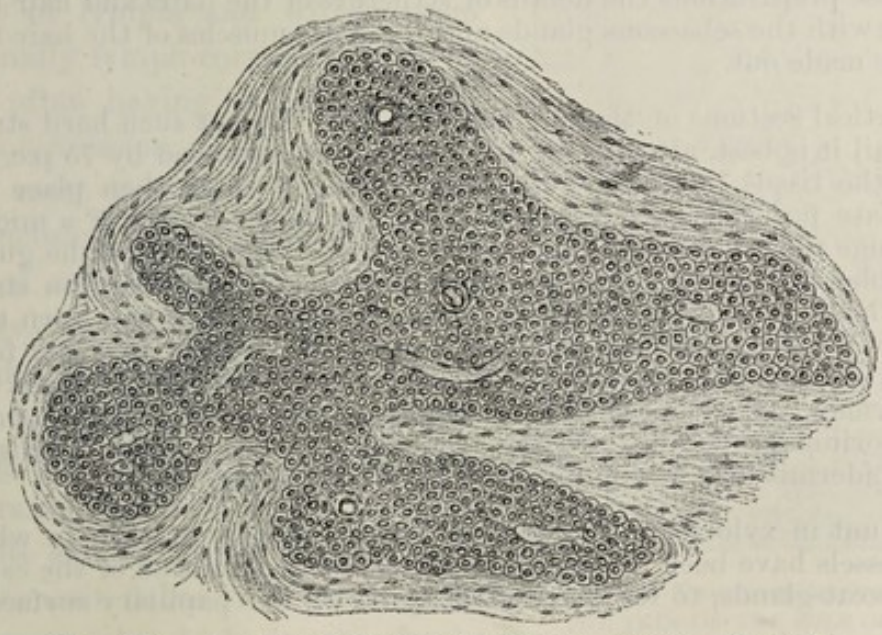


FIG. 223.—A NODULE OF THE COCCYGEAL GLAND. (Sertoli.)

the carotid gland stain brown with chromic acid like those of the medulla of the suprarenal body.

LESSON XXVII.

THE SKIN.

1. Sections of skin from the palmar surface of the fingers. The skin is best hardened in picric acid or formol, followed by alcohol. The sections are to be made vertical to the surface, and should extend down as far as the subcutaneous tissue. They may be stained with carmalum or hæmalum, followed by picric alcohol, and mounted in xylol balsam. In these sections notice the layers of the epidermis and their different behaviour to the staining fluids. Notice also the papillæ projecting from the corium into the epidermis and look for tactile corpuscles within them. In very thin parts of the sections the fine intercellular channels in the deeper parts of the epithelium (see Lesson VI.) may be seen with a high power. The convoluted tubes of the sweat-glands are visible here and there in the deeper parts of the corium, and in thick sections the corkscrew-like channels by which the sweat is conducted through the epidermis may also be observed. Make a sketch showing the general structure under a low power, and other sketches to exhibit the most important details under a high power. Measure the thickness of the epidermis and the length of the papillæ.

2. Sections of the skin of the scalp, vertical to the surface and parallel to the slope of the hair-follicles, and others parallel to the surface, and therefore across the hair-follicles. Stain and mount in the same way as in the last preparation. Examine also the structure of the hairs.

In these preparations the details of structure of the hairs and hair-follicles, together with the sebaceous glands and the little muscles of the hair-follicles, are to be made out.

3. Vertical sections of the nail and nail-bed. To cut such hard structures as the nail it is best, after fixing with picric acid, followed by 75 p.c. alcohol, to soak the tissue in strong gum arabic for a few days, then place it in an appropriate position upon a cork or upon the object-carrier of a microtome, and plunge the whole into 70 per cent. alcohol. This renders the gum hard, and enables sections to be cut of sufficient fineness. A plane iron should be used with the microtome, since the hardness of the nail will turn the edge of a razor. To remove the gum the sections are placed in water for a few hours ; they may then be stained with hæmalum or carmalum, passed through picric alcohol, and mounted in xylol balsam. Notice the ridges (not papillæ) of the corium projecting into the epidermis. Observe also the distinction of the epidermis into Malpighian layer and nail proper.

4. Mount in xylol balsam a section from a portion of skin in which the blood-vessels have been injected, and notice the distribution of the capillaries to the sweat-glands, to the hair-follicles, and to the papillary surface of the corium.

5. The cells which compose the nails and hairs can be isolated by warming a small piece of nail or hair in strong sulphuric acid ; after this treatment they are readily separated from one another by pressure upon the cover-glass.

The **skin** is composed of two parts, *epidermis* and *cutis vera* (fig. 224).

The **epidermis**, or scarf skin, is a stratified epithelium (fig. 225). It is composed of a number of layers of cells, the deeper of which are soft and protoplasmic, and form the *rete mucosum* of Malpighi, whilst the superficial layers are hard and horny, this horny portion sometimes constituting the greater part of the thickness of the epidermis. The deepest cells of the *rete mucosum*, which are set on the surface of the cutis vera, are columnar in shape. In the coloured races of mankind these cells contain pigment-granules. In the layers immediately above them the cells are polyhedral. Between all these cells of the rete mucosum there are fine intercellular clefts which separate the cells from one another, but are bridged across by fine fibres which pass from cell to cell, and also through the substance of the cells (Ranvier, Delépine). The intercellular channels serve for the passage of lymph, and within them occasionally lymph-corpuscles may be found, often having a stellate figure from compression.

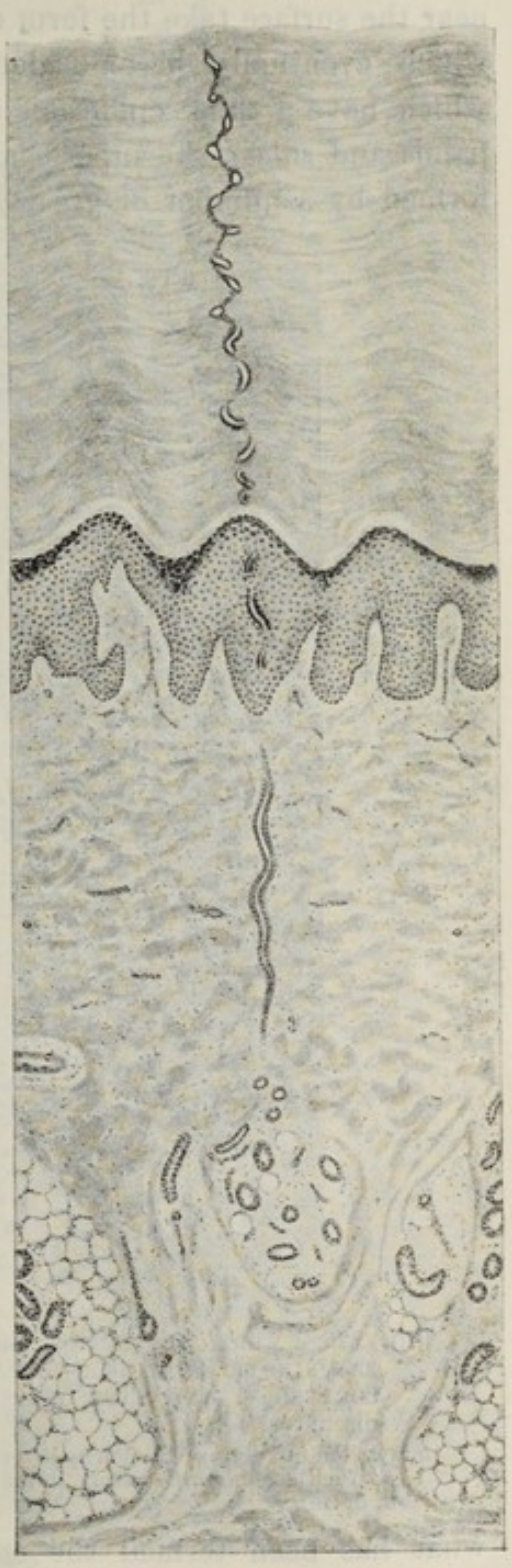


FIG. 224.—VERTICAL SECTION THROUGH THE SKIN OF THE SOLE OF THE FOOT. (About 26 diameters.)

The most superficial layer of the rete mucosum is formed of somewhat flattened cells filled with granules or droplets of a material (eleidin) which stains deeply with carmine and hæmatoxylin (*stratum granulosum*, fig. 225, *s.gr*; fig. 226, *c*). Superficial to the stratum granulosum is a layer in which the cells are indistinct and some of which contain flakes or larger droplets of a material which is chemically similar to the granules in the last layer. This layer has a clear appearance in section, and is known as the *stratum lucidum* (*s.l.*). Immediately superficial to this layer is the

horny part of the epidermis. It is composed of a number of strata of distinct cells, the nuclei of which are no longer visible. These cells near the surface take the form of thin horny scales (*stratum squamosum*), which eventually become detached (fig. 227, *s*). In certain parts which have a thick epidermis and are not covered with hair (*e.g.* the palms and soles), the superficial part of the epidermis is a layer mainly formed by a number of greatly swollen cells (*sw*), forming collectively

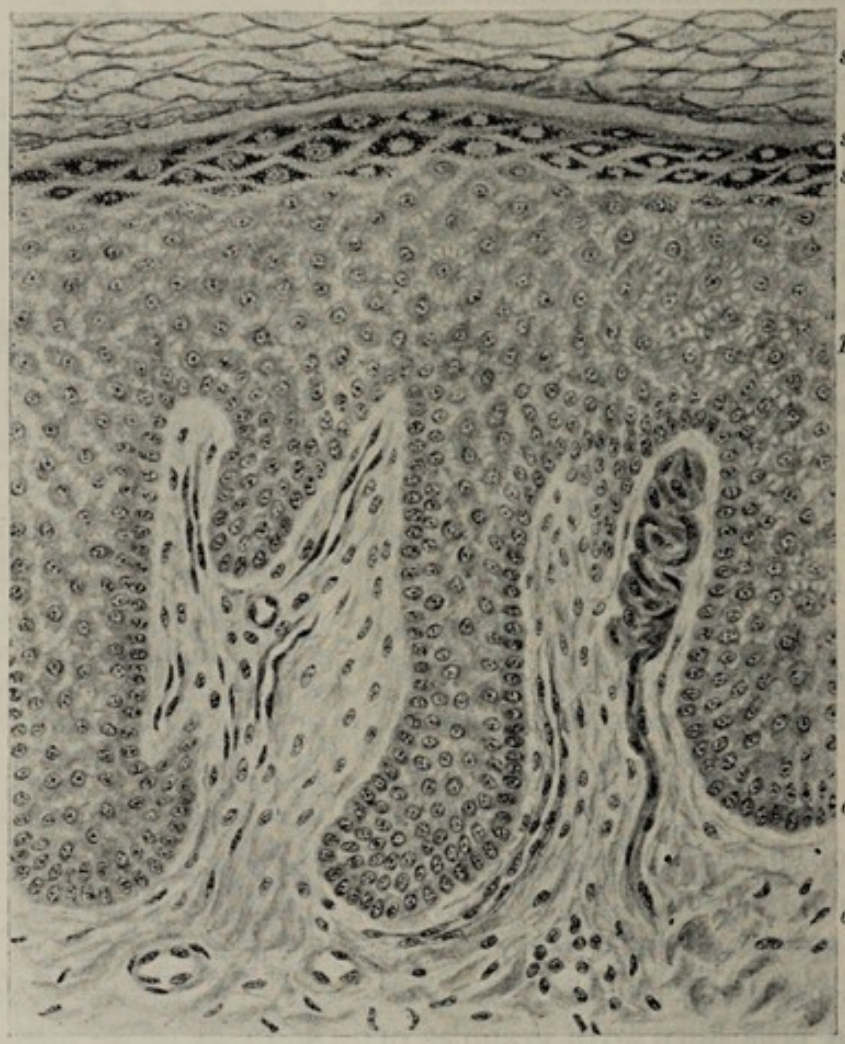


FIG. 225.—VERTICAL SECTION THROUGH THE SKIN OF THE PALMAR SIDE OF THE FINGER SHOWING TWO PAPILLÆ (ONE OF WHICH CONTAINS A TACTILE CORPUSCLE) AND THE DEEPER LAYER OF THE EPIDERMIS. (About 200 diameters.)

sw, swollen out cells of the horny layer; *s.l*, stratum lucidum; *s.gr*, stratum granulosum; *p*, prickle-cells, with intercellular channels and bridging fibres; *c*, columnar cells; *d*, dermis.

what has been termed the *epitrichial layer*. In the embryo in the second and third month of intrauterine life it covers the whole body, but is thrown off where hairs are developed.

The growth of the epidermis takes place by a multiplication of the cells of the deeper layers. The newly formed cells, as they grow, push towards the surface those which were previously formed, and in their

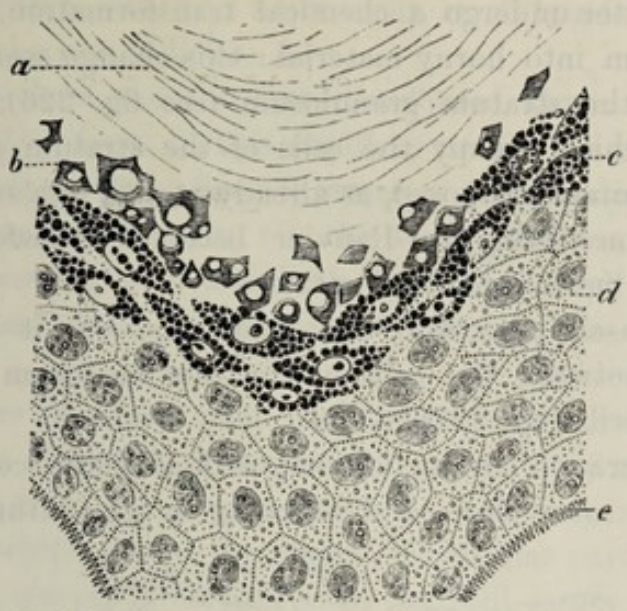


FIG. 226.—PORTION OF EPIDERMIS FROM A SECTION OF THE SKIN OF THE FINGER, COLOURED WITH PICROCARMINE. (Ranvier.)

a, stratum corneum; *b*, stratum lucidum with diffused flakes of eleidin; *c*, stratum granulosum, the cells filled with drops of eleidin; *d*, prickle-cells; *e*, dentate projections by which the deepest cells of the epidermis are fixed to the cutis vera.

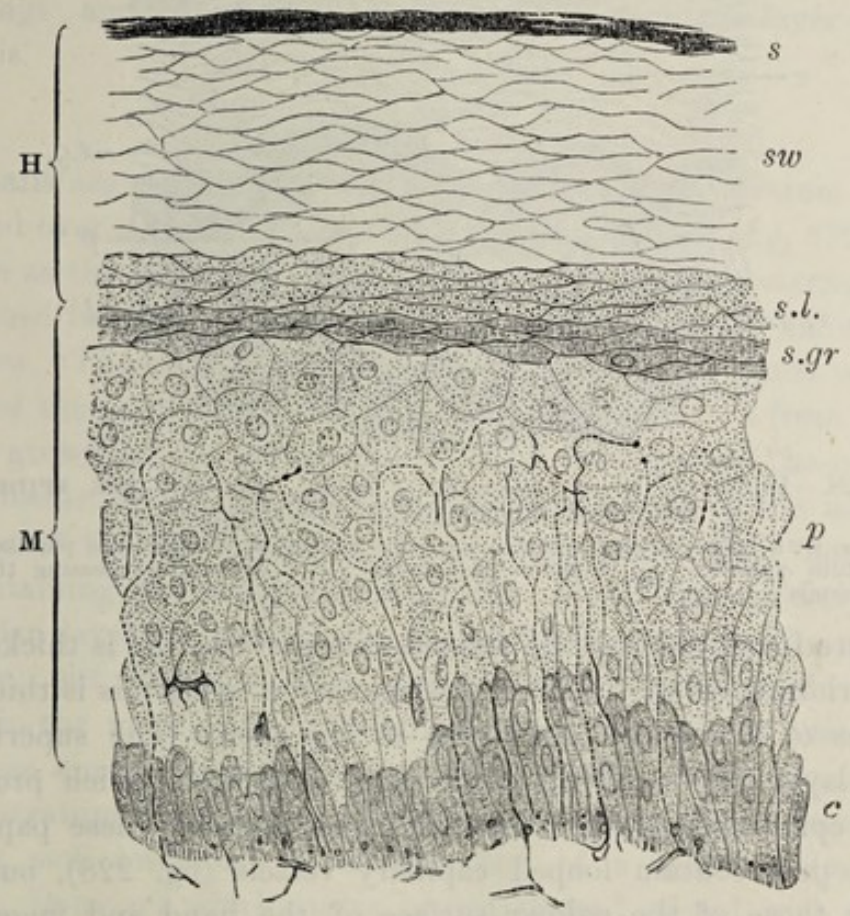


FIG. 227.—SECTION OF EPIDERMIS. (Ranvier.)

H, horny layer, consisting of *s*, superficial horny scales; *sw*, swollen horny cells; *s.l.*, stratum lucidum; M, rete mucosum or Malpighian layer, consisting of *p*, prickle-cells, several rows deep; *c*, elongated cells forming a single stratum near the corium; and *s.gr*, stratum granulosum of Langerhans, just below the stratum lucidum. Part of a plexus of nerve-fibres is seen in the superficial layer of the cutis vera. From this plexus fine varicose nerve-fibrils may be traced passing up between the epithelium-cells of the Malpighian layer.

progress the latter undergo a chemical transformation, which converts their protoplasm into horny material: this change seems to occur just at and above the stratum granulosum (see fig. 226). The granules and droplets which occupy the cells of the stratum granulosum and stratum lucidum are composed, as already stated, of a substance termed *eleidin*, which according to Ranvier becomes transformed into the keratin of the more superficial strata.

No blood-vessels pass into the epidermis, but it receives nerves which ramify between the cells of the rete mucosum in the form of fine varicose fibrils (fig. 227).

The **cutis vera** or corium is composed of dense connective tissue, which becomes more open and reticular in its texture in its deeper

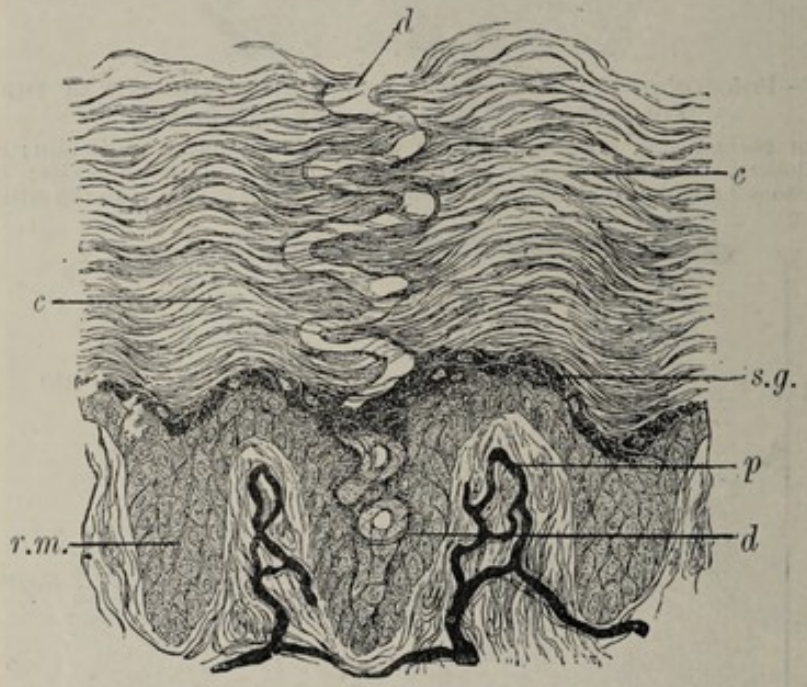


FIG. 228.—DUCT OF A SWEAT-GLAND PASSING THROUGH THE EPIDERMIS. (Magnified 200 diameters.) (Heitzmann.)

p, papillæ with blood-vessels injected; *r.m.*, rete mucosum between the papillæ; *c*, *c*, stratum corneum; *s.g.*, stratum granulosum; *d*, *d*, sweat-duct passing through epidermis.

part, where it merges into the subcutaneous tissue. It is thickest over the posterior aspect of the trunk, whereas the epidermis is thickest on the palms of the hands and soles of the feet. The superficial or vascular layer of the corium bears minute *papillæ*, which project up into the epidermis, which is moulded over them. These papillæ for the most part contain looped capillary vessels (fig. 228), but some, especially those of the palmar surface of the hand and fingers, and the corresponding part of the foot, contain tactile corpuscles, to which medullated nerve-fibres pass (fig. 225).

In some parts of the body (scrotum, penis, nipple, and its areola), involuntary muscular tissue occurs in the deeper portions of the cutis

vera, and in addition, wherever hairs occur, small bundles of this tissue are attached to the hair-follicles.

The blood-vessels of the skin are distributed almost entirely to the surface, where they form a close capillary network, sending up loops into the papillæ (fig. 228). Special branches are also distributed to the various appendages of the skin, viz. the sweat-glands and hair-follicles, with their sebaceous glands and little muscles, as well as to the little masses of adipose tissue which may be found in the deeper parts of the cutis.

The lymphatics originate near the surface in a network of vessels, which is placed a little deeper than the blood-capillary network. They receive branches from the papillæ, and pass into larger vessels, which are valved, and which run in the deeper or reticular part of the corium. From these the lymph is carried away by still larger vessels, which course in the subcutaneous tissue.

The **appendages of the skin** are the *nails*, the *hairs*, with their *sebaceous glands*, and the *sweat-glands*. They are all developed as thickenings and downgrowths of the Malpighian layer of the epidermis.

The Nails.

The **nails** are thickenings of the deeper part of the stratum corneum developed over a specially modified portion of the skin (fig. 229), which is known as the *bed of the nail*, the depression at the posterior part of the nail-bed from which the root of the nail grows being known as the *nail-groove*. The part of the bed which occupies the inner or central portion of the groove is termed the *nail-matrix*, since it is from this part that the growth of the nail proceeds. The distal part of the nail forms the *free border*, and is the thickest part of the body of the nail. The substance of the nail (fig. 230, *N*) is composed of clear horny cells, each containing the remains of a nucleus; it rests immediately upon a Malpighian layer (*B*) similar to that which is found in the epidermis generally, but destitute of a defined stratum granulosum. Nevertheless, in the more superficial cells both of the bed and matrix there are a large number of granules to be seen, which may represent those of the stratum granulosum of the epidermis. These granules are, however, not composed of eleidin, but of a material (*onychogenic substance*, Ranvier) which stains brown instead of red with carmine; a similar material occurs in the cells which form the fibrous substance and cuticula of the hairs. The corium of the nail-bed is beset with longitudinal ridges instead of the papillæ which are present over the rest of the skin; these, like the rest of the superficial part of the

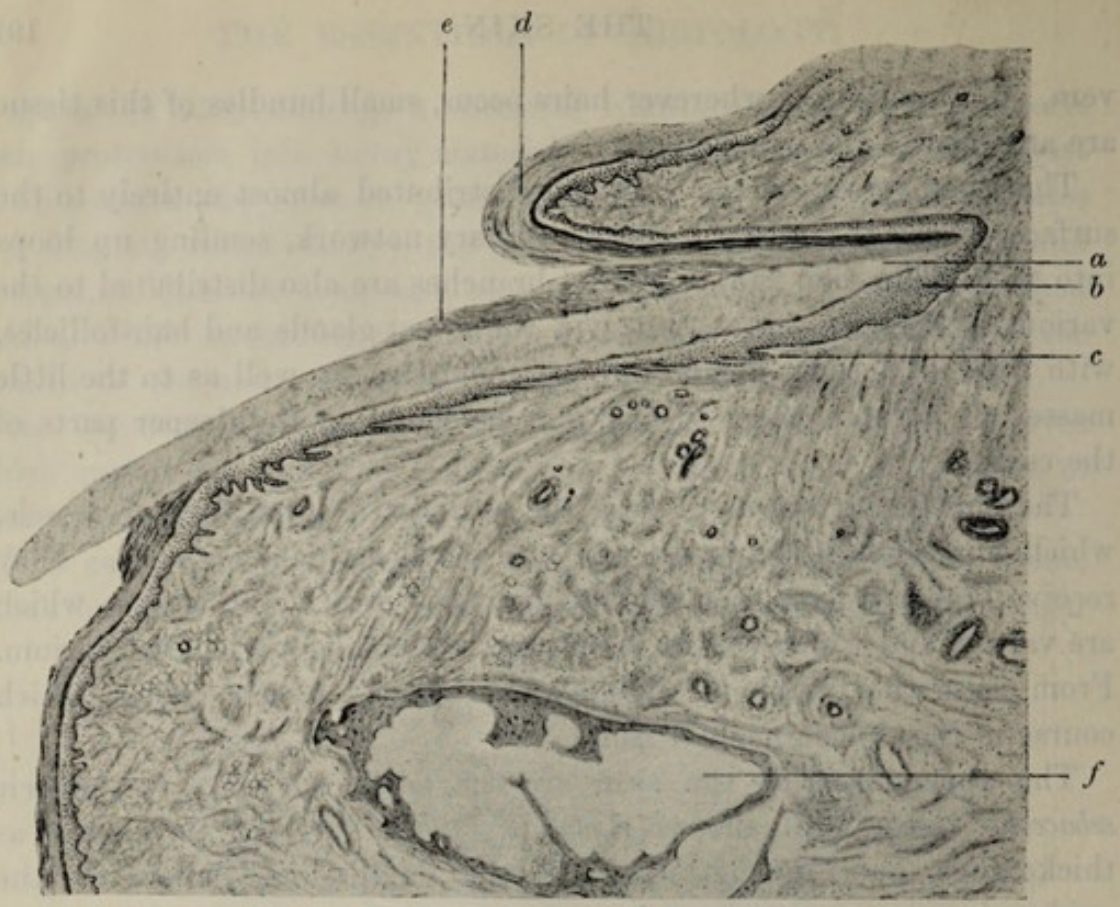


FIG. 229.—LONGITUDINAL SECTION THROUGH THE ROOT OF THE NAIL AND ITS MATRIX. (Magnified about 10 diameters.)

a, root of nail; *b*, Malpighian layer of matrix; *c*, folds in dermis of nail-bed; *d*, epitrichial layer of epidermis; *e*, eponychium; *f*, bone (terminal phalanx) of finger.

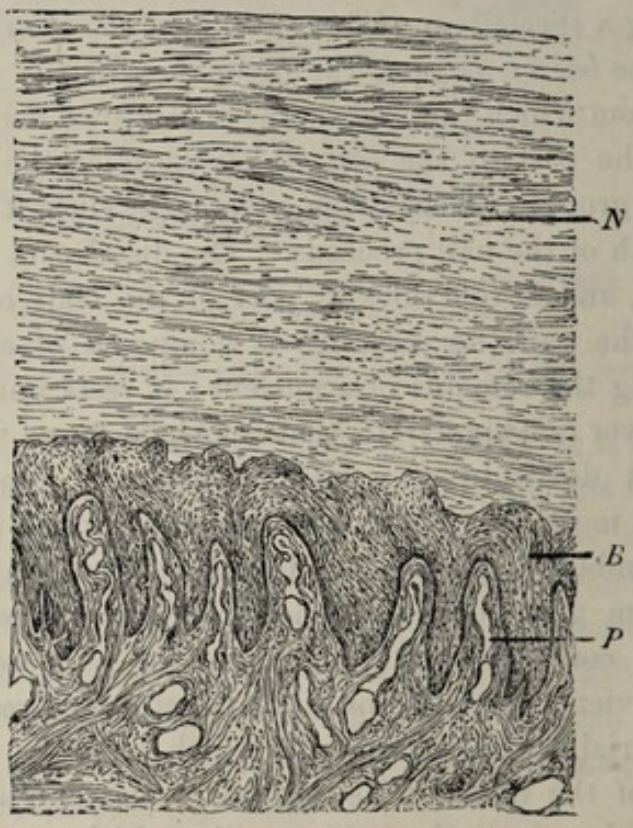


FIG. 230.—SECTION ACROSS THE NAIL AND NAIL-BED. (100 diameters.) (Heitzmann.)

P, ridges with blood-vessels; *B*, rete mucosum; *N*, nail.

corium, are extremely vascular. The nails are developed in the fœtus at about the third month, the groove being formed at this time in the

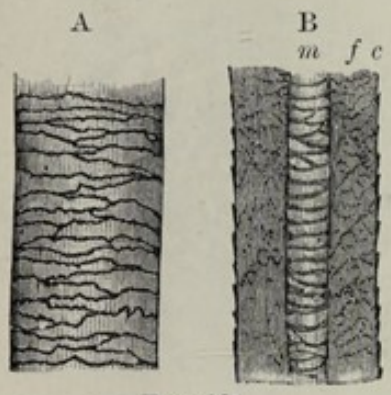


FIG. 231.

FIG. 231.—PIECE OF HUMAN HAIR. (Magnified.)

A, seen from the surface; B, in optical section. *c*, cuticle; *f*, fibrous substance; *m*, medulla, the air having been expelled by Canada balsam.

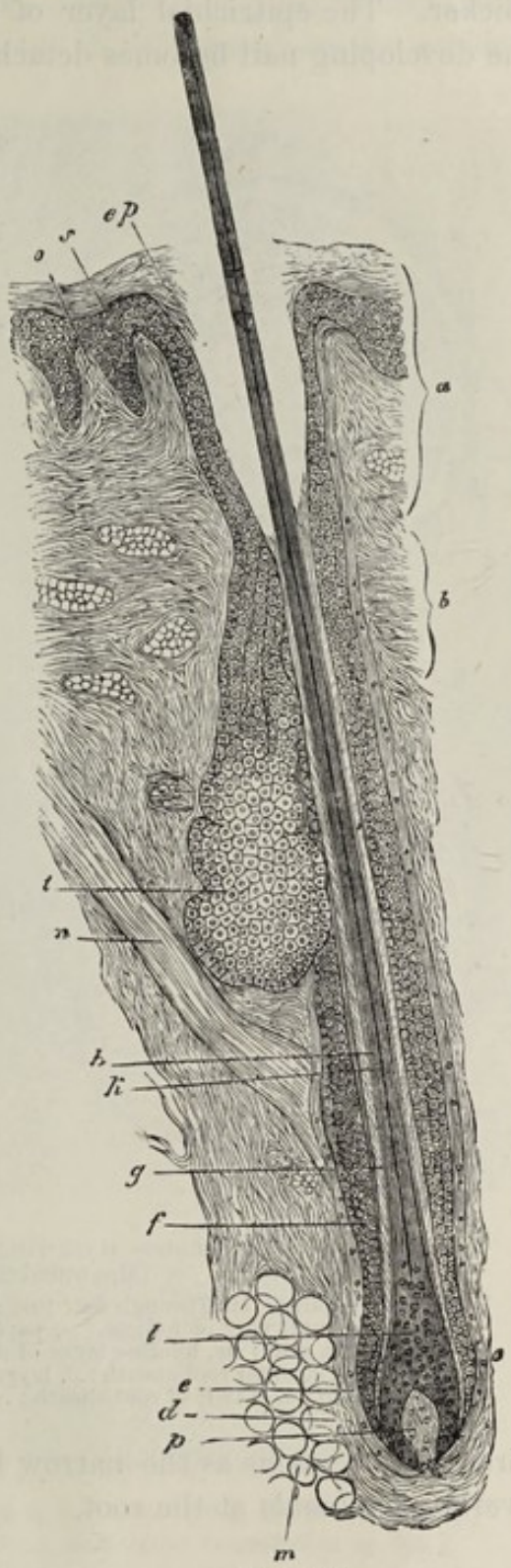


FIG. 232.

FIG. 232.—HAIR-FOLLICLE IN LONGITUDINAL SECTION. (After Biesiadecki.)

a, mouth of follicle; *b*, neck; *c*, bulb; *d*, *e*, dermic coat; *f*, outer root-sheath; *g*, inner root-sheath; *h*, hair; *k*, its medulla; *l*, hair-knob; *m*, adipose tissue; *r*, hair-muscle; *o*, papilla of skin; *p*, papilla of hair; *s*, rete mucosum, continuous with outer root-sheath; *ep*, horny layer; *t*, sebaceous gland.

corium, and the nail rudiment appearing in it as a thickening of the stratum lucidum, which lies over the bed. It becomes free in the sixth month, its free end being at first thin, but as it grows forward over the

bed it appears to receive additions on its under surface—at least in the posterior part of the bed—so that after a time the distal end becomes thicker. The epitrichial layer of the cuticle which originally covered the developing nail becomes detached about the fifth month, and, after

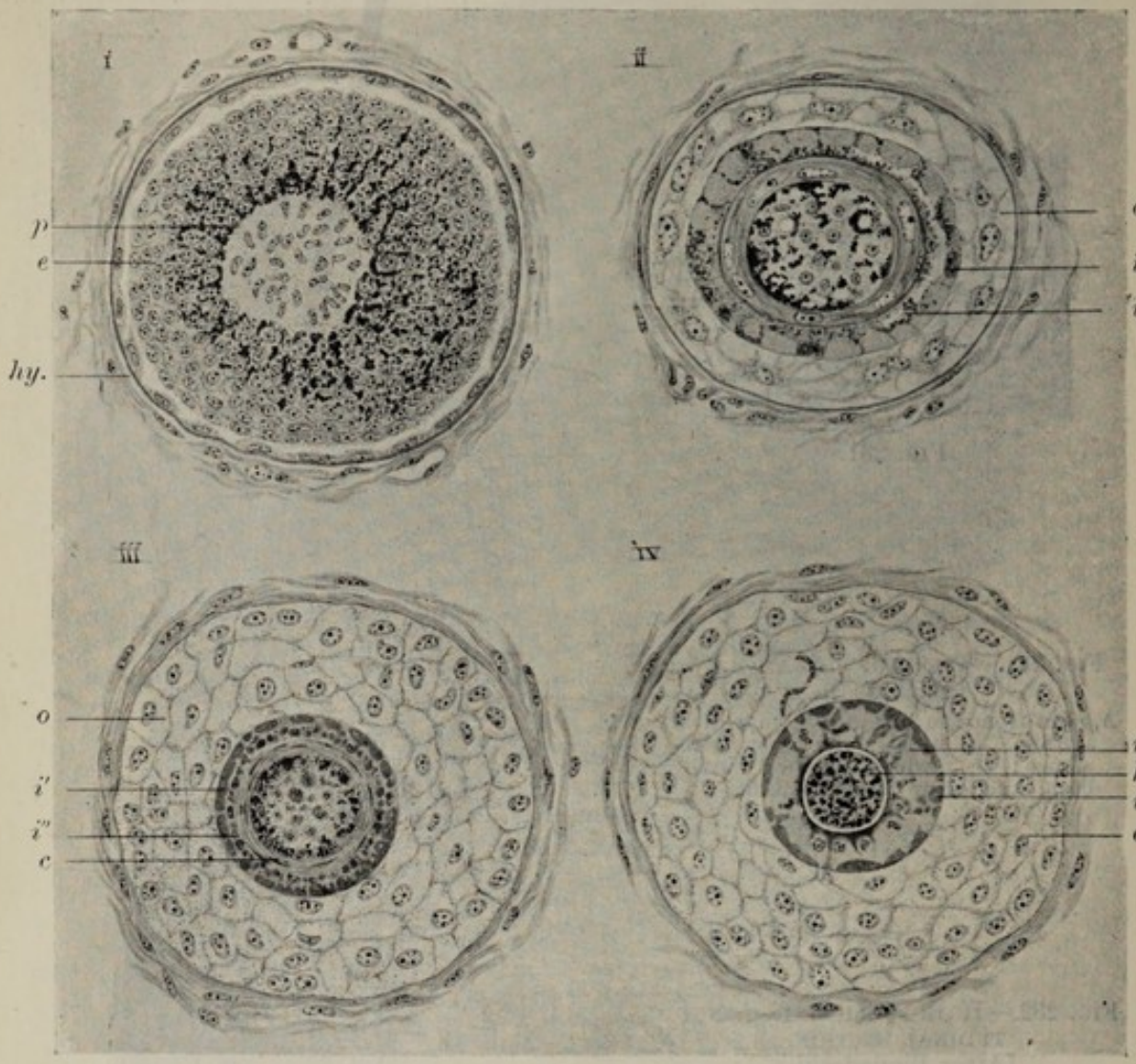


FIG. 233.—SECTIONS ACROSS HAIR-FOLLICLES FROM THE SCALP OF AN INFANT. (Magnified 250 diameters.)

I. Through papilla. II. Through hair just above papilla. III. About middle of follicle. IV. Near outer part of follicle. *p*, papilla; *e*, epithelium surrounding papilla, with pigment in cells; *hy*, hyaline layer of dermic coat with thin outer root-sheath just within it; *o*, outer root-sheath; *i'*, layer of Henle and *i''*, layer of Huxley of the inner root-sheath; *c*, cuticle of root-sheath; *h*, hair.

birth, only remains as the narrow border of cuticle (*eponychium*) which overlies the *lunula* at the root.

HAIRS.

The **hairs** are growths of the epidermis, developed in little pits—the *hair-follicles*—which extend downwards into the deeper part of the corium, or even into the subcutaneous tissue. The hair grows from

the bottom of the follicle, the part which thus lies within the follicle being known as the *root* (fig. 232).

The substance of a hair is mainly composed of a pigmented, horny, *fibrous material* (fig. 231 *f*), which can be separated by the action of

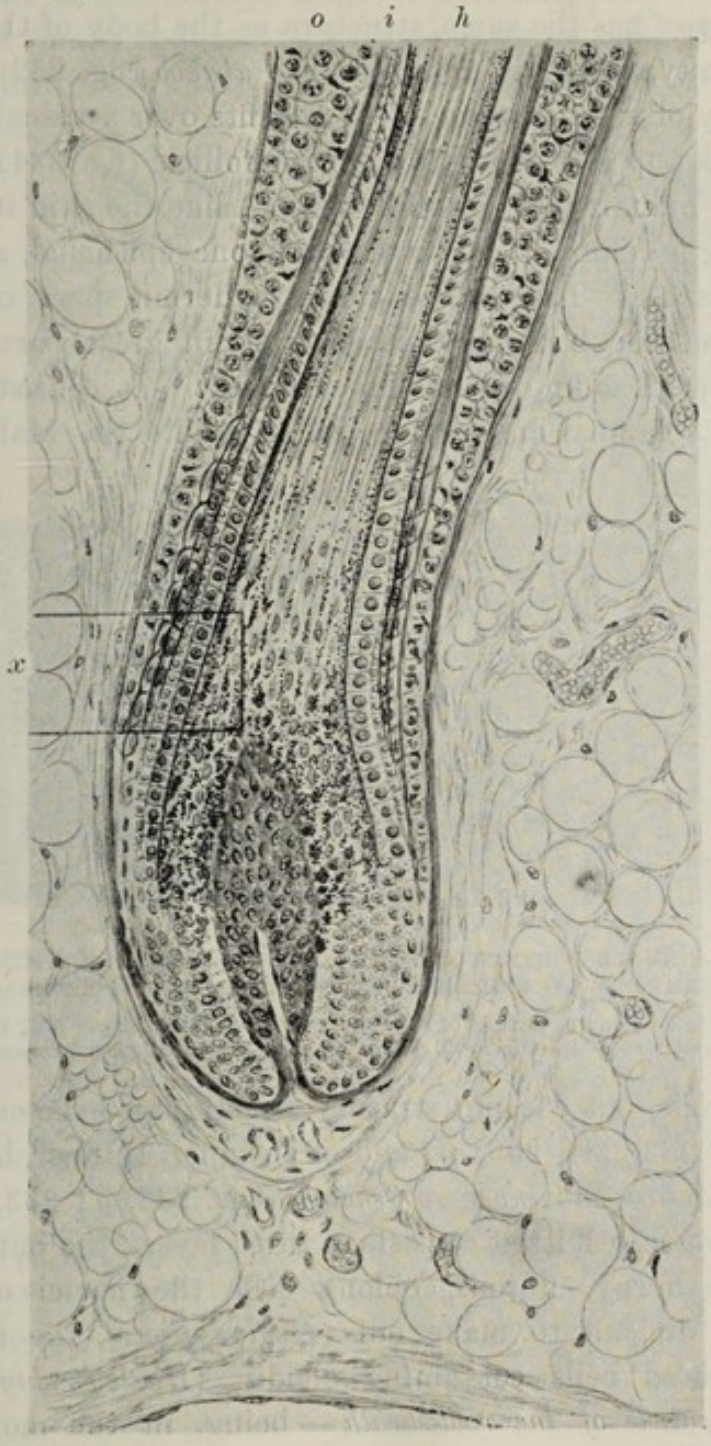


FIG. 234.—LONGITUDINAL SECTION OF A HAIR-FOLLICLE. (200 Diameters.)
o, outer; *i*, inner root-sheath; *h*, hair; *x*, part shown magnified in fig. 235.

sulphuric acid into long tapering fibrillated cells, the nuclei of which are still visible. The fibrous substance of the hair is covered by a layer of delicate imbricated scales, termed the *hair-cuticle* (*c*). In many hairs, but not in all, the centre is occupied by an axial substance

(*medulla*, *m*), formed of angular cells which contain granules of eleidin, and frequently have a dark appearance from the presence of minute air-bubbles. The latter may also occur in interstices in the fibrous substance. When they are present, the hair looks white by reflected light. The *root* has the same structure as the body of the hair, except at its extremity, which is enlarged into a *knob* (fig. 232); this is composed mainly of soft, growing cells, and fits over a vascular *papilla* (*p*), which projects up into the bottom of the follicle (fig. 234).

Structure of hair-follicle.—The follicle, like the skin itself, of which it is a recess, is composed of two parts: one epithelial, and the other connective-tissue. The epithelial or epidermic part of the follicle closely invests the hair-root, and is often in great part dragged out with it; hence it is known as the *root-sheath*. It consists of an outer layer of soft columnar and polyhedral cells, like the Malpighian layer

FIG. 235.—A SMALL PORTION OF THE SECTION SHOWN IN FIG. 234 ENLARGED TO 800 DIAMETERS TO EXHIBIT THE STRUCTURE OF THE SEVERAL LAYERS.

h, hair; *c''*, its cuticle; *c'*, cuticle of root-sheath; *i''*, Huxley's layer; *i'*, Henle's layer; *o*, outer root-sheath; *hy*, hyaline layer; *d*, dermic coat; *f*, fat-cells.

of the epidermis, but without stratum granulosum—the *outer root-sheath* (figs. 232, *f*; 233, 234, 235, *o*); and of an inner, thinner, horny stratum next to the hair—the *inner root-sheath* (figs. 232, *g*; 233, 234, 235, *i*). The inner root-sheath itself consists of three layers, the outermost being composed of horny, fibrous, oblong cells the nuclei of which are obscure and difficult to make out (*Henle's layer*), the next of polyhedral nucleated cells containing eleidin (*Huxley's layer*), and the third — the *cuticle of the root-sheath* — being, in the more superficial part of the follicle, a layer of downwardly imbricated scales, which fit over the upwardly imbricated scales of the hair itself. In the more superficial part of the hair-follicle the layers of Huxley and Henle are indistinguishable, the cells of both being clear and keratinized; even lower down where distinguishable they show a tendency to dovetail into one another. At the bottom of the follicle no differ-

entiation into layers can be made out in the root-sheath, which is here formed by a uniform mass of soft cells surrounding the papilla.

In the greater extent of the follicle the outer root-sheath is several layers deep, but as the bottom of the follicle is approached it becomes thinner and is finally reduced to a single layer of cells which become flattened out into a very thin layer in the papillary part (fig. 233, I.).

FIG. 236.

FIG. 236.—FROM A SECTION OF SKIN PREPARED BY THE CHROMATE OF SILVER METHOD, SHOWING THE UPPER PART OF TWO HAIRS AND THE TERMINAL ARBORISATIONS OF NERVE-FIBRES IN THEIR ROOT-SHEATHS. (v. Gehuchten.)

FIG. 237.—LONGITUDINAL SECTION THROUGH THE FOLLICLE OF A HAIR WHICH HAS CEASED TO GROW AND THE ROOT OF WHICH IS UNDERGOING ABSORPTION. (Magnified 200 diameters.)

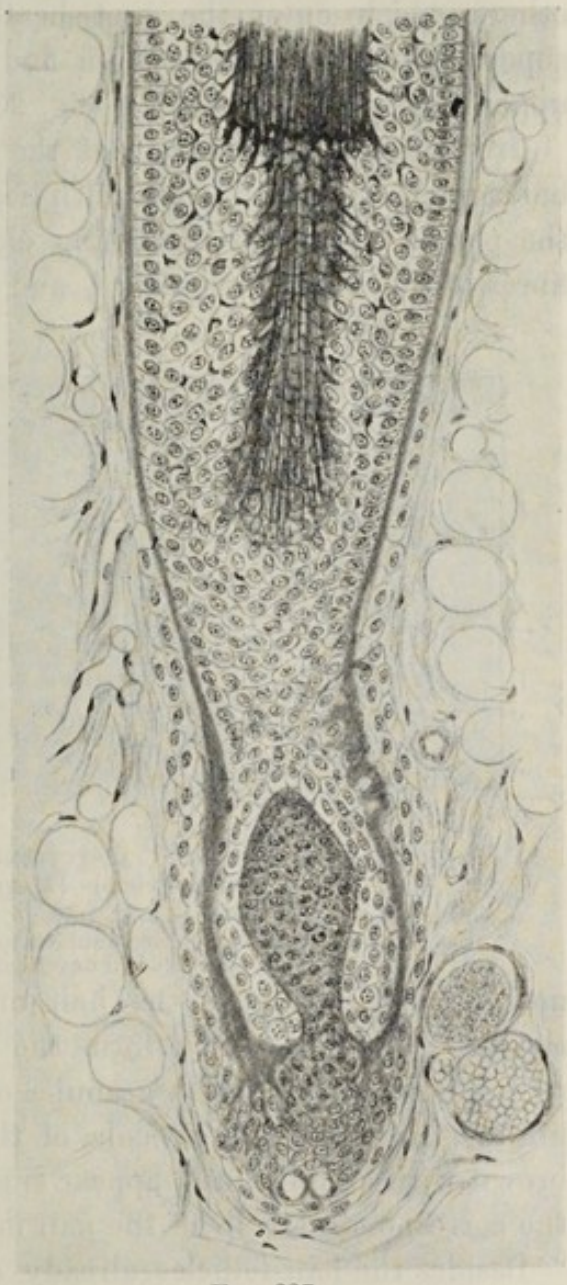


FIG. 237.

The connective tissue or dermic part of the hair-follicle (figs. 232, 233, 234) is composed internally of a vascular layer, which is separated from the root-sheath by a basement-membrane termed the *hyaline layer* of the follicle. This inner vascular layer corresponds to the superficial layer of the cutis vera. Its fibres and cells have a regular circular arrangement around the follicle, the cells being flattened against the

hyaline layer. Externally the dermic coat of the follicle has a more open texture, corresponding to the reticular part of the cutis, and contains the larger branches of the arteries and veins. In the large tactile hairs of animals, the veins near the bottom of the follicle are dilated into sinuses, so as to produce a kind of erectile structure.

The hair-follicle receives nerve-fibres which pass into the papilla, and others which enter the root-sheath. These last descend from the superficial nerves of the corium and form ring-like arborisations in the upper part of the hair follicle (fig. 236).

Growth and replacement of the hairs.—The hair grows from the bottom of the follicle by multiplication of the soft cells which cover the papilla, these cells becoming elongated and pigmented to form the fibres of the fibrous substance, and otherwise modified to produce the

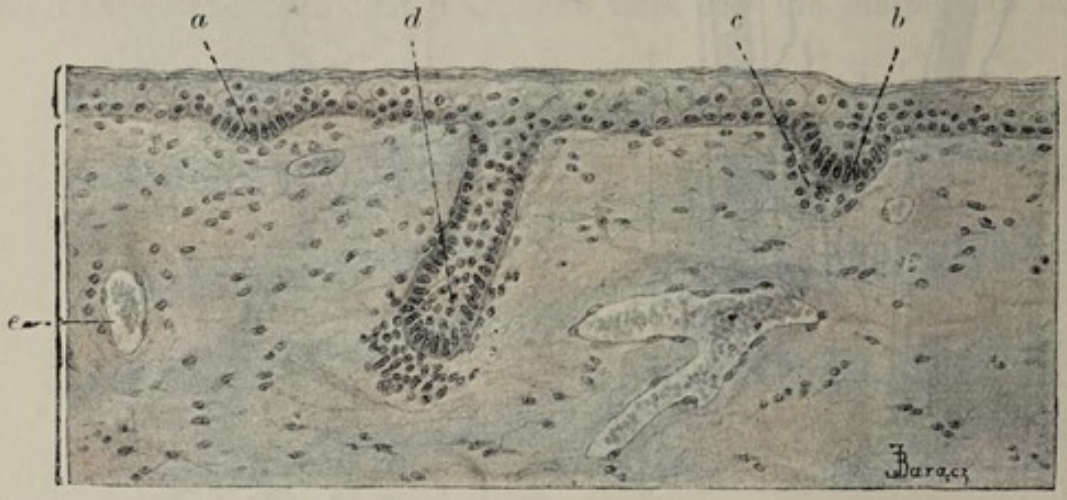


FIG. 238.—HAIR-GERMS IN A SECTION OF THE SCALP OF A HUMAN FŒTUS. (Szymonowicz.) (Magnified 230 diameters.)

a, commencing down-growth of epidermis; *b*, further stage of down-growth; *c*, connective tissue cells beginning to accumulate to produce the dermic coat of the follicle; *d*, hair-follicle more advanced in development; *e*, section of a blood-vessel.

medulla and cuticle of the hair and the several layers of the root-sheath. The cells which form the medulla of the hair and the inner root-sheath are filled with granules of eleidin, but those which form the fibrous substance and cuticula of the hair have granules which stain brown with carmine, and appear similar to those which are met with in the corresponding cells of the nail matrix (Ranvier) (see p. 191).

Besides the hair-follicles already described, which are provided with a papilla, from the cells on the surface of which the hair and its inner root-sheath are continuously growing (*papillated hairs, hairs with hollow bulb*), there are many hairs which are unprovided with a papilla and the follicle of which ceases at the level of attachment of the arrector pili muscle (*non-papillated hairs, hairs with solid bulb*). These are hairs which have lost their papilla and have ceased to grow; they are more easily eradicated than the growing hairs, and

tend to fall out after a time, which is never the case with those hairs which are still provided with a papilla. In these follicles the whole of the lower part, including the original papilla and the soft growing cells which cover it, have entirely disappeared, the hair being now attached at its sides and below to the root-sheath. A hair which has thus ceased to grow eventually becomes lost, but its place is presently supplied by a new hair, which becomes developed in a down-growth from either the bottom or the side of the follicle, a new papilla becoming formed at the extremity of the down-growth (fig. 237). If not previously detached, the old hair is pushed out from the follicle by the one which replaces it.

The detachment of the non-papillated hairs is preceded by an absorption of the root of the hair and of the investing inner root-sheath. This absorption appears to be effected by the cells of the outer sheath, which erode the keratinized parts of the hair root and thus undermine its attachment to the follicle (fig. 237).

The hairs are originally developed in the embryo in the form of small solid down-growths from the Malpighian layer of the epidermis (fig. 238). The hair-germ, as it is called (although it gives rise not only to the hair proper but to the epithelium-cells of the hair-follicle also), is at first composed entirely of soft growing cells; but presently those in the centre become differentiated, so as to produce a minute hair invested by inner root-sheath, its base resting upon a papilla which has become inclosed by the extremity of the hair-germ and which is continuous with the connective tissue of the corium (fig. 239). As the minute hair grows, it pushes its way through the layers of the epidermis, which it finally perforates, the epitrichial layer being

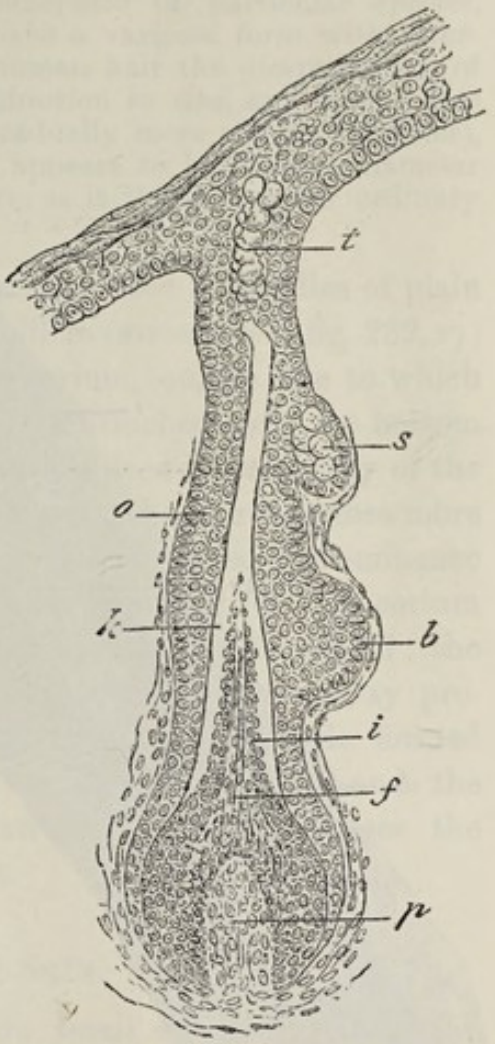


FIG. 239.—DEVELOPING HAIR FROM HUMAN EMBRYO OF 4½ MONTHS. (Ranvier.)

p, papilla; *f*, hair-rudiment; *i*, cells from which the inner root-sheath is becoming formed; *k*, keratinised part of inner root-sheath, uncoloured by carmine; *o*, outer root-sheath; *b*, epithelial projection for insertion of arrector pili; *s*, sebaceous gland; *t*, sebaceous degeneration of cells in the part which will become the neck of the follicle. This forms a channel for the passage of the hair-point through the Malpighian layer.

thrown off (p. 188). At the same time the follicle tends to penetrate more deeply into the cutis vera, carrying the papilla down with it.

The hair-rudiments begin to appear at the third or fourth month of fœtal life; their growth is completed about the fifth or sixth month,

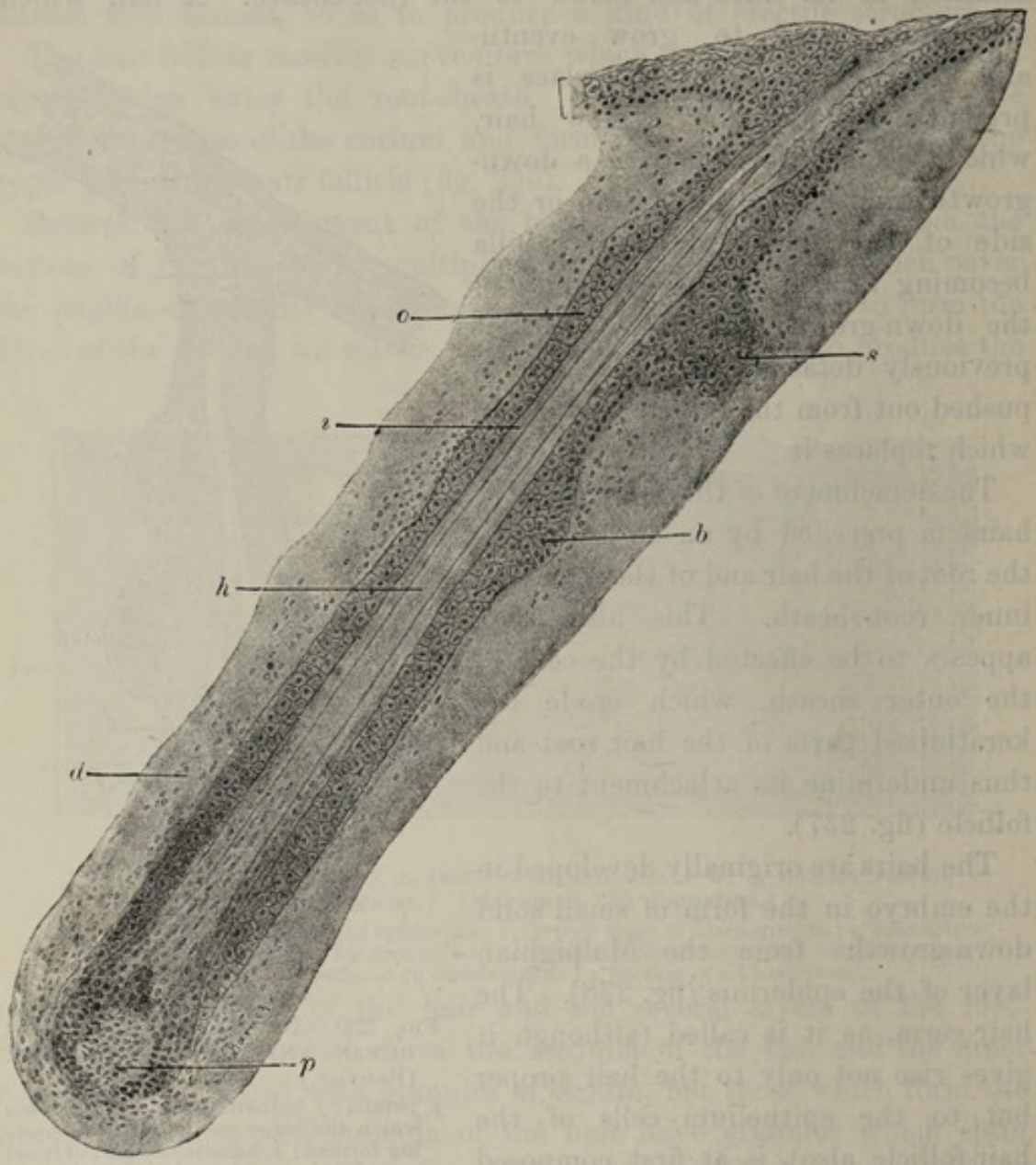


FIG. 240.—LONGITUDINAL SECTION OF A HAIR WITH ITS FOLLICLE FROM A SIX-MONTHS' HUMAN EMBRYO. (Szymonowicz.) (Magnified about 150 diameters.)

p, papilla; *h*, young hair; *i*, inner root-sheath; *d*, dermic coat of follicle; *o*, outer root-sheath; *s*, sebaceous gland rudiment; *b*, projection for insertion of arrector pili.

and the fine hairs which they form constitute a complete hairy covering termed the *lanugo*. This is entirely shed within a few months of birth, the new hairs being formed in down-growths from the old hair-follicles in the manner already mentioned.

Hairs grow at the rate of half an inch per month. They are found all over the body except on the palms of the hands and the soles of the

feet, and on the distal phalanges of the fingers and toes. They usually slant, and in the negro the hair-follicles are even considerably curved. On the scalp they are set in groups, as is well seen in a horizontal section.

The hairs of animals are often curiously marked by the arrangement of their medulla, the markings being characteristic of particular species. In some animals, *e.g.* the mole, the hairs have a varicose form with alternate enlargements and constrictions. In human hair the disappearance of the papilla is preceded by its gradual diminution in size, and during this period the root of the hair is becoming gradually more slender (Ranvier), so that when such a hair is pulled out it appears to be of least diameter near the bulb, instead of being largest there, as is the case under ordinary circumstances.

Muscles of the hairs.—A small muscle composed of bundles of plain muscular tissue is attached to each hair-follicle (*arrector pili*, fig. 232, *r*); it passes from the superficial part of the corium, on the side to which the hair slopes, obliquely downwards, to be attached near the bottom of the follicle to a projection formed by a localised hypertrophy of the outer root-sheath. When the muscle contracts, the hair becomes more erect, and the follicle is dragged upwards so as to cause a prominence on the general surface of the skin, whilst the part of the corium from which the little muscle arises is correspondingly depressed; the roughened condition known as 'goose skin' being in this way produced. There is always a sebaceous gland in the triangle formed between the arrector pili, the mouth of the hair-follicle, and the epidermis, so the contraction of the arrector generally causes the secretion of the gland to be forced out.

Glands of the Skin.

The **sebaceous glands** (fig. 232, *t*) are small saccular glands, the ducts from which open into the mouths of the hair-follicles, but they are also found in a few situations which are devoid of hairs (margin of lips, labia minora, glans, and prepuce). The Meibomian glands of the eyelid may also be regarded as modified sebaceous glands. Both the duct and the saccules are lined by epithelium, which becomes charged with fatty matter. This sebaceous matter is discharged into the cavity of the saccule, probably owing to the disintegration of the cells within which it is formed. There may be more than one sebaceous gland attached to each hair-follicle.

The sebaceous glands are developed as outgrowths from the outer root-sheath (figs. 239, 240, *s*).

The **sweat-glands** are abundant over the whole skin, but they are most numerous on the palm of the hand and on the sole of the foot.

They are composed of coiled tubes, which lie in the deeper part of the integument and send their ducts up through the cutis to open on the surface by corkscrew-like channels in the epidermis (figs. 224, 228).

The *glandular* or *secreting tube* is a convoluted tube composed of a basement-membrane lined by a single layer of cubical or columnar epithelium-cells, and with a layer of longitudinally or obliquely dis-

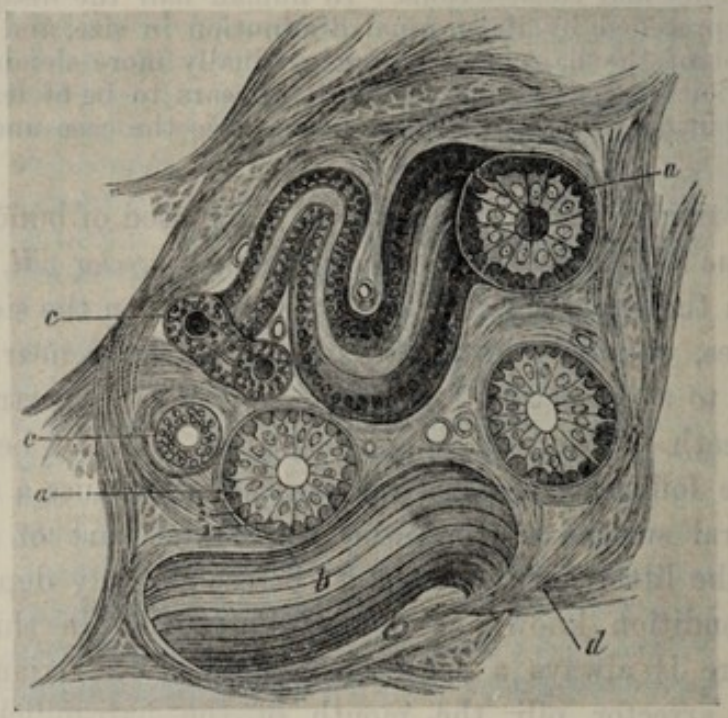


FIG. 241.—SECTION OF A SWEAT-GLAND IN THE SKIN OF MAN.

a, *a*, secreting tube in section; *b*, a coil seen from above; *c*, *c*, efferent tube; *d*, intertubular connective tissue with blood-vessels. 1, basement-membrane; 2, muscular fibres cut across; 3, secreting epithelium of tubule.

posed fibres between the epithelium and basement-membrane. These fibres are usually regarded as muscular, but the evidence on this point is not conclusive. The secreting tube is considerably larger than the *efferent tube* or *duct*, which begins within the gland and usually makes several convolutions before leaving the gland to traverse the cutis vera. The efferent tube has an epithelium consisting of two or three layers of cells, within which is a well-marked cuticular lining, but there is no muscular layer. The passage through the epidermis has no proper wall, but is merely a channel excavated between the epithelium-cells.

The *ceruminous glands* of the ear (fig. 242) are modified sweat-glands. The secretion is of a sebaceous nature, instead of being watery like that of the ordinary sweat-glands.

The sweat-glands are developed, like the hairs, from down-growths of the Malpighian layer of the epidermis into the corium, the rudiments which are thus formed becoming eventually coiled up at their

extremities and converted into hollow tubes. The muscular fibres of the tubes as well as the secreting epithelium cells are thus ectodermic structures.

The sweat-glands receive nerve-fibres, and each gland has a special cluster of capillary blood-vessels.

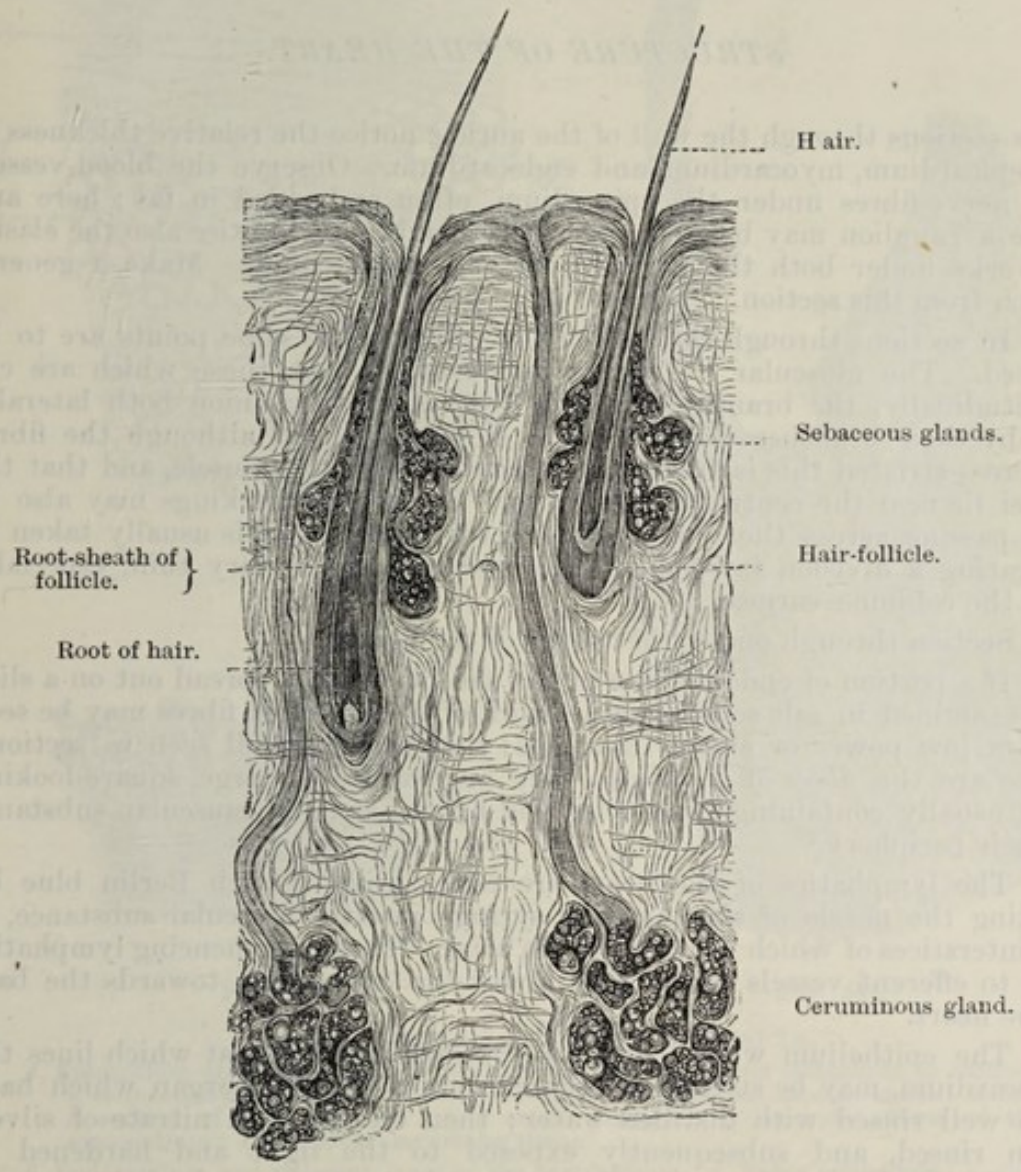


FIG. 242.—SECTION OF SKIN OF AUDITORY MEATUS, INCLUDING TWO HAIR-FOLLICLES WITH THEIR SEBACEOUS GLANDS AND TWO CERUMINOUS GLANDS. (Grüber.)

LESSON XXVIII.

STRUCTURE OF THE HEART.

1. In sections through the wall of the auricle notice the relative thickness of the epicardium, myocardium, and endocardium. Observe the blood-vessels and nerve-fibres under the epicardium, often embedded in fat; here and there a ganglion may be seen under this membrane. Notice also the elastic networks under both the pericardium and endocardium. Make a general sketch from this section.

2. In sections through the wall of the ventricle the same points are to be noticed. The muscular fibres are variously cut. In those which are cut longitudinally, the branching of the fibres and their union both laterally and by their branches may be seen. Notice also that although the fibres are cross-striated this is less distinct than in voluntary muscle, and that the nuclei lie near the centre of each fibre. Transverse markings may also be seen passing across the fibres between the nuclei; this is usually taken as indicating a division into cells. The endocardium is very thin, especially over the columnæ carneæ.

3. Section through one of the valves of the heart.[1]

4. If a portion of endocardium of the sheep's heart is spread out on a slide and examined in salt solution, a network of large beaded fibres may be seen with a low power or even with a lens; they are also well seen in sections. These are the *fibres of Purkinje*; they are formed of large, square-looking cells, usually containing two nuclei, and having striated muscular substance at their periphery.[2]

5. The lymphatics of the heart are easily injected with Berlin blue by sticking the nozzle of the injecting syringe into the muscular substance, in the interstices of which the lymphatics arise. These commencing lymphatics lead to efferent vessels which pass under the epicardium towards the base of the heart.

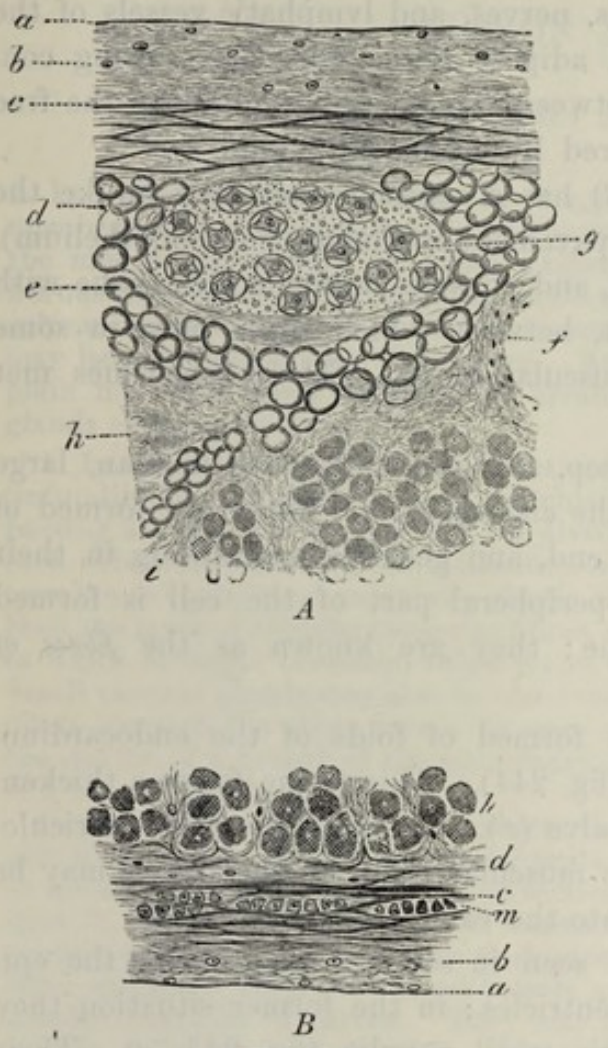
6. The epithelium which covers the epicardium, and that which lines the endocardium, may be studied in preparations of the fresh organ which have been well rinsed with distilled water; then treated with nitrate of silver, again rinsed, and subsequently exposed to the light and hardened in alcohol. Surface sections are to be made and mounted in xylol balsam.

The muscular tissue of the heart (*myocardium*) forms the main thickness of the ventricles and also of parts of the auricles. It is composed of a network of fibres which are formed of uninucleated transversely striated cells, the structure of which has already been studied (Lesson XVII., p. 108).

[1] The appearances which are to be studied in sections 1, 2, and 3 can all be obtained in one preparation, viz. a vertical section including a portion of auricle and ventricle and a flap of the intervening auriculo-ventricular valve.

[2] The fibres of Purkinje may also be seen in sections of the heart.

In the interstices of the muscular bundles there is a little areolar



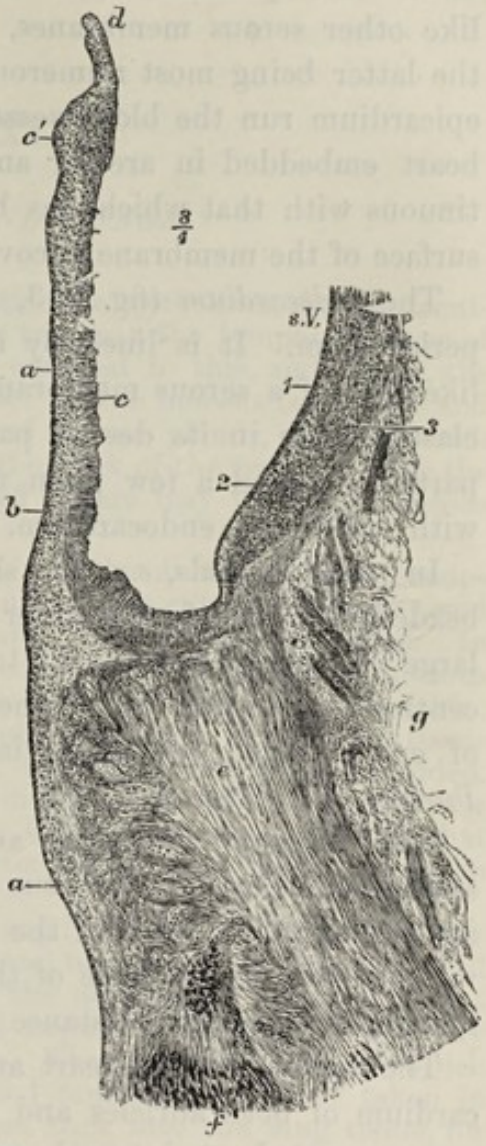


FIG. 243. FIG. 244.

FIG. 243.—SECTION OF THE RIGHT AURICLE.

A, Epicardium and adjacent part of the myocardium. *a*, serous epithelium in section; *b*, connective-tissue layer; *c*, elastic network; *d*, subserous areolar tissue; *e*, fat; *f*, section of a blood-vessel; *g*, a small ganglion; *h*, muscular fibres of the myocardium; *i*, intermuscular areolar tissue.

B, Endocardium and adjacent layer of the myocardium. *a*, lining epithelium; *b*, connective tissue with fine elastic fibres; *c*, layer with coarser elastic fibres; *d*, subendocardial connective tissue continuous with the intermuscular tissue of the myocardium; *h*, muscular fibres of the myocardium; *m*, plain muscular tissue in the endocardium.

FIG. 244.—SECTION THROUGH ONE OF THE FLAPS OF THE AORTIC VALVE, AND PART OF THE CORRESPONDING SINUS OF VALSALVA, WITH THE ADJOINING PART OF THE VENTRICULAR WALL. (Drawn by V. Horsley.)

a, endocardium, prolonged over the valve; *b*, sub-endocardial tissue; *c*, fibrous tissue of the valve, thickened at *c'* near the free edge; *d*, section of the lunula; *e*, section of the fibrous ring; *f*, muscular fibres of the ventricle attached to it; *g*, loose areolar tissue at the base of the ventricle; *s.V.* sinus Valsalvæ; *1*, *2*, *3*, inner, middle, and outer coats of the aorta.

tissue in which run the very numerous blood-capillaries and the lacunar lymphatics.

The myocardium is covered externally by a layer of serous membrane—the *epicardium* (cardiac pericardium, fig. 243, *A*)—composed, like other serous membranes, of connective tissue and elastic fibres, the latter being most numerous in its deeper parts. Underneath the epicardium run the blood-vessels, nerves, and lymphatic vessels of the heart embedded in areolar and adipose tissue, this tissue being continuous with that which lies between the muscular bundles; the free surface of the membrane is covered by serous epithelium.

The *endocardium* (fig. 243, *B*) has a structure not very unlike the pericardium. It is lined by a pavement-epithelium (or endothelium), like that of a serous membrane, and consists of connective tissue with elastic fibres in its deeper part, between which there may, in some parts, be found a few plain muscular fibres. Fat is sometimes met with under the endocardium.

In some animals, *e.g.* the sheep, and sometimes also in man, large beaded fibres are found under the endocardium. These are formed of large clear cells joined end to end, and generally containing in their centre two nuclei, whilst the peripheral part of the cell is formed of cross-striated muscular tissue; they are known as the *fibres of Purkinje* (fig. 126, p. 110).

The *valves* of the heart are formed of folds of the endocardium strengthened by fibrous tissue (fig. 244). This tissue forms a thickening near the free edge of the valve (*c'*). At the base of the auriculo-ventricular valves a little of the muscular tissue of the auricle may be found passing a short distance into the valve.

The nerves of the heart are seen in sections underneath the epicardium of both auricles and ventricles; in the former situation they are connected at intervals with small ganglia (fig. 243, *g*). Their branches pass to the muscular substance, and after dividing into fine fibrils, these end in enlarged extremities, which are applied directly to the muscular fibres (Ranvier).

LESSON XXIX.

THE TRACHEA AND LUNGS.

1. In sections of the trachea and larynx, notice the epithelium, the basement-membrane (of some thickness in the human trachea), the lymphoid tissue of the mucous membrane, the elastic tissue external to this, and, lastly, the fibrous membrane containing the cartilages. In the mucous membrane and submucous areolar tissue look for sections of mucous glands, ducts of which may be seen opening on the surface. At the back of the trachea notice the plain muscular fibres transversely arranged; there may be larger mucous glands external to these.

2. In sections of lung notice the sections of the alveoli collected into groups (infundibula). Find sections of bronchial tubes, some cut longitudinally and passing at their extremities into the alveolar passages, others cut across. In each tube notice the ciliated epithelium internally. Next to this the mucous membrane containing numerous elastic fibres and often thrown into folds; then the layer of circular muscular fibres, and, outside this, loose fibrous tissue in which in larger bronchial tubes pieces of cartilage may be seen embedded. Small mucous glands may also be observed in the fibrous tissue sending their ducts through the other layers to open on the inner surface. Notice that the section of a branch of the pulmonary artery always accompanies a section of a bronchial tube.

In the sections of the alveoli observe the capillary vessels passing from one side to the other of the intervening septa; and in places where the thin wall of an alveolus is to be seen in the section, the network of blood-capillaries upon it. Notice within the alveoli nucleated corpuscles which very frequently contain dark particles in their protoplasm. They are amœboid cells which have migrated from the blood-vessels and lymphatics, and have taken in inhaled particles of carbon. They may pass back into the lung tissue, for similar cells are seen in this. Make a sketch of part of the wall of a bronchial tube and of one or two of the alveoli.

3. In sections of a fresh lung the air-cells of which have been filled with a mixture of gelatine and nitrate of silver solution, the epithelium of the alveoli may be studied. The sections can be made with the freezing microtome, and mounted in glycerine, which should be warmed after the cover-glass is applied in order to melt the gelatine.

4. Mount in xylol balsam a section of lung in which the pulmonary vessels have been injected. Study the general arrangement of the vessels with a low power, and the network of capillaries of the alveoli with a high power. Observe that the veins run apart from the arteries. Sketch the capillary network of one or two adjoining alveoli.

The Trachea.

The **trachea** or windpipe is a fibrous and muscular tube, the wall of which is rendered somewhat rigid by **C**-shaped hoops of cartilage which are embedded in the fibrous tissue. The muscular tissue, which

is of the plain variety, forms a flat band, the fibres of which run transversely at the back of the tube. The trachea is lined by a *mucous membrane* (fig. 245, *a* to *d*), which has a ciliated epithelium upon its inner surface. The epithelium-cells have been already described (Lesson VII.): they rest upon a thick basement-membrane. The mucous membrane proper consists of areolar and lymphoid tissue, and contains numerous blood-vessels and lymphatics. In its deepest part

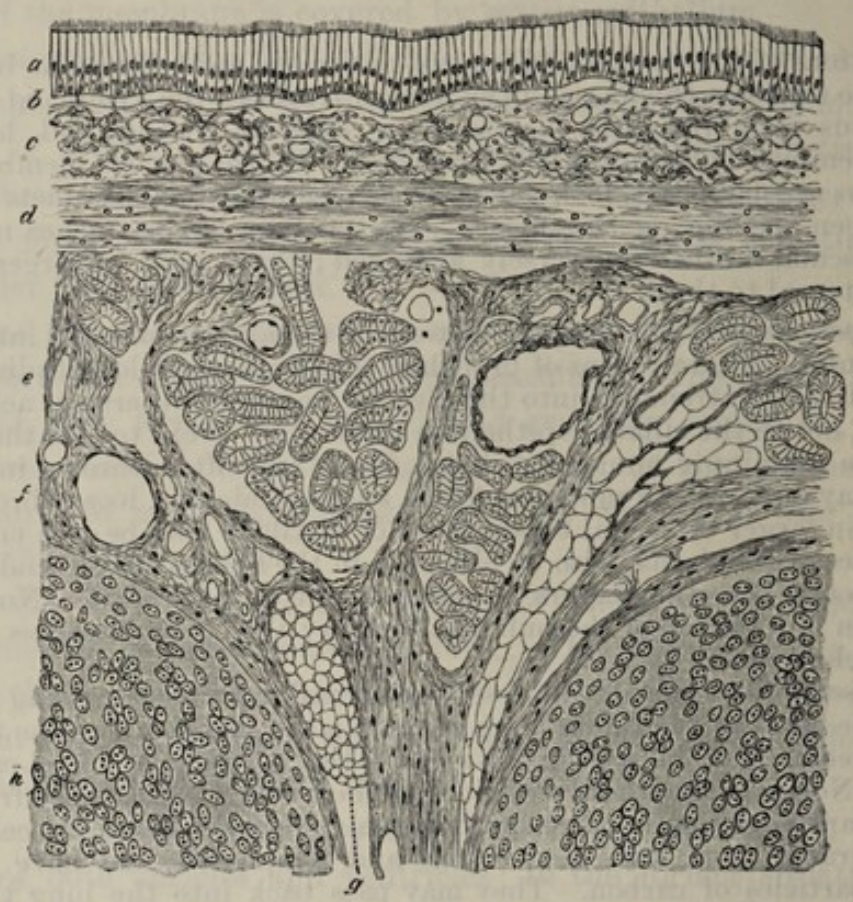


FIG. 245.—LONGITUDINAL SECTION OF THE HUMAN TRACHEA, INCLUDING PORTIONS OF TWO CARTILAGINOUS RINGS. (Klein.) (Moderately magnified.)

a, ciliated epithelium; *b*, basement-membrane; *c*, superficial part of the mucous membrane, containing the sections of numerous capillary blood-vessels and much lymphoid tissue; *d*, deeper part of the mucous membrane, consisting mainly of elastic fibres; *e*, submucous areolar tissue, containing the larger blood-vessels, small mucous glands (their ducts and alveoli are seen in section), fat, etc.; *f*, fibrous tissue investing and uniting the cartilages; *g*, a small mass of adipose tissue in the fibrous layer; *h*, cartilage.

is a well-marked layer of longitudinal elastic fibres (*d*). Many small glands for the secretion of mucus are found in the wall of the trachea. They may lie either within the mucous membrane or in the submucous areolar tissue (*e*) or, lastly, at the back of the trachea, outside the transverse muscular fibres.

The two divisions of the trachea, the *bronchi*, are precisely similar in structure to the main tube.

The **larynx** is also very like the trachea so far as the structure of the mucous membrane is concerned, but over the true vocal cords and

upon the epiglottis, as well as here and there in the part above the glottis, stratified epithelium is found; and taste-buds (see Lesson XXXI.) may occur in this epithelium, except over the vocal cords.

The lymphoid tissue is especially abundant in the mucous membrane of the ventricle of Morgagni (fig. 246, *l*), and a large number of mucous glands open into this cavity and into that of the sacculus.

The true vocal cords are composed of fine elastic fibres.

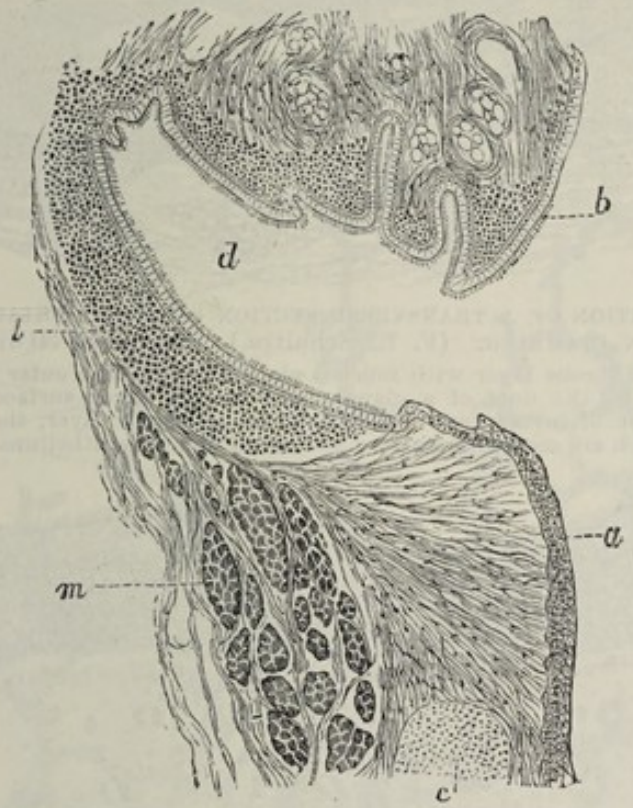


FIG. 246.—LONGITUDINAL SECTION THROUGH THE VENTRICLE OF THE LARYNX OF A CHILD. (Klein.)

a, true vocal cord; *b*, false vocal cord; *c*, nodule of cartilage; *d*, ventricle of Morgagni; *l*, lymphoid tissue; *m*, thyro-arytenoid muscle.

The cartilages of the trachea and larynx are hyaline, except the epiglottis and the cartilages of Santorini and of Wrisberg, which are composed of elastic fibro-cartilage. This is also the case with the tip of the arytenoid in some animals.

THE LUNGS.

The lungs are formed by the ramifications of the *bronchial tubes* and their terminal expansions, which form groups (*lobules*) of sacculated dilatations (*air-sacs, infundibula*), beset everywhere with small hemispherical or cubical bulgings, known as the *air-cells* or *pulmonary alveoli*.

The **bronchial tubes** (figs. 247, 248) are lined in their whole extent by ciliated epithelium which rests on a basement-membrane. External to this is the corium of the mucous membrane, containing a large

number of longitudinal elastic fibres and some lymphoid tissue. Outside this again is a complete layer of plain muscular fibres encircling

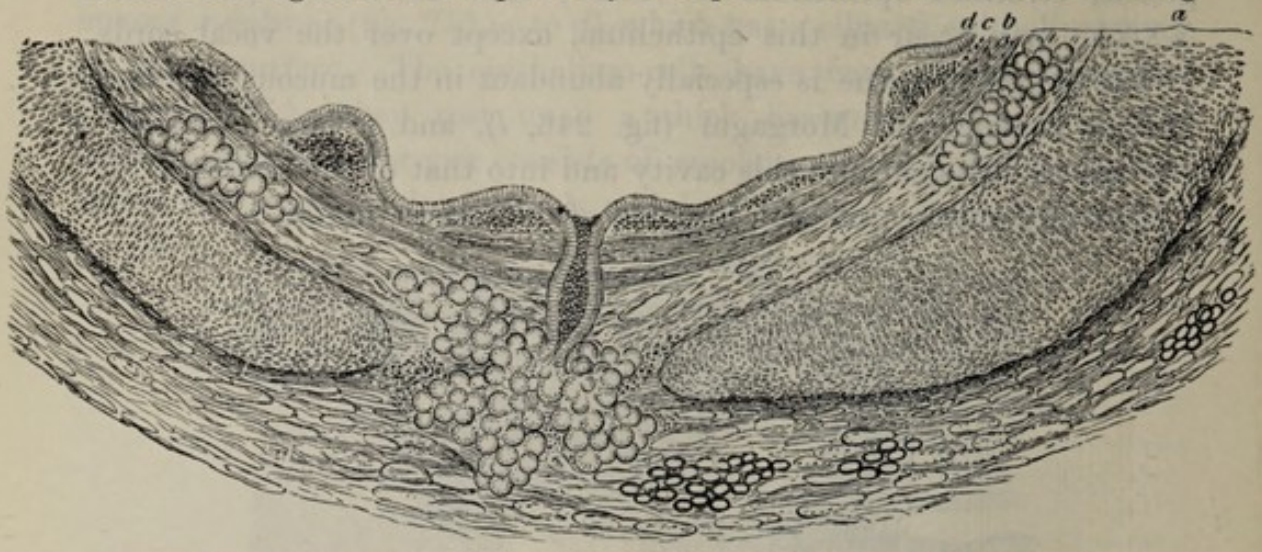


FIG. 247.—PORTION OF A TRANSVERSE SECTION OF A BRONCHIAL TUBE, HUMAN, 6 MM. IN DIAMETER. (F. E. Schultze.) (Magnified 30 diameters.)

a, cartilage and fibrous layer with mucous glands, and, in the outer part, a little fat; in the middle, the duct of a gland opens on the inner surface of the tube; *b*, annular layer of involuntary muscular fibres; *c*, elastic layer, the elastic fibres in bundles which are seen cut across; *d*, columnar ciliated epithelium.

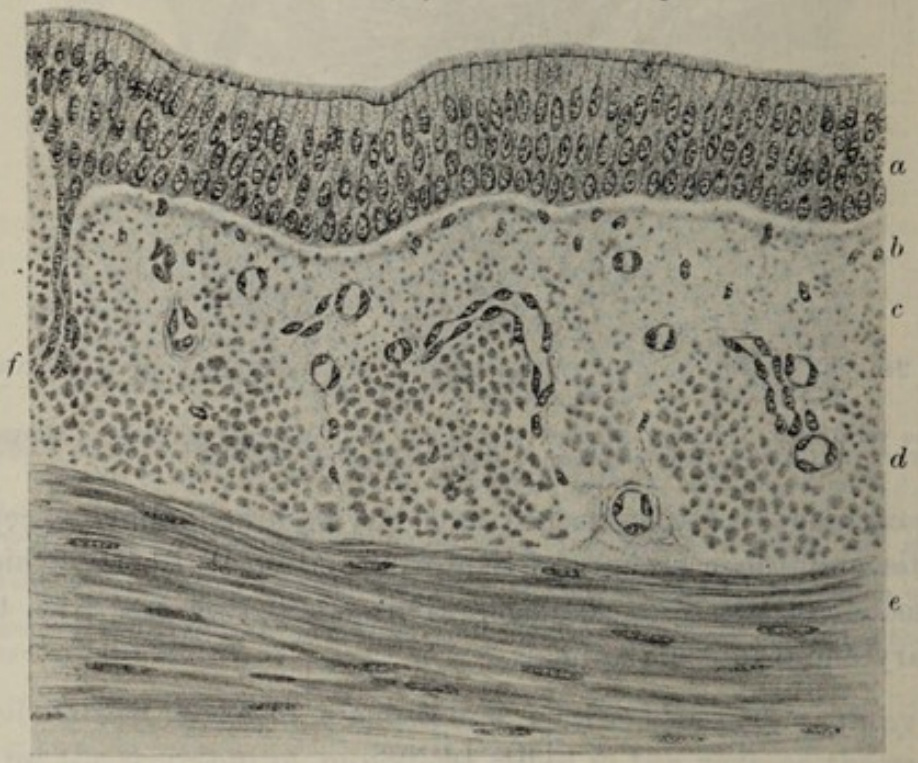


FIG. 248.—SECTION OF PART OF A BRONCHIAL TUBE. (Magnified 200 diameters.)

a, ciliated epithelium; *b*, basement membrane; *c*, superficial part of mucous membrane, with fine elastic fibres; *d*, deeper part with numerous coarser fibres; *e*, plain muscle of bronchus: *f*, duct of gland passing through mucous membrane.

the tube. Next comes a loose fibrous layer in which, in the larger tubes (fig. 247), small plates of cartilage are embedded. Mucous glands are also present in this tissue.

The *terminal* or *lobular bronchial tubes* expand into passages (*alveolar*

passages), the walls of which are beset with alveoli, and which end in a number of blind and often funnel shaped diverticula completely covered with alveoli, which are known as *air sacs or infundibula.*

According to Miller, two or more air-sacs open into a common chamber (*atrium*), and several atria into a common terminal portion (*vestibule*) of the expanded lobular bronchiole.

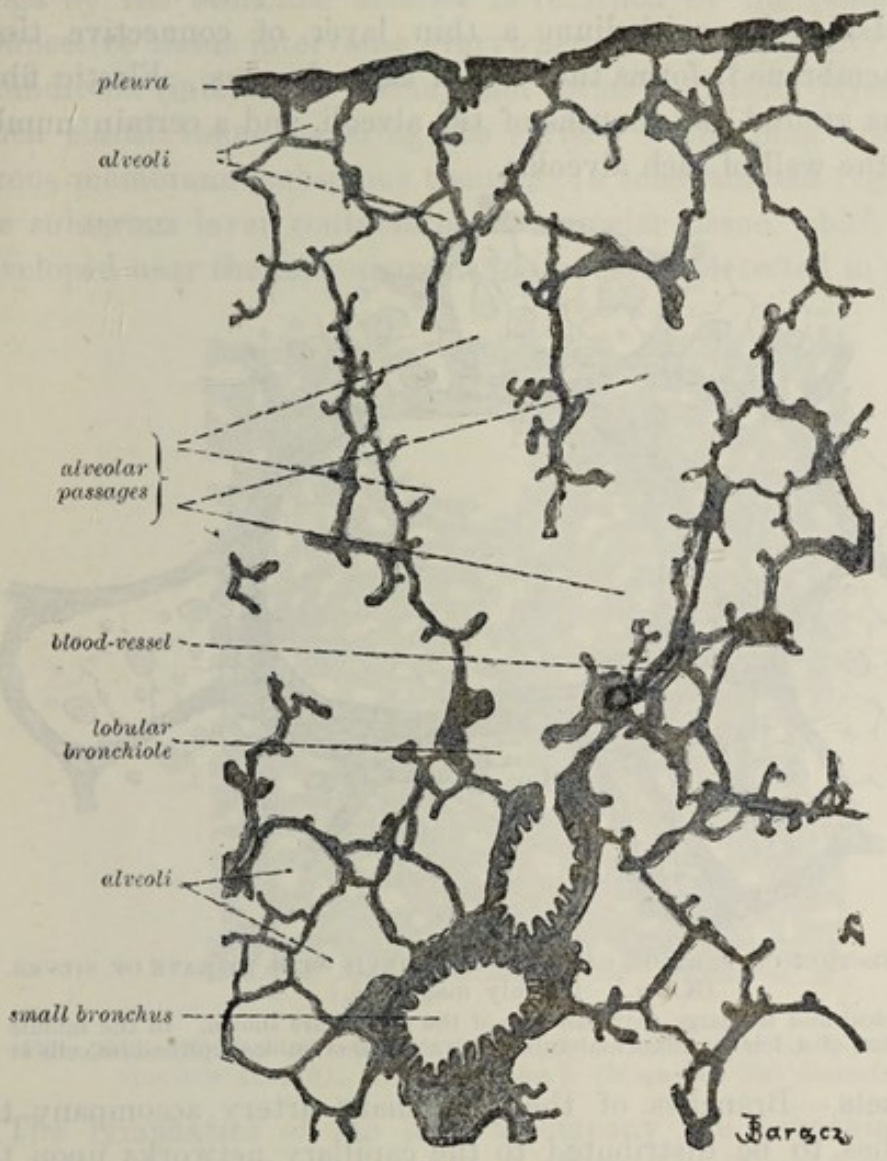


FIG. 249.—SECTION OF LUNG OF CAT. (Szymonowicz.) (Magnified 50 diameters.)

The epithelium of the bronchial tubes changes in the alveolar passages; from columnar and ciliated it becomes cubical and non-ciliated, and there are patches of the respiratory epithelium not only in the alveoli of the passages, but also elsewhere in their wall. The plain muscular tissue of the bronchiole is continued on the walls of the alveolar passages, but not on those of the atria, although some occurs round the mouths of the atria and even of the alveoli.

The **alveoli** are lined by large irregular flattened cells (fig. 250), which form an extremely delicate layer (respiratory epithelium),

separating the blood-capillaries from the air within the alveoli. Amongst the flattened cells are here and there groups of smaller and thicker (cubical) epithelium-cells. The capillary network of the alveoli is very close (fig. 251), and the capillary vessels of adjoining alveoli are in complete continuity, the vessels passing first to one side and then to the other of the septa which separate the adjacent alveoli. Outside the epithelium a thin layer of connective tissue (basement membrane ?) forms the wall of each alveolus. Elastic fibres are numerous around the mouths of the alveoli, and a certain number course over the wall of each alveolus.

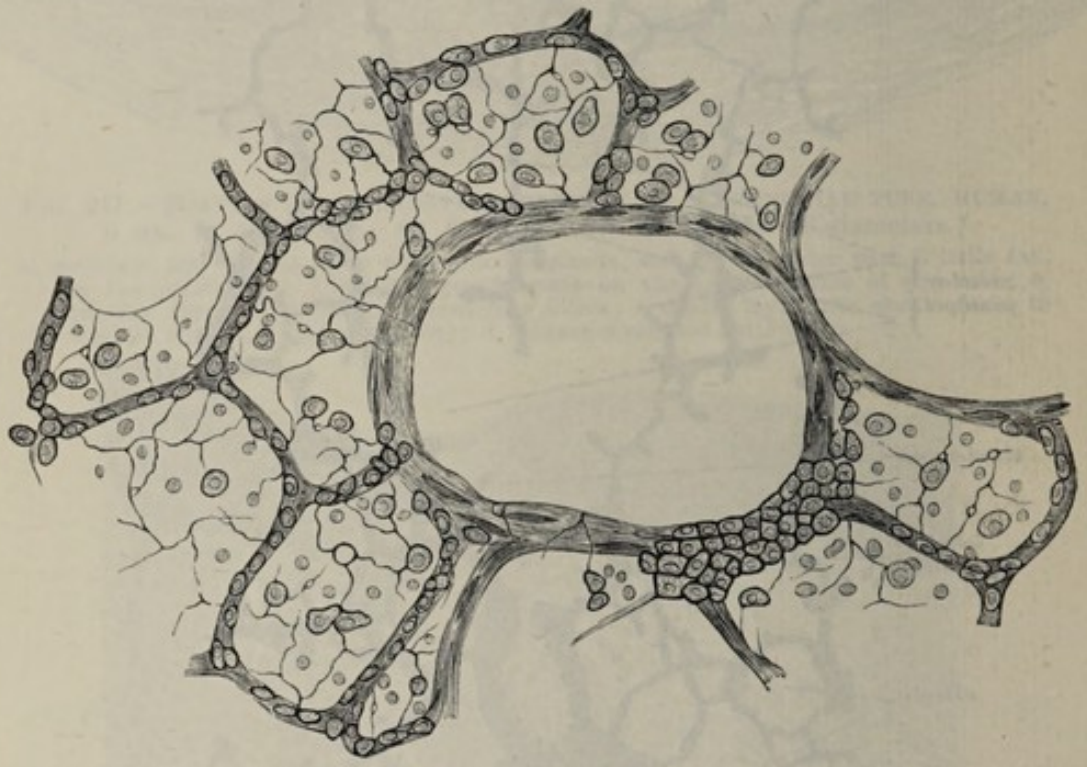


FIG. 250.—SECTION OF PART OF CAT'S LUNG, STAINED WITH NITRATE OF SILVER. (Klein.) (Highly magnified.)

Both the cubical and the large flattened cells of the alveoli are shown. In the middle is a section of a lobular bronchial tube, with a patch of cubical epithelium cells at one side.

Blood-vessels.—Branches of the pulmonary artery accompany the bronchial tubes to be distributed to the capillary networks upon the alveoli, from which the blood is returned by the pulmonary veins. An arteriole runs with each lobular bronchiole, and, dividing into as many branches as there are atria, is distributed to the capillary networks of all the air-cells with which the bronchiole is connected (Miller). From these networks one or two venules collect the blood, usually coursing (independently of the arteriole) on the outer border of the group of infundibula, and unite with other venules to form efferent veins. The venules of the superficial lobules are connected with a vascular network at the surface of the lung underneath the pleura. The veins, pursuing a separate course

through the tissue of the lung, join with others to form larger vessels which pass to the root of the lung. Branches from the bronchial arteries are distributed to the walls of the bronchial tubes, and to the connective tissue of the lung. The bronchial veins at first accompany the bronchial arteries, but most of the blood brought to the lungs by the bronchial arteries is returned by the pulmonary veins. Connective tissue intervenes everywhere in small quantity between the infundibula (interstitial tissue), and forms a distinct layer, containing much elastic tissue, covering the surface of the lung underneath the serous membrane (subserous tissue). In some animals (*e.g.* guinea-pig) the subserous layer contains plain muscular tissue, which is especially developed near the lung-apex; it has not been detected in man.

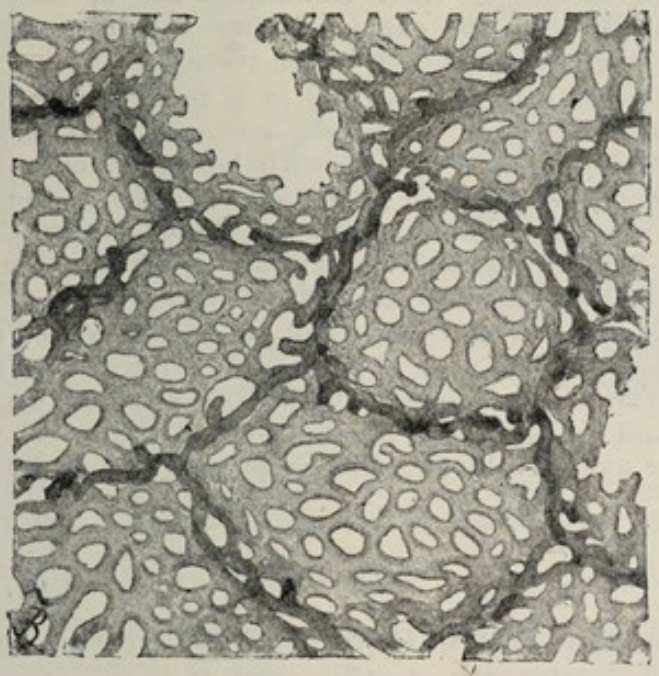


FIG. 251.—SECTION OF INJECTED LUNG OF RABBIT, INCLUDING SEVERAL CONTIGUOUS ALVEOLI. (Szymonowicz.) (Magnified 300 diameters.)

The **lymphatics** of the lung accompany the bronchial tubes, the branches of the pulmonary artery, and the branches of the pulmonary vein; and they also form a network in the subserous tissue. All the lymphatics tend towards the hilum, and enter lymphatic glands at the root of the lung. Those in the subserous tissue have been said to communicate, by means of stomata between the epithelial cells of the serous membrane, with the cavity of the pleura, but this connection is denied by Miller.

The **pleura**, which covers the surface of the lung, has the usual structure of a serous membrane. It is provided with a special network of blood-vessels, which is supplied from the pulmonary vessels of the superficial lobules.

LESSON XXX.

STRUCTURE AND DEVELOPMENT OF THE TEETH.

1. Study first with the low power and afterwards with the high power a longitudinal section of a human tooth which has been prepared by grinding. It is better to purchase this specimen, for the process of preparation is difficult and tedious without the aid of special apparatus.[1] Examine carefully the enamel, the dentine, and the cement. The dark appearance of the dentinal tubules is due to their containing air in the dried specimen. Measure the diameter of the enamel prisms and of some of the dentinal tubules. Make sketches from each of the tissues.

2. Mount in xylol balsam a section of a tooth *in situ*, which has been decalcified in chromic acid or in phloroglucin and nitric acid, after fixation in picric or chromic acid, and stained with hæmalum or carmalum. In this section the mode of implantation of a tooth, as well as the structure of the pulp, can be made out. Make a general sketch under a low power, and under a high power draw a small piece of the pulp showing the processes of the odontoblasts extending into the dentinal tubules.

3. The development of the teeth and the formation of their tissues are studied in sections made across the snout and lower jaw of fœtal animals. The preparation should be stained in bulk with alcoholic magenta, carmalum or hæmalum, and embedded in paraffin or celloidin; if the former, the sections must be mounted by an adhesive process (see Appendix).

The Teeth.

A **tooth** consists in man of three calcified tissues; the *enamel*, which is of epithelial origin, the *dentine*, and the *cement*, or *crusta petrosa*. The dentine forms the main substance of a tooth, the enamel covers the crown, and the cement is a layer of bone which invests the root (fig. 252).

Enamel is formed of elongated hexagonal *prisms* (figs. 253, 254), which are set vertically, or with a slight curvature, upon the surface of the dentine. They are marked at tolerably regular intervals with slight transverse shadings producing an indistinct cross-striated appearance. Sometimes coloured lines run through the enamel across the direction of its prisms. The enamel prisms have when first laid down a fibrous structure (fig. 262), but this becomes almost entirely obscured after their calcification is complete. C. Tomes has shown that the enamel of the fully-formed tooth contains only an extremely minute

[1] Details of methods which are useful in dental histology are given in *Course of Practical Histology*.

proportion of animal matter: practically it is wholly composed of earthy matter (lime salts).

Dentine is constituted of a hard dense substance like bone, but containing no Haversian canals or lacunæ. It is pierced everywhere,

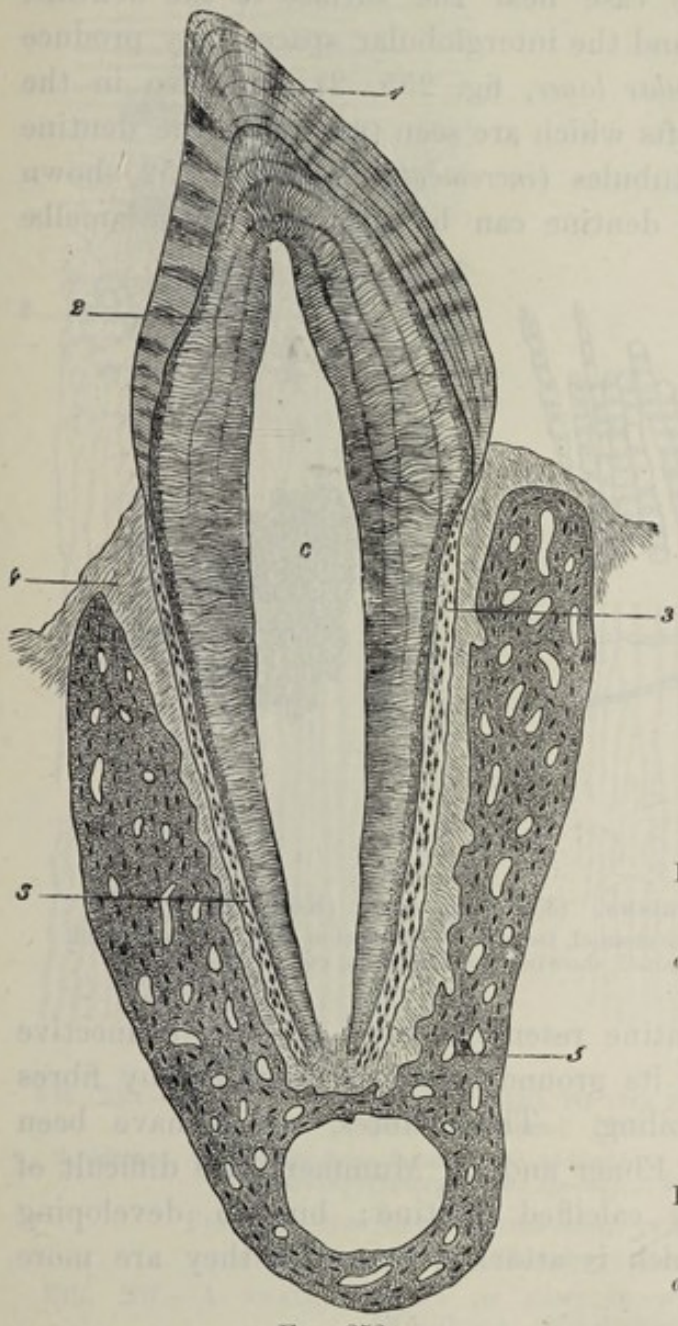


FIG. 252.

FIG. 253.

FIG. 252.—VERTICAL SECTION OF A TOOTH IN SITU. (15 diameters.) (Waldeyer.)

c, is placed in the pulp-cavity, opposite the cervix or neck of the tooth; the part above is the crown, that below is the root (fang). *1*, enamel with radial and concentric markings; *2*, dentine with tubules and incremental lines; *3*, cement or crusta petrosa, with bone-corpuscles; *4*, dental periosteum; *5*, bone of lower jaw.

FIG. 253.—SECTION THROUGH THE ENAMEL OF A TOOTH. (Magnified 200 diameters.) (Rauber.)

a, projection of dentine, showing some of its tubules, *b*, penetrating into the enamel; *c*, *c*, enamel fibres cut longitudinally; *d*, *d*, prisms cut transversely; *e*, cuticle of the enamel.

however, by fine canaliculi (*dentinal tubules*, figs. 255, 256), radiating outwards from a central cavity which, during life, contains the pulp. The tubules branch at acute angles as they pass outwards; their branches become gradually finer towards the periphery of the dentine.

The tubules have a proper wall of their own, which can be isolated by steeping a section of tooth in strong hydrochloric acid. In the living

tooth they are occupied by protoplasmic fibres, which are prolonged from the superficial cells of the pulp.

The intertubular substance appears for the most part homogeneous, but here and there indications can be seen in it of a globular formation. This is especially the case near the surface of the dentine, where the globular deposit and the interglobular spaces may produce a granular appearance (*granular layer*, fig. 255, 2), and also in the course of certain lines or clefts which are seen traversing the dentine across the direction of the tubules (*incremental lines*, fig. 252, shown magnified in fig. 257). The dentine can be separated into lamellæ along these incremental lines.

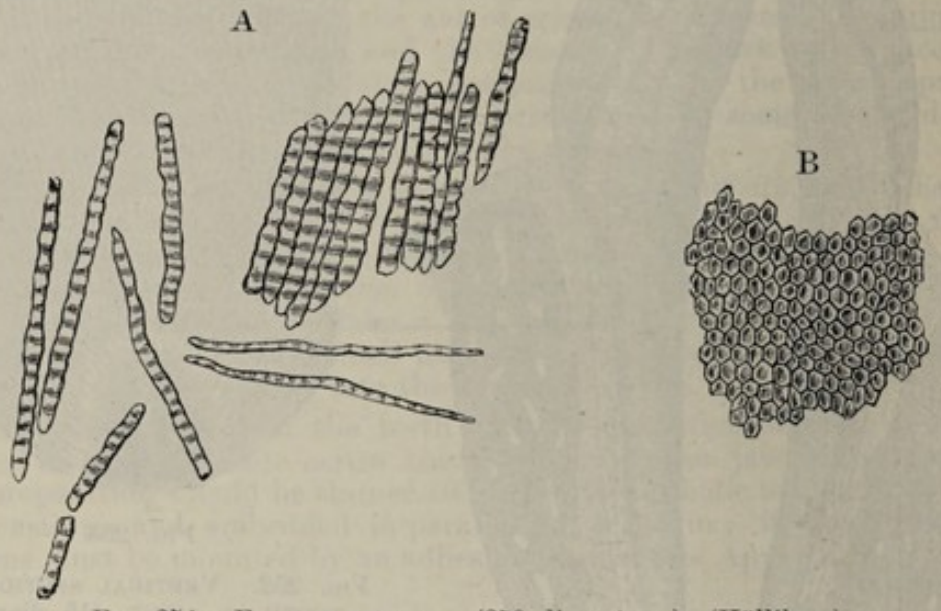


FIG. 254.—ENAMEL PRISMS. (350 diameters.) (Kölliker.)
A, Fragments and single fibres of the enamel, isolated by the action of hydrochloric acid.
B, Surface of a small fragment of enamel, showing the hexagonal ends of the fibres.

The animal matter of dentine resembles bone and the connective tissues generally in having its ground-substance pervaded by fibres which yield gelatine on boiling. These fibres, which have been especially investigated by v. Ebner and by Mummery, are difficult of demonstration in the fully calcified dentine; but in developing dentine and in dentine which is attacked by caries they are more easily shown.

The **pulp** (fig. 258) consists of a soft, somewhat jelly-like, connective tissue, containing many branched cells, a network of blood-vessels, and some nerve-fibres which pass into the pulp-cavity along with the blood-vessels by a minute canal at the apex of the fang. The superficial cells of the pulp form an almost continuous layer, like an epithelium (fig. 258, *od*, *od'*). They are known as *odontoblasts*, from having been concerned in the formation of the dentine. The nerve-fibres are said to pass eventually between the odontoblasts and to end in arborisa-

tions close to the dentine, but they have not been followed into the dentinal tubules.

The **crusta petrosa** (fig. 255, *1*) is a layer of lamellated bone including lacunæ and canaliculi, but without Haversian canals, at least

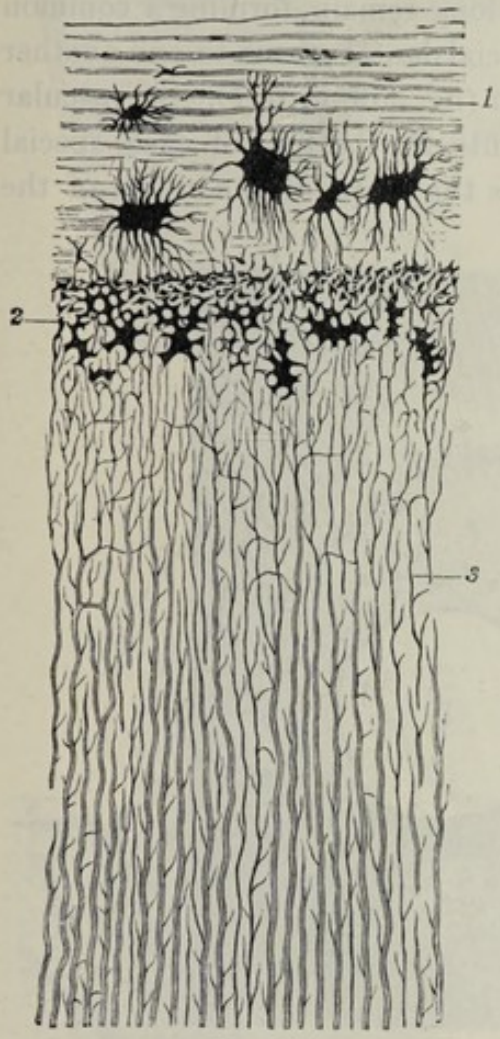


Fig. 255.

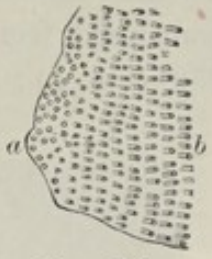


Fig. 256.

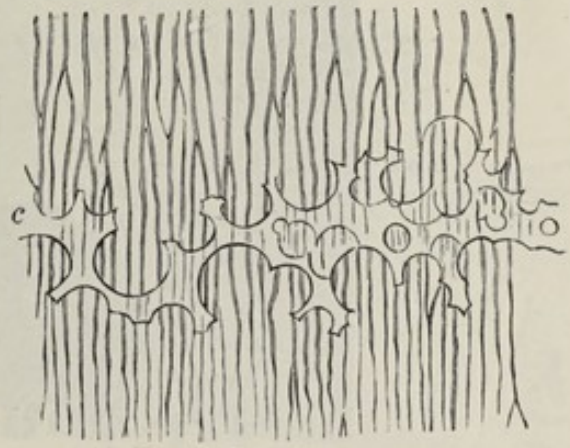


Fig. 257.

Fig. 255.—Section of fang, parallel to the dentinal tubules. (Magnified 300 diameters.) (Waldeyer.)

1, cement, with large bone lacunæ and indications of lamellæ; *2*, granular layer of Purkinje (interglobular spaces); *3*, dentinal tubules.

Fig. 256—Sections of dentinal tubules. (Fraenckel.)

a, cut across; *b*, cut obliquely. (About 300 diameters.)

Fig. 257.—A small portion of dentine with interglobular spaces. (Kölliker.) (350 diameters.)

c, portion of incremental line formed by the interglobular spaces, which are here filled up by a transparent material.

normally, in the human teeth. It is covered with periosteum (*dental periosteum*), which also lines the socket, and serves to fix the tooth securely.

Formation of the teeth.—The teeth are developed similarly to the hairs. A continuous thickening of the epithelium occurs along the line of the gums, and grows into the corium of the mucous membrane (*common dental germ* or *dental lamina*, fig. 259, A). At regular intervals

there is yet a further thickening and growth from the common germ into the tissue of the mucous membrane, each of these special rudiments, which are ten in number, swelling out below into a flask-shaped mass of cells, the *special dental germ* (fig. 259, B) of a milk tooth. The intermediate parts of the dental lamina long remain, forming a common epithelial strand uniting the several special dental germs to one another and to the epithelium covering the gum (fig. 259, C, D, *f*). A vascular *papilla* is continued from the corium into the bottom of each special germ (fig. 259, C, D, *p*); this papilla has the shape of the crown of the

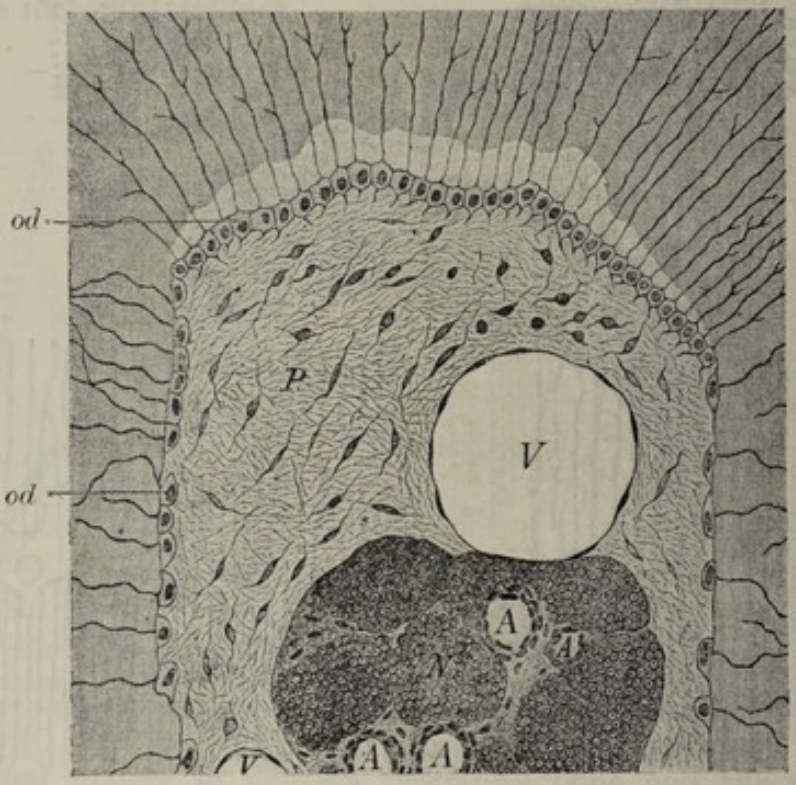


FIG. 258.—SECTION ACROSS THE ROOT OF A YOUNG TOOTH SHOWING THE PULP IN SITU. (Röse.)

P, pulp; *V*, *V*, veins; *A*, *A*, *A*, arterioles; *N*, nerve bundles; *od*, columnar odontoblasts still depositing dentine; *od'*, flattened odontoblasts which have ceased to form dentine.

future tooth. Each special dental germ, with its included papilla, presently becomes almost entirely cut off from the epithelium of the mouth, and surrounded by a vascular membrane—the *dental sac*. The papilla becomes transformed into the dentine and pulp of the future tooth, and the enamel is deposited upon its surface by the epithelial cells of the dental germ. The root of the tooth, with its covering of cement, is formed at a later period, when the tooth is beginning to grow up through the gum, by a gradual elongation of the base of the papilla. The shaping of this into the form of the root is determined by a growth of the epithelium of the edge of the enamel

germ, which extends in the form of a fold (the *epithelial sheath*) towards the future apex of each fang.

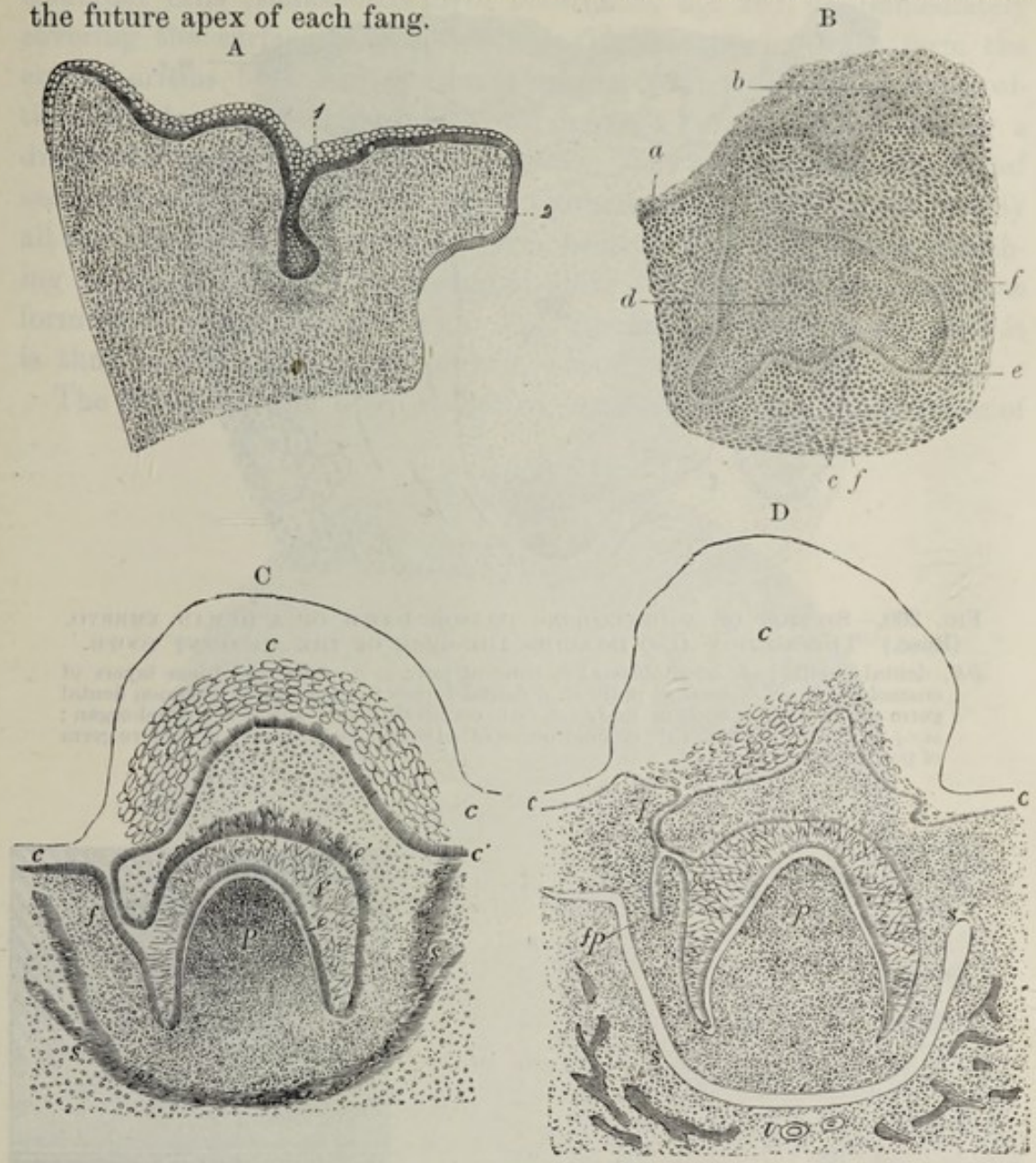


FIG. 259.

A. SECTION ACROSS THE UPPER JAW OF A FŒTAL SHEEP, 3 CENTIMETRES LONG. (Waldeyer.)

1, common dental lamina dipping down into the mucous membrane where it is half surrounded by a horseshoe-shaped more dense-looking tissue, the germ of the dentine and dental sac; *2*, palatine process of the maxilla.

B. SECTION FROM FŒTAL CALF SIMILAR TO THAT SHOWN IN A, BUT PASSING THROUGH ONE OF THE SPECIAL DENTAL GERMS HERE BECOMING FLASK-SHAPED. (Röse.)

c, epithelium of mouth, thickened at *b*, above special dental germ; *c*, papilla; *d*, special dental germ; *e*, enamel epithelium; *f*, dental sac.

C AND D. SECTIONS AT LATER STAGES THAN A AND B, THE PAPILLA HAVING BECOME FORMED AND HAVING INDENTED THE EPITHELIAL GERM, WHICH HAS AT THE SAME TIME GROWN PARTLY ROUND IT. (Kölliker.)

c, epithelium of gum, sketched in outline; *f*, neck of dental germ; *f'*, enamel-organ; *e*, its deeper columnar cells; *e'*, projections into the corium; *p*, papilla; *s*, dental sac forming. In D, the dental germ (*fp*) of the corresponding permanent tooth is seen.

Previously to the deposition of the enamel, the dental germ undergoes a peculiar transformation of its previously polyhedral epithelium-

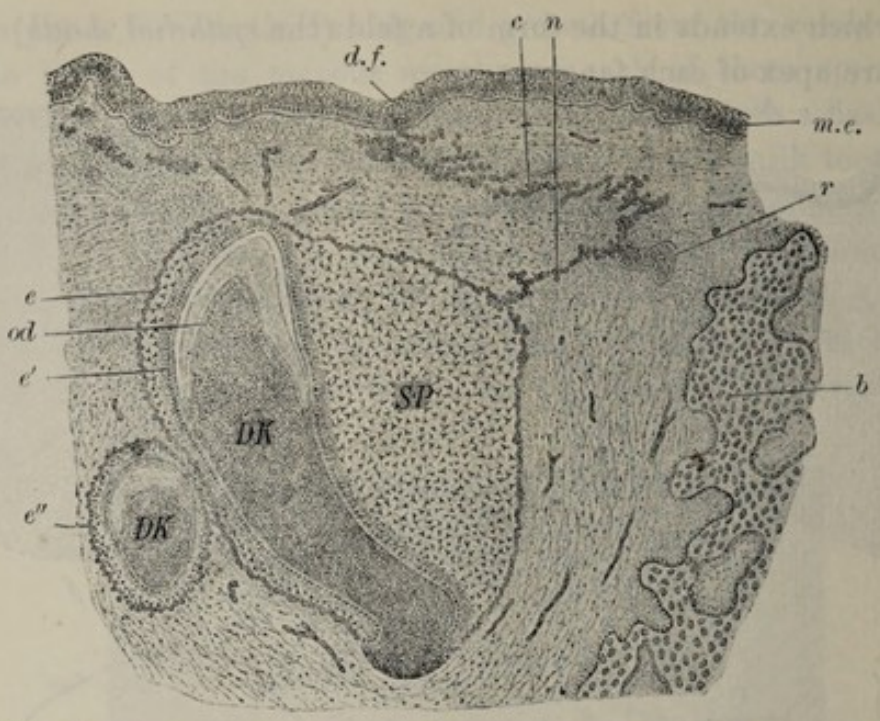


FIG. 260.—SECTION OF A DEVELOPING INCISOR TOOTH OF A HUMAN EMBRYO. (Röse.) THE SECTION ALSO INCLUDES THE GERM OF THE ADJACENT TOOTH.

DK, dental papilla; *od*, odontoblasts; *b*, bone of jaw; *e*, *e'*, outer and inner layers of enamel-organ; *S.P.*, enamel pulp; *d. f.* dental furrow; *c*, remains of common dental germ or lamina; *n*, neck or bridge of cells connecting this with the enamel-organ; *m.e.*, mouth-epithelium; *e''*, enamel organ of adjacent tooth germ; *r*, reserve germ of permanent tooth.

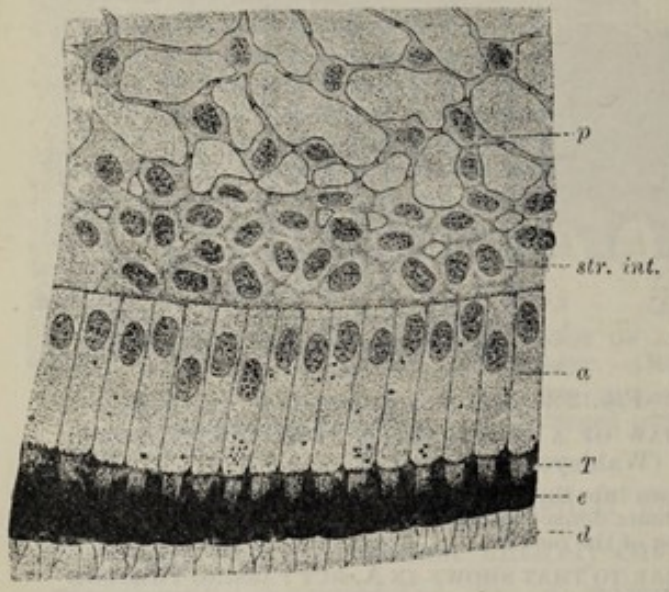


FIG. 261.

FIG. 262.

FIG. 261.—SECTION SHOWING THE STRUCTURE OF THE PART OF THE ENAMEL ORGAN WHICH LIES NEXT TO THE DENTINE. (Röse.)

d, dentine; *e*, newly formed enamel stained black by osmic acid; *T*, Tomes' processes from the ameloblasts, *a*; *str. int.*, stratum intermedium of enamel-organ; *p*, branched cells of enamel pulp.

FIG. 262.—DEVELOPING ENAMEL SHOWING AMELOBLASTS AND THE FIBROUS SUBSTANCE PRODUCED BY THESE CELLS, WHICH FORMS THE BASIS OF THE ENAMEL PRISMS. (From a photograph by Leon Williams.)

a, portions of the ameloblasts; *f*, fibrous basis of enamel prisms; *e*, calcified part of enamel.

cells into three layers of modified cells. One of these is a layer of columnar cells (*adamantoblasts* or *ameloblasts*, fig. 261, *a*), immediately covering the surface of the dentine. These columnar cells form the enamel-prisms by a fibrous formation (fig. 262) followed by a deposition of calcareous salts external to the cells (or, as some hold, by a direct calcification of their protoplasm). The cells next to the dental sac form a single layer of cubical epithelium (fig. 260, *e*), and nearly all the other cells of the dental germ become transformed into branching corpuscles (fig. 261, *p*) communicating by their processes, and thus forming a continuous network. This part of the dental germ, after it is thus modified, is known as the *enamel organ*.

The *dentine* of the tooth is formed by calcification of the surface of

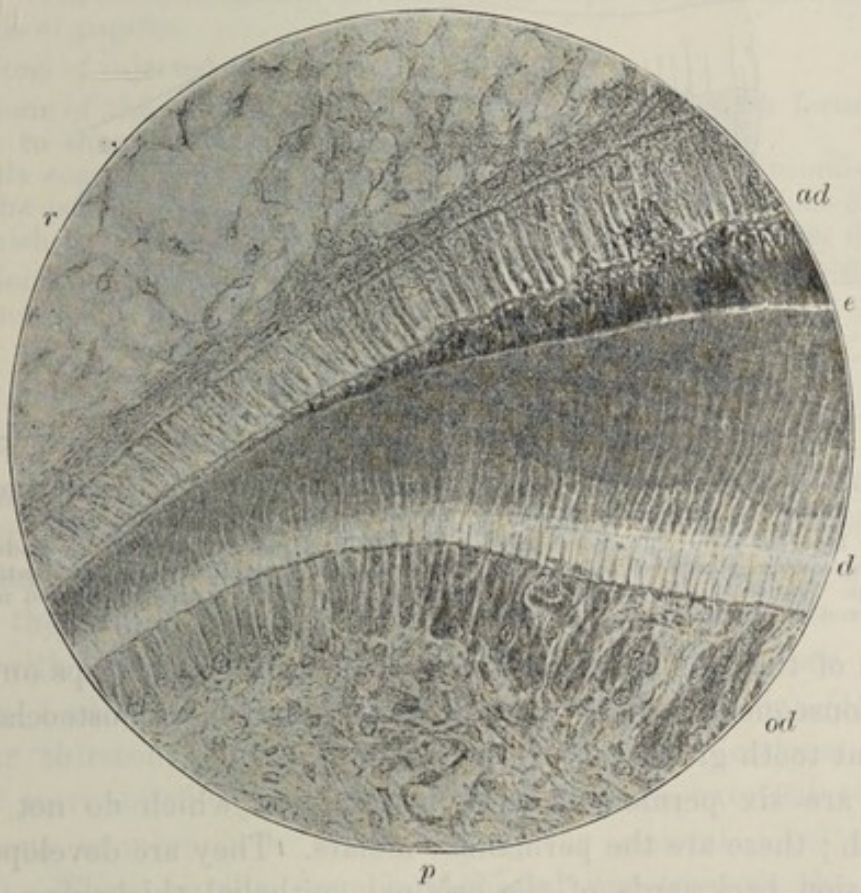


FIG. 263.—SECTION OF PART OF A DEVELOPING TOOTH. (From a photograph by Leon Williams.)

d, dentine; *od*, odontoblasts sending their processes into the dentine tubercules; *p*, branched cells of the pulp; *e*, developing enamel; *ad*, ameloblasts; *r*, reticulum or spongework of the enamel organ.

the papilla. At this surface there is a well-marked layer of odontoblasts (fig. 263, *od*, fig. 264, *c*), and these produce a layer of dentinal matrix which forms a sort of cap to the papilla, and which soon becomes calcified by the deposition of globules of calcareous matter. Processes of the odontoblasts remain in the dentine as it is forming, and thus the dentinal tubules are produced. Subsequently other layers

of dentine are formed within the first by a repetition of the same process, and in this way the papilla gradually becomes calcified. A part, however, remains unaltered in the centre of the tooth, and with its covering of odontoblasts forms the pulp.

The ten milk-teeth are formed in each jaw in the manner described. These, however, become lost within a few years after birth, and are replaced by permanent teeth in much the same way that a new succession of hairs occurs. A small outgrowth takes place at an early period from the dental germ close to each of the milk-teeth (fig. 259, D, *fp*), and this eventually becomes the germ of the corresponding permanent tooth. It gradually enlarges, acquires a papilla, forms an enamel organ: in short, passes through the same phases of development as

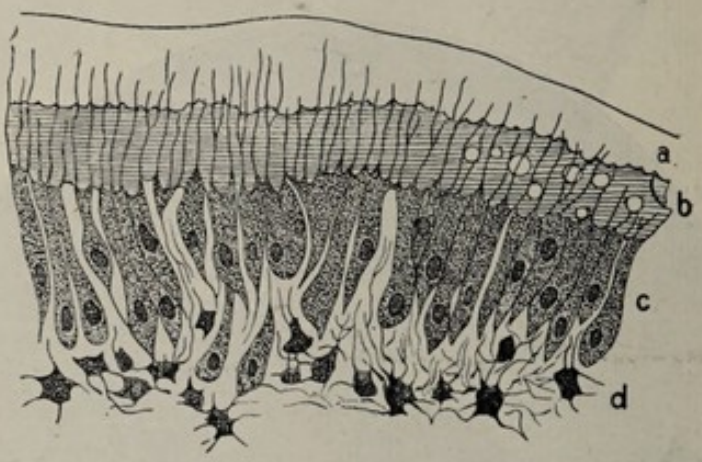


FIG. 264.—PART OF SECTION OF DEVELOPING TOOTH OF YOUNG RAT, SHOWING THE MODE OF DEPOSITION OF THE DENTINE. (Highly magnified.)

a, outer layer of fully calcified dentine; *b*, uncalcified matrix, with a few nodules of calcareous matter; *c*, odontoblasts with processes extending into the dentine; *d*, pulp. The section is stained with carmine, which colours the uncalcified matrix, but not the calcified part.

the germ of the milk-tooth; and when the milk-tooth drops out of the jaw in consequence of the absorption of its roots (by osteoclasts) the permanent tooth grows up into its place.

There are six permanent teeth in each jaw which do not succeed milk-teeth; these are the permanent molars. They are developed from an extension backwards of the original epithelial thickening or common dental germ and by the downgrowth from this into the corium of three successive special germs at comparatively long intervals of time. Within these the tissues of the permanent molars become formed in a manner exactly similar to that in which the milk-teeth are developed.

LESSON XXXI.

THE TONGUE; THE GUSTATORY ORGANS; THE MUCOUS MEMBRANE OF THE MOUTH; THE PHARYNX AND ŒSOPHAGUS.

1. Sections of the tongue vertical to the surface, stained with hæmatoxylin and eosin. The sections should be taken from different parts and include *all* three kinds of papillæ.

2. Sections of injected tongue.

3. Sections of the papilla foliata of the rabbit, stained with hæmatoxylin and eosin to show the taste-buds *in situ*.

The cells composing the taste-buds are studied by teasing osmic preparations of the papilla foliata; the nerve-endings are seen in sections of papilla foliata which have been treated by Golgi's osmic-bichromate-silver method.

4. Sections of the pharynx and of the œsophagus stained with hæmatoxylin and eosin.

The Tongue.

The **tongue** is mainly composed of striated muscular fibres, running some longitudinally, and others transversely. It is covered by a mucous membrane, the epithelium of which, like that of the rest of the mouth, is thick and stratified, and conceals microscopic papillæ (fig. 265) like those of the skin. Besides these, the upper surface of the organ is covered with larger papillæ, which give it a rough appearance. These, which are termed the *lingual papillæ*, are of three kinds: (1) About twelve or thirteen comparatively large circular projections, each of which is surrounded by a narrow groove (fossa), external to which the mucous membrane is raised above the general level (vallum) (fig. 266). These papillæ form a **V**-shaped line towards the back of the tongue; they receive filaments of the glosso-pharyngeal nerve, and have taste-buds in the epithelium which covers their sides, and in that of the side of the vallum. They are known as the *circumvallate papillæ*. (2) All the rest of the papillary surface of the tongue is covered by *conical papillæ*, so named from the conical pointed cap of epithelium which is borne by each; sometimes this cap is fringed with fine epithelial filaments, when they are termed *filiform* (fig. 267). (3) Scattered here and there amongst the conical papillæ are other larger papillæ, the *fungiform* (fig. 268). These are very vascular,

FIG. 265.—SECTION OF MUCOUS MEMBRANE OF MOUTH, SHOWING THREE MICROSCOPIC PAPILLÆ AND STRATIFIED EPITHELIUM. THE BLOOD-VESSELS HAVE BEEN INJECTED. (Toldt.)

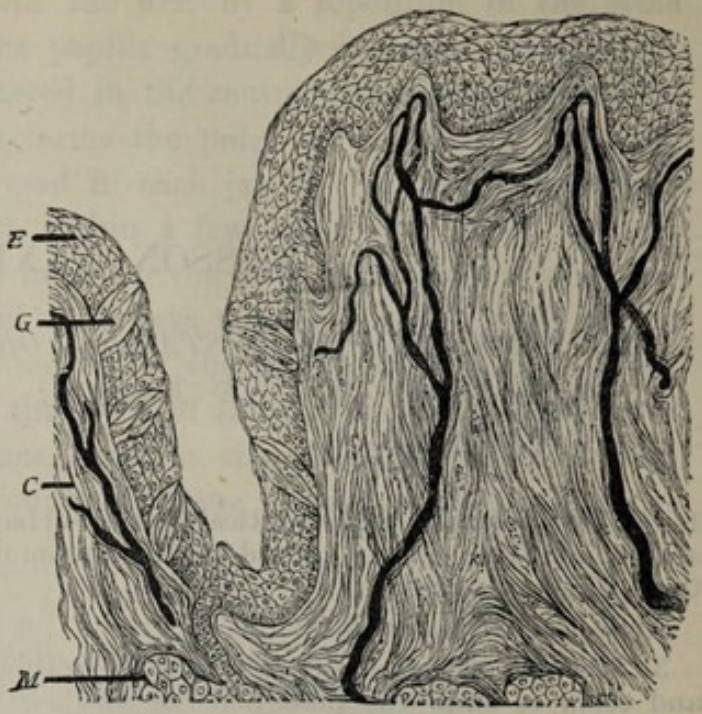


FIG. 266.—SECTION OF CIRCUMVALLATE PAPILLA, HUMAN. THE FIGURE INCLUDES ONE SIDE OF THE PAPILLA AND THE ADJOINING PART OF THE VALLUM. (Magnified 150 diameters.) (Heitzmann.)

E, epithelium; *G*, taste-bud; *C*, corium with injected blood-vessels; *M*, gland with duct.

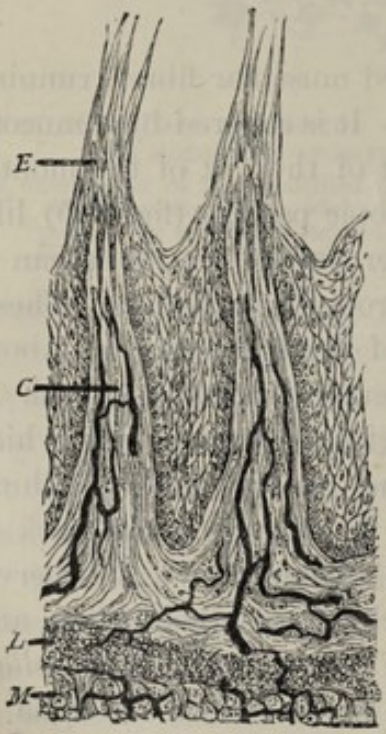


FIG. 267.—SECTION OF TWO FILIFORM PAPILLÆ, HUMAN. (Heitzmann.)

E, epithelium; *C*, corium; *L*, lymphoid tissue; *M*, muscular fibres of tongue.

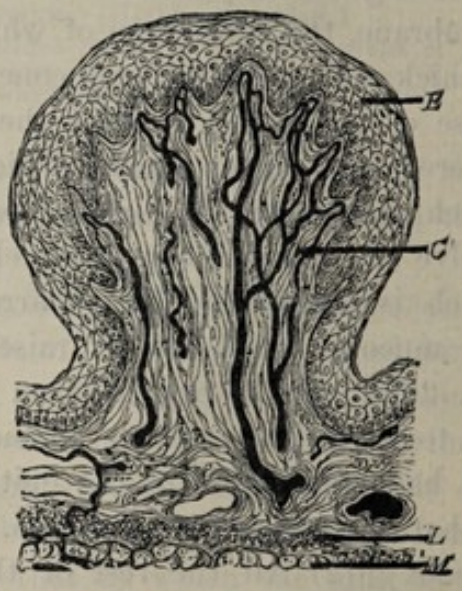


FIG. 268.—SECTION OF FUNGIFORM PAPILLA, HUMAN. (Heitzmann.) (Letters as in previous figure.)

and lie partly embedded in little depressions of the mucous membrane.

Small tubular glands may be seen between the superficial muscular

fibres sending their ducts to the surface. Most of them secrete mucus, but those which open into the trenches of the circumvallate papillæ, and a few others elsewhere, yield a serous secretion (*glands of Ebner*).

The mucous membrane at the back of the tongue contains a large amount of lymphoid tissue.

The Taste-Buds.

The minute gustatory organs which are known as *taste-buds* may be seen in sections which pass through the papillæ vallatæ or the papillæ

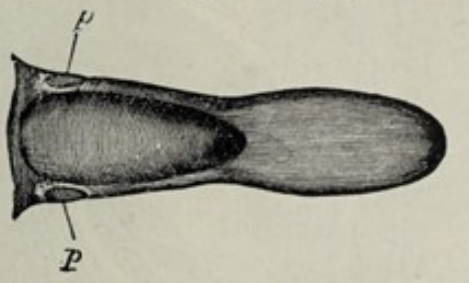


Fig. 269.—Tongue of rabbit, showing the situation of the papillæ foliatæ, *p*.

fungiformes; they are also present here and there in the epithelium of the general mucous membrane of the tongue, especially at the back and sides, and occur also upon the under surface of the soft palate, and on

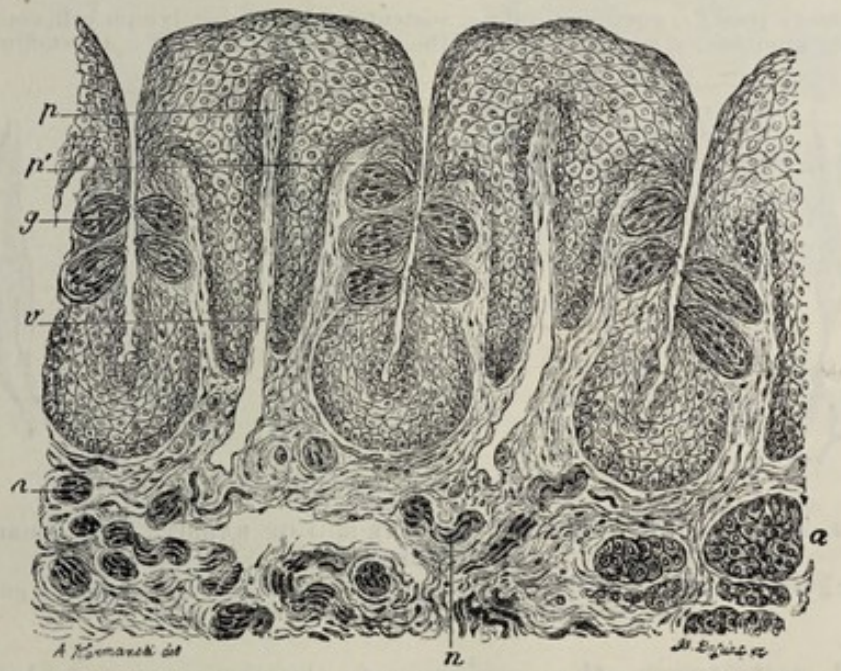


Fig. 270.—Vertical section of papilla foliata of the rabbit, passing across the foliæ. (Ranvier.)

p, central lamina of the corium; *v*, section across a vein, which traverses the whole length of the folia; *p'*, lateral lamina in which the nerve-fibres run; *g*, taste-bud; *n*, sections of nerve-bundles; *a*, serous gland.

the epiglottis. But they are most easily studied in the papillæ foliatæ of the rabbit, two small oval areas lying on either side of the back of the tongue and marked transversely with a number of small ridges or

laminæ with intervening furrows (see fig. 269). Sections across the ridges show numerous taste-buds embedded in the thick epithelium which clothes their sides (fig. 270).

The taste-buds are ovoid clusters of epithelium-cells which lie in cavities in the stratified epithelium (fig. 271). The base of the

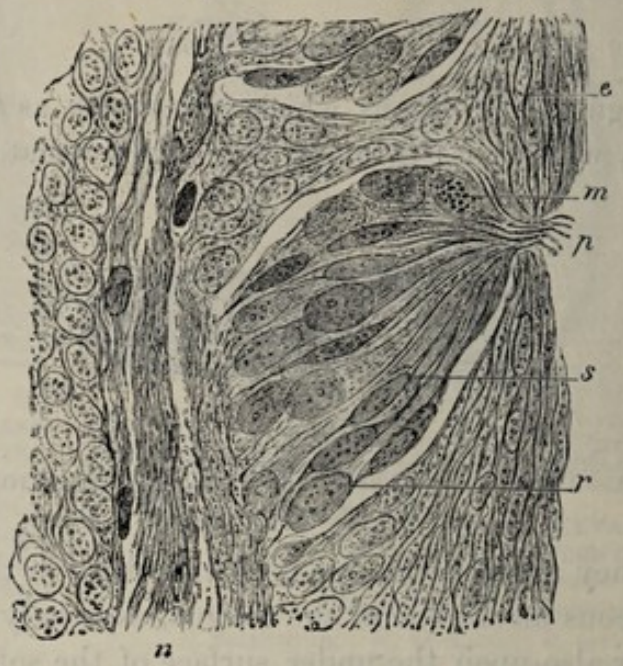


FIG. 271.—SECTION THROUGH THE MIDDLE OF A TASTE-BUD. (Ranvier.)
p, gustatory pore; *s*, gustatory cell; *r*, sustentacular cell; *m*, lymph cell, containing fatty granules; *e*, superficial cells of the stratified epithelium; *n*, nerve-fibres.

FIG. 272.—VARIOUS CELLS FROM TASTE-BUD OF RABBIT. (Engelmann.)
(600 diameters.)
a, four gustatory cells from central part; *b*, two sustentacular cells, and one gustatory cell, in connection; *c*, three sustentacular cells.

taste-bud rests upon the corium of the mucous membrane, and receives a branch of the glosso-pharyngeal nerve; the apex is narrow and communicates with the cavity of the mouth by a small pore in the superficial epithelium (*gustatory pore*, fig. 271, *p*).

The cells which compose the taste-buds are of two kinds, viz.: 1. The *gustatory cells* (fig. 272, *a*), which are delicate fusiform or bipolar cells composed of the cell-body or nucleated enlargement, and

of two processes, one distal, the other proximal. The distal process is nearly straight, and passes towards the apex of the taste-bud, where it terminates in a small, highly refracting cilium-like appendage, which projects into the gustatory pore above mentioned, but the cell-body does not itself quite reach the pore. The proximal process is more delicate than the other, and is often branched and varicose. The nerve-fibres (fig. 273) terminate in ramifications amongst the gusta-

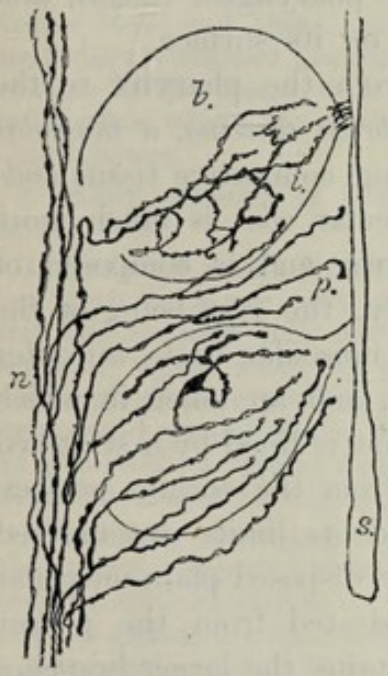


Fig. 273.

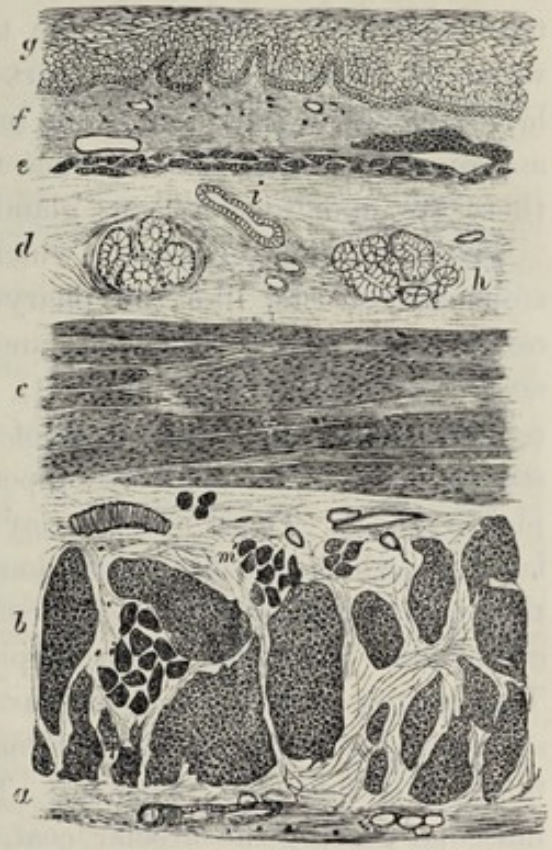


Fig. 274.

Fig. 273.—Nerve-endings in taste-buds. (G. Retzius.)

n, nerve-fibres; *b*, taste-buds in outline; *i*, ending of fibrils within taste-bud; *p*, ending in epithelium between taste-buds; *s*, sulcus into which the gustatory pores open.

Fig. 274.—Section of the human œsophagus. (Drawn by V. Horsley.)

The section is transverse, and from near the middle of the gullet. *a*, fibrous covering; *b*, divided fibres of the longitudinal muscular coat; *c*, transverse muscular fibres; *d*, submucous or areolar layer; *e*, muscularis mucosæ; *f*, papillæ of mucous membrane; *g*, laminated epithelial lining; *h*, mucous gland; *i*, gland duct; *m'*, striated muscular fibres in section.

tory cells (Retzius). 2. The *sustentacular cells* (fig. 272, *c*), which are elongated cells, mostly flattened, and pointed at their ends; they lie between the gustatory cells, which they thus appear to support, and in addition they form a sort of envelope or covering to the taste-bud. Between the cells of the taste-bud lymph-corpuscles are often seen, having probably wandered hither from the subjacent mucous membrane.

The Pharynx and Œsophagus.

The **pharynx** is composed of a *fibrous membrane*, which is encircled by striated muscles, the *constrictors*, and lined by *mucous membrane*. The mucous membrane is lined in the upper part of the pharynx and on the upper surface of the soft palate with ciliated epithelium, which is continuous with that of the nostrils, and through the Eustachian tube with that of the tympanum. Below the level of the soft palate the epithelium is stratified like that of the mouth and gullet, into which it passes. In certain parts the mucous membrane contains a large amount of lymphoid tissue (especially at the back, where it forms a projection which is sometimes termed the pharyngeal tonsil), and there are numerous mucous glands opening on its surface.

The **œsophagus** or gullet, which passes from the pharynx to the stomach, consists, like the pharynx, of a *fibrous covering*, a *muscular coat*, a lining *mucous membrane*, and intervening connective tissue (*submucous* or *areolar coat*) (fig. 274). The muscular coat is much more regularly arranged than that of the pharynx, and is composed of striated muscle in about its upper third only, the rest being of the plain variety. There are two layers of the muscular coat—an outer layer, in which the fibres run longitudinally, and an inner, in which they course circularly. The mucous membrane is lined by a stratified epithelium, into which microscopic papillæ from the corium project. The corium is formed of areolar tissue, and its limits are marked externally by a narrow layer of longitudinally disposed plain muscular fibres, the *muscularis mucosæ*. This is separated from the proper muscular coat by the areolar coat, which contains the larger branches of the blood-vessels and lymphatics, and also most of the mucous glands of the membrane. The ducts of these glands are large and usually pass through a nodule of lymphoid tissue. Lymph-cells from this tissue infiltrate the epithelium of the duct and may pass out into the duct lumen.

LESSON XXXII.

THE SALIVARY GLANDS.

1. STUDY sections of the submaxillary gland of a dog. The gland may be hardened in alcohol and stained with hæmatoxylin, eosin, or with iron hæmatoxylin by Heidenhain's method. Notice the acini filled with clear (mucous-secreting) cells, the nuclei of which usually lie near the basement-membrane. Notice here and there, outside the clear cells, demilunes or crescents of small darkly stained granular-looking (albuminous) cells. Observe also the sections of the ducts with their striated columnar epithelium. If possible find a place where one of the ducts is passing into the alveoli. Sketch under a high power.

2. Study sections of the parotid and sublingual glands prepared in a similar way.

3. Examine small pieces of both submaxillary and parotid gland of the dog fresh in 2 per cent. salt solution. In the submaxillary gland notice that the alveolar cells are swollen out with large granules or droplets of mucigen, which swell up in water to form large clear vacuoles. Dilute acids and alkalies produce a similar change but more rapidly. The cells of the parotid gland are also filled with granules, but they are smaller. They are also swollen up and dissolved by these fluids. Make a sketch from each preparation under a high power.

4. To study the changes which the alveolar cells undergo during secretion, pilocarpine is injected subcutaneously into an animal in sufficient amount to produce copious salivation ; after half an hour the animal is killed and its salivary glands are examined as in preparation 3. The granules are not seen in preparations that have been in alcohol, but osmic acid preserves them moderately well ; they are best seen in the fresh tissue.

The **salivary glands** may be looked upon as typical of secreting glands in general. They are composed of a number of *lobules* bound together loosely by connective tissue. Each small lobule is formed of a group of saccular or somewhat tubular *alveoli* or *acini* from which a duct passes, and this, after uniting with other ducts to form larger and larger tubes, eventually leaves the gland to open upon the surface of the mucous membrane of the mouth.

The alveoli are inclosed by a basement-membrane, which is reticular (fig. 275). It may be shown by teasing the fresh gland substance in water (Langley). This basement-membrane is continued along the ducts. Within it is the epithelium, which in the alveoli is composed of polyhedral cells (fig. 276, *a*), but in the ducts is regularly columnar, except in that part of the duct which immediately opens into the

alveoli (*junctional part*); in this it is flattened (*d'*). The columnar epithelium of the ducts is peculiar, in that the cells show a distinction into two unequal zones, an outer, larger, striated zone, and an inner, smaller, granular one (fig. 276, *d*).

The cells of the alveoli differ according to the substance they secrete. In alveoli which secrete mucus, such as all the alveoli of the dog's

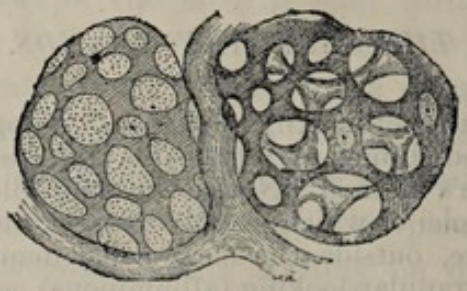


FIG. 275.—MEMBRANA PROPRIA OF TWO ALVEOLI ISOLATED. (R. Heidenhain.)
The preparation is taken from the orbital gland of the dog, which is similar in structure to a mucous salivary gland.

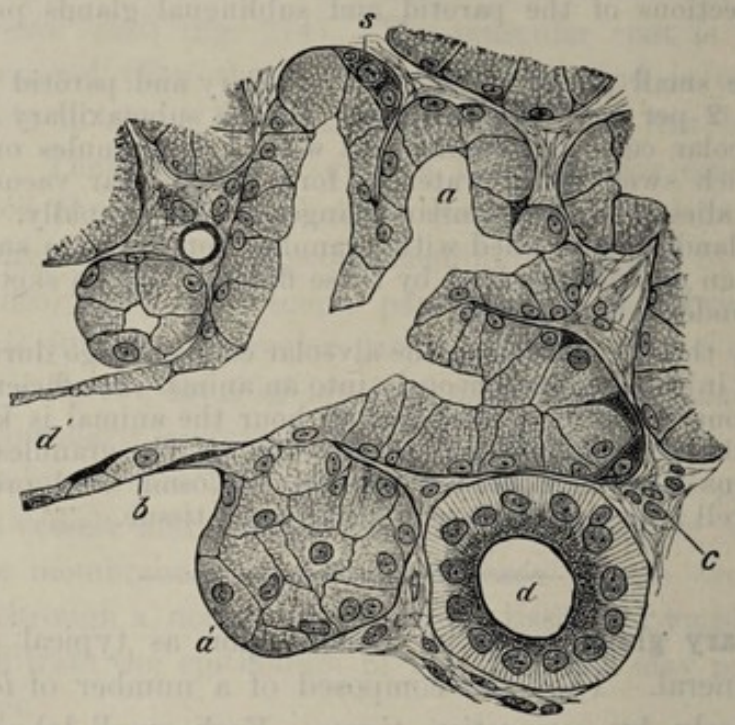


FIG. 276.—SECTION OF THE SUBMAXILLARY GLAND OF THE DOG, SHOWING THE COMMENCEMENT OF A DUCT IN THE ALVEOLI. (Magnified 425 diameters.)
a, one of the alveoli, several of which are in the section shown grouped around the commencement of the duct *d'*; *a'*, an alveolus, not opened by the section; *b*, basement-membrane in section; *c*, interstitial connective tissue of the gland; *d*, section of a duct which has passed away from the alveoli, and is now lined with characteristically striated columnar cells; *s*, semilunar group of darkly stained cells at the periphery of an alveolus.

submaxillary (fig. 277), and some of the alveoli of the same gland in man (fig. 279), the cells, if examined in normal saline solution or after hardening with alcohol, are clear and swollen. But if examined rapidly in serum, or in solutions of salt of from 2 to 5 per cent., they are seen to be occupied by large and distinct granules (Langley),

formed of a substance which is known as *mucigen* (fig. 281, *a*). The mucigen is dissolved out of the cell and discharged as *mucus* into the lumen of the alveolus and into the ducts, when the gland is stimulated to activity. The cells are known as *mucous cells.* But in each alveolus there are some smaller cells which do not contain mucigen, but small

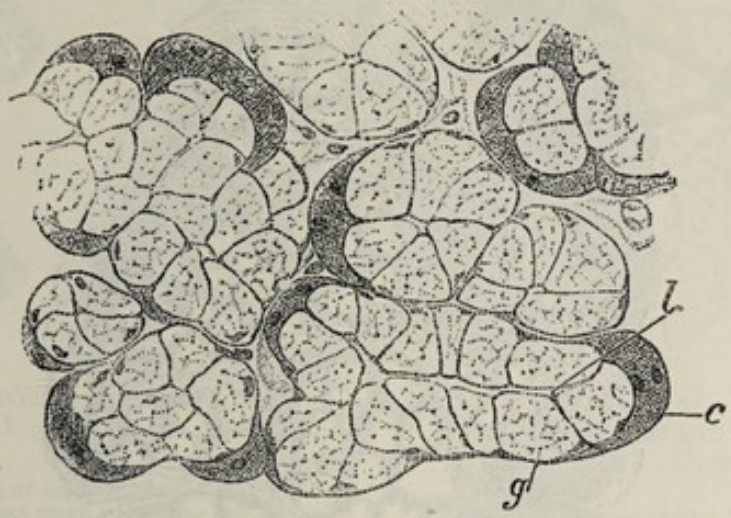


FIG. 277.—SECTION OF A DOG'S SUBMAXILLARY, AFTER A PROLONGED PERIOD OF REST. (Ranvier.)

l, lumen of alveolus; *g*, mucus-secreting cells; *c*, crescent, formed of albuminous cells.

albuminous granules, and these often form crescentic groups which lie next to the basement-membrane (figs. 276, *s*, 277, *c*). These are the so-called *crescents of Gianuzzi*; their constituent cells are known also as

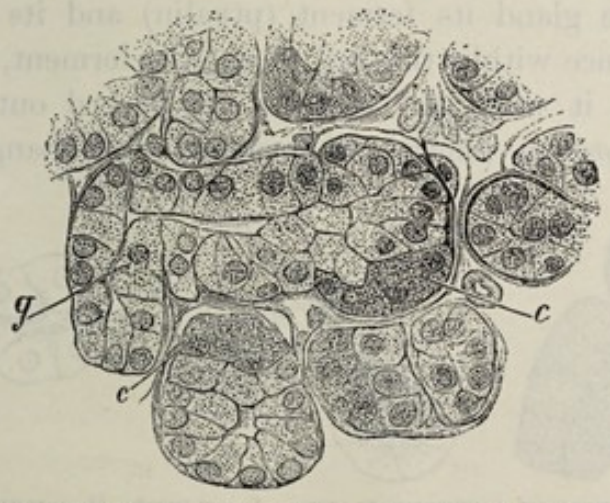


FIG. 278.—SUBMAXILLARY OF DOG, AFTER A PERIOD OF ACTIVITY. (Ranvier.)

The mucus-secreting cells, *g*, have discharged their secretion, and are smaller and stain better; the albuminous cells of the crescents, *c*, are enlarged.

marginal or *albuminous cells.* Special diverticula pass from the lumen of the alveoli between the mucous cells to penetrate to the crescents and to branch amongst their constituent cells; these diverticula are best shown by the Golgi method of staining (fig. 282). In alveoli, on the other hand, which do not secrete mucus, but watery or albuminous

saliva, such as the parotid in all animals, and some of the alveoli of the human submaxillary, all the cells are filled with small granules when the gland is at rest, which do not swell with water nor form mucin; they appear to be albuminous in nature, and probably yield to the

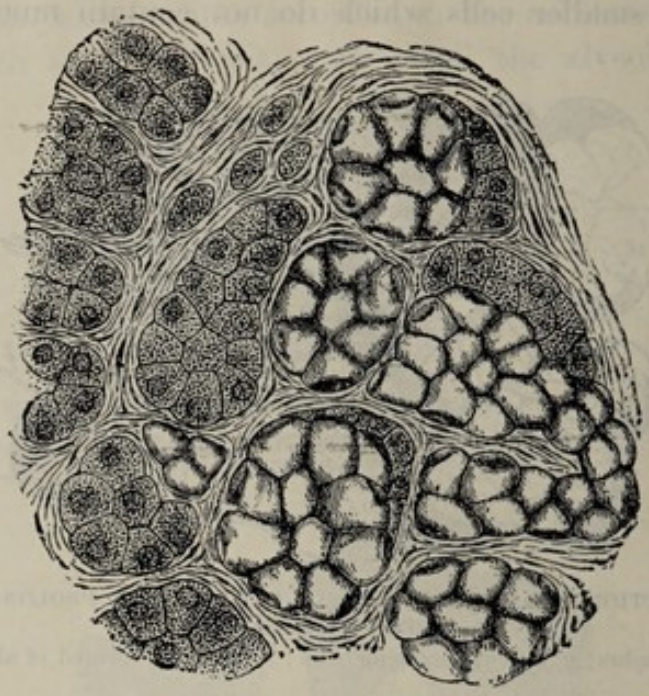


FIG. 279.—SECTION OF PART OF THE HUMAN SUBMAXILLARY GLAND. (Heidenhain.)
To the right of the figure is a group of mucous alveoli; to the left a group of serous alveoli.

secretion of the gland its ferment (ptyalin) and its albumen. The granular substance within the cell is not the ferment, but the ferment is formed from it when the secretion is poured out. Hence it has been termed *zymogen* (mother of ferment). As Langley showed, the

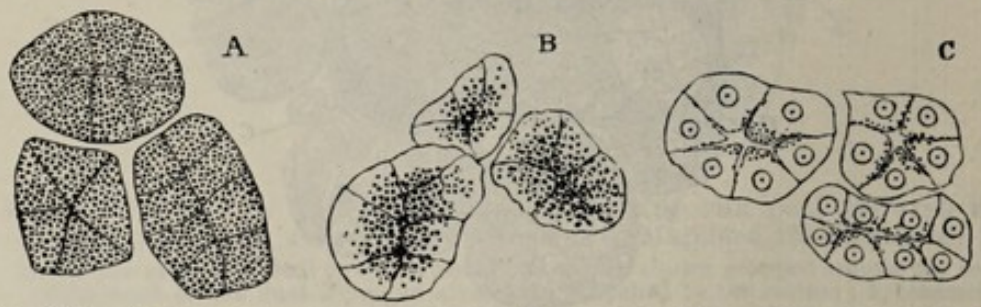


FIG. 280.—ALVEOLI OF A SEROUS GLAND. A, AT REST. B, AFTER A SHORT PERIOD OF ACTIVITY. C, AFTER A PROLONGED PERIOD OF ACTIVITY. (Langley.)
In A and B the nuclei are obscured by the granules of zymogen.

outer part of each cell becomes clear and free from granules after secretion (fig. 280).

The largest ducts have a wall of connective tissue outside the basement-membrane, and also a few plain muscular cells. The blood-vessels of the salivary gland form a capillary network around each

alveolus. The lymphatics commence in the form of lacunar vessels encircling the alveoli. The nerve-fibres, which are derived both from the cerebro-spinal nerves and from the sympathetic, have only recently

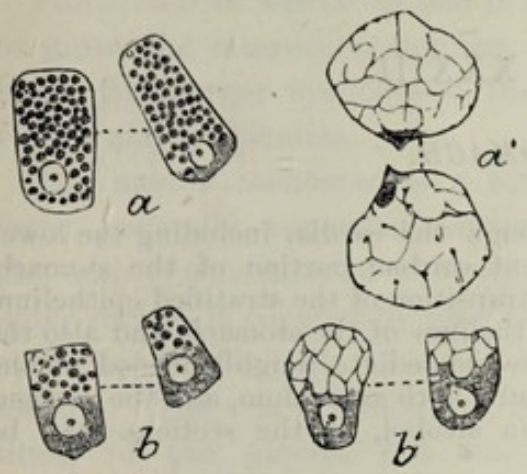


FIG. 281.—MUCOUS CELLS FROM FRESH SUBMAXILLARY GLANDS OF THE DOG. (Langley.)

a, from a resting or loaded gland; *b*, from a gland which has been secreting for some time; *a'*, *b'*, similar cells which have been treated with dilute acid.

FIG. 282.—ALVEOLI OF THE SUBMAXILLARY GLAND OF THE DOG. (G. Retzius.) Chromate of silver method.

The extensions of the lumen into the crescents of Gianuzzi are shown, and also the endings of the nerve-fibrils.

been satisfactorily traced to their termination; they ramify as fine varicose fibrils amongst the alveolar cells (fig. 282). The salivary glands are developed as buds from the epithelium of the buccal cavity.

LESSON XXXIII.

THE STOMACH.

1. Vertical longitudinal sections through the cardia, including the lower end of the œsophagus and the adjacent cardiac portion of the stomach. These are intended to show the abrupt transition of the stratified epithelium of the œsophagus into the columnar epithelium of the stomach, and also the character of the gastric glands in the immediate neighbourhood of the cardia. The tissue may be stained in bulk with carmalum, and the sections passed through picric acid dissolved in alcohol, or the sections may be stained with hæmatoxylin and eosin.

2. Sections of the fundus of the dog's stomach, cut perpendicularly to the surface of the mucous membrane. The tissue is stained with hæmalum or methyl-blue, and eosin, and the sections are mounted in Canada balsam.

In these sections the general arrangement of the coats of the stomach is to be studied, and sketches are to be made under a low power illustrating this arrangement, and others under a high power showing the structure of the glands of the mucous membrane.

Measure the whole thickness of the mucous membrane, the thickness of the muscular coat, the size of the columnar epithelium-cells of the surface, and that of the cells in the deeper parts of the glands.

3. Sections of the mucous membrane of the fundus, cut parallel to the surface.

These sections will show better than the others the arrangement of the cells in the glands.

4. Vertical sections of the mucous membrane from the pyloric region of the dog's stomach. If the section is taken longitudinally through the pylorus, the transition of the gastric glands into the glands of Brunner of the duodenum will be made manifest. Make a sketch under a low power of one of the glands in its whole length, filling up some of the details with the high power.

5. Study the arrangement of the blood-vessels of the stomach in vertical sections of the wall of an organ the vessels of which have been injected.

The wall of the **stomach** consists of four coats, which, enumerated from without in, are as follows, viz.: *serous*, *muscular*, *areolar*, or *sub-mucous*, and *mucous membrane*.

The *serous coat* is a layer which is derived from the peritoneum. It is deficient only along the lines of the lesser and greater curvatures.

The *muscular coat* consists of three layers of plain muscular fibres. Of these the bundles of the outer layer run longitudinally, those of the middle layer circularly, and those of the inner layer obliquely. The longitudinal and circular bundles become thicker and stronger towards the pylorus, at which they pass into the corresponding layers

of the small intestine; at the pylorus itself the circular layer is greatly thickened to form the *sphincter muscle*. The oblique fibres are only present in the left or cardiac part of the stomach.

The *areolar* or *submucous coat* is a layer of areolar tissue, which serves to unite the mucous membrane loosely to the muscular coat; in it ramify the larger branches of the blood-vessels and lymphatics.

The *mucous membrane* is a soft thick layer, generally somewhat corrugated in the empty condition of the organ. Its inner surface is covered by long columnar epithelium cells, all of which secrete mucus. They are prolonged into the ducts of the glands, but when these divide to form the tubules the cells become shorter (cubical). The thickness of the mucous membrane is due to the fact that it is largely made up of long tubular glands, which open upon the inner surface. Between the glands the mucous membrane is formed of retiform with some lymphoid tissue. Externally it is bounded by the *muscularis mucosæ*, which consists of an external longitudinal and an inner circular layer of plain muscular fibres.

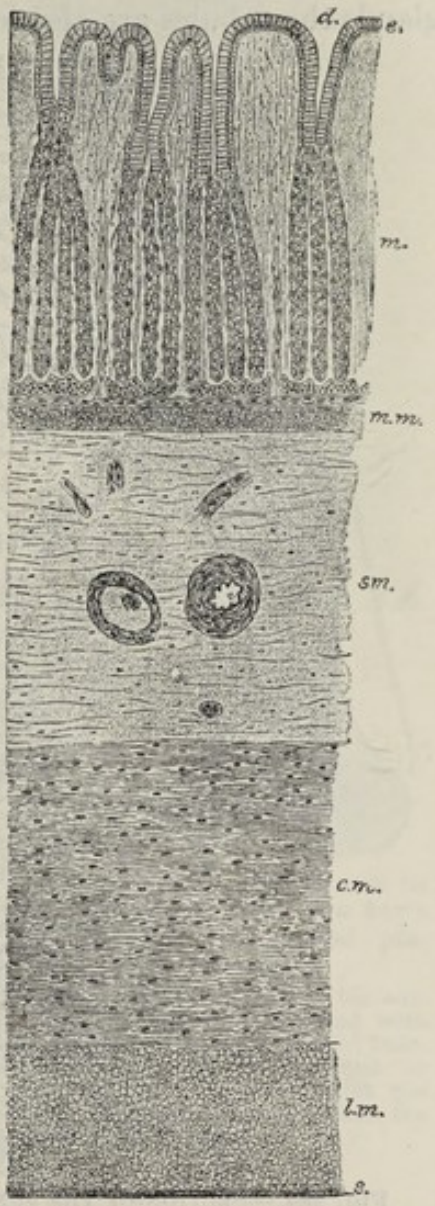


FIG. 283.—DIAGRAM OF SECTION THROUGH THE COATS OF THE STOMACH. (Mall.)

m, mucous membrane; *e*, epithelium; *d*, orifice of gland-duct; *m.m.*, muscularis mucosæ; *sm.*, submucosa; *c.m.*, circular muscular layer; *l.m.*, longitudinal muscular layer; *s*, serous coat.

Gastric glands.—These are formed of a basement-membrane lined with epithelium. Each gland consists of *secreting tubules* from one to four in number, opening at the surface into a larger tube, the *duct* of the gland. The duct is in all cases lined by columnar epithelium of the same character as that which covers the inner surface of the mucous membrane, but the epithelium of the secreting tubules is different from this, and also differs somewhat in the glands of different regions of the organ. The following varieties are met with:—

(1) *Glands of the cardia.*—These are found close to the œsophageal opening or cardia (fig. 284); they are long and usually simple. Their secreting tubules are lined by cells which are granular in appearance and of a short columnar form, and of the same nature throughout the

length of the tubule, except near the orifice (duct), where they give place to columnar mucus-secreting cells. These glands were first described in the kangaroo, but have since been shown to be of general occurrence.

(2) *Glands of the fundus* or *oxyntic glands* (figs. 285, 286, 287).—In these glands the tubules are also long, and the duct short. The epithelium of

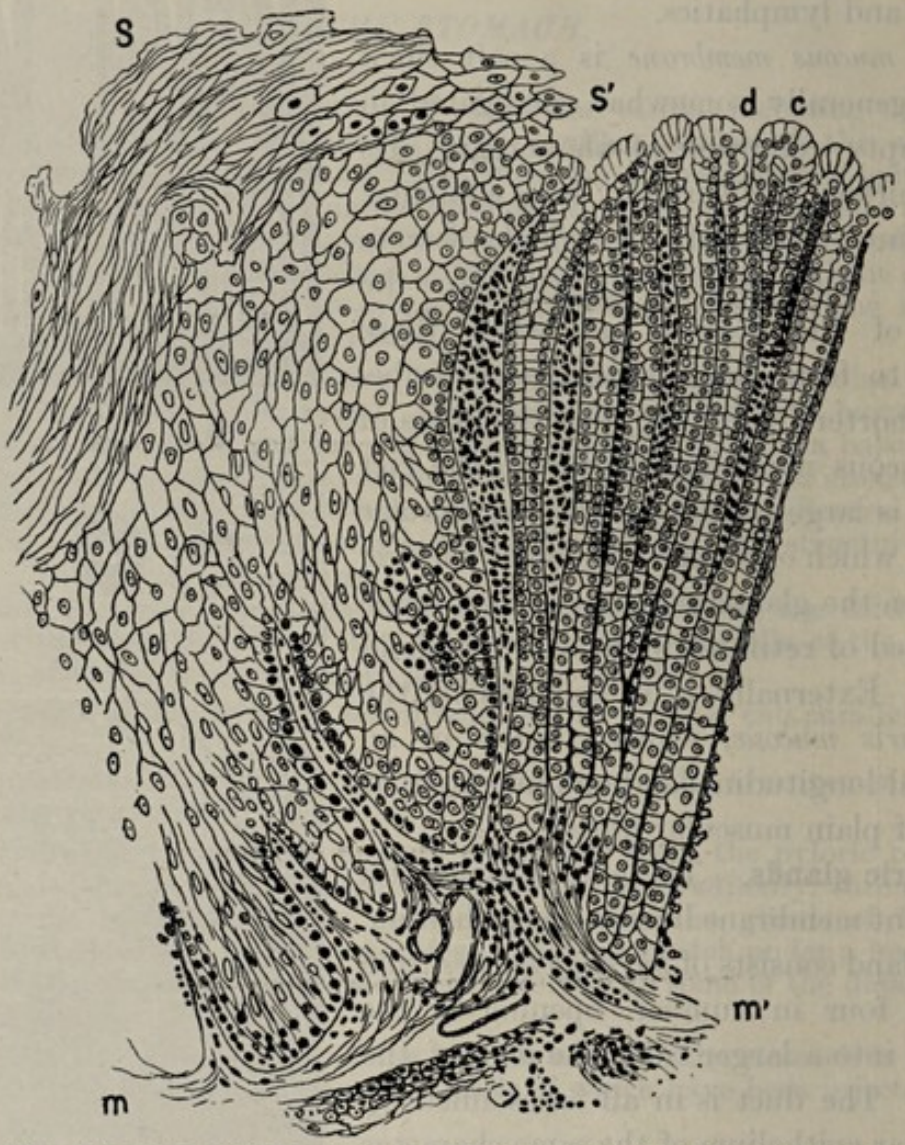
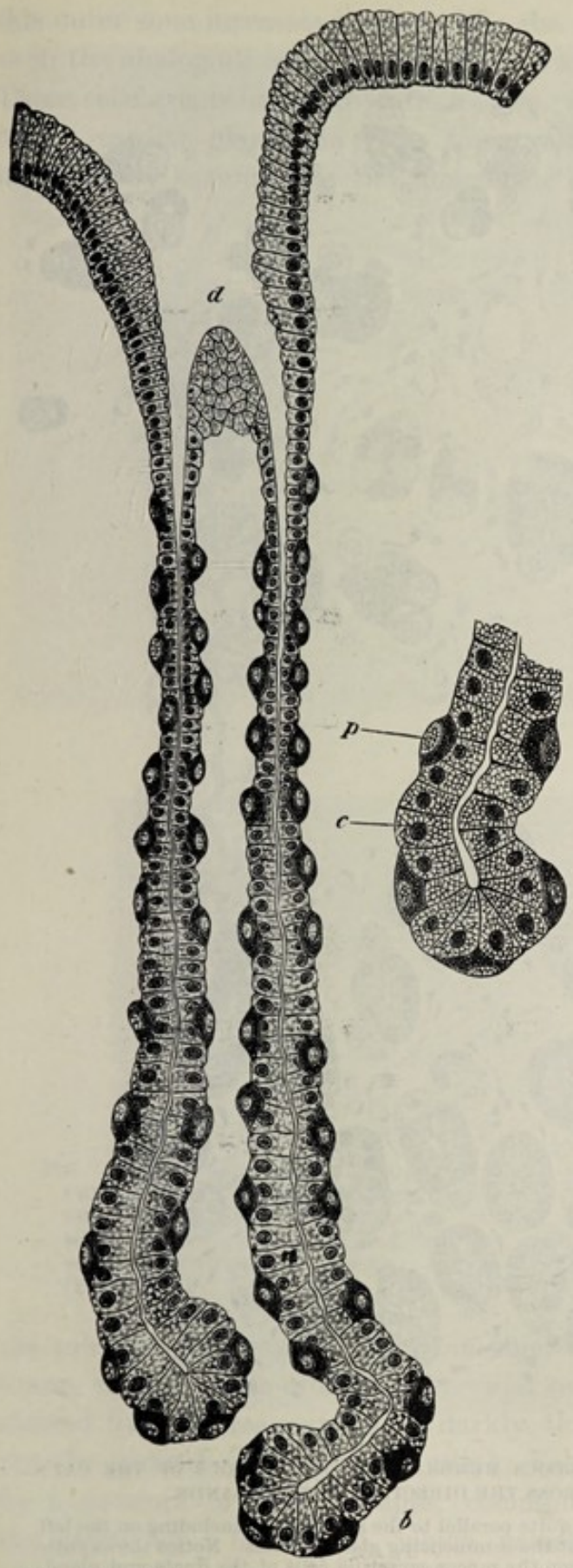


FIG. 284.—SECTION OF THE JUNCTION OF THE ŒSOPHAGEAL AND GASTRIC MUCOUS MEMBRANE OF THE KANGAROO. (135 diameters.)

S, stratified epithelium continuous with that of œsophagus abruptly discontinued at *S'*; *c*, columnar epithelium of gastric mucous membrane, continuous with lowermost columnar cells of Malpighian layer of œsophageal epithelium; *d*, orifices or ducts of cardiac glands; *m*, corium of œsophageal mucous membrane sending papillæ into the epithelium; *m'*, corium of gastric mucous membrane.

the tubules is composed of two kinds of cells. Those of the one kind, which form a continuous lining to the tubule, are somewhat polyhedral in shape, and in stained sections look clearer and smaller than the others, but in the fresh glands, and in osmic preparations, they appear filled with granules (fig. 286). The granules are most numerous at the inner part of the cell, an outer zone being left clear. After prolonged activity



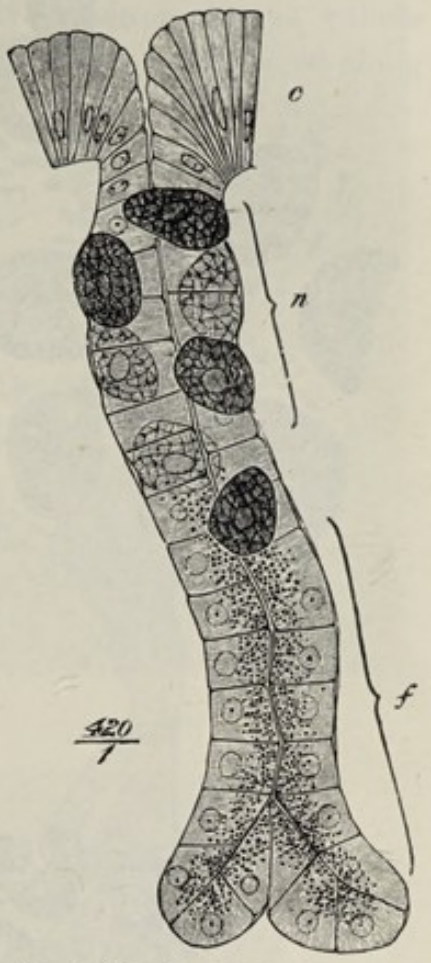


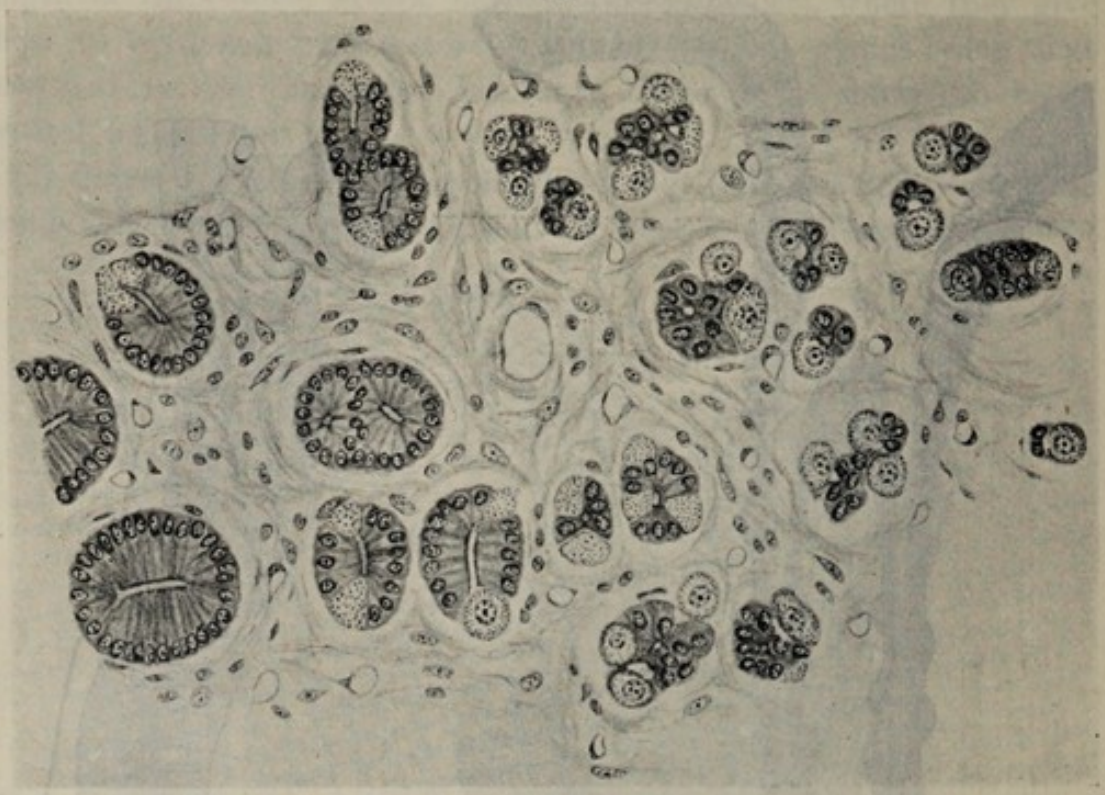
FIG. 286.—A FUNDUS GLAND OF SIMPLE FORM FROM THE BAT'S STOMACH. (Osmic acid preparation.) (Langley.)

c, columnar epithelium of the surface; *n*, neck of the gland with central and parietal cells; *f*, base, occupied only by principal or central cells, which exhibit the granules accumulated towards the lumen of the gland.

FIG. 285.—A FUNDUS GLAND FROM THE DOG'S STOMACH. (Highly magnified.) (Klein.)

d, duct or mouth of the gland; *b*, base of one of its tubules. On the right the base of a tubule more highly magnified; *c*, central cell; *p*, parietal cell.

A



B

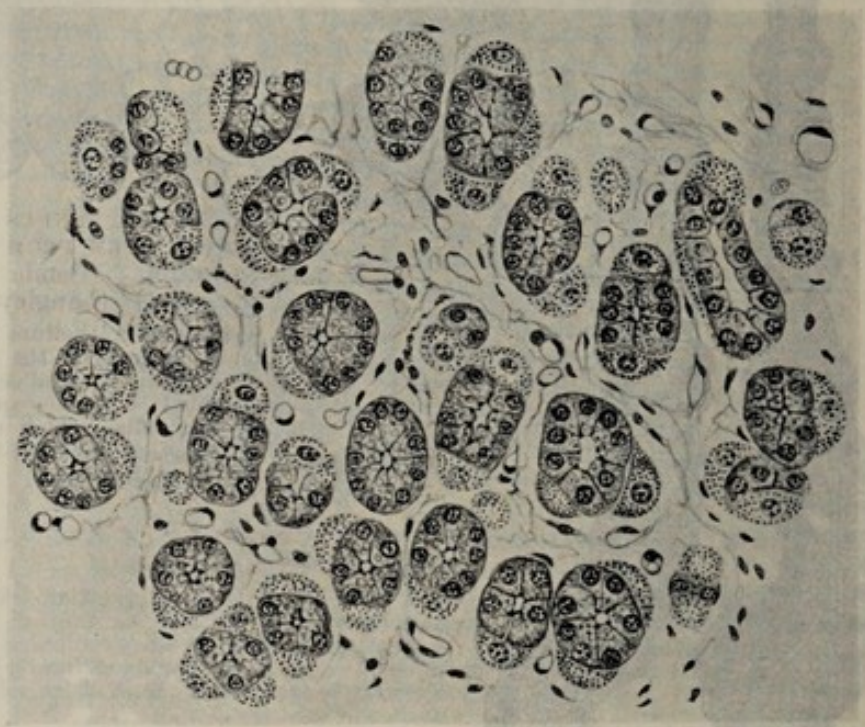


FIG. 287.—SECTIONS OF THE MUCOUS MEMBRANE OF THE FUNDUS OF THE CAT'S STOMACH TAKEN ACROSS THE DIRECTION OF THE GLANDS.

A. Section passing close to but not quite parallel to the surface, and including on the left the gland ducts and on the right the commencing gland tubules. Notice the oxyntic cells beginning to appear between the mucus-secreting cells of the ducts and gland-necks.

B. Section passing through the deepest part of the glands, showing the chief cells surrounding the lumen, and the oxyntic cells altogether outside them.

this outer zone increases in size while the granules diminish in number as in the analogous cases of the pancreas and parotid glands (Langley). These cells are believed to form pepsin, and are termed the *chief cells* of the cardiac glands, or from their relative position in the tubule immediately surrounding the lumen, the *central cells.* Scattered along

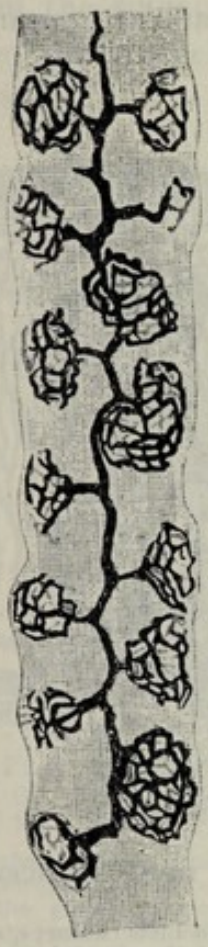


FIG. 288.—A FUNDUS GLAND PREPARED BY GOLGI'S METHOD, SHOWING THE MODE OF COMMUNICATION OF THE PARIETAL CELLS WITH THE GLAND-LUMEN. (E. Müller.)

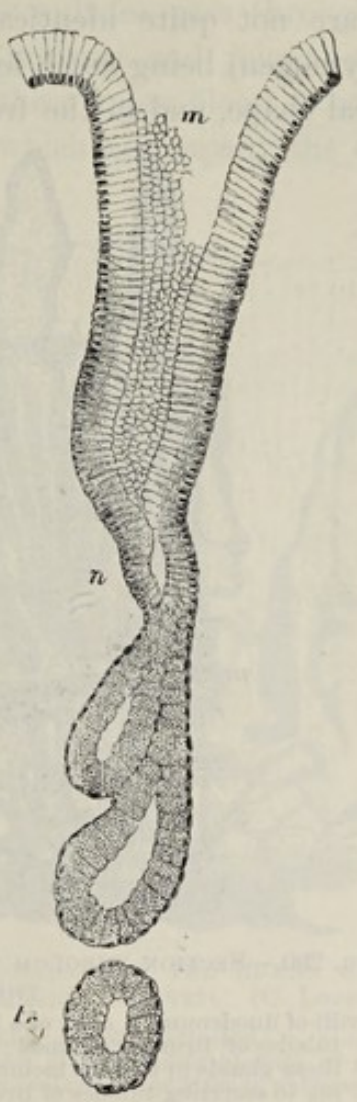


FIG. 289.—A PYLORIC GLAND, FROM A SECTION OF THE DOG'S STOMACH. (Ebstein.)

m, mouth; *n*, neck; *tr*, a deep portion of a tubule cut transversely.

the tubule, and lying between the chief cells and the basement-membrane, are a number of large spheroidal or ovoidal cells, which become stained by most reagents more darkly than the central cells. These are the *parietal cells* or *oxyntic cells.*[1] Each parietal cell is surrounded by a network of fine passages, communicating with the lumen of the gland by a fine canal, which passes between the central cells (fig. 288), but in the neck of the gland the parietal cells abut against

[1] So called because they are believed to produce the acid of the gastric secretion.

the lumen, being here wedged in between columnar and cubical mucus secreting cells (fig. 287, A).

(3) *Pyloric glands* (fig. 289).—In these the *ducts* are much longer than in the fundus glands, and the secreting tubules possess cells of only one kind.[1] These correspond to the chief cells of the fundus glands, but are not quite identical with them in appearance, the granules (of zymogen) being much less distinct. The cells are of a columnar or cubical shape, and in the fresh condition of a granular appearance, and

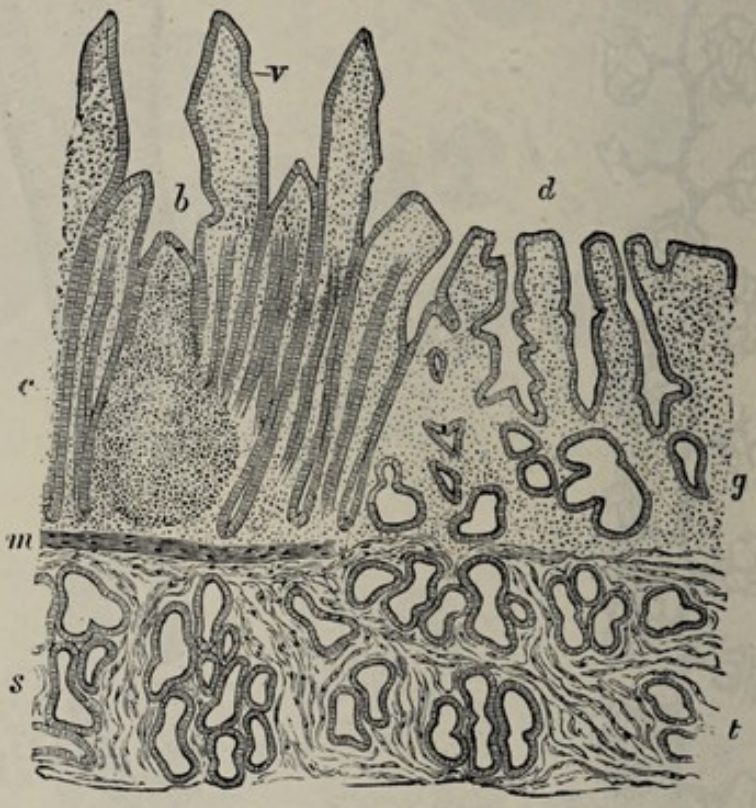


FIG. 290.—SECTION THROUGH THE PYLORUS, INCLUDING THE COMMENCEMENT OF THE DUODENUM. (Klein.)

v, villi of duodenum; *b*, apex of a lymphoid nodule; *c*, crypts of Lieberkühn; *s*, secreting tubules of Brunner's glands; *d*, ducts of pyloric glands of the stomach; *g*, tubes of these glands in mucous membrane; *t*, deeper lying tubes in submucosa, corresponding to secreting tubules of Brunner's glands of duodenum; *m*, muscularis mucosæ.

quite unlike the columnar epithelium-cells of the surface, which are long tapering cells, the outer part of which is filled with mucigen.

At the pylorus itself these glands become considerably lengthened and enlarged, and are continued into the submucous tissue, the muscularis mucosæ being here absent; they thus present transitions to the glands of Brunner, which lie in the submucous tissue of the duodenum (fig. 290).

The *blood-vessels* of the stomach are very numerous, and pass to the organ along its curvatures. The arteries traverse the muscular coat, giving off branches to the capillary network of the muscular tissue,

[1] In man it is only quite near the pylorus that oxyntic cells are altogether absent.

and ramify in the areolar coat. From this, small arteries pierce the muscularis mucosæ, and break up into capillaries near the bases of the glands (fig. 291). The capillary network extends between the glands to the surface, close to which it terminates in a plexus of relatively large venous capillaries which encircle the mouths of the glands. From this plexus straight venous radicles pass through the mucous membrane, pierce the muscularis mucosæ, and join a plexus of veins in the submucous tissue. From these veins blood is carried away from the stomach by efferent veins, which accompany the entering arteries.

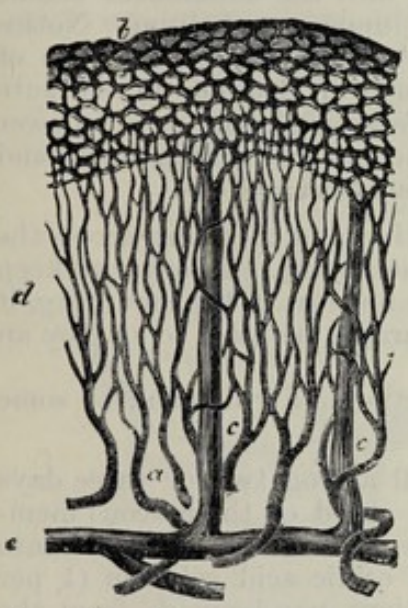


FIG. 291.—PLAN OF THE BLOOD-VESSELS OF THE STOMACH. (Modified from Brinton.)

a, small arteries passing to break up into the fine capillary network, *d*, between the glands; *b*, coarser capillary network around the mouths of the glands; *c*, *c*, veins passing vertically downwards from the superficial network; *e*, larger vessels in the submucosa.

FIG. 292.—LYMPHATICS OF THE HUMAN GASTRIC MUCOUS MEMBRANE, INJECTED. (C. Lovèn.)

The tubules are only faintly indicated; *a*, muscularis mucosæ; *b*, plexus of fine vessels at base of glands; *c*, plexus of larger valved lymphatics in submucosa.

The *lymphatics* (fig. 292) arise in the mucous membrane by a plexus of large vessels dilated at intervals, and looking in sections like clefts in the interglandular tissue. From this plexus the lymph is carried into large valved vessels in the submucous coat, and from these, efferent vessels pass through the muscular coat to reach the serous membrane, underneath which they pass away from the organ. The muscular coat has its own network of lymphatic vessels. These lie between the two principal layers, and their lymph is poured into the efferent lymphatics of the organ.

The nerves have the same arrangement and mode of distribution as those of the intestine (see next Lesson).

LESSON XXXIV.

1. Sections of the duodenum, jejunum, and ileum, vertical to the surface. The three parts of the intestine may be embedded in the same paraffin block, and the sections stained and mounted together. Choose a part of the ileum which includes a Peyer's patch. Observe the nodules of lymphoid tissue which constitute the patch and which extend into the submucous tissue. Observe the lymphoid cells in the superjacent columnar epithelium. Notice also the sinus-like lymphatic or lacteal vessel which encircles the base of each nodule. In the duodenum study the glands of Brunner in the submucous tissue. Make a general sketch of each section under a low power and draw a villus under the high power. The general arrangement and structure of the intestinal wall is to be studied in these sections.

2. Sections parallel to the surface of the intestine, and therefore across the long axis of the villi and glands of the mucous membrane. In order to keep the sections of the villi together so that they are not lost in the mounting, it is necessary either to embed in celloidin or, if paraffin be used, to employ an adhesive method of mounting.

In this preparation, sketch the transverse section of a villus and of some of the crypts of Lieberkühn.

3. To study the process of fat-absorption, kill a frog two or three days after feeding with bacon fat. Put a very small shred of the mucous membrane of the intestine into osmic acid (0·5 per cent.) and another piece into a mixture of 2 parts Müller's fluid and 1 part osmic acid solution (1 per cent.). After forty-eight hours teased preparations may be made from the osmic acid preparation, in the same manner as directed in Lesson VII., § 2. The piece in Müller and osmic acid may be left for ten days or more in the fluid. When hardened, sections are made either by the freezing or paraffin method.

4. Sections of small intestine the blood-vessels of which have been injected. Notice the arrangement of the vessels in the several layers. Sketch carefully the vascular network of a villus.

5. From a piece of intestine which has been stained with chloride of gold tear off broad strips of the longitudinal muscular coat, and mount them in glycerine. It will generally be found that portions of the nervous plexus of Auerbach remain adherent to the strips, and the plexus can in this way easily be studied.

From the remainder of the piece of intestine tear off with forceps the fibres of the circular muscular layer on the one side, and the mucous membrane on the other side, so as to leave only the submucous tissue and the muscularis mucosæ. This tissue is also to be mounted flat in glycerine: it contains the plexus of Meissner.

Sketch a small portion of each plexus under a high power. The plexus can also be studied by the methylene-blue method (see Appendix).

6. Sections of the large intestine, perpendicular to the surface. These will show the general structure and arrangement of the coats. Sketch under a low power.

7. Sections of the mucous membrane of the large intestine parallel to the

surface, and therefore across the glands. Sketch some of the glands and the interglandular tissue under a high power.

8. The arrangement of the blood-vessels of the large intestine may be studied in sections of the injected organ.

The Small Intestine.

The wall of the **small intestine** consists, like the stomach, of four coats.

The *serous coat* is complete except over part of the duodenum.

The *muscular coat* is composed of two layers of muscular tissue, an outer longitudinal and an inner circular. Between them lies a

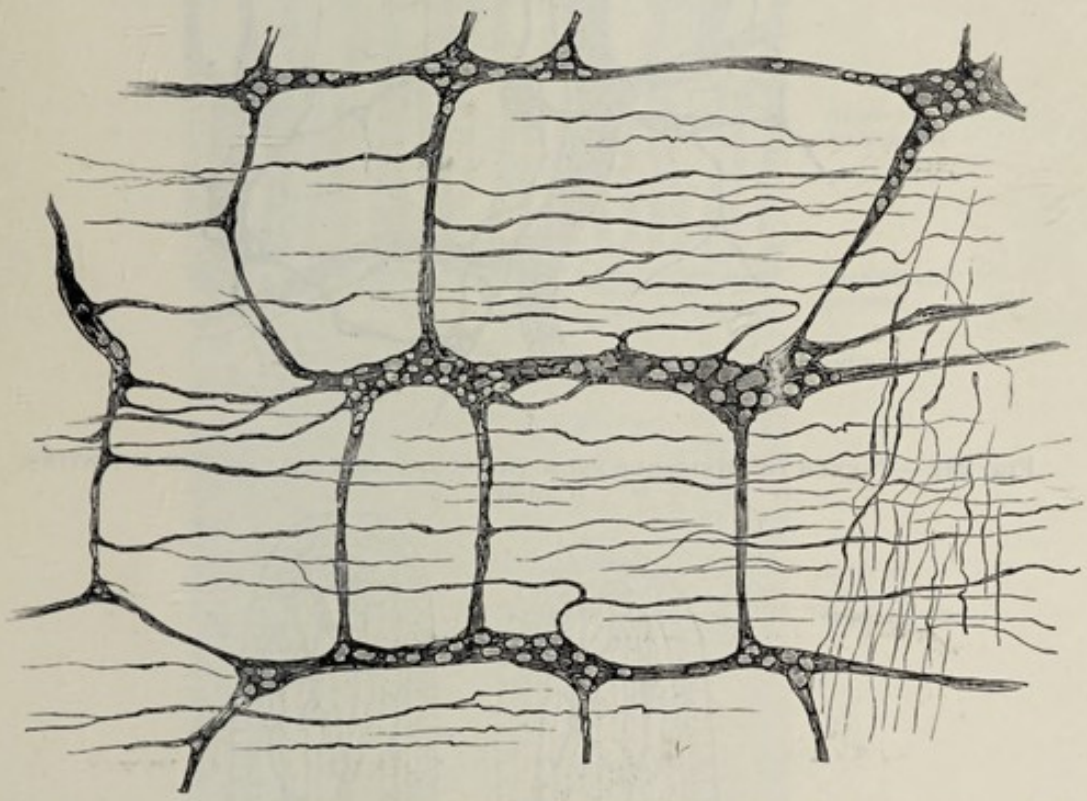


Fig. 293.—Plexus of Auerbach, between the two layers of the muscular coat of the intestine. (Cadiat.)

network of lymphatic vessels and also the close gangliated plexus of non-medullated nerve-fibres known as the *plexus myentericus* of Auerbach. The ganglia of this plexus may usually be seen in vertical sections of the intestinal wall (in figs. 298, 299), but the plexus, like the one in the submucous coat immediately to be described, can only be properly displayed in preparations made with chloride of gold (fig. 293) or methylene-blue or by Golgi's method.

The *submucous coat* is like that of the stomach ; in it the blood-vessels and lacteals ramify before entering or after leaving the mucous membrane, and it contains a gangliated plexus of nerve-fibres—the *plexus of Meissner*—which is finer than that of Auerbach and has fewer

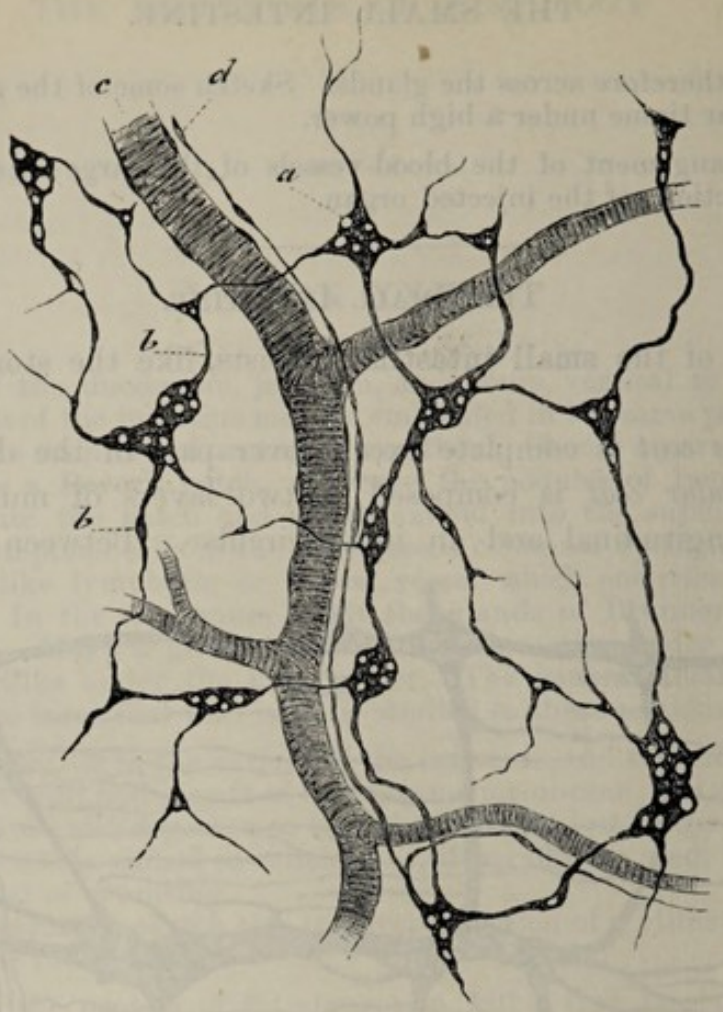


FIG. 294.—PLEXUS OF MEISSNER FROM THE SUBMUCOUS COAT OF THE INTESTINE. (Cadiat.)

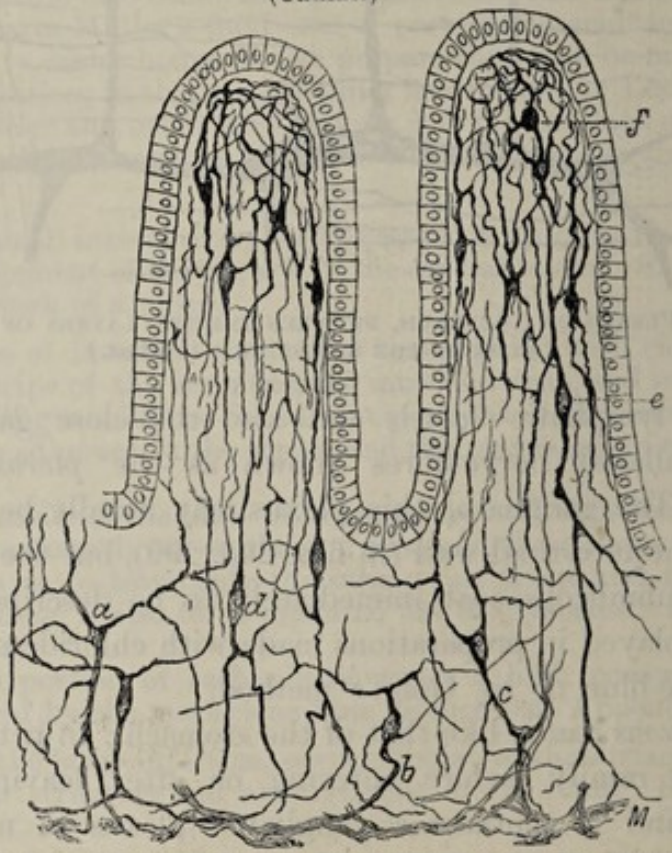


FIG. 295.—NERVES OF THE MUCOUS MEMBRANE OF THE SMALL INTESTINE. (S. Ramón y Cajal.)

M, part of Meissner's plexus; *a-f*, small nerve-cells in the tissue of the mucous membrane and villi.

ganglion-cells (fig. 294). Its branches are chiefly supplied to the muscular fibres of the mucous membrane, but also to the glands and villi (fig. 295).

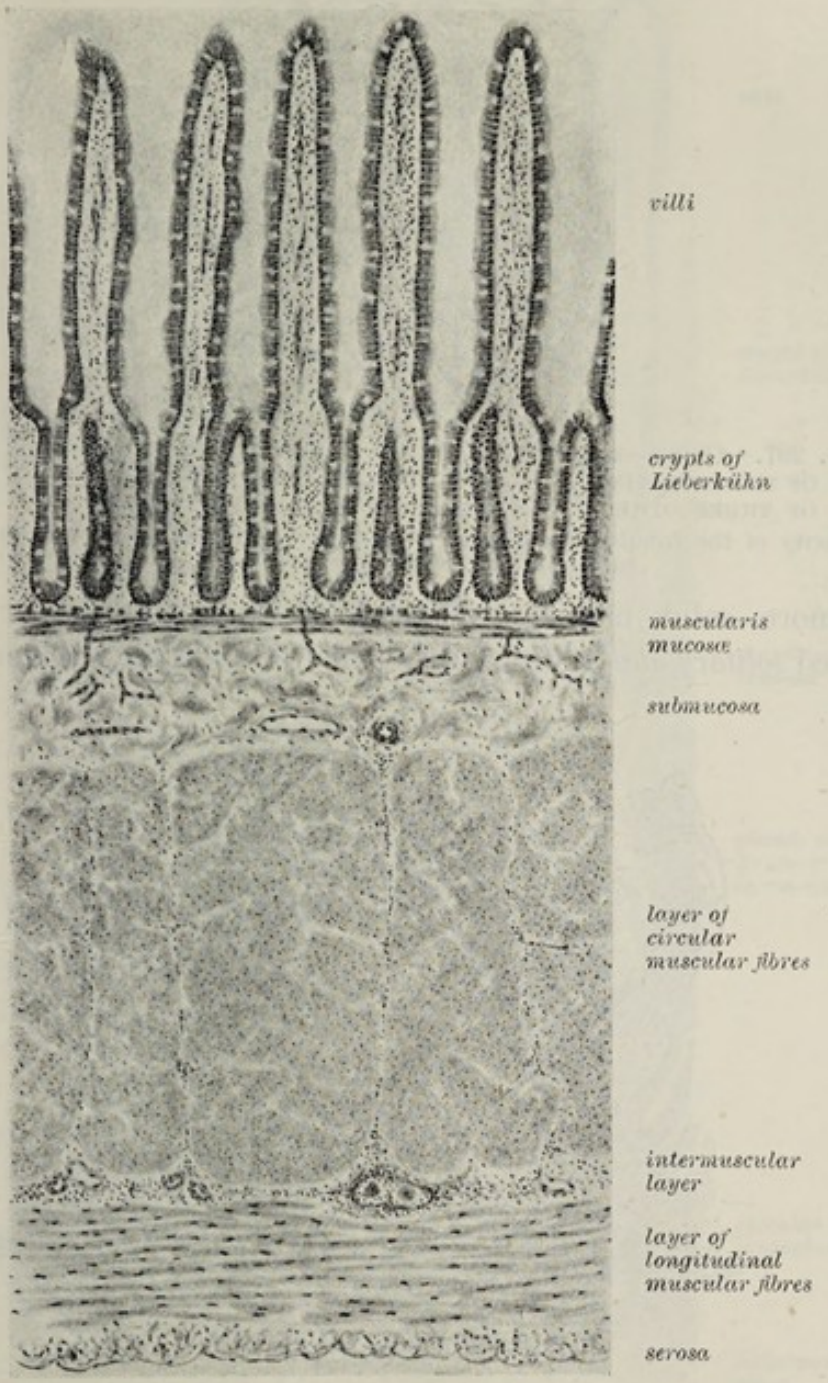


FIG. 296.—SECTION OF THE SMALL INTESTINE (JEJUNUM) OF CAT.
(Magnified about 40 diameters.)

The *mucous membrane* is bounded next to the submucous coat by a double layer of plain muscular fibres (*muscularis mucosæ*). Bundles from this pass inwards through the membrane towards the inner surface and penetrate also into the villi. The mucous membrane proper is pervaded with simple tubular glands—the *crypts of Lieberkühn*—which are lined throughout by a columnar epithelium like that which covers

the surface and the villi. The mucous membrane between these glands is mainly composed of lymphoid tissue, which is aggregated at intervals

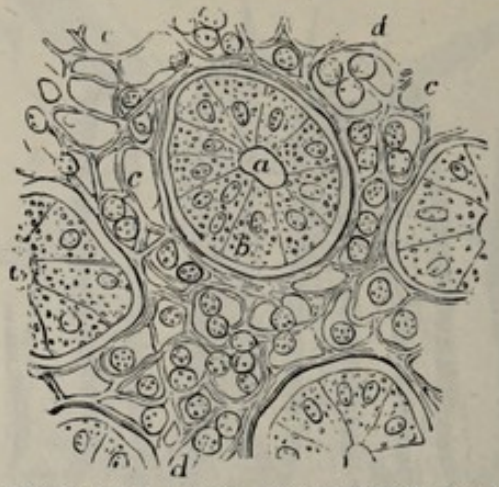


FIG. 297.—CROSS-SECTION OF A SMALL FRAGMENT OF THE MUCOUS MEMBRANE OF THE INTESTINE, INCLUDING ONE ENTIRE CRYPT OF LIEBERKÜHN AND PARTS OF THREE OTHERS. (Magnified 400 diameters.) (Frey.)

a, cavity of the tubular glands or crypts; *b*, one of the lining epithelium-cells; *c*, the interglandular retiform tissue; *d*, lymph-cells.

into more solid nodules constituting when they occur singly the so-called *solitary glands* of the intestine (fig. 298), and when aggregated

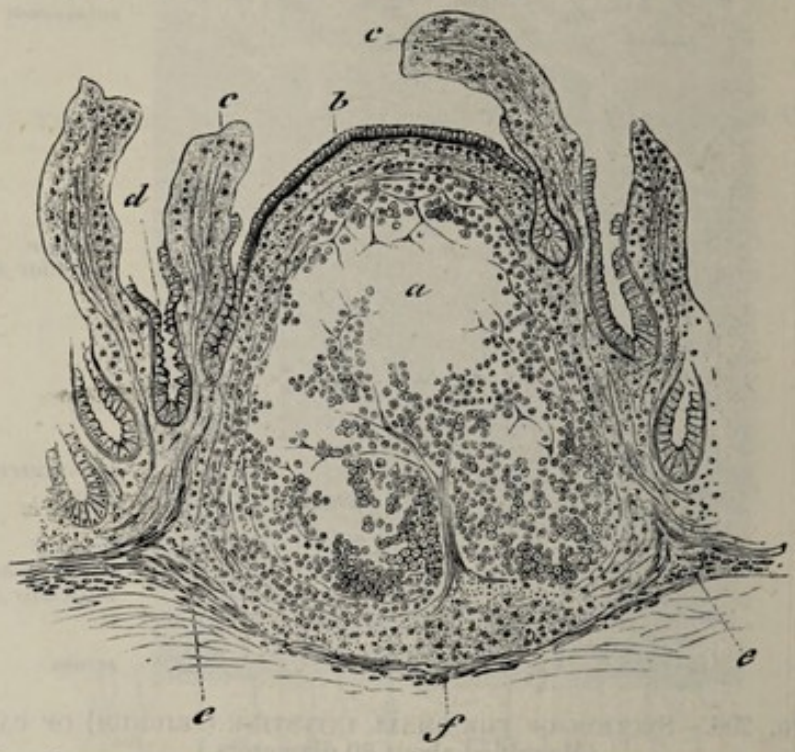


FIG. 298.—SECTION OF THE ILEUM THROUGH A LYMPHOID NODULE. (Cadiat.)

a, middle of the nodule with the lymphoid tissue partly fallen away from the section; *b*, epithelium of the intestine; *c*, villi: their epithelium is partly broken away; *d*, crypts of Lieberkühn.

together form the *agminated glands* or *patches of Peyer* (fig. 302). The latter occur chiefly in the ileum.

The *glands of Brunner*, which have been already noticed (p. 240), occur in the duodenum. They are small tubulo-racemose glands in the

submucosa; they send their ducts to the inner surface of the mucous membrane between the crypts of Lieberbkühn.

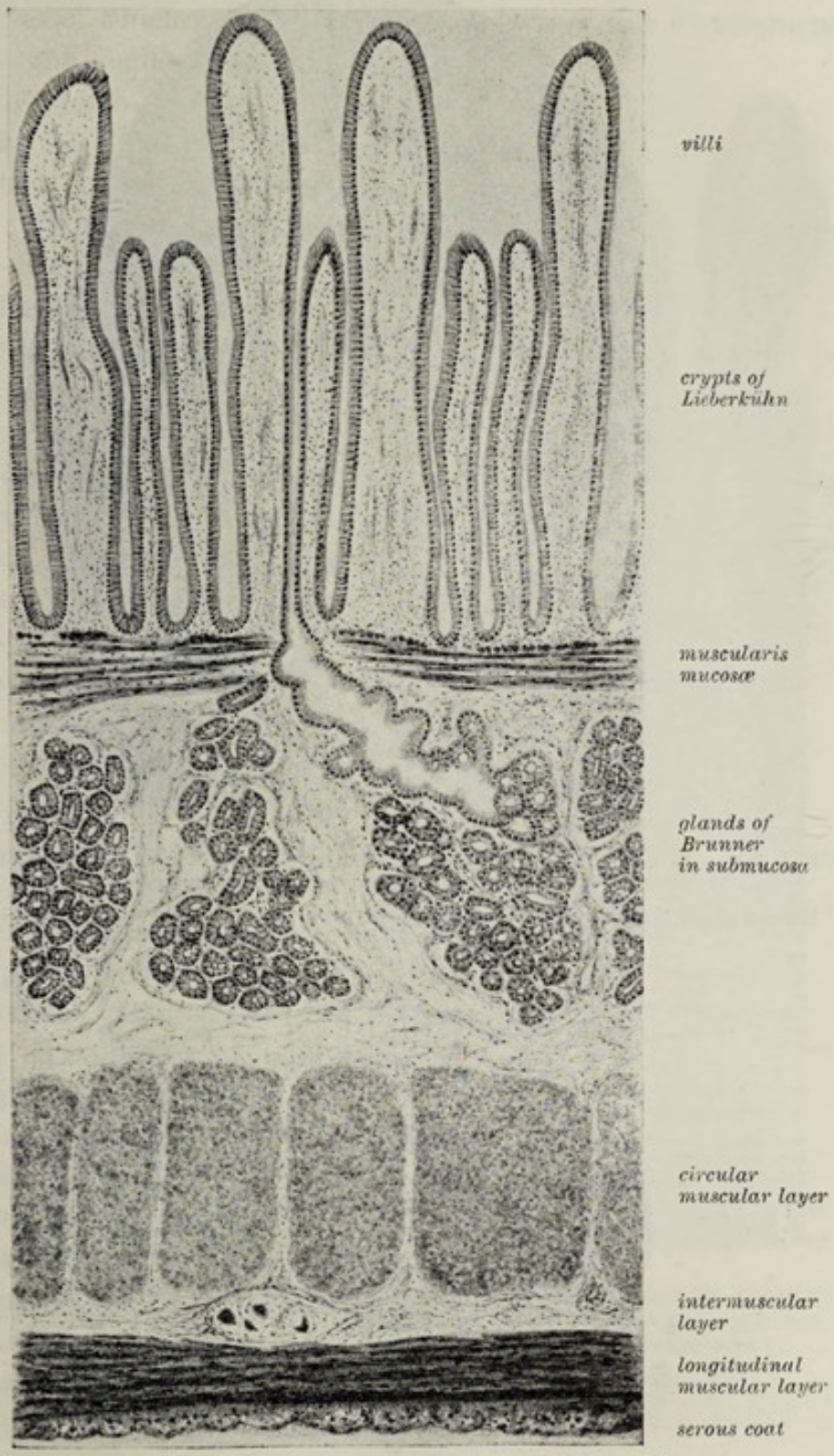


FIG. 299.—SECTION OF DUODENUM OF CAT, SHOWING BRUNNER'S GLANDS. (Magnified about 60 diameters.)

The *villi* with which the whole of the inner surface of the small intestine is closely beset are clavate or finger-shaped projections of the mucous membrane, and are composed, like that, of retiform tissue

covered with columnar epithelium (fig. 300). The characters of this

FIG. 300.—LONGITUDINAL SECTION OF A VILLUS FROM A RAT KILLED THREE HOURS AFTER FEEDING WITH BREAD AND WATER.

The columnar epithelium shows numerous lymph-corpuscles between the cells; *l*, lacteal, containing lymph-corpuscles, *c*, some partly disintegrated.

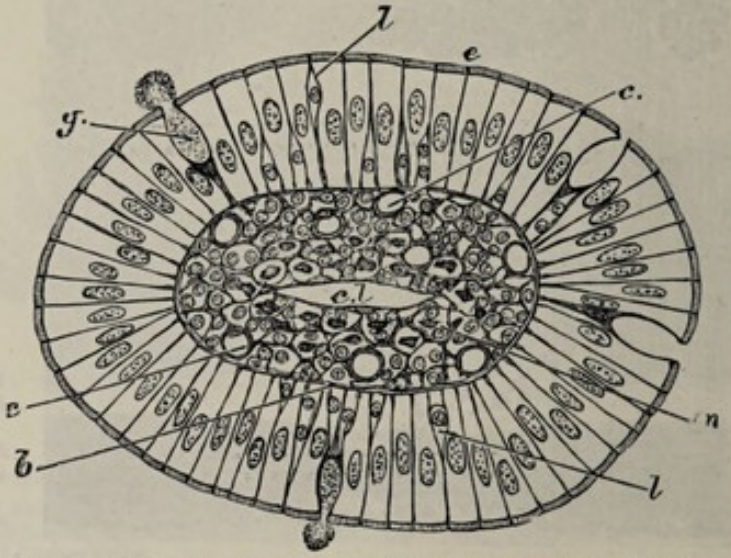


FIG. 300 A.—CROSS-SECTION OF AN INTESTINAL VILLUS, NEAR ITS BASE.

e, columnar epithelium; *g*, goblet-cell, its mucus is seen partly extruded; *l*, lymph-corpuscles between the epithelium-cells; *b*, basement-membrane; *c*, blood-capillaries; *m*, section of plain muscular fibres; *c.l*, central lacteal.

epithelium have been already described (Lesson VII.). Between and at the base of the epithelium-cells many lymph-corpuscles occur, as well

as in the meshes of the retiform tissue. The epithelium rests upon a basement-membrane formed of flattened cells. In the middle of the villus is a lacteal vessel which may be somewhat enlarged near its commencement, but the enlargement is replaced in some animals by a network of lacteals. Surrounding this vessel are small bundles of plain muscular tissue prolonged from the muscularis mucosæ. The network of blood-capillaries (figs. 300, 301) lies for the most part near the surface within the basement-membrane; it is supplied with blood by a small artery which joins the capillary network at the base of the villus; the corresponding vein generally rises near the extremity.

The *lymphatics* (lacteals) of the mucous membrane (fig. 302), after receiving the central lacteals of the villi, pour their contents into a plexus of large valved lymphatics which lie in the submucous tissue and form sinuses around the bases of the lymphoid nodules. From the submucous tissue efferent vessels pass through the muscular coat, receiving the lymph from an intramuscular plexus of lymphatics, and are conveyed away between the layers of the mesentery.

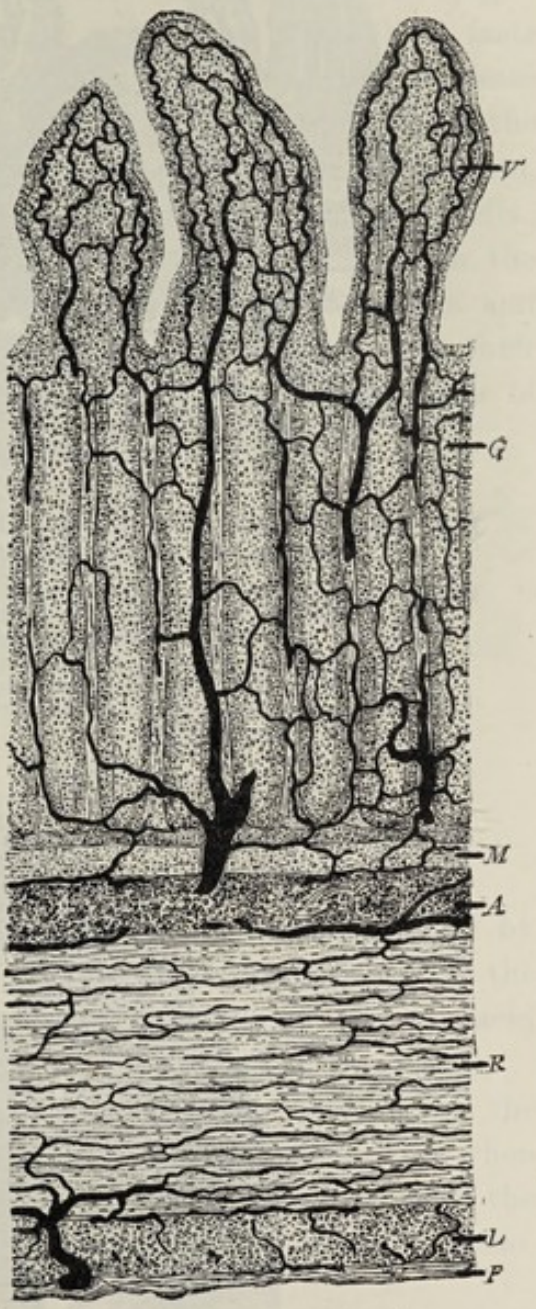


FIG. 301. — SMALL INTESTINE (VERTICAL TRANSVERSE SECTION), WITH THE BLOOD-VESSELS INJECTED. (Heitzmann.)

V, a villus; *G*, glands of Lieberkühn; *M*, muscularis mucosæ; *A*, areolar coat; *R*, circular muscular coat; *L*, longitudinal muscular coat; *P*, peritoneal coat.

Absorption of fat.—In order to study the process of fat transference in the intestine, it is convenient to stain the fat with osmic acid, which colours it black. It can then be observed that in animals which have been fed with food containing fat, particles of fat are present (1) in the columnar epithelium-cells; (2) in the lymph-cells; and (3) in the central lacteal of the villus. The lymph-cells are present not only in the reticular tissue of the villus, but also in considerable numbers

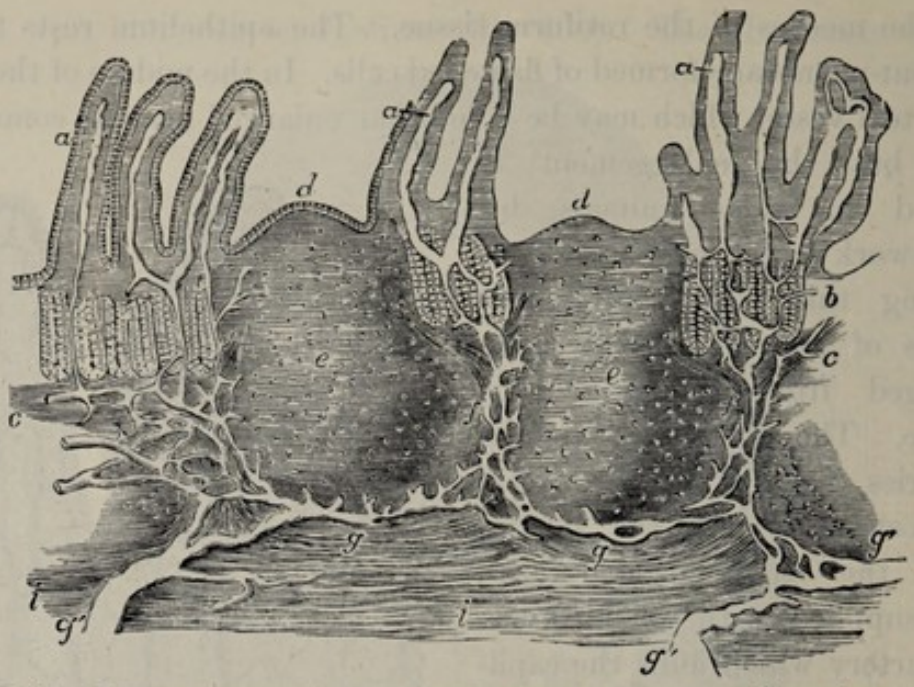


FIG. 302.—VERTICAL SECTION OF A PORTION OF A PATCH OF PEYER'S GLANDS WITH THE LACTEAL VESSELS INJECTED. (32 diameters.) (Frey.)

The specimen is from the lower part of the ileum: *a*, villi, with their lacteals left white; *b*, some of the tubular glands; *c*, the muscular layer of the mucous membrane; *d*, cupola or projecting part of the nodule: *e*, central part; *f*, the reticulated lacteal vessels occupying the lymphoid tissue between the nodules, joined above by the lacteals from the villi and mucous surface, and passing below into *g*, the sinus-like lacteals under the nodules, which again pass into the large efferent lacteals, *g'*; *i*, part of the muscular coat.

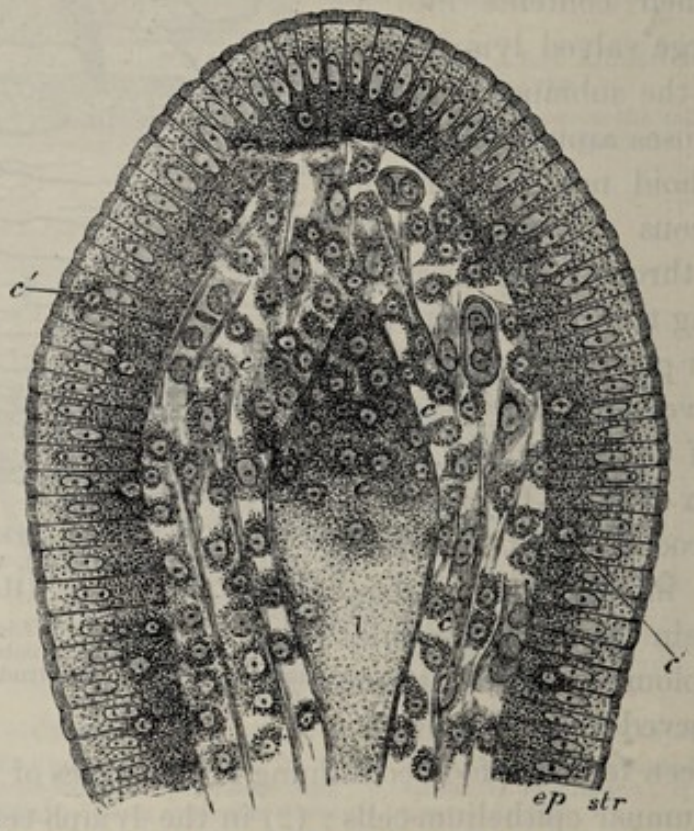


FIG. 303.—SECTION OF THE VILLUS OF A RAT KILLED DURING FAT-ABSORPTION.

ep, epithelium; *str*, striated border; *c*, lymph-cells; *c'*, lymph-cells in the epithelium *l*, central lacteal containing chyle and disintegrating lymph-corpuscles.

between and at the base of the epithelium-cells; and they can also be seen in thin sections from bichromate-osmic preparations within the commencing lacteal; in the last situation they are undergoing disintegration (figs. 303, 304). These observations are easily made in the frog.

Since the lymph-cells are amœboid, it is probable from these facts that the mechanism of fat-absorption consists of the following processes —viz. (1) absorption of fat into the columnar epithelium-cells of the surface; (2) inception of fat by lymph-corpuscles in the epithelium, these taking it up after it has passed out of the epithelium-cells; (3) migration of lymph-corpuscles carrying fat particles through the tissue of the villus and into the central lacteal; (4) disintegration and solution of the immigrated lymph-corpuscles, and setting free their contents. Since fat particles are never seen in the striated border of

FIG. 304.—MUCOUS MEMBRANE OF FROG'S INTESTINE DURING FAT-ABSORPTION.
ep, epithelium; *str*, striated border; *c*, lymph-corpuscles; *l*, lacteal.

the columnar cell it is probable that the fat first becomes saponified by the action of the digestive juices, and reaches the epithelium-cell in the form of dissolved soap; the fat which is seen and stained by osmic acid within the cells having become re-formed by a process of synthesis.

This migration of the lymph-corpuscles into the lacteals of the villi is not a special feature of fat-absorption, but occurs even when absorption of other matters is proceeding (fig. 300); so that the transference of fat-particles is merely a part of a more general phenomenon accompanying absorption.

THE LARGE INTESTINE.

The **large intestine** has the usual four coats, except near its termination, where the serous coat is absent. The *muscular coat* is peculiar in the fact that along the cæcum and colon the longitudinal muscular fibres are gathered up into three thickened bands which produce puckerings in the wall of the gut.

The *mucous membrane* of the large intestine is beset with simple tubular glands somewhat resembling the crypts of Lieberkühn of the

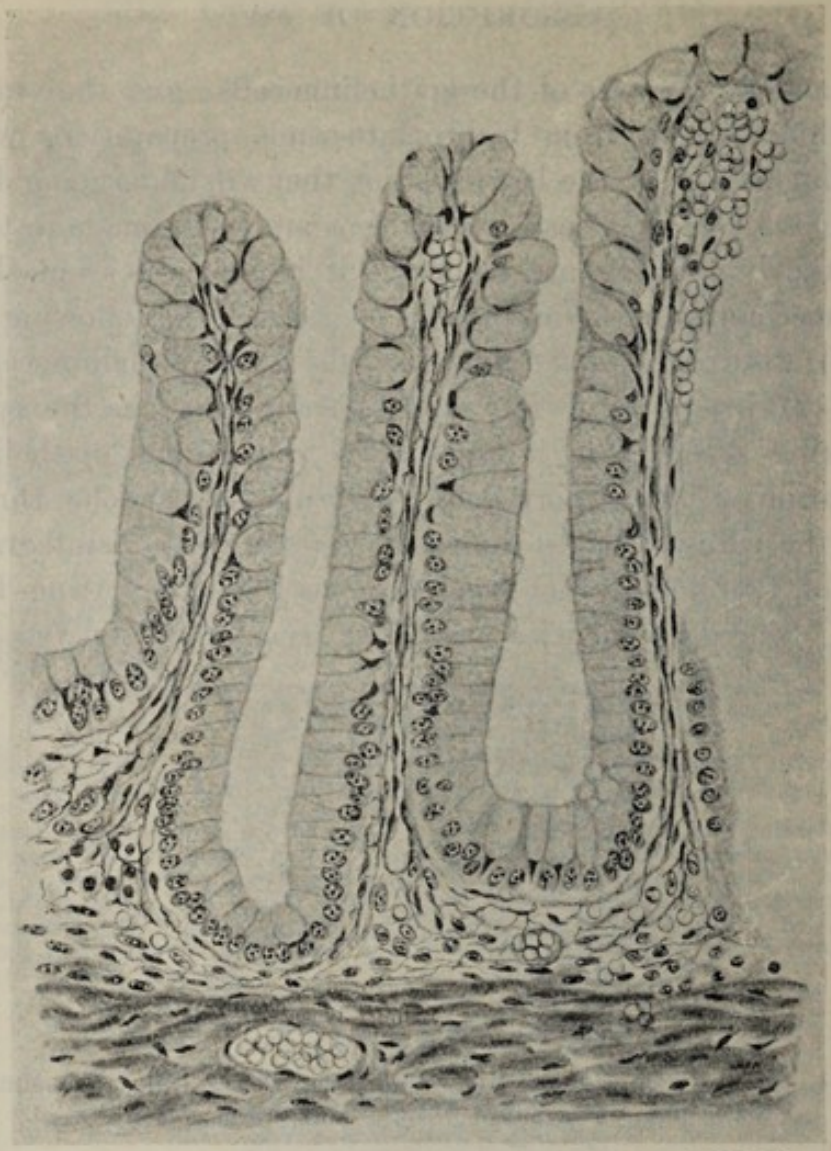


FIG. 305.—GLANDS OF THE LARGE INTESTINE OF CHILD. (300 diameters.)

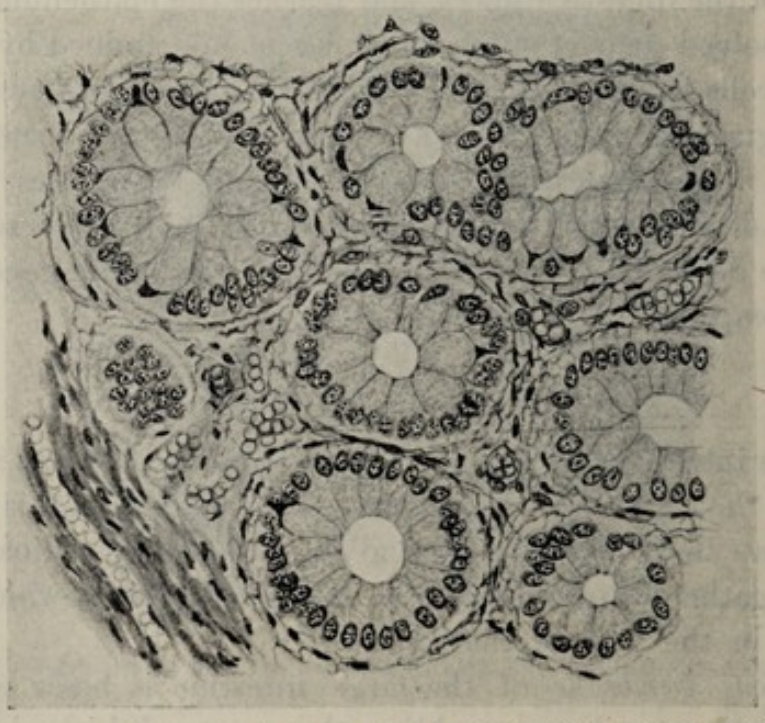


FIG. 306.—CROSS SECTION OF GLANDS OF LARGE INTESTINE OF CHILD. (300 diameters.)

small intestine, and lined by columnar epithelium similar to that of the inner surface of the gut, but containing many more mucus-secreting or goblet-cells (fig. 305). The extremity of each gland is usually slightly dilated. The interglandular tissue is a retiform tissue (fig. 306) and is beset here and there with solitary (lymphoid) glands, especially in the cæcum. The mucous membrane of the vermiform appendix is in great part of its extent packed full of similar lymphoid nodules. The arrangement of the blood-vessels and lymphatics in the large intestine resembles that in the stomach. The nerves of the large intestine also resemble those of the stomach and small intestine in their arrangement.

At the lower end of the rectum the circular muscular fibres of the gut become thickened a little above the anus to form the *internal sphincter* muscle. In the anal region also there are a number of compound racemose mucous glands opening on the surface of the mucous membrane (*anal glands*). The anus has a lining of stratified epithelium continuous with that of the skin.

LESSON XXXV.

STRUCTURE OF THE LIVER AND PANCREAS.

1. Make sections of liver from pieces hardened in Müller's fluid, and study them carefully with a low and high power. Sketch the general arrangement of the cells in a lobule under the low power; and under the high power make very careful drawings of some of the hepatic cells and also of a portal canal. If from the pig, the outlines of the lobules are observed to be very well marked.

2. To observe the glycogen and the iron-containing pigment within the liver-cells, kill a rabbit or rat (for glycogen preferably about six hours after a full meal of carrot), and at once throw a thin piece of the liver into 96 per cent. alcohol. When well hardened the piece may be embedded in paraffin in the usual way, or sections may be cut with the free hand without embedding. Some of the sections so obtained are to be treated with a 1 per cent. solution of iodine in potassic iodide for five minutes; they may then be mounted in a nearly saturated solution of potassium acetate, the cover-glass being cemented with gold size. These are to exhibit the glycogen within the liver cells. Other sections are to be treated first with potassic ferrocyanide solution and then with hydrochloric acid and alcohol (1 to 10), passed through absolute alcohol into xylol and mounted in xylol balsam; in these many of the pigment granules will be stained blue (presence of iron); or the sections may simply be placed in an aqueous solution of hæmatoxylin (1 to 300), with or without previous treatment with alcohol containing 10 parts per cent. hydrochloric acid (to set free organically combined iron), after which they are mounted in the ordinary way (Macallum's method).

3. Study, first with the low power and afterwards with a high power, a section of the liver in which the blood-vessels have been injected from the portal vein. Occasionally the injection will be found to have penetrated into canaliculi within the liver cells themselves. Make a general sketch of a lobule under the low power and draw a small part of the network of capillaries under the high power.

4. Take a small piece of liver which has been several weeks in 2 per cent. bichromate of potassium solution or Müller's fluid and plunge it in 1 per cent. nitrate of silver solution, changing the fluid after half an hour. Leave the piece of liver in the silver solution overnight. It may then be transferred to alcohol, and after complete dehydration embedded and cut in paraffin in the usual way and the sections mounted in Canada balsam. In many parts of such sections the bile canaliculi are seen.

They can also be brought to view at the periphery of the lobules by injection with solution of Berlin blue from the hepatic duct, or throughout the whole of the lobule by injecting about 60 c.c. of saturated sulphindigotate of soda solution in three successive portions, at intervals of half an hour, into the blood-vessels of a cat or rabbit *intra vitam*, and two hours after the last injection killing the animal, washing out the blood-vessels with saturated solution of potassium chloride and fixing with absolute alcohol; but the chromate of silver method is far easier and surer than the injection methods.

5. Tease a piece of fresh liver in serum or salt solution for the study of the appearance of the hepatic cells in the recent or living condition.

6. Stained sections of pancreas from a gland which has been hardened in alcohol, or in formol followed by alcohol. Small pieces of the gland are stained in bulk with carmalum and the sections, after differentiation with alcoholic solution of picric acid, mounted in the usual way in Canada balsam.

Make sketches under both low and high power.

7. Tease a small piece of fresh pancreas in serum or salt solution. Notice the granules in the alveolar cells, chiefly accumulated in the half of the cell which is nearest the lumen of the alveolus, leaving the outer zone of the cell clear.

Sketch a small portion of an alveolus under a high power.

The Liver.

The **liver** is a solid glandular organ, made up of the *hepatic lobules*. These are polyhedral masses about 1 mm. ($\frac{1}{25}$ inch) in diameter,

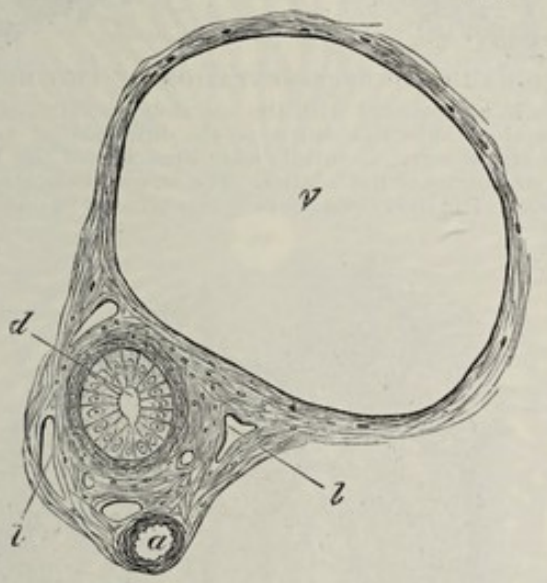


Fig. 307.—Section of a portal canal.

a, branch of hepatic artery; *v*, branch of portal vein; *d*, bile-duct; *l*, *l*, lymphatics in the areolar tissue of Glisson's capsule which incloses the vessels.

composed of cells, and separated from one another by connective tissue. In some animals, as in the pig, this separation is complete, and each lobule is isolated, but in man it is incomplete. There is also a layer of connective tissue underneath the serous covering of the liver, forming the so-called *capsule* of the organ.

The *blood-vessels of the liver* (portal vein and hepatic artery) enter it on its under surface, where also the bile-duct passes away from the gland. The branches of these three vessels accompany one another in their course through the organ, and are inclosed by loose connective tissue (capsule of Glisson), in which are lymphatic vessels, the whole being termed a *portal canal* (fig. 307). The smallest branches of the vessels penetrate to the intervals between the hepatic lobules, and are known as the interlobular branches. The blood leaves the liver at the

back of the organ by the hepatic veins; the branches of these run through the gland unaccompanied by other vessels (except lymphatics)

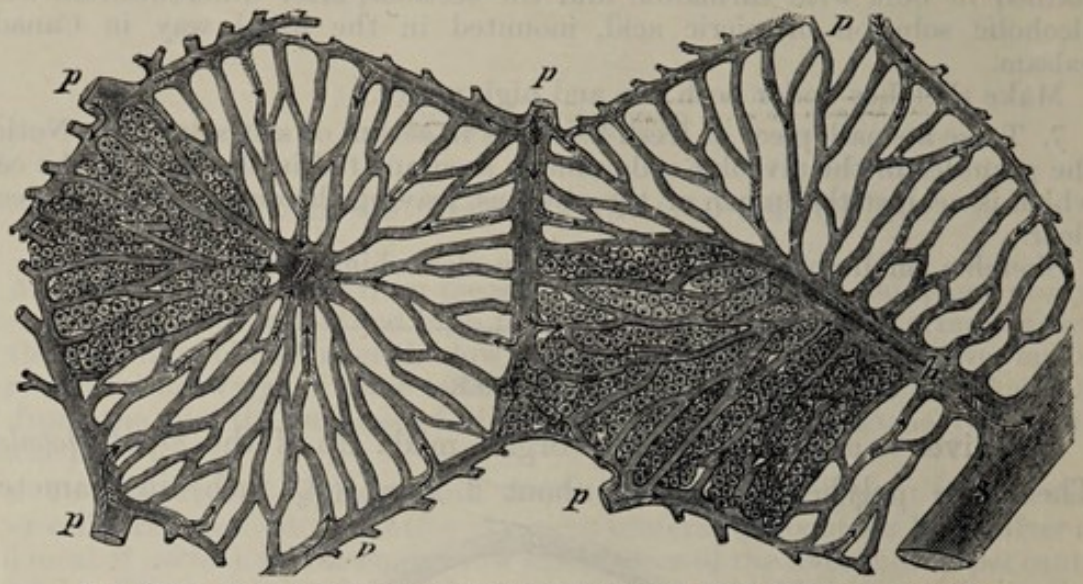


FIG. 308.—DIAGRAMMATIC REPRESENTATION OF TWO HEPATIC LOBULES.

The left-hand lobule is represented with the intralobular vein cut across; in the right-hand one the section takes the course of the intralobular vein. *p*, intralobular branches of the portal vein; *h*, intralobular branches of the hepatic veins; *s*, sublobular vein; *c*, capillaries of the lobules. The arrows indicate the direction of the course of the blood. The liver-cells are only represented in one part of each lobule.

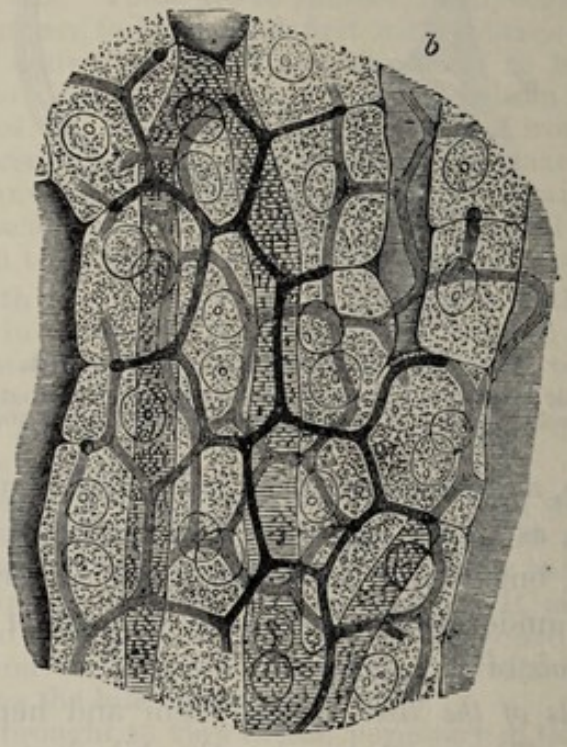


FIG. 309.—SECTION OF RABBIT'S LIVER WITH THE INTERCELLULAR NETWORK OF BILE-CANALICULI INJECTED. (Highly magnified.) (Hering.)

Two or three layers of cells are represented; *b*, blood-capillaries.

and can also be traced to the lobules, from each of which they receive a minute branch (intralobular vein) which passes from the centre of the lobule, and opens directly into the (sublobular) branch of the hepatic vein.

Each lobule is a mass of hepatic cells pierced everywhere with a network of blood-capillaries (fig. 308), which arise at the periphery of the lobule, there receiving blood from the interlobular branches of the portal vein (*p*), and converge to the centre of the lobule, where they unite to form the intralobular branch of the hepatic vein. The

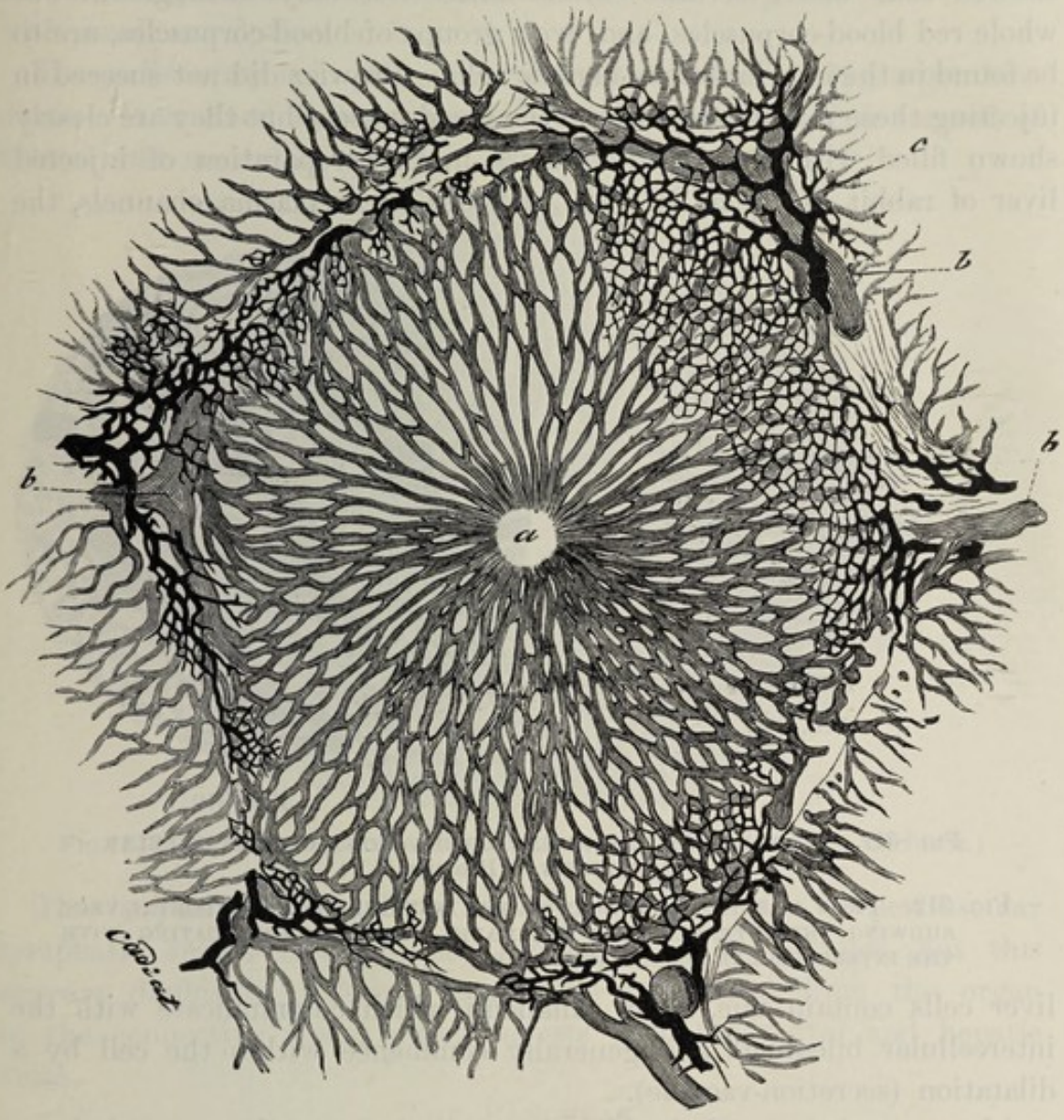


FIG. 310.—LOBULE OF RABBIT'S LIVER, VESSELS AND BILE-DUCTS INJECTED. (Cadiat.)

a, central vein; *b*, *b*, peripheral or interlobular veins; *c*, interlobular bile-duct. The liver-cells are not represented.

interlobular branches of the hepatic arteries join this capillary network a short distance from the periphery of the lobule.

The *hepatic cells* (figs. 308, 309, 312), which everywhere lie between and surround the capillaries, are polyhedral, somewhat granular-looking cells, each containing a spherical nucleus. The protoplasm of each cell is pervaded by an irregular network of fine canaliculi (fig. 311), which

in preparations of liver injected from the portal vein sometimes become filled with the injection material, which has passed into them from the blood-vessels. They thus form a system of intracellular canals which probably receive the blood-plasma directly from the vessels. Such canals were conjectured to exist by Browicz, who showed that under certain circumstances not only hæmoglobin but whole red blood-corpuscles, and even groups of blood-corpuscles, are to be found in the interior of the hepatic cells. Browicz did not succeed in injecting these minute canals from the blood-vessels, but they are clearly shown filled with the injection mass in the preparation of injected liver of rabbit shown in fig. 312. Besides these plasma channels, the

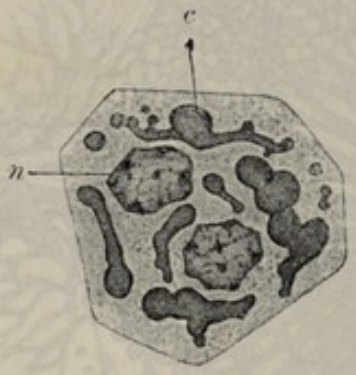


FIG. 311.

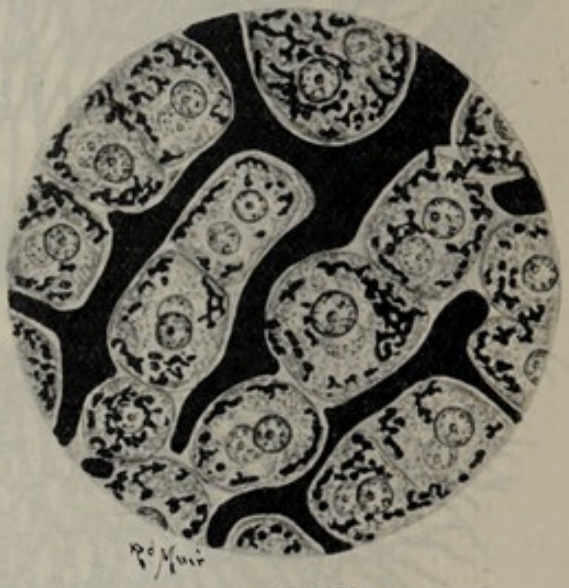


FIG. 312.

FIG. 311.—A CELL FROM THE HUMAN LIVER, SHOWING INTRACELLULAR CANALICULI. (Browicz.)

FIG. 312.—FROM A SECTION OF RABBIT'S LIVER INJECTED FROM THE PORTAL VEIN, SHOWING THE INTRACELLULAR PLASMATIC CANALS COMMUNICATING WITH THE INTERCELLULAR BLOOD-CAPILLARIES.

liver cells contain fine, short canaliculi which communicate with the intercellular bile-ducts and generally commence within the cell by a dilatation (secretion-vacuole).

After a meal many of the cells may contain fat, and masses of glycogen can also be seen within the cells (fig. 313) if the liver be hardened in alcohol and treated in the manner described in section 2. The cells also contain pigment-granules, many of which are stained by potassic ferrocyanide and hydrochloric acid, or by pure hæmatoxylin (presence of iron[1]).

The *ducts* commence between the hepatic cells in the form of *bile-canaliculi*, which lie between the adjacent sides of two cells, and appear

[1] The iron which is in organic combination can be set free by treatment for a short time with alcohol to which 10 p.c. hydrochloric acid has been added.

to form a network, the meshes of which correspond in size to the cells (fig. 309). At the periphery of the lobule these canaliculi pass into the interlobular bile-ducts (fig. 310).

The bile-ducts are lined by clear columnar epithelium (fig. 307, *d*). Outside this is a basement-membrane, and in the larger ducts some fibrous and plain muscular tissue. Many of the larger ducts are beset with small cæcal diverticula.

The *gall-bladder* is in its general structure similar to the larger bile-ducts. It is lined by columnar epithelium, and its wall is formed of fibrous and muscular tissue.

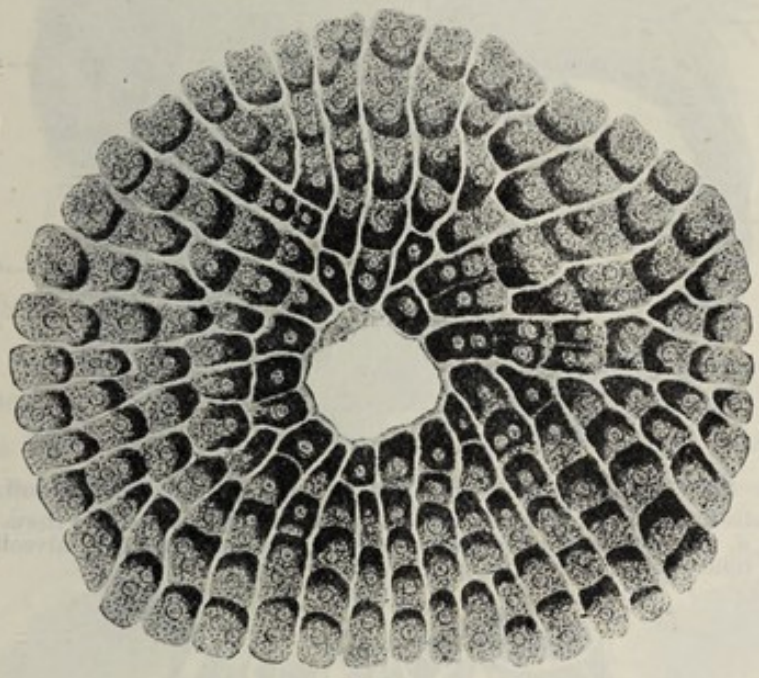


FIG. 313.—LIVER CELLS CONTAINING GLYCOGEN. (Dunham, from Barfurth.)

The *lymphatics* of the liver are said to commence as perivascular lymphatic spaces inclosing the capillaries of the lobules, but this appears doubtful. Efferent lymphatics pass away from the organ in the connective tissue which invests both the portal and hepatic veins.

THE PANCREAS.

The **pancreas** is a tubulo-racemose gland, resembling the salivary glands, so far as its general structure is concerned, but differing from them in the fact that the alveoli are longer and more tubular in character. Moreover, the connective tissue of the gland is somewhat looser, and there occur in it at intervals small groups of epithelium-like cells (*islets of Langerhans*) (fig. 314, *a*; fig. 315), which are supplied with a close network of large convoluted capillary vessels (fig. 316); their function is unknown, but their presence is very characteristic of the pancreas.

The cells which line the alveoli are columnar or polyhedral in shape. When examined in the fresh condition, or in osmic preparations, their protoplasm is filled in the inner two-thirds with small granules, but

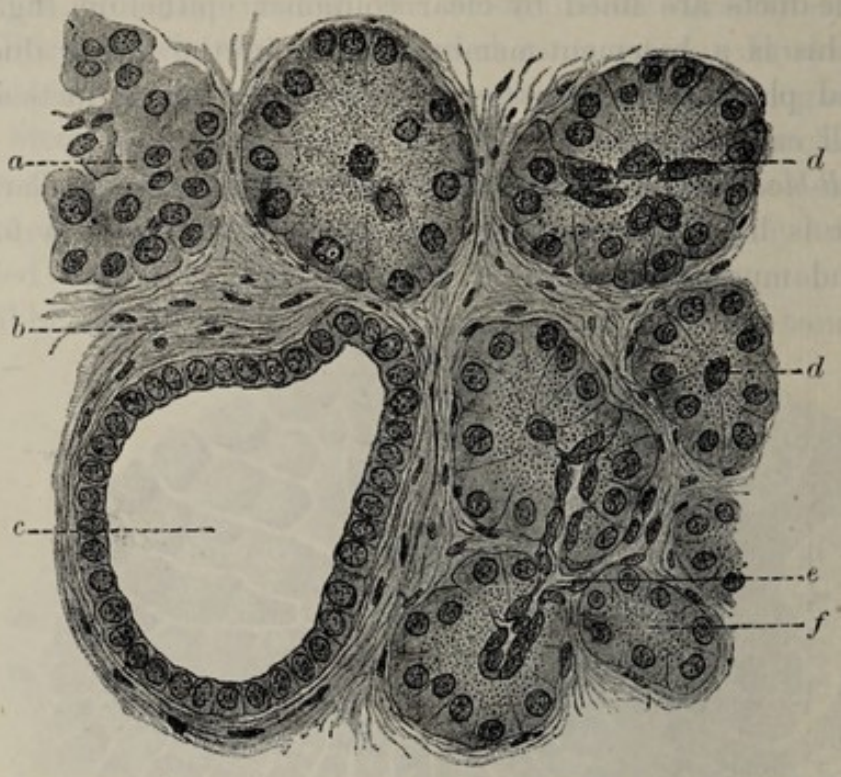


FIG. 314.—SECTION OF HUMAN PANCREAS. (Böhm and v. Davidoff.) $\frac{450}{1}$.

a, group of cells in interstitial tissue (islet of Langerhans); *b*, connective tissue, *c*, larger duct; *d*, *d*, alveoli with centro-acinar cells; *e*, duct passing into alveoli; *f*, inner granular zone of alveolus.

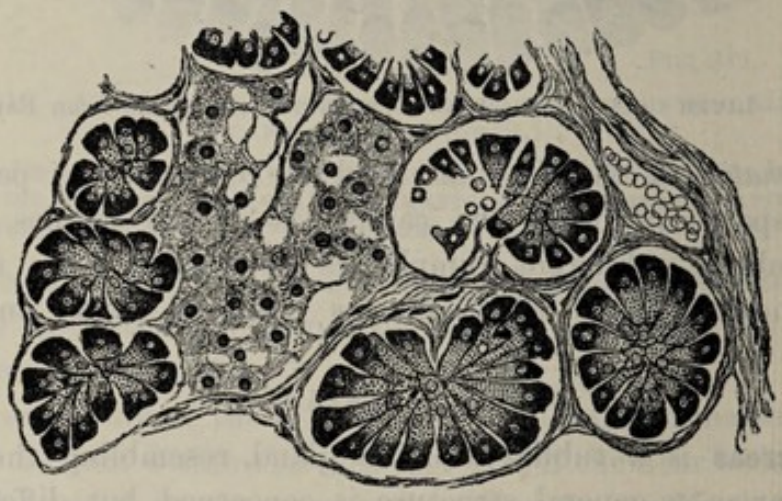


FIG. 315.—SECTION OF PANCREAS OF ARMADILLO SHOWING SEVERAL ALVEOLI AND A LARGE INTERALVEOLAR CELL-ISLET. (V. D. Harris.)

The cells of the alveoli are shrunken, but they show markedly the two zones, the outer or nongranular stained deeply by hæmatoxylin.

the outer third is left clear (fig. 317, *A*). After a period of activity the clear part of the cell becomes larger, and the granular part smaller (*B*). In stained sections the outer part is coloured more deeply than the inner (figs. 314, 315).

In the centre of each acinus there may generally be seen some spindle-shaped cells (*centro-acinar cells* of Langerhans—fig. 314, *d*), the nature of which has not been definitely determined ; but they appear to

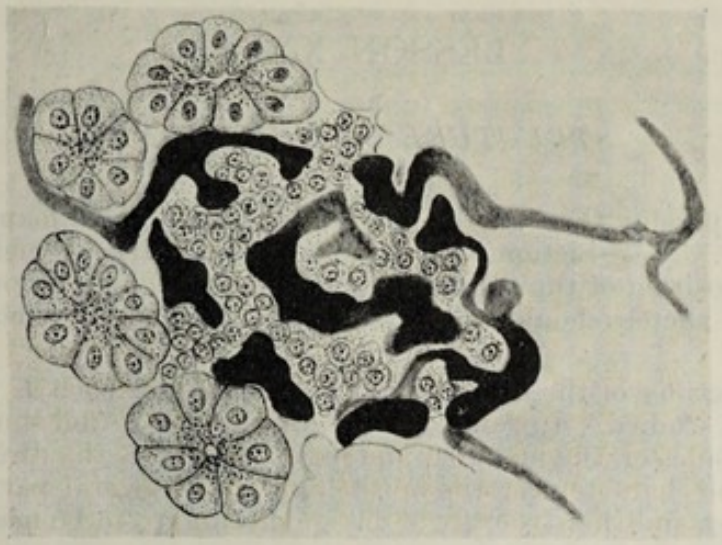


FIG. 316.—INJECTION OF BLOOD-VESSELS OF AN "ISLET" OF THE PANCREAS. (Kühne and Lea.)

be continued from the cells which line the smallest ducts (fig. 314, *e*). Diverticula from the lumen penetrate between the alveolar cells, as in the salivary glands (p. 231). The pancreas has many nerves, with

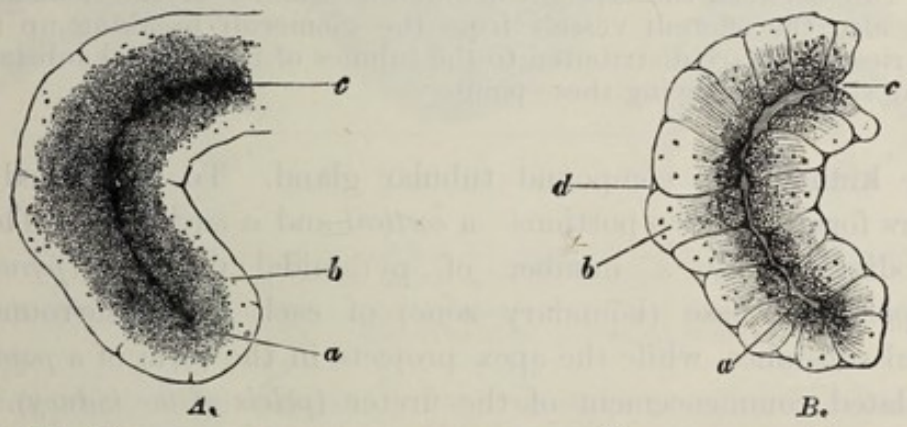


FIG. 317.—PART OF AN ALVEOLUS OF THE RABBIT'S PANCREAS. *A*, AT REST; *B*, AFTER ACTIVE SECRETION. (From Foster, after Kühne and Lea.)

a, the inner granular zone, which in *A* is larger and more closely studded with fine granules than in *B*, in which the granules are fewer and coarser; *b*, the outer transparent zone, small in *A*, larger in *B*, and in the latter marked with faint striæ; *c*, the lumen, very obvious in *B*, but indistinct in *A* ; *d*, an indentation at the junction of two cells, only distinct in *B*.

numerous small nerve-cells distributed upon their course; the nerve-fibrils end by ramifying amongst the cells of the alveoli, as in the salivary glands. In the cat, which has Pacinian bodies in its mesentery, these terminal organs are also found numerously in the substance of the pancreas (V. D. Harris).

LESSON XXXVI.

STRUCTURE OF THE KIDNEY.

1. Sections passing through the whole kidney of a small mammal, such as a mouse or rat. These sections will show the general arrangement of the organ and the disposition of the tubules and of the Malpighian corpuscles.

A general sketch should be made of one of these sections under a low power.

2. Thin sections of the kidney of a larger mammal, such as the dog or cat, may next be studied. In some the direction of the section should be parallel with the tubules of the medulla, and in others across the direction of those tubules. The characters of the epithelium of the several parts of the uriniferous tubules and the structure of the glomeruli are to be made out in these sections.

3. Separate portions of the uriniferous tubules may be studied in teased preparations from a kidney which has been subjected to some process which renders it possible to unravel the uriniferous tubules for a certain distance.[1]

4. Thick sections of a kidney in which the blood-vessels have been injected. Examine these with a low power of the microscope. Follow the course of the arteries—those to the cortex sending their branches to the glomeruli, those to the medulla rapidly dividing into pencils of fine vessels which run between the straight uriniferous tubules of the boundary zone. Notice also the efferent vessels from the glomeruli breaking up into the capillaries which are distributed to the tubules of the cortical substance.

Make sketches showing these points.

The **kidney** is a compound tubular gland. To the naked eye it appears formed of two portions—a *cortical* and a *medullary*. The latter is subdivided into a number of pyramidal portions (*pyramids of Malpighi*), the base (boundary zone) of each being surrounded by cortical substance, while the apex projects in the form of a *papilla* into the dilated commencement of the ureter (*pelvis of the kidney*).[2] Both cortex and medulla are composed entirely of tubules—the *uriniferous tubules*—which have a straight direction in the medulla and a contorted arrangement in the cortex; but groups of straight tubules also pass from the medulla through the thickness of the cortex (*medullary rays*, see fig. 318).

The **uriniferous tubules** begin in the cortical part of the organ in dilatations, each inclosing a tuft or glomerulus of convoluted capillary

[1] For a method which may be employed for this purpose, see *Course of Practical Histology*.

[2] In many animals (*e.g.* dog, cat, rabbit) the whole kidney is formed of only a single pyramid, but in man there are about twelve.

blood-vessels (*corpuscles of Malpighi*), the dilated commencement of the tubule being known as the *capsule* (fig. 321, 1). The glomerulus is lobulated, the lobules being all united by the afferent and efferent vessels but projecting freely into the capsule, where they are each covered by a layer of thin epithelium reflected from that lining the capsule. The amount to which the glomerulus fills the capsule depends upon the condition of dilatation of the capillaries. The tubule leaves the capsule by a *neck* (2), which is rarely narrower than the rest of the tubule in mammals, but in some animals (*e.g.* frog) is long, and has ciliated epithelium; the tubule is at first convoluted (*first convoluted*

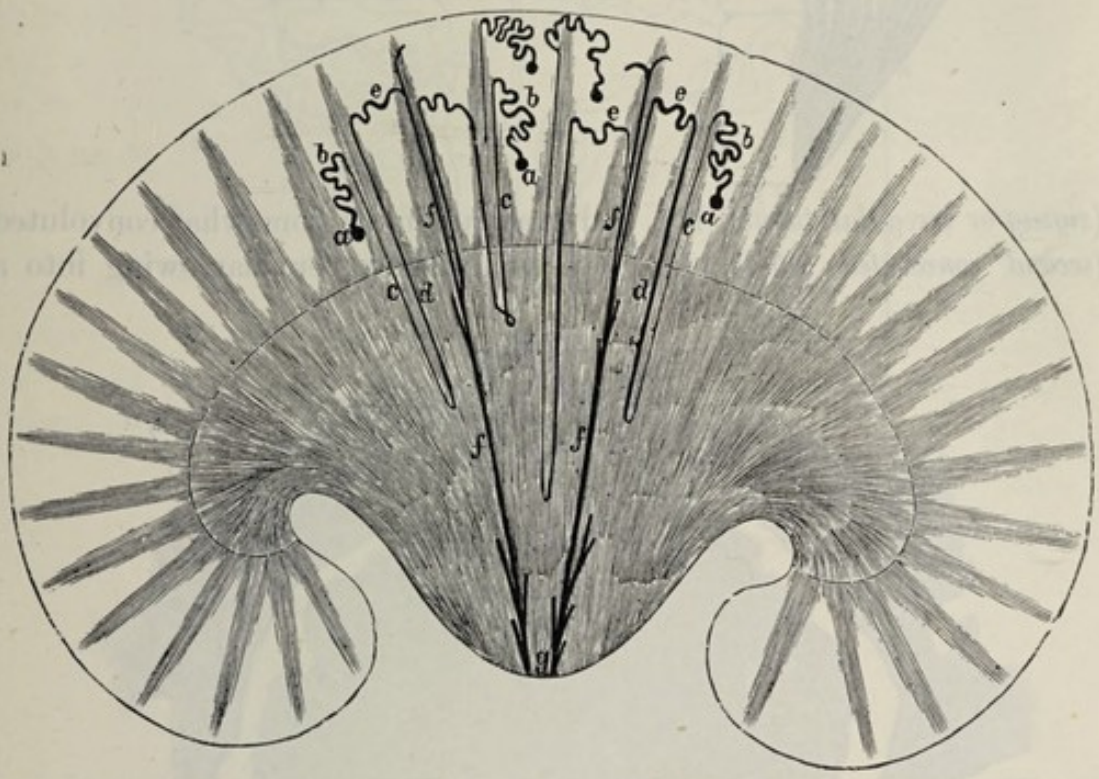


FIG. 318.—DIAGRAM OF THE COURSE OF THE TUBULES IN A UNIPYRAMIDAL KIDNEY, SUCH AS THAT OF THE RABBIT. (Toldt.)

a, Malpighian bodies; *b*, first convoluted tubule; *c*, *d*, looped tube of Henle; *e*, second convoluted; *f*, collecting tube; *g*, ducts of Bellini.

tubule, 3), but soon becomes nearly straight or slightly spiral only (*spiral tubule*, 4), and then, rapidly narrowing, passes down into the medulla towards the dilated commencement of the ureter as the *descending tubule of Henle* (5). It does not at once, however, open into the pelvis of the kidney, but before reaching the end of the papilla it turns round in the form of a loop (*loop of Henle*, 6) and passes upwards again towards the cortex, parallel to its former course, and at first somewhat larger than before, but afterwards diminishing in size (*ascending tubule of Henle*, 7, 8, 9). Arrived at the cortex, it approaches close to the capsule from which the tubule took origin, but at a point opposite to the origin, viz. near the afferent and efferent vessels of the

glomerulus (Golgi). It then becomes larger and irregularly zigzag

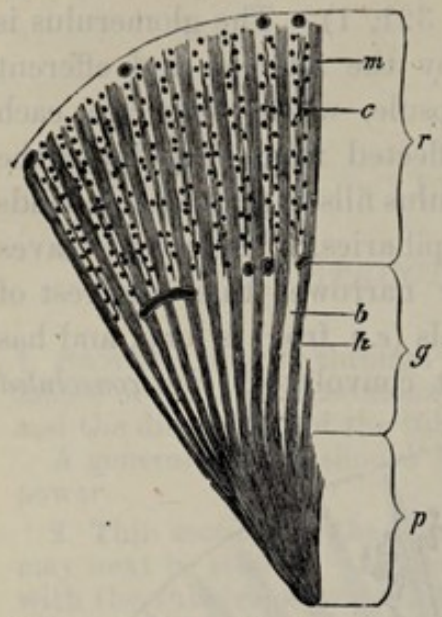


FIG. 319. — SECTION THROUGH PART OF A DOG'S KIDNEY. (Ludwig.)

p, papillary, and *g*, boundary zones of the medulla; *r*, cortical layer; *k*, bundles of tubules in the boundary layer, separated by spaces, *b*, containing bunches of vessels (not here represented), and prolonged into the cortex as the medullary rays, *m*; *c*, intervals of cortex, composed chiefly of convoluted tubules, with irregular rows of glomeruli, between the medullary rays.

(*zigzag or irregular tubule*, 10), and may again be somewhat convoluted (*second convoluted tubule*, 11), eventually, however, narrowing into a

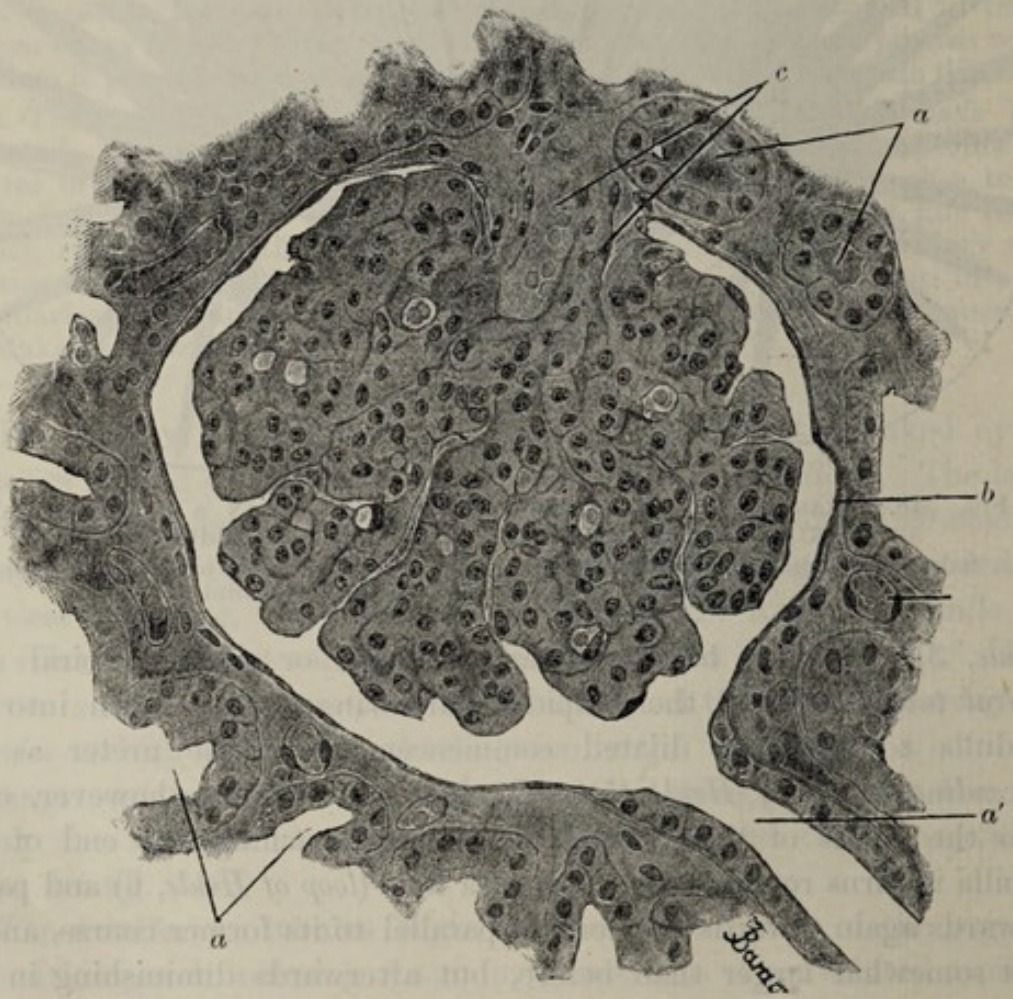


FIG. 320.—A MALPIGHIAN CORPUSCLE FROM THE KIDNEY OF THE MONKEY. (Szymonowicz.) (Magnified 350 diameters.)

a, *a*, sections of convoluted tubules; *a'*, commencement of convoluted tube from capsule; *b*, capsule; *c*, afferent and efferent vessels of glomerulus.

vessel (*junctional tubule*, 12), which joins a straight or *collecting tubule* (13). This now passes through the medullary substance of the kidney (14) to open at the apex of the papilla as one of the *ducts of Bellini* (15).

The tubules are throughout bounded by a basement-membrane, which

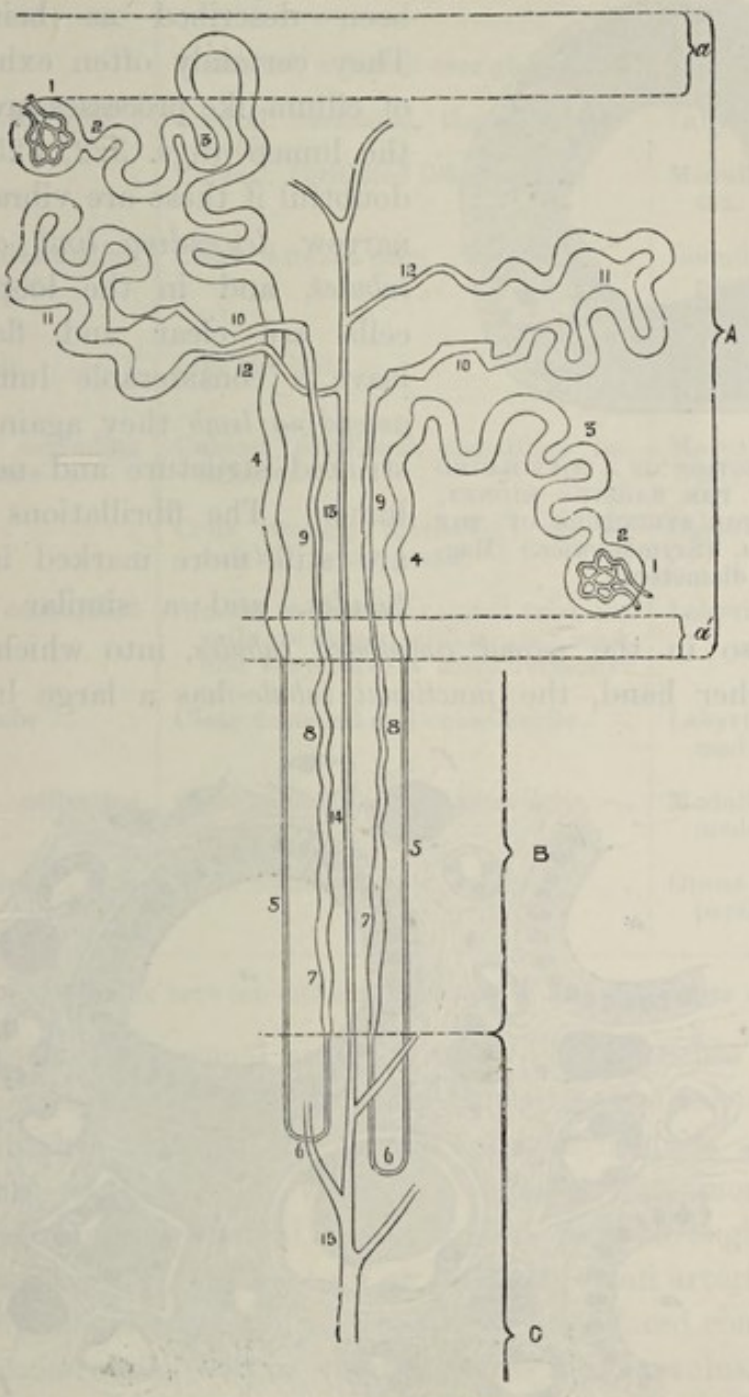


FIG. 321.—DIAGRAM OF THE COURSE OF TWO URINIFEROUS TUBULES. (Klein.)
A, cortex; B, boundary zone; C, papillary zone of the medulla; *a*, *a'*, superficial and deep layers of cortex, free from glomeruli. For the explanation of the numerals, see the text.

is lined by epithelium, but the characters of the epithelium-cells vary in the different parts of a tubule. In the *capsule* the epithelium is flattened and is reflected over the glomerulus. In some animals (*e.g.* mouse) the fibrillar epithelium of the convoluted tube is prolonged

a little way into the capsule. In the first *convoluted* and *spiral tubules* the epithelium is thick, and the cells show a marked fibrillar structure (figs. 320, 322). Moreover, they interlock laterally and are difficult of isolation; in some animals they have been described as being ciliated. They certainly often exhibit a brush of cilium-like processes projecting into the lumen (figs. 322, 325), but it is doubtful if these are vibratile. In the narrow *descending limb of the looped tubules*, and in the loop itself, the cells are clear and flattened and leave a considerable lumen; in the *ascending limb* they again acquire the striated structure and nearly fill the lumen. The fibrillations of the cells are still more marked in the *zigzag tubules*, and a similar structure is present also in the *second convoluted tubules*, into which these pass. On the other hand, the *junctional tubule* has a large lumen and is

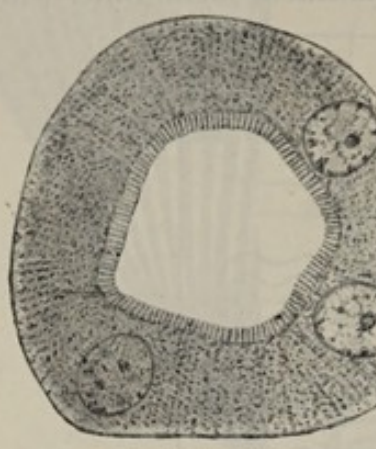


FIG. 322.—SECTION OF A CONVOLUTED TUBULE OF THE RABBIT'S KIDNEY, SHOWING THE STRUCTURE OF THE EPITHELIUM. (Szymonowicz.) (Magnified 1100 diameters.)

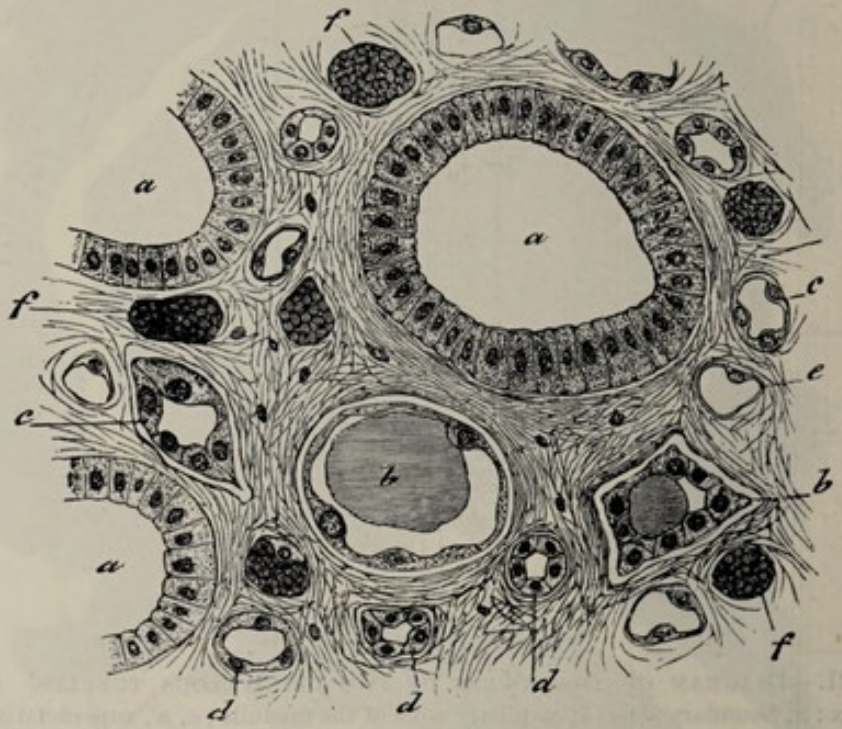


FIG. 323.—SECTION ACROSS A PAPILLA OF THE KIDNEY. (Cadiat.)
a, large collecting tubes (ducts of Bellini); *b*, *c*, *d*, tubules of Henle; *e*, *f*, blood-capillaries.

lined by clear flattened cells, and the *collecting tubes* have also a very distinct lumen and are lined by a clear cubical or columnar epithelium (fig. 323, *a*).

The following gives a tabular view of the parts which compose a uriniferous tubule, and the nature of the epithelium in each part :—

Portion of Tubule.	Nature of Epithelium.	Position of Tubule.
Capsule	Flattened, reflected over glomerulus	Labyrinth of cortex.[1]
First convoluted tube	Cubical, fibrillated, the cells interlocking	Labyrinth of cortex.
Spiral tube	Cubical, fibrillated (like the last)	Medullary ray of cortex.
Small or descending tube of Henle	Clear flattened cells	Boundary zone and partly papillary zone of medulla.
Loop of Henle	Like the last	Papillary zone of medulla.
Larger or ascending tube of Henle	Cubical, fibrillated, sometimes imbricated.	Medulla, and medullary ray of cortex.
Zigzag tube	Cells strongly fibrillated; varying height; lumen small	Labyrinth of cortex.
Second convoluted tube	Similar to first convoluted tube, but cells are longer, with larger nuclei, and they have a more refractive aspect	Labyrinth of cortex.
Junctional tube	Clear flattened and cubical cells	Labyrinth passing to medullary ray.
Straight or collecting tube	Clear cubical and columnar cells	Medullary ray and medulla.
Duct of Bellini	Clear columnar cells	Opens at apex of papilla.

[1] The part of the cortex between and surrounding the medullary rays is so named.

Blood-vessels.—The renal artery divides into branches on entering the organ, and these branches pass towards the cortex, forming incomplete arches between the cortex and the medulla (fig. 324, *a*). The branches of the renal vein form similar but more complete arches (*g*).—From the arterial arches vessels pass through the cortex (*interlobular arteries*, *b*), and give off at intervals small arterioles (*efferent vessels of the glomeruli*), each of which enters the dilated commencement of a uriniferous tubule, within which it forms a glomerulus. From the glomerulus a somewhat smaller *efferent vessel* passes out, and this at once again breaks up into capillaries, which are distributed amongst the tubules of the cortex (*e*); their blood is collected by veins which accompany the arteries and join the venous arches between the cortex and the medulla, receiving in their course certain other veins which arise by radicles having a somewhat stellate arrangement near the capsule (*venæ stellulæ*, *j*).

The medulla derives its blood-supply from special offsets of the arterial arches, which almost immediately break up into pencils of fine straight arterioles running in groups between the straight tubules

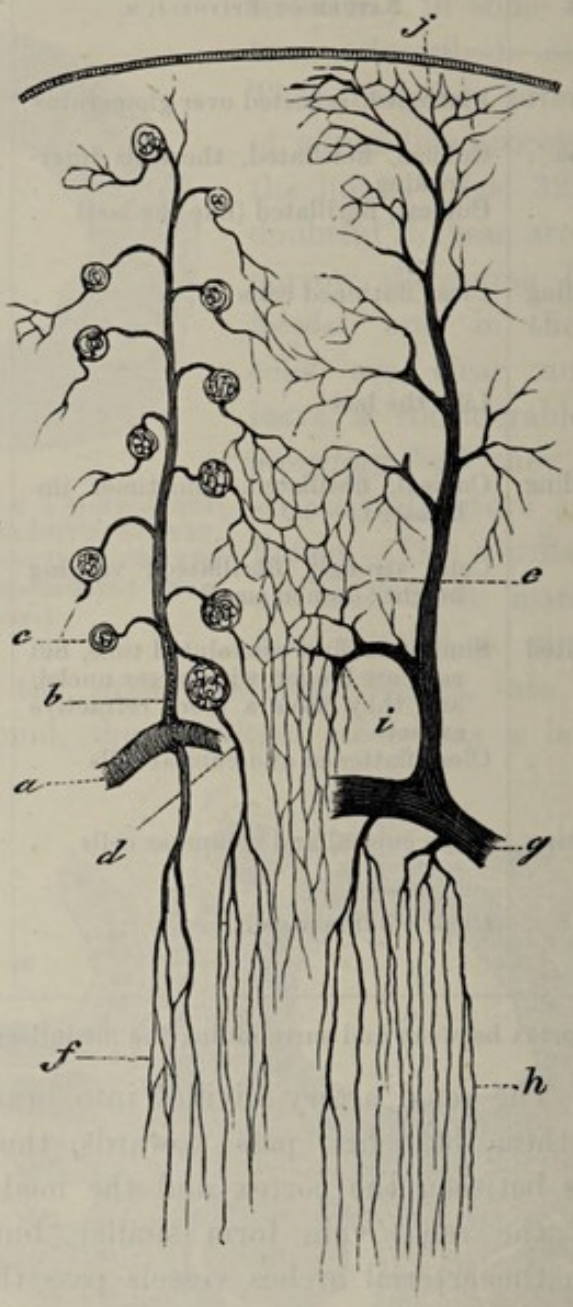


FIG. 324.—VASCULAR SUPPLY OF KIDNEY. (Cadiat.) Diagrammatic.

a, part of arterial arch; *b*, interlobular artery; *c*, glomerulus; *d*, efferent vessel passing to medulla as false arteria recta; *e*, capillaries of cortex; *f*, capillaries of medulla; *g*, venous arch; *h*, straight veins of medulla; *j*, vena stellula; *i*, interlobular vein.

of the medulla. These arterioles break up into a capillary network with elongated meshes which pervade the medulla (fig. 324, *f*), and which terminates in a plexus of somewhat larger venous capillaries in the papillæ. From these and from the other capillaries the veins collect the blood, and pass, accompanying the straight arterioles, into the venous arches between the cortex and medulla. The groups of

small arteries and veins (*vasa recta*) in the part of the medulla nearest to the cortex alternate with groups of the uriniferous tubules, and this arrangement confers a striated aspect upon this portion of the medulla (*boundary zone*, fig. 319, *g*).

The efferent vessels of those glomeruli which are situated nearest to the medulla may also break up into pencils of fine vessels (*false arteriæ rectæ*) and join the capillary network of the medulla (fig. 324, *d*).

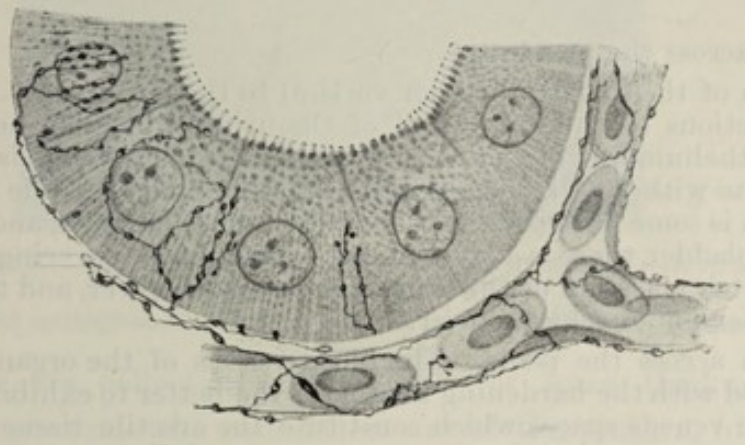


FIG. 325.—NERVE FIBRILS ENDING OVER CAPILLARY BLOOD-VESSELS AND AMONGST THE EPITHELIUM CELLS OF A CONVOLUTED TUBE OF THE FROG'S KIDNEY. (Smirnow.)

Between the uriniferous tubules, and supporting the blood-vessels, is a certain amount of connective tissue (fig. 323), within which are cleft-like spaces from which the lymphatics of the organ originate.

Nerve-fibrils have been described as ramifying amongst the epithelium-cells of the tubules, but most of the nerves to the kidneys are distributed to the blood-vessels.

LESSON XXXVII.

STRUCTURE OF THE URETER, BLADDER, AND MALE GENERATIVE ORGANS.

1. Section across the ureter.

2. Section of the urinary bladder vertical to the surface.

In the sections of the ureter and of the urinary bladder, notice the transitional epithelium resting on a mucous membrane, which is composed of areolar tissue without glands, and the muscular coat outside this. In the ureter there is some fibrous tissue outside the muscular coat, and at the upper part of the bladder there is a layer of serous membrane covering the muscular tissue. Sketch a section of the ureter under a low power, and the epithelium of the bladder under a high power.

3. Section across the penis. The blood-vessels of the organ should have been injected with the hardening fluid so as the better to exhibit the arrangement of the venous spaces which constitute the erectile tissue. Notice the large venous sinuses of the corpora cavernosa and the smaller spaces of the corpus spongiosum, in the middle of which is seen the tube of the urethra.

4. Section across the testis and epididymis. The sections are best made from a rat's testis which has been hardened in alcohol, and thin pieces of which have been stained in bulk in hæmatoxylin. In these sections notice the strong capsule surrounding the gland, the substance of which consists of tubules which are variously cut, and the epithelium of the tubules, which is in different phases of development in different tubules. Observe the strands of polyhedral interstitial cells, much more numerous in some animals (*e.g.* cat), lying in the loose tissue between the tubules; also the lymphatic clefts in that tissue. Notice in sections through the epididymis the epithelium of that tube.

Sketch carefully under a high power the contents of some of the seminiferous tubules so as to illustrate the mode of formation of the spermatozoa.

5. Examination of spermatozoa. Spermatozoa may be obtained fresh from the testicle or seminal vesicles of a recently killed animal and examined in saline solution. Their movements may be studied on the warm stage; to display their structure a very high power of the microscope is necessary. Measure and sketch three or four spermatozoa.

The **ureter** is a muscular tube lined by mucous membrane. The *muscular coat* consists of two layers of plain muscular tissue, an outer circular, and an inner longitudinal. In the lower part there are some longitudinal bundles external to the circular. Outside the muscular coat is a *layer of fibrous tissue* in which the blood-vessels and nerves ramify before entering the muscular layer.

The *mucous membrane* is composed of areolar tissue and is lined by transitional epithelium similar to that of the urinary bladder.

The **urinary bladder** has a muscular wall lined by a strong mucous membrane and covered in part by a serous coat.

The *muscular coat* consists of three layers, but the innermost is incomplete. The principal fibres run longitudinally and circularly, and the

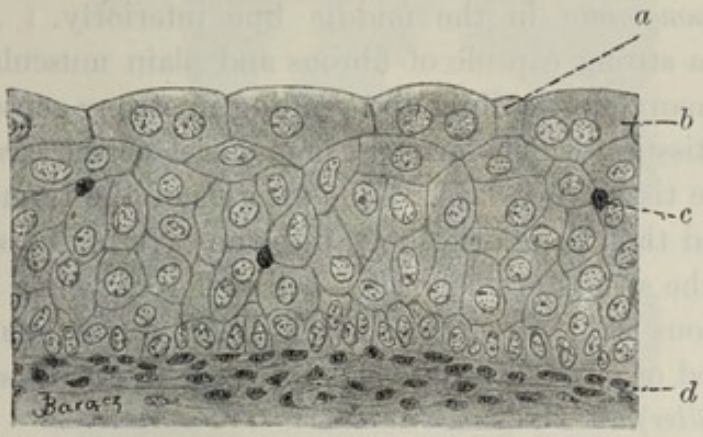


FIG. 326.—SECTION OF THE MUCOUS MEMBRANE OF THE BLADDER TO SHOW ITS EPITHELIUM. (Szymonowicz.)

a, *b*, superficial epithelium-cells; *c*, leucocyte; *d*, areolar tissue of mucous membrane.

circular fibres are collected into a layer of some thickness which immediately surrounds the commencement of the urethra, forming the

FIG. 327.—SECTION OF ERECTILE TISSUE. (Cadiat.)

a, trabeculæ of connective tissue, with elastic fibres, and bundles of plain muscular tissue, some cut across (*c*); *b*, venous spaces.

sphincter vesicæ. The *mucous membrane* is lined by a transitional stratified epithelium (fig. 326). The shape and structure of the cells have already been studied (Lesson VII.).

The *nerves* to the bladder form gangliated plexuses, and are dis

tributed mainly to the muscular tissue and blood-vessels, but some are said to enter the epithelium.

The **penis** is mainly composed of cavernous tissue which is collected into two principal tracts—the *corpora cavernosa*, one on each side, and the *corpus spongiosum* in the middle line inferiorly. All these are bounded by a strong capsule of fibrous and plain muscular tissue, containing also many elastic fibres and sending in strong septa or trabeculæ of the same tissues, which form the boundaries of the cavernous spaces of the erectile tissue (fig. 327). The arteries of the tissue run in these trabeculæ, and their capillaries open into the cavernous spaces. On the other hand, the spaces are connected with efferent veins. The arteries of the cavernous tissue may sometimes in injected specimens be observed to form looped or twisted projections into the cavernous spaces (*helicine arteries of Müller*).

Urethra.—The cross-section of the urethra appears in the middle of the corpus spongiosum in the form of a transverse slit. It is lined in the prostatic part by transitional, but elsewhere by columnar epithelium, except near its orifice, where the epithelium is stratified. In the female urethra it is stratified throughout. The epithelium rests upon a vascular mucous membrane, and this again is supported by a coating of submucous tissue, containing two layers of plain muscular fibre—an inner longitudinal and an outer circular. Outside this again is a close plexus of small veins which is connected with, and may be said to form part of, the corpus spongiosum.

The *mucous membrane* of the urethra is beset with small mucous glands, simple and compound (*glands of Littré*). There are also a number of oblique recesses termed *lacunæ*. Besides these small glands and glandular recesses, two compound racemose glands open into the bulbous portion of the urethra (*Cowper's glands*). Their acini are lined by clear columnar cells which yield a mucous secretion.

The **prostate**, which surrounds the commencement of the urethra, is a muscular and glandular mass, the glands of which are composed of tubular alveoli, lined by columnar epithelium, with smaller cells lying between them and the basement-membrane (fig. 328). Their ducts open upon the floor of the urethra. In old subjects the tubules often contain calcareous concretions.

The integument of the penis contains numerous special nerve end-organs of the nature of end-bulbs, and Pacinian bodies are also found upon the nerves. Lymphatic vessels are numerous in the integument of the organ and also in the submucous tissue of the urethra.

The **testicle** is inclosed by a strong fibrous capsule, the *tunica albuginea* (fig. 329, *b*). This is covered externally with a layer of serous

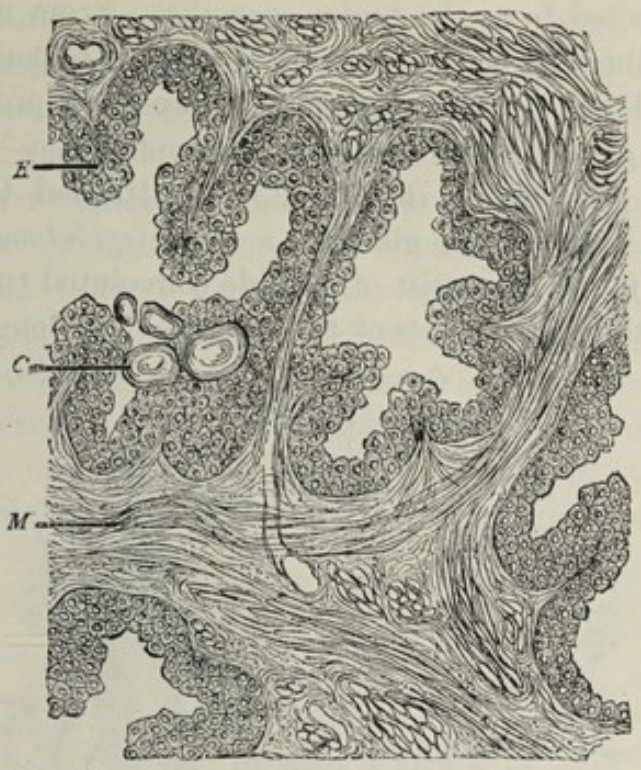


FIG. 328.—SECTION OF PROSTATE. (Heitzmann.)
M, muscular tissue; E, epithelium; C, concretions.

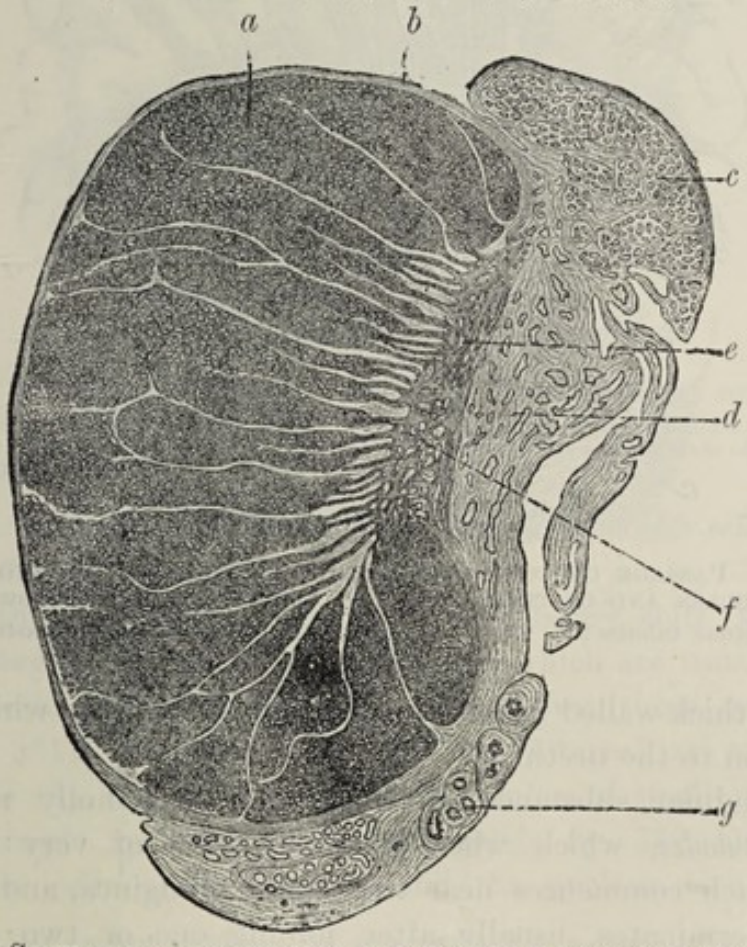


FIG. 329.—SECTION OF HUMAN TESTIS AND EPIDIDYMIS, SOMEWHAT MAGNIFIED.
(Böhm and v. Davidoff.)

a, glandular substance divided into lobules by septa of connective tissue; *b*, tunica albuginea; *c*, head of epididymis; *d*, middle part or body of epididymis; *f*, mediastinum giving origin to the septa; *g*, sections of the commencing vas deferens.

epithelium reflected from the *tunica vaginalis*. From its inner surface there proceed fibrous processes or *trabeculæ*, which imperfectly subdivide the organ into lobules, and posteriorly the capsule is prolonged into the interior of the gland in the form of a mass of fibrous tissue, which is known as the *mediastinum* (fig. 329, *f*). Attached to the posterior margin of the body of the gland is a mass (*epididymis*) which when investigated is found to consist of a single convoluted tube, receiving at its upper end the *efferent ducts* of the testis and prolonged at its lower

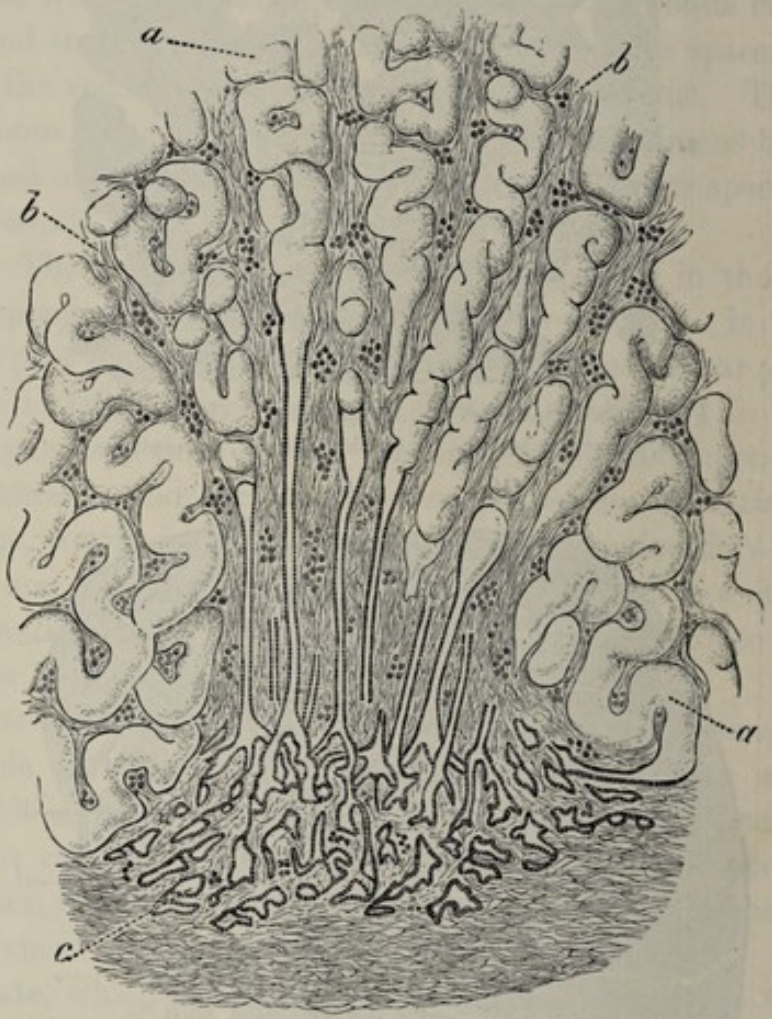


FIG. 330.—PASSAGE OF CONVOLUTED SEMINIFEROUS TUBULES INTO STRAIGHT TUBULES AND OF THESE INTO THE RETE TESTIS. (Mihalkowicz.)
a, seminiferous tubules; *b*, fibrous stroma continued from the mediastinum testis; *c*, rete testis.

end into a thick-walled muscular tube, the *vas deferens*, which conducts the secretion to the urethra.

The glandular substance of the testicle is wholly made up of *convoluted tubules*, which when unravelled are of very considerable length. Each commences near the tunica albuginea, and after many windings terminates, usually after joining one or two others, in a *straight tubule*, which passes into the mediastinum, and there forms, by uniting with the other straight tubules, a network of intercom-

municating vessels, which is known as the *rete testis* (fig. 330). From the rete a certain number of efferent tubules arise, and after a few convolutions pass into the tube of the epididymis.

Structure of the tubules.—The *seminiferous tubules* are formed of a thick basement-membrane, and contain several layers of epithelium-cells. Of these layers, the one next to the basement-membrane is a stratum of clear cubical cells (*lining epithelium-cells, spermatogonia*, figs. 331; 337, *a*), the nuclei of which, for the most part, exhibit the irregular network which is characteristic of the resting condition, but in certain tubules show indications of division. Here and there these epithelium-cells appear enlarged, and project between the more internal layers, being connected with groups of developing

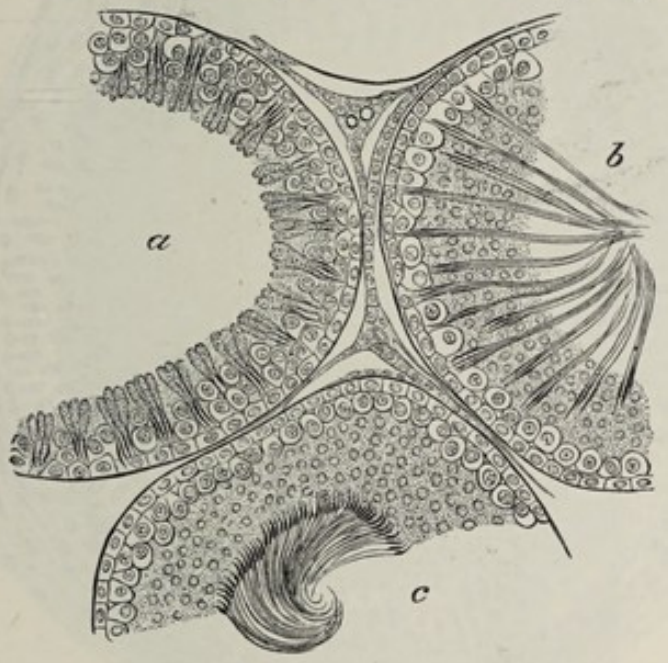


FIG. 331.—SECTION OF PARTS OF THREE SEMINIFEROUS TUBULES OF THE RAT.
a, with the spermatozoa least advanced in development; *b*, more advanced; *c*, containing fully developed spermatozoa. Between the tubules are seen strands of interstitial cells with blood-vessels and lymph-spaces.

spermatozoa. These enlarged cells are the *sustentacular cells*, or *cells of Sertoli* (fig. 337, *a'*; fig. 340).[1]

Next to this epithelium is seen a zone of larger cells (*spermatogenic cells, spermatocysts*, fig. 337, *b*), the nuclei of which are usually in some stage of mitotic division; these cells may be two, three, or more deep (as in *a*, fig. 331). Next to them, and most internal, are to be seen in some tubules (fig. 331, *b* and *c*) a large number of small protoplasmic cells with simple spherical nuclei (*spermatids*, fig. 337, *c*). In other tubules these cells are elongated, and the nucleus is at one end,

[1] These are the 'spermatoblasts' of some authors—a name given to them on the erroneous supposition that they directly produce the spermatozoa. The term 'spermatoblast' is more applicable to the small cells (spermatids) of the third layer or zone.

and in others again these elongated cells are converted into evident spermatozoa, which lie in groups with their heads projecting between the deeper cells and connected with one of the enlarged cells of the lining epithelium, and their tails emerging into the lumen of the tubule (fig. 331, *b*). As they become matured they gradually pass altogether towards the lumen, where they eventually become free (*c*). During the time that this crop of spermatozoa has been forming, another set of spermatoblasts has been produced by the division of the spermatogenic

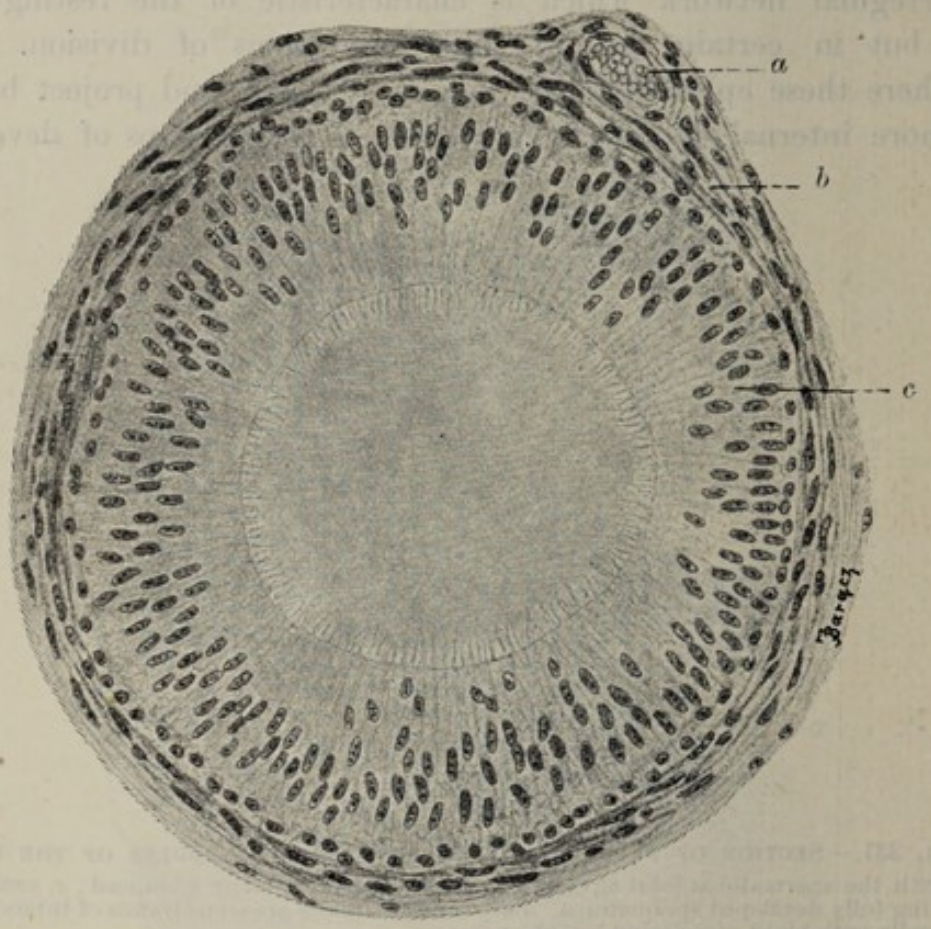


FIG. 332.—SECTION OF THE TUBE OF THE EPIDIDYMIS. (Szymonowicz.)
(Magnified 300 diameters.)
a, blood-vessel; *b*, circular muscular fibres; *c*, epithelium.

cells, and on the discharge of the spermatozoa the process is repeated as before.

The *straight tubules* which lead from the convoluted seminiferous tubes into the rete testis (fig. 330) are lined only by a single layer of clear flattened or cubical epithelium. The tubules of the *rete* also have a simple epithelial lining, but the basement-membrane is here absent, the epithelium being supported directly by the connective tissue of the mediastinum.

The *efferent tubules* which pass from the rete to the epididymis are lined by columnar ciliated epithelium, the cilia being very long. The

tube of the epididymis is also lined by long columnar cells, with what appear to be bunches of cilium-like fibrils projecting into the lumen of the tube. These apparent cilia are, however, not contractile as was formerly supposed, and are therefore not true cilia (Myers-Ward). They appear to vary in development in different cells, and are probably connected in some way with the formation of the epididymal secretion and its extrusion into the lumen of the tube. The tube of the epididymis has a considerable amount of plain muscular tissue in its wall (fig. 332).

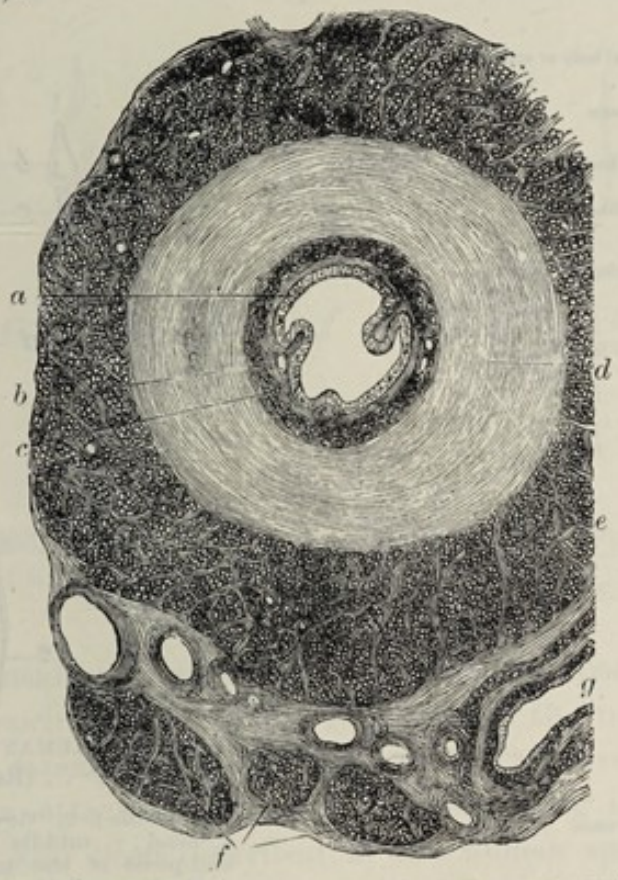


FIG. 33.—SECTION ACROSS THE COMMENCEMENT OF THE VAS DEFERENS. (Klein.)
a, epithelium; *b*, mucous membrane; *c*, *d*, *e*, inner, middle, and outer layers of the muscular coat; *f*, bundles of the internal cremaster muscle; *g*, section of a blood-vessel.

The *vas deferens* (fig. 333) is a thick tube, the wall of which is formed of an outer thick layer of longitudinal bundles of plain muscular tissue; within this an equally thick layer of circular bundles of the same tissue, and within this again a layer of longitudinal muscle. The tube is lined by a mucous membrane, the inner surface of which is covered by columnar non-ciliated epithelium.

The *ampullæ* of the vas deferentia, and the *vesiculæ seminales*, are in structure similar to the vas deferens, but their corrugated walls are much thinner and less muscular.

The connective tissue between the tubules of the testis is of very loose texture, and contains numerous lymphatic clefts, which form an

intercommunicating system of commencing lymphatic vessels. Lying in this intertubular tissue are strands of polyhedral epithelium-like cells (*interstitial cells*, see fig. 331) of a yellowish colour; they are much more abundant in some species of animals (cat, boar) than in others. They accompany the blood-vessels before these break up to form the capillary networks which cover the walls of the seminiferous tubules.

The interstitial cells contain in many animals abundant fat-globules (staining with osmic acid). Similar globules which occur in the Sertoli

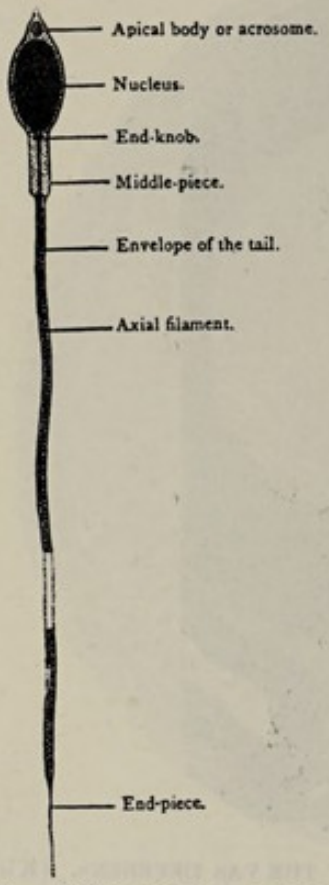


FIG. 334.—DIAGRAM OF A SPERMATOZOON. (Wilson.)

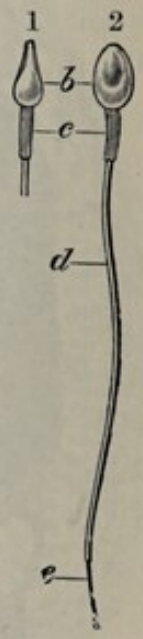


FIG. 335.—HUMAN SPERMATOZOA. $\frac{1000}{1}$. (Retzius.)

1, in profile; 2, viewed on the flat; *b*, head; *c*, middle piece; *d*, tail; *e*, end-piece of the tail, which is described as a distinct part by Retzius.

cells of the seminiferous tubules (fig. 340) have been thought to pass into these from the interstitial tissue.

The **spermatozoa.**—Each spermatozoon consists of three parts, a *head*, a *middle part* or *body*, and a long tapering and vibratile *tail* (fig. 334). In man (fig. 335) the head is of a flattened oval shape, somewhat more flattened and pointed anteriorly; in some animals it bears a small barb-like projection at its extremity. The *middle-piece* is short and cylindrical, and appears to have a spiral fibre passing round it. An *axial fibre* passes from a knob close to the head right through the body and tail. The *tail* is the longest part of the spermatozoon, and when examined with the microscope in the fresh

condition is seen to be in continual vibratile motion, the action resembling that of the cilia of a ciliated epithelium-cell. The extremity of the tail (*end-piece*) forms a distinct part of the spermatozoon, and in some animals may become split up into two or three fibrils; these can also sometimes be traced along the whole length of the tail. Human spermatozoa are about 0·06 mm. ($\frac{1}{400}$ inch) long. In different animals the shape of the head and the extent of middle-piece and tail vary greatly (fig. 336). In the rat (fig. 338, 7) the head is long, and is recurved anteriorly; it is set obliquely on the middle-piece, which is

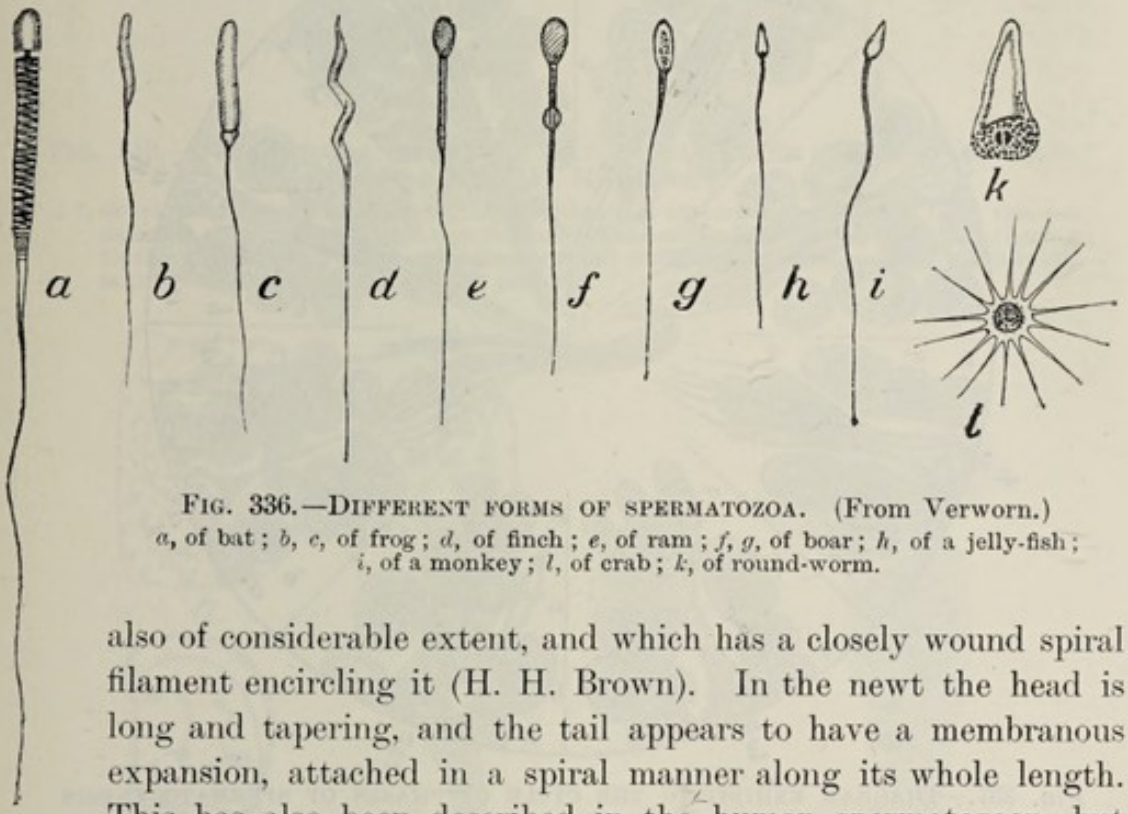


FIG. 336.—DIFFERENT FORMS OF SPERMATOZOA. (From Verworn.)
a, of bat; *b*, *c*, of frog; *d*, of finch; *e*, of ram; *f*, *g*, of boar; *h*, of a jelly-fish; *i*, of a monkey; *l*, of crab; *k*, of round-worm.

also of considerable extent, and which has a closely wound spiral filament encircling it (H. H. Brown). In the newt the head is long and tapering, and the tail appears to have a membranous expansion, attached in a spiral manner along its whole length. This has also been described in the human spermatozoon, but its existence here is doubtful. In arthropods which possess no cilia, the spermatozoa have no vibratile tail. Sometimes two distinct kinds of spermatozoa are met with in the same species of animal, one kind being far the larger in size (giant spermatozoa) but much less numerous. Such giant spermatozoa have been observed in man.

Spermatogenesis.—The spermatozoa are developed from the small cells (spermatoblasts, spermatids) which form the innermost stratum of the seminal epithelium, and these are themselves produced by the division of the large spermatogenic or mother-cells (spermatocysts) of the second layer. It is probable that these mother-cells again are formed by division of some of the lining epithelium-cells or spermatogonia. The cycle of changes therefore which appears to take place is as follows:—1. Division of a lining epithelium-cell into two, one of which becomes a spermatocyst, and passes into the second layer, while the other remains in the first layer, undergoes enlargement, and becomes a sustentacular cell. 2. Division of the spermatocyst. 3. Further division and multiplication of the spermatocysts and the conversion

of the resulting daughter-cells into a group of spermatoblasts (spermatids). 4. Elongation of the spermatids and their gradual conversion into mature spermatozoa. As they undergo this conversion their grouping becomes more evident, and each group is found to be connected with a cell of Sertoli (figs. 337, *a'*, 340), which probably ministers to their nutrition. This cell undergoes a gradual process of elongation so that the spermatozoa by the time they are fully developed are brought to the lumen of the tube, in which they then become free. In the meantime other alternate groups of daughter-cells from which the next crop of spermatozoa will be derived are being formed in the

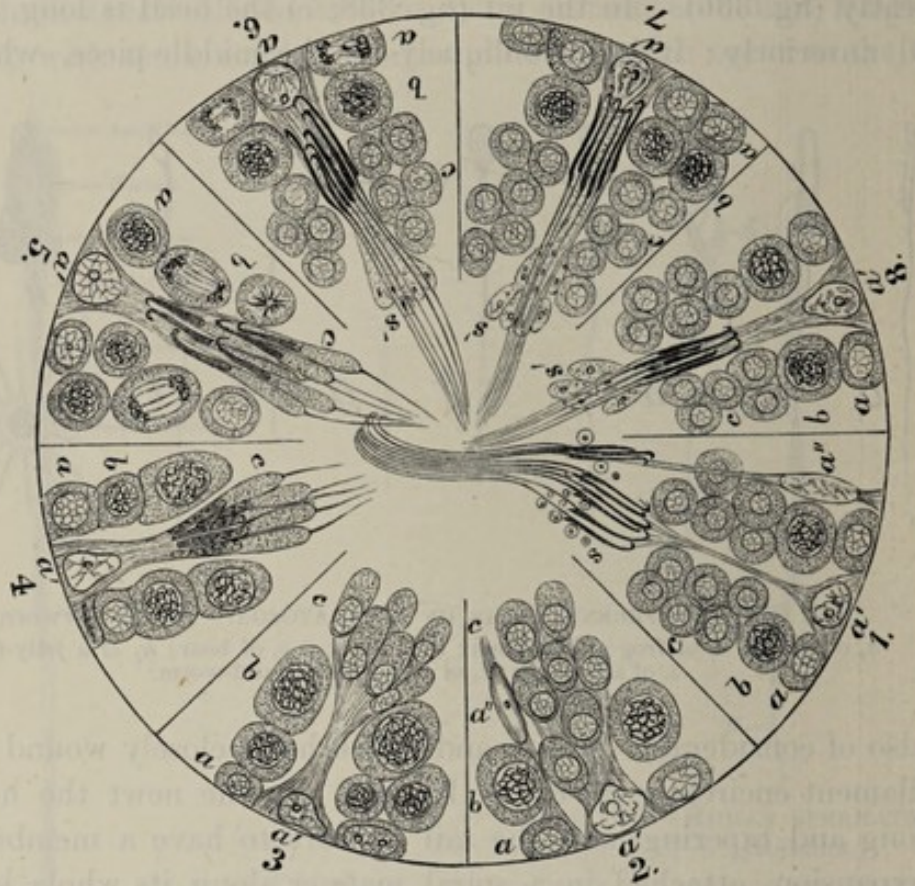


FIG. 337.—DIAGRAM EXHIBITING THE CYCLE OF PHASES OF SPERMATOGENESIS (RAT).

a, lining epithelium-cells or spermatogonia, seen dividing in *6*; *a'*, sustentacular cells; *b*, spermatogenic or mother-cells (spermatocysts), with skein-like nuclear filaments. These cells are seen actively dividing in *5*. *c*, spermatoblasts or spermatids, forming an irregular column or clump in *6*, *7*, *8*, and *1*, and connected to an enlarged supporting cell, *a'*, of the lining epithelium in *2*, *3*, *4*, and *5*. In *6*, *7*, and *8* advanced spermatozoa of one crop are seen between columns of spermatoblasts of the next crop. *s'*, parts of the spermatoblasts which are disintegrated when the spermatozoa are fully formed; *s*, seminal granules resulting from their disintegration; *a''*, in *1* and *2* are nuclei of supporting cells which are probably becoming extruded.

same manner, passing through the same cycle of changes. So that in a section of the same tubule, at least two different phases of development may be observed, and in different tubules of the same testicle every phase may be traced. The accompanying diagram (fig. 337), which is constructed from drawings by H. H. Brown, illustrates the cycle of changes above described: it is divided into eight parts, each of which shows the condition of the epithelium of a seminiferous tubule at a particular stage.

Each spermatoblast becomes converted into a spermatozoon in the following manner (figs. 337 to 340). The nucleus forms the head, while the tail develops as a fine filament within the protoplasm, growing out from the (double) centrosome of the cell. The centrosome takes up a position close to the

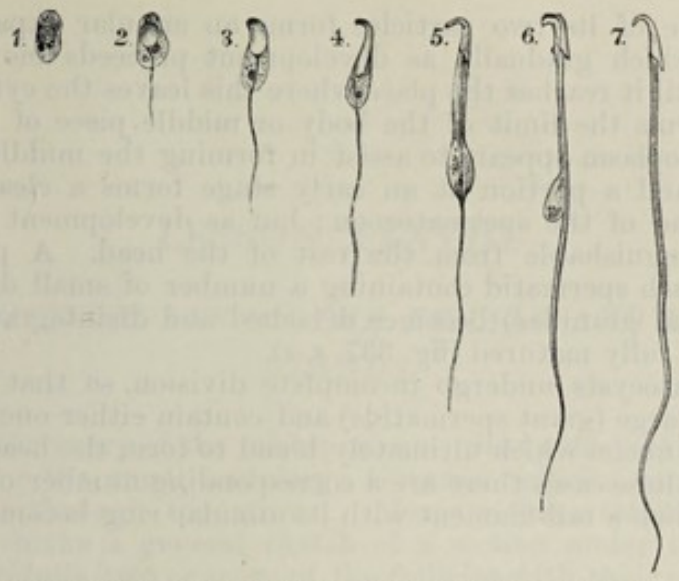


FIG. 338.—SPERMATOZOA FROM THE RAT IN DIFFERENT STAGES OF DEVELOPMENT. (H. H. Brown.)

1-6, developing spermatozoa from the testicle; *7*, a mature spermatozoon from the vas deferens. The remains of the protoplasm of the cell, which is seen in *6* still adhering to the middle piece of the spermatozoon and containing a number of dark granules, is thrown off as the spermatozoon matures.

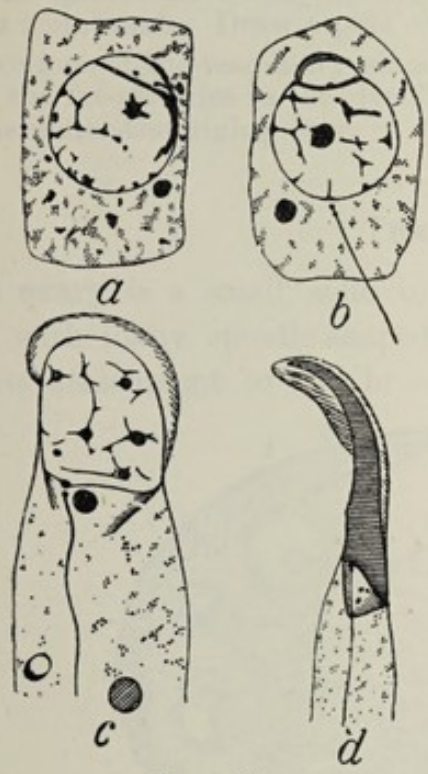


FIG. 339.

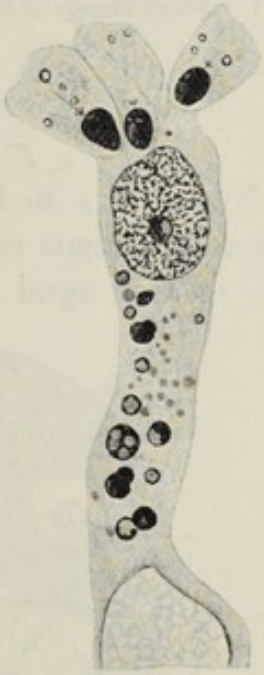


FIG. 340.

FIG. 339.—CHANGES IN THE SPERMATIDS IN THE COURSE OF FORMATION OF THE SPERMATOZOA. (Lenhossék.)

a, *b*, *c*, *d*, four stages of transformation; from the rat. The tail filament is seen to extend from the centrosome, which lies close to the nucleus. The head-cap (shown in *c* and *d*) is produced by a transformation of part of the archoplasm.

FIG. 340.—A CELL OF SERTOLI WITH WHICH THE SPERMATIDS (THREE OF WHICH ARE SHOWN) ARE BEGINNING TO BE CONNECTED: HUMAN. (Braman.)

The cell contains globules (of nutritive substance) staining with osmic acid, and similar but smaller globules are also seen in the spermatids. The "ring" formed around the tail filament by one of the particles of the centrosome (see text) is shown in each of these spermatids close to the "head."

nucleus, and one of its two particles forms an annular expansion or ring (see fig. 340) which gradually as development proceeds moves down the tail-filament until it reaches the place where this leaves the cytoplasm : here it ultimately forms the limit of the body or middle piece of the spermatozoon. The archoplasm appears to assist in forming the middle piece of the spermatozoon, and a portion at an early stage forms a clear cap for the nucleus and head of the spermatozoon ; but as development proceeds, this becomes indistinguishable from the rest of the head. A portion of the protoplasm of each spermatid containing a number of small darkly staining particles (seminal granules) becomes detached and disintegrated before the spermatozoon is fully matured (fig. 337, *s*, *s*).

A few spermatocysts undergo incomplete division, so that the resulting spermatids are large (giant spermatids) and contain either one large nucleus or two or more nuclei which ultimately blend to form the head of the spermatozoon. In these cases there are a corresponding number of centrosomes, from each of which a tail-filament with its annular ring becomes developed.

LESSON XXXVIII.

GENERATIVE ORGANS OF THE FEMALE AND MAMMARY GLANDS.

1. Sections of the ovary of the rabbit or cat. Study the sections with a low power, observing the small and large Graafian follicles, each inclosing an ovum, scattered through the stroma. Measure some Graafian follicles of different sizes; make a general sketch of a section under the low power. Then sketch carefully two or more of the follicles with their contents.

2. Sections across the Fallopian tube. Sketch a section under the low power.

3. Section across the body of the uterus. Observe with the naked eye the thickness of the muscular and mucous coats respectively. Notice the ciliated columnar epithelium lining the organ and extending into the glands of the mucous membrane. Draw a part of the section under the low power.

4. Sections of the mammary gland from an animal killed during lactation. Notice the fat-globules in the alveoli and also in the alveolar cells. Draw an alveolus under the high power.

The Ovary.

The **ovary** is a small solid organ, composed of a *stroma* of fibrous tissue, with many spindle-shaped cells, and also containing, especially near its attachment to the broad ligament, a large number of plain

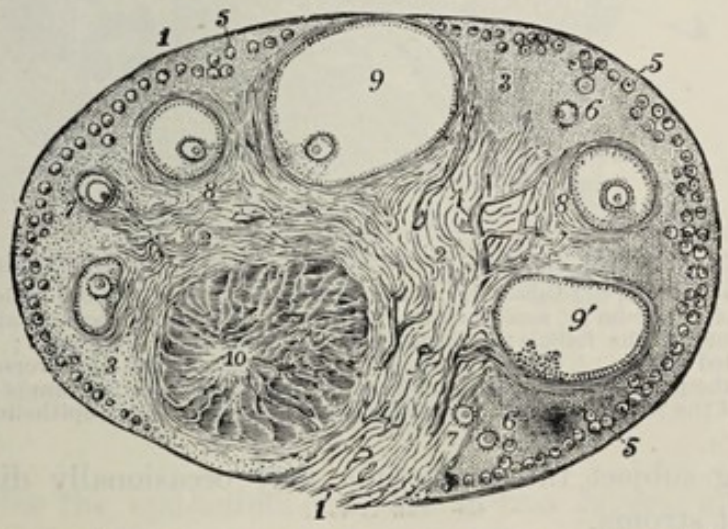


Fig. 341.—Section of the ovary of the cat. $\frac{6}{1}$. (Schron.)

1, outer covering and free border of the ovary; *1'*, attached border; *2*, the central ovarian stroma, showing a fibrous and vascular structure; *3*, peripheral stroma; *4*, blood-vessels; *5*, Graafian follicles in their earliest stages lying near the surface; *6*, *7*, *8*, more advanced follicles which are embedded more deeply in the stroma; *9*, an almost mature follicle containing the ovum in its deepest part; *9'*, a follicle from which the ovum has fallen out in preparing the section; *10*, corpus luteum.

muscular fibres. It is covered by a layer of small columnar epithelium-cells (*germinal epithelium*, fig. 342, *a*), between which may here and there be seen a few larger spheroidal cells, with large round nuclei.

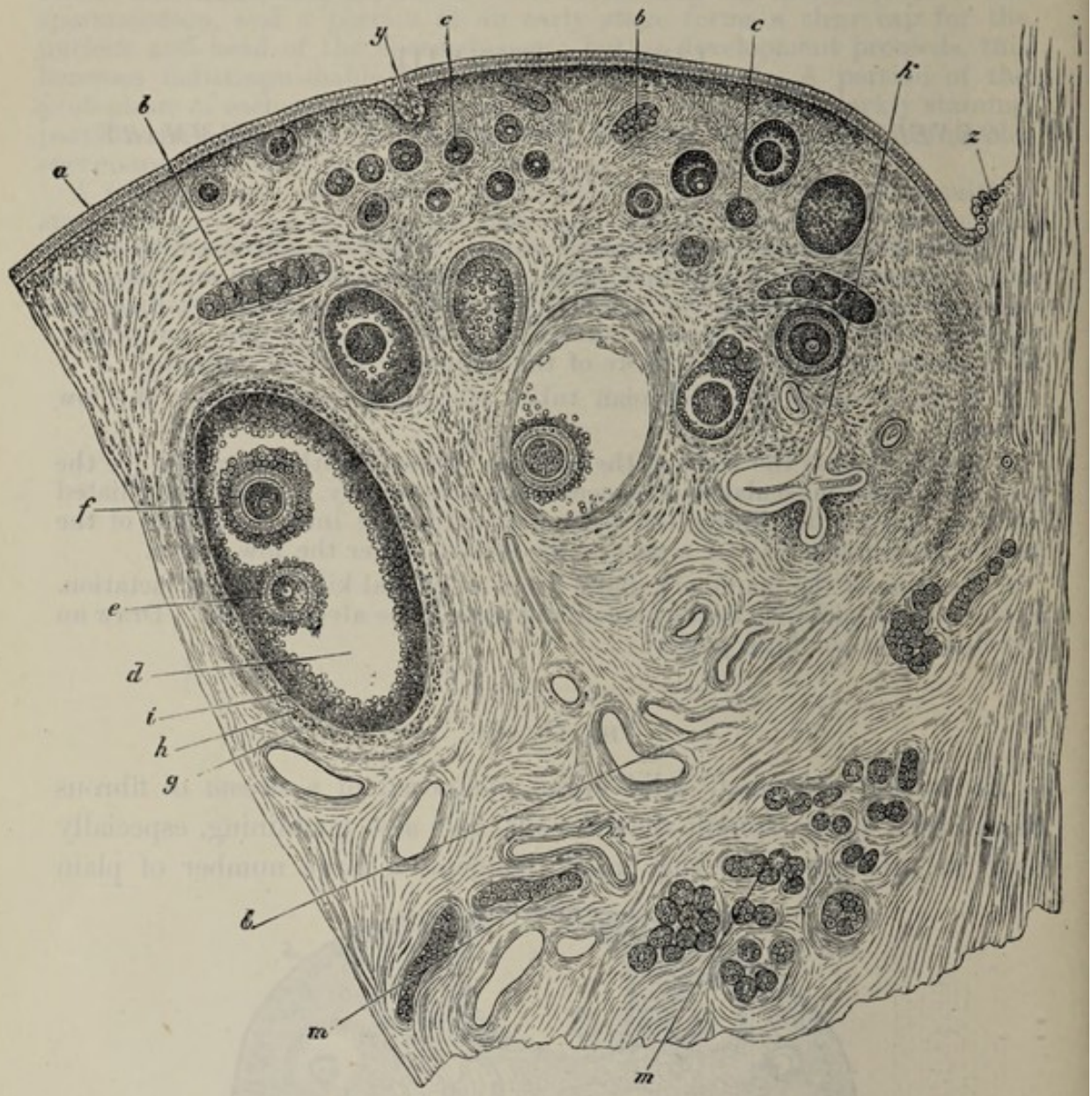


FIG. 342.—SECTION OF THE OVARY OF AN ADULT BITCH. (Waldeyer.)

a, germ-epithelium; *b*, egg-tubes; *c*, *c*, small follicles; *d*, more advanced follicle; *e*, discus proligerus and ovum; *f*, second ovum in the same follicle (this occurs but rarely); *g*, outer tunic of the follicle; *h*, inner tube; *i*, membrana granulosa; *k*, collapsed retrograded follicle; *l*, blood-vessels; *m*, *m*, longitudinal and transverse sections of tubes of the parovarium; *y*, involuted portion of the germ-epithelium of the surface; *z*, place of the transition from peritoneal to germinal or ovarian epithelium.

In the young subject the epithelium may occasionally dip down into the subjacent stroma.

The stroma is beset with vesicles of different sizes, the smallest being near the surface of the organ, the larger ones placed more deeply in the stroma, although, as they increase in size, they may extend towards the surface.

These vesicles are the *Graafian follicles*. Each Graafian follicle has a proper wall (*theca folliculi*) formed of a layer derived from the stroma, and contains an *ovum* and *epithelium*. In the smallest follicles the ovum is small, and the epithelium of the follicle is formed of a single layer of cells, which may be flattened against the ovum. In somewhat

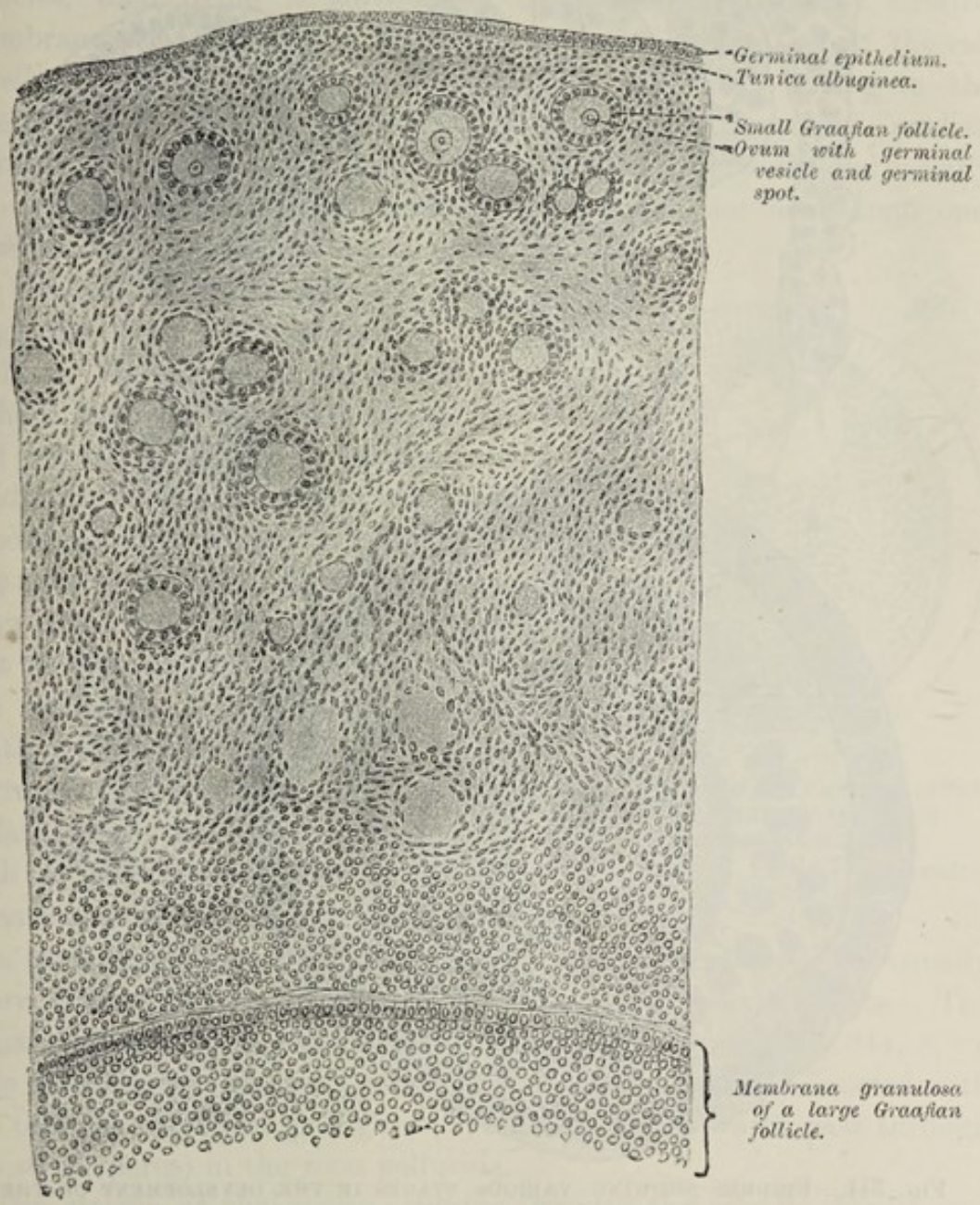


FIG. 343.—SECTION OF PART OF OVARY OF A YOUNG GIRL. $\frac{1}{1}\frac{0}{0}$. (Böhm and v. Davidoff.)

larger follicles the epithelium-cells are in two layers, and these are columnar in shape (fig. 344, E). In still larger ones, each of these two layers is formed of several strata of cells, and fluid has begun to collect between the layers at one part. Or the two layers, the one which lines the cavity of the follicle is termed the *membrana granulosa*, while

the mass of cells which more immediately surrounds the ovum is known as the *discus proligerus*.

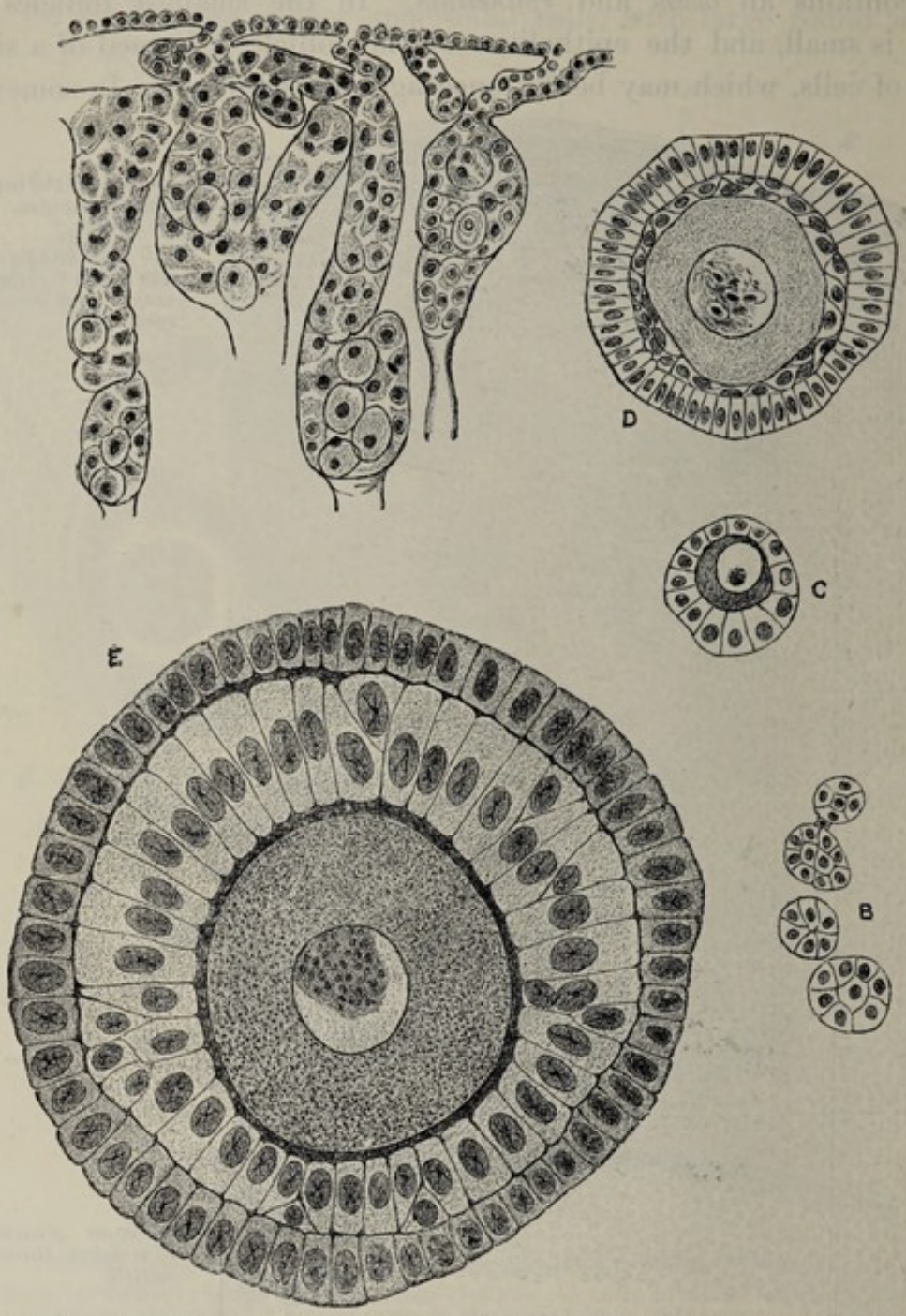


FIG. 344.—FIGURES SHOWING VARIOUS STAGES IN THE DEVELOPMENT OF THE GRAAFIAN FOLLICLES OF THE RABBIT.

A, from ovary of young rabbit, showing "egg-tubes" of Pflüger growing in from germinal epithelium; some of the tubes contain primitive ova; B, primitive Graafian follicles formed from the breaking up of an egg-tube; C, a young Graafian follicle, with a single layer of follicle-epithelium; D, a somewhat older follicle, with the second layer forming within the first; E, a more advanced follicle, showing two complete layers of columnar epithelium surrounding the ovum within the follicle.

In the largest follicles the fluid has much increased in amount, so that the follicle has become gradually larger and more tense. Finally it reaches the surface of the ovary, and projects from that surface,

where it eventually bursts, and the liquor folliculi, with its contained ovum, is set free. This event is believed usually to occur at about the time of menstruation.[1]

The ova are large spherical cells (fig. 345), about 0·2 mm. ($\frac{1}{125}$ inch) in diameter. When mature, as in the largest Graafian follicles, each ovum is surrounded by a thick transparent striated membrane (*zona pellucida*). Within this is the protoplasm of the cell (*vitellus*), filled with fatty and albuminous granules. Lying in the vitellus, generally eccentrically, is the large clear round nucleus (*germinal vesicle*), which contains an intranuclear network, and usually one well-marked nucleolus (*germinal spot*), sometimes more than one. Both the ova and the epithelium of the Graafian follicles are developed originally from the germinal epithelium. In the embryo, this forms a thick layer, covering the fibrous and vascular stroma. After a time solid cords of epithelium-cells, which in some animals are partly tubular (*egg-tubes* of Pflüger; fig. 344, A), grow down into the stroma, whilst this at the same time grows into the epithelium. The cords presently become broken up by the ingrowths of stroma into small isolated nests of epithelium-cells, each of which may represent a Graafian follicle. To form the ova, some of the germinal epithelium-cells become enlarged, and usually there is one such enlarged cell in each of the isolated nests. The remaining cells form the epithelium of the follicle (see fig. 344, B, C). It is believed that the protoplasm of the ovum remains connected with the cells of the discus proligerus by fine processes which pass through the striæ (pores) in the zona pellucida.

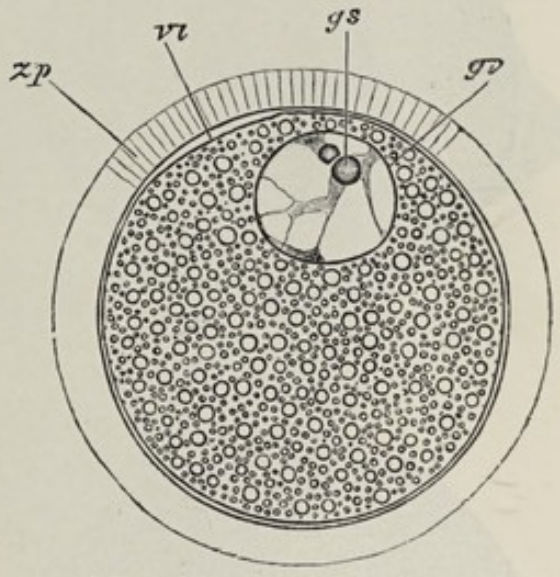


FIG. 345. — SEMI-DIAGRAMMATIC REPRESENTATION OF A MAMMALIAN OVUM. (Highly magnified.)

zp, zona pellucida; *vi*, vitellus; *gv*, germinal vesicle; *gs*, germinal spot.

The stroma of the ovary contains, besides the spindle-shaped connective-tissue cells and plain muscular fibres already mentioned, a number of epithelium-like *interstitial cells*, like those found in the intertubular tissue of the testis. They are most abundant near the hilum. *Corpora lutea* may also be seen in the stroma. These are

[1] Some of the Graafian follicles do not burst, but, after attaining a certain stage of maturity, undergo a process of retrograde metamorphosis and eventually disappear.

large yellow nodules, which are developed out of the Graafian follicles after the ovum has been extruded (fig. 346). They consist of columns of large yellowish cells (*luteal cells*), with intervening trabeculæ of vascular fibrous tissue, which converge to a central strand of connective tissue occupying the axis of the nodule (fig. 347). The columns of cells are not unlike those of the cortex of the suprarenal capsule. The corpus luteum is derived from the wall (?epithelium) of the follicle,

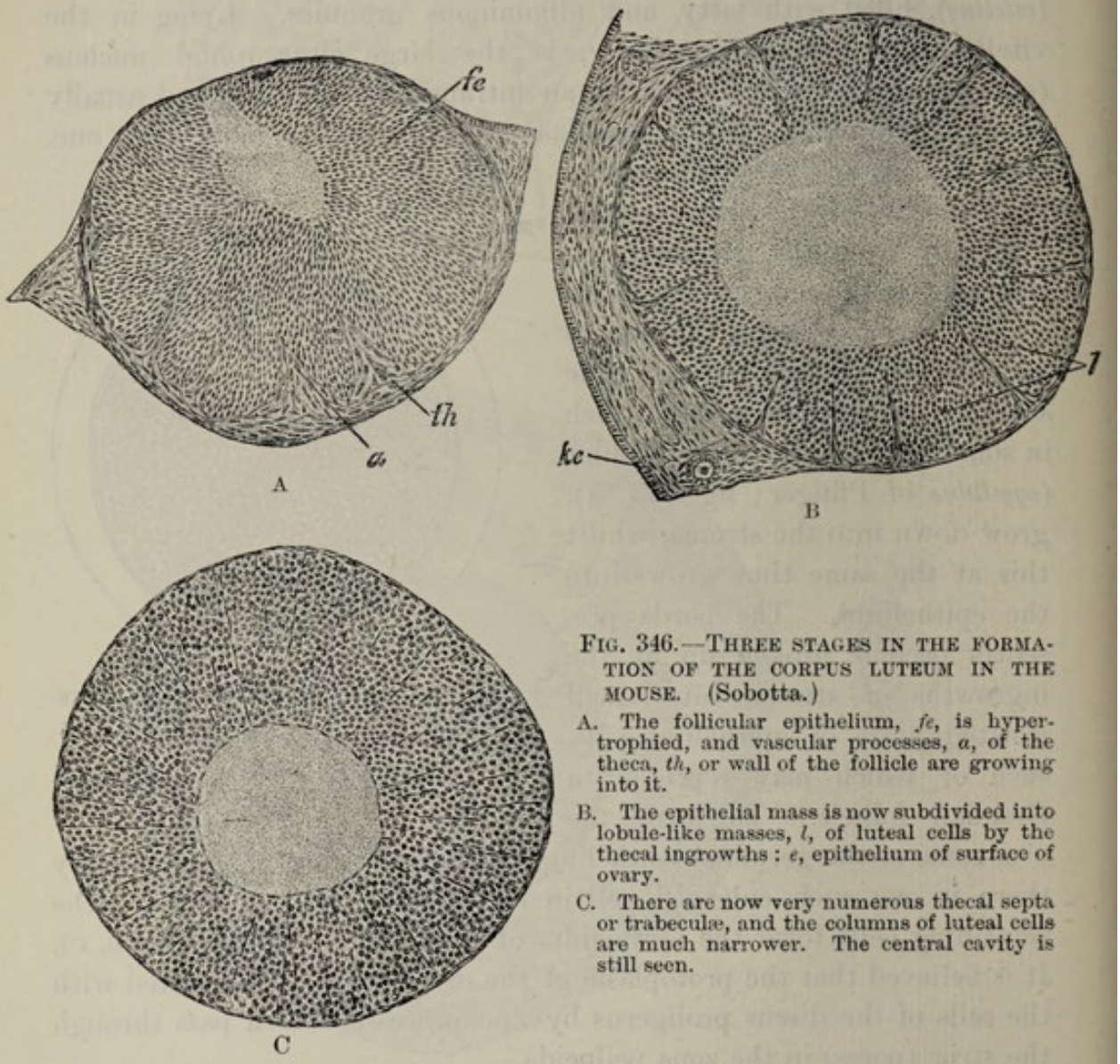


FIG. 346.—THREE STAGES IN THE FORMATION OF THE CORPUS LUTEUM IN THE MOUSE. (Sobotta.)

A. The follicular epithelium, *fe*, is hypertrophied, and vascular processes, *a*, of the theca, *th*, or wall of the follicle are growing into it.

B. The epithelial mass is now subdivided into lobule-like masses, *l*, of luteal cells by the thecal ingrowths : *e*, epithelium of surface of ovary.

C. There are now very numerous thecal septa or trabeculæ, and the columns of luteal cells are much narrower. The central cavity is still seen.

which becomes thickened and folded by multiplication and hypertrophy of its cells ; between the folds connective tissue and blood-vessels grow in from the wall or theca folliculi towards the centre, and in this way the columnar arrangement above mentioned is produced. After persisting for a time the corpus luteum gradually disappears, its tissue becoming merged in the surrounding stroma. Corpora lutea grow much larger and remain much longer persistent in the event of pregnancy supervening.

The use of the corpus luteum is not known certainly, but it has recently been suggested that it may yield an internal secretion, the effect of which is to produce the fixation of the fertilized ovum in the uterine mucous membrane (Born). In confirmation of this, experiments seem to indicate that gestation does not supervene in rabbits whose corpora lutea have been destroyed (Fraenkel and Cohn).

The blood-vessels of the ovary are very large and numerous, and are especially distributed to the walls of the Graafian follicles, over which they form a close network.

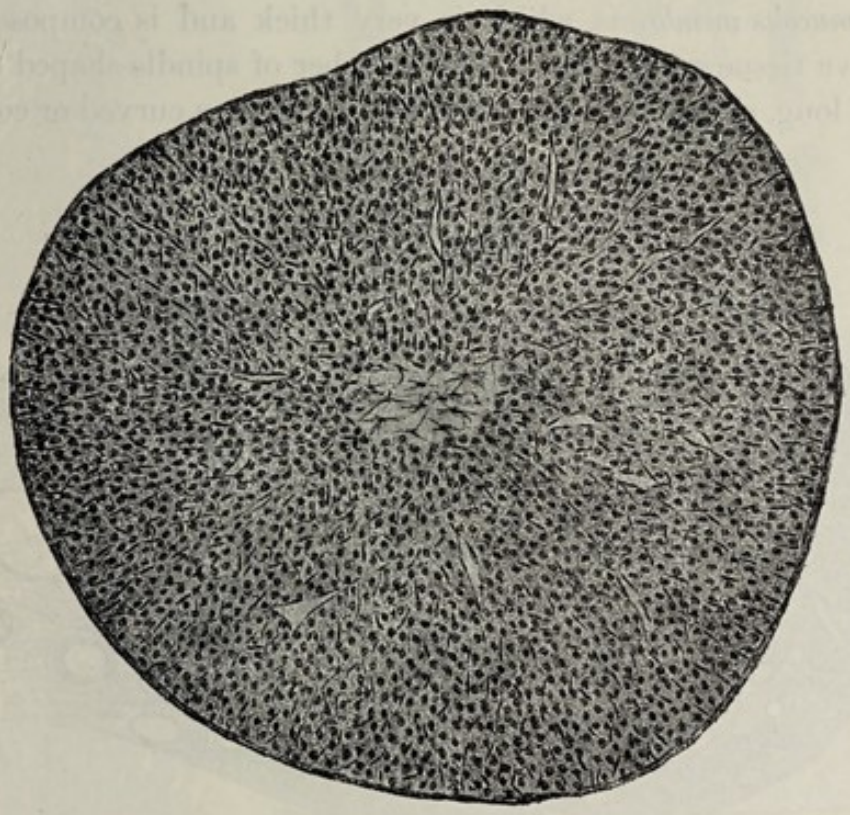


FIG. 347.—CORPUS LUTEUM OF MOUSE. (Sobotta.)
This figure shows a more advanced stage of development, the luteal tissue being now vascularized and the central cavity obliterated.

THE FALLOPIAN TUBES AND UTERUS.

The **Fallopian tubes** are lined by a very vascular mucous membrane which is covered with ciliated epithelium, and has numerous longitudinal folds (fig. 348). Externally they are covered by a serous coat, within which is a thin longitudinal layer of plain muscular fibres overlying circular fibres of the same tissue.

The **uterus** is usually described as composed of two parts, the body and cervix. The wall of the uterus is formed of the following layers:

1. A *serous layer*, derived from the peritoneum, which covers the greater part of the fundus.

2. A *muscular layer*, which is of considerable thickness and is formed of plain muscular fibres disposed in two strata. Of these the outer has its fibres arranged partly longitudinally, partly circularly. The inner

muscular layer, on the other hand, is thick; its fibres run in different directions, but chiefly circularly, and it is prolonged internally into the deeper part of the mucous membrane, the extremities of the uterine glands extending between and amongst its fibres. It is imperfectly separated from the thinner external layer by the ramifications of the larger blood-vessels, and, according to some authorities, represents a much-hypertrophied muscularis mucosæ.

3. A *mucous membrane*, which is very thick and is composed of soft connective tissue containing a large number of spindle-shaped cells. It contains long, simple, tubular glands, which take a curved or convoluted

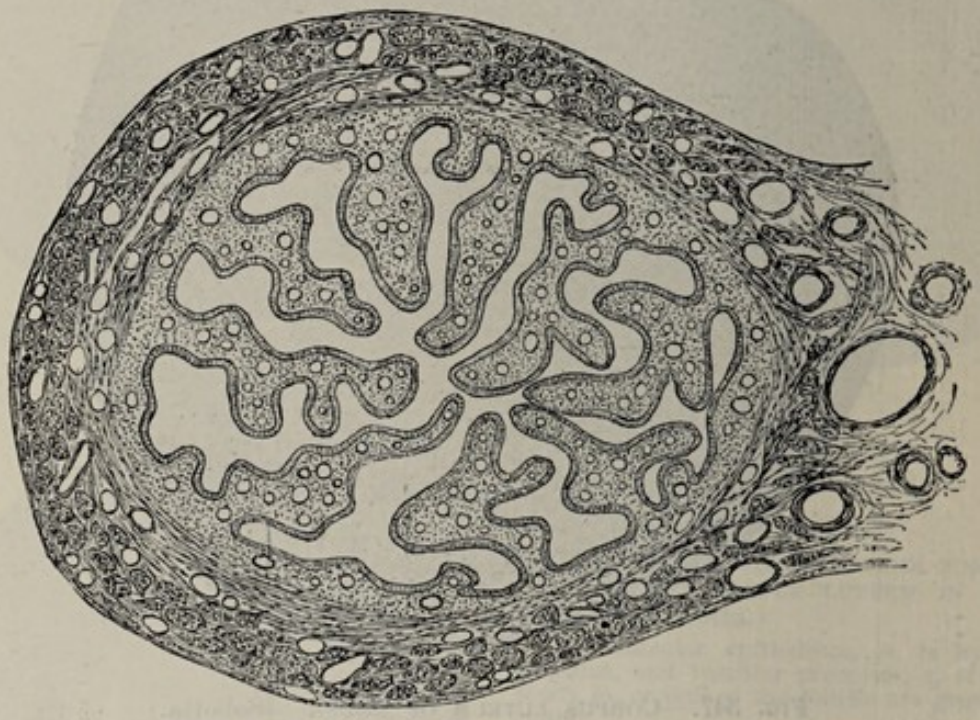


FIG. 348.—SECTION ACROSS THE FALLOPIAN TUBE. (Semi-diagrammatic.)

course in passing through the membrane (fig. 349). They are lined by ciliated epithelium continuous with that which covers the inner surface of the mucous membrane. In the cervix the mucous membrane is marked by longitudinal and oblique ridges, and the glands are shorter than those of the body of the uterus. Near the os uteri the epithelium becomes stratified and overlies vascular papillæ of the corium. The mucous membrane is exceedingly vascular, and it also contains a large number of lymphatic vessels.

In many animals the uterus is composed of two long tubes (cornua uteri), and the arrangement of the muscular tissue in these is simpler than in the human uterus, which has been formed by the fusion of two such tubes. Fig. 350 exhibits the structure of a cornu of the uterus of a rabbit.

At each menstrual period the mucous membrane of the uterus

undergoes a partial process of disintegration accompanied by an escape of blood from the capillaries of the membrane. This is succeeded by a rapid renewal of the disintegrated part. Should gestation supervene, the process of renewal results in the formation of a greatly thickened

FIG. 349.

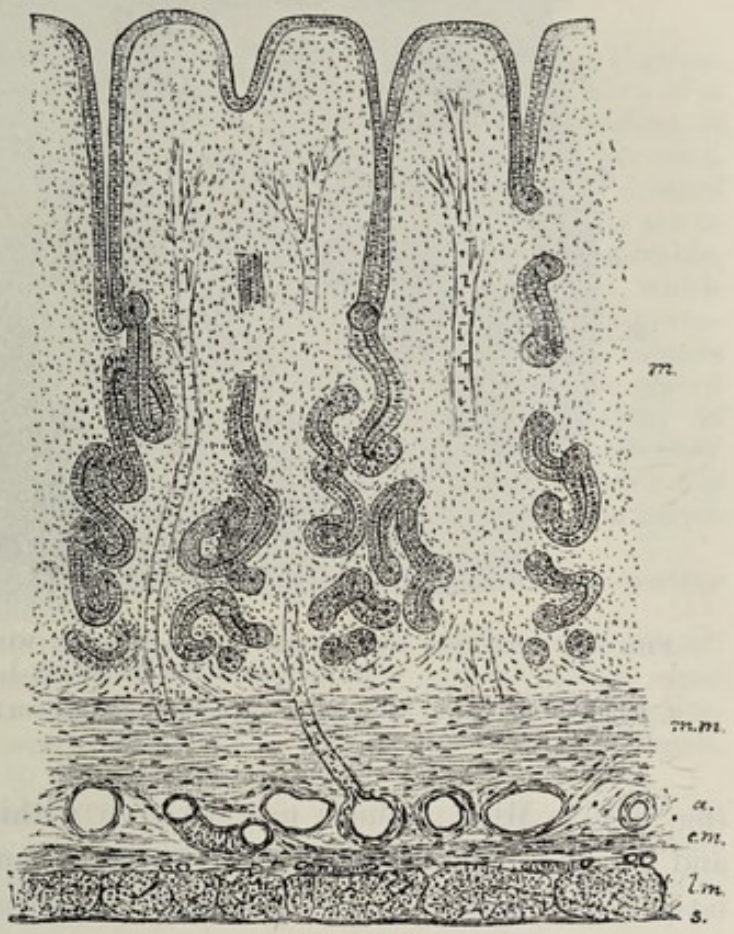


FIG. 350.

FIG. 349.—SECTION OF THE MUCOUS MEMBRANE OF THE HUMAN UTERUS. (J. Williams.)

a, epithelium of surface; *b*, *b*, glands; *b'*, their ends amongst the muscular fibres, *d*, in the deeper part of the mucous membrane; *c*, interglandular tissue.

FIG. 350.—SECTION OF THE MUCOUS MEMBRANE OF THE RABBIT'S UTERUS.

s, serous layer; *l.m.*, longitudinal muscular fibres; *c.m.*, circular muscular fibres of the muscular coat; *a*, areolar tissue, with large blood-vessels; *m.m.*, muscularis mucosæ; *m*, mucous membrane.

mucous membrane, with long convoluted glands, which is then known as the decidua.

THE MAMMARY GLANDS.

The **mammary glands** are compound racemose glands which open by numerous ducts upon the apex of the nipple. The ducts are dilated into small reservoirs just before reaching the nipple. If traced backwards, they are found to commence in groups of saccular

alveoli (fig. 351). The walls of the ducts and alveoli are formed of a basement-membrane lined by a simple layer of flattened epithelium

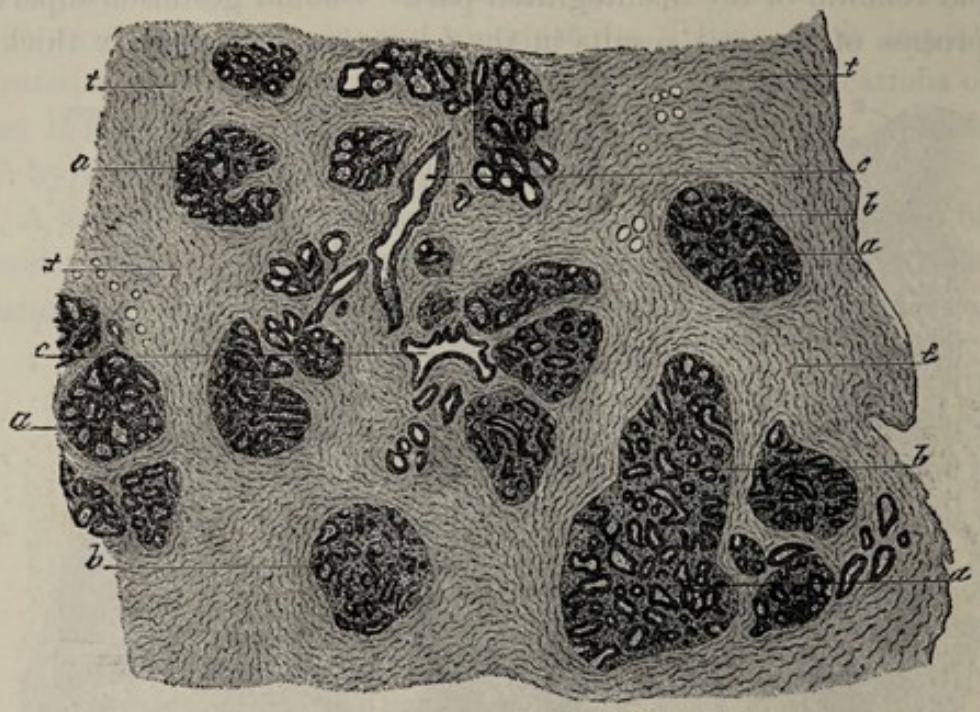


FIG. 351.—SECTION OF MAMMARY GLAND OF WOMAN DURING LACTATION. (Testut after de Sinéty.)

a, lobule of gland; *b*, acini lined by cubical epithelium; *c*, duct; *t*, connective-tissue stroma.

(fig. 352). Milk globules may be seen within the alveoli and ducts, and at the commencement of lactation amœboid cells containing fat-particles appear in the secretion (*colostrum corpuscles*). These are

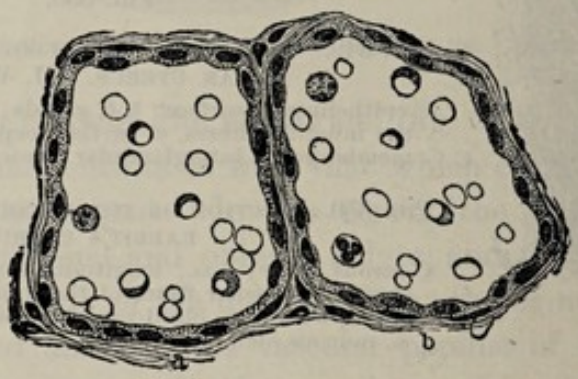


FIG. 352.—ALVEOLI OF THE MAMMARY GLAND OF THE BITCH. (Heidenhain.)

probably emigrated lymph-corpuscles similar to the salivary corpuscles of saliva, but some have been looked upon as epithelium-cells or portions of epithelium-cells which have become detached from the general lining of the alveoli.

LESSON XXXIX.

STRUCTURE OF THE SPINAL CORD.

1. Sections of the spinal cord from the cervical, dorsal, and lumbar regions. If the human spinal cord cannot be obtained sufficiently fresh, that of a dog, cat, or monkey may be used. It is to be hardened by suspending it immediately after removal from the body in a tall jar of formol (5 per cent. solution). After a few days it may be transferred to alcohol, but if desired it can be preserved for a long time in the formol solution. Sections are to be made either by the paraffin or celloidin method : the former is preferable, especially for small cords. They may be stained by Nissl's method, which brings to view the nerve-cells and also stains the axis-cylinders of the nerve-fibres. If it is desired to stain by the Weigert-Pal method, which colours the medullary sheaths of the nerve-fibres, the pieces of cord should be placed in 2 per cent. bichromate of potash solution or Müller's fluid (either at once or after formol) and should be left for about a month, after which they are cut by a freezing microtome. (For the details of these methods see Appendix.) Carminate of ammonia may also be employed to stain the nerve-cells and axis-cylinders.

Notice the relative extent of the grey as compared with the white matter in the different regions of the cord.

Sketch a section from each region under a low power. Sketch also a small portion of the white substance, two or three nerve-cells, and the central canal with its lining epithelium and surrounding neuroglia under the high power.

Measure the diameter of some of the nerve-fibres in the anterior columns, in the lateral columns, and in the posterior columns.

2. Tracts in the spinal cord. The conducting tracts of the spinal cord may be studied in two ways, viz.: (1) by preparing sections of embryonic cords (from the 5th to the 9th month), the sections being stained by the Weigert-Pal process (Flechsig's method); (2) by preparing sections from the cord of an animal in which either a complete section or a hemi-section has been performed about ten days before the animal is killed, and staining thin pieces of the cord from below and from above the section by placing them in a solution consisting of two parts of Müller's fluid and 1 part of 1 per cent. osmic acid (Marchi's method). The cord must first be partly hardened by placing it for a few days in Müller's fluid.

The **spinal cord** is composed of grey matter in the centre and of white matter externally. It is closely invested by a layer of connective-tissue containing numerous blood-vessels (*pia mater*), and less closely by two other membranes (fig. 353). One of these is an areolar membrane, resembling a serous membrane in general structure, but non-vascular and more delicate in texture (*arachnoid*). The other, which lines the vertebral canal, is a strong fibrous membrane known as the *dura mater*. At the middle of the anterior and posterior (ventral and dorsal) surfaces the pia mater dips into the substance of the cord in the *anterior* and *posterior median fissures*, so as to divide it almost completely into two lateral halves. These are, however, united by an isthmus or

bridge, which is composed anteriorly of transversely crossing white fibres (*white commissure*), posteriorly of grey matter (*grey commissure*), in the middle of which is a minute canal lined by ciliated epithelium (*central canal*).

Each lateral half of the spinal cord contains a crescent of grey matter, which is joined to the corresponding crescent of the opposite side by the grey commissure. Of the two horns of the crescent the

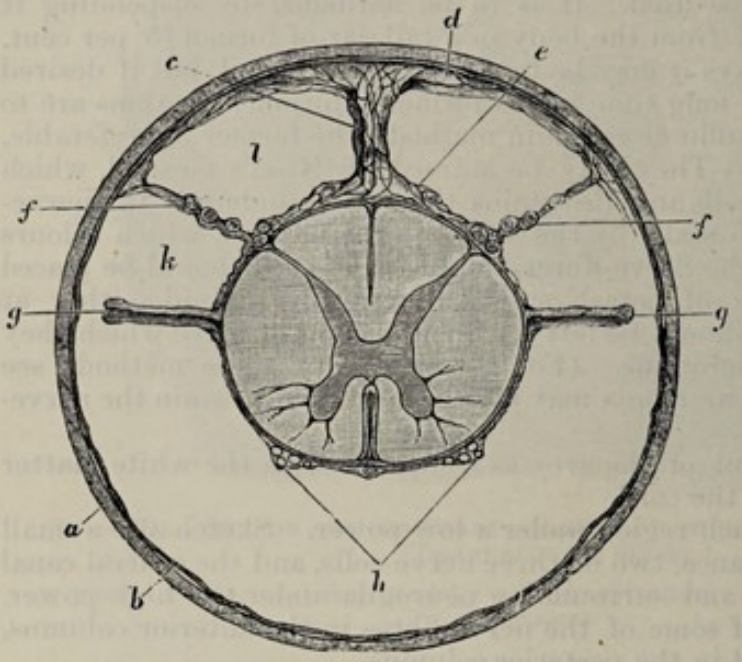


FIG. 353.—SECTION OF THE SPINAL CORD WITHIN ITS MEMBRANES. (Key and Retzius.)

a, dura mater; *b*, arachnoid; *c*, septum of arachnoid; *d*, *e*, trabeculæ of arachnoid; *g*, ligamentum denticulatum; *f*, bundles of posterior root; *h*, bundles of anterior root; *k*, *l*, subarachnoid space.

posterior or dorsal is the narrower and comes near the surface of the cord; close to it the bundles of the posterior nerve-roots enter the cord. The bundles of the anterior nerve-roots enter the anterior horn.

The *white matter* of each half of the cord is subdivided by the approach of the posterior horn to the surface into two principal columns—*antero-lateral* and *posterior*. A distinction is sometimes drawn between anterior and lateral portions of the antero-lateral column, although there is no line of demarcation between them. In the upper part of the cord the posterior column is subdivided by a septum of connective tissue into two—the *postero-mesial column* or *funiculus gracilis*, and the *postero-lateral column* or *funiculus cuneatus*. The white matter is composed of longitudinally coursing medullated nerve-fibres, which in sections stained with carmine or toluidin blue appear as clear circular areas with a stained dot, the axis-cylinder, near the middle (fig. 355); while in sections stained by the Weigert-Pal method they appear as black circles with a clear centre. The nerve-fibres vary in size in different parts; on the whole those which are nearest to the surface of the cord are larger than those nearest to the grey matter, but there is a bundle of very small fibres (M, fig. 356) opposite the tip of the posterior horn.

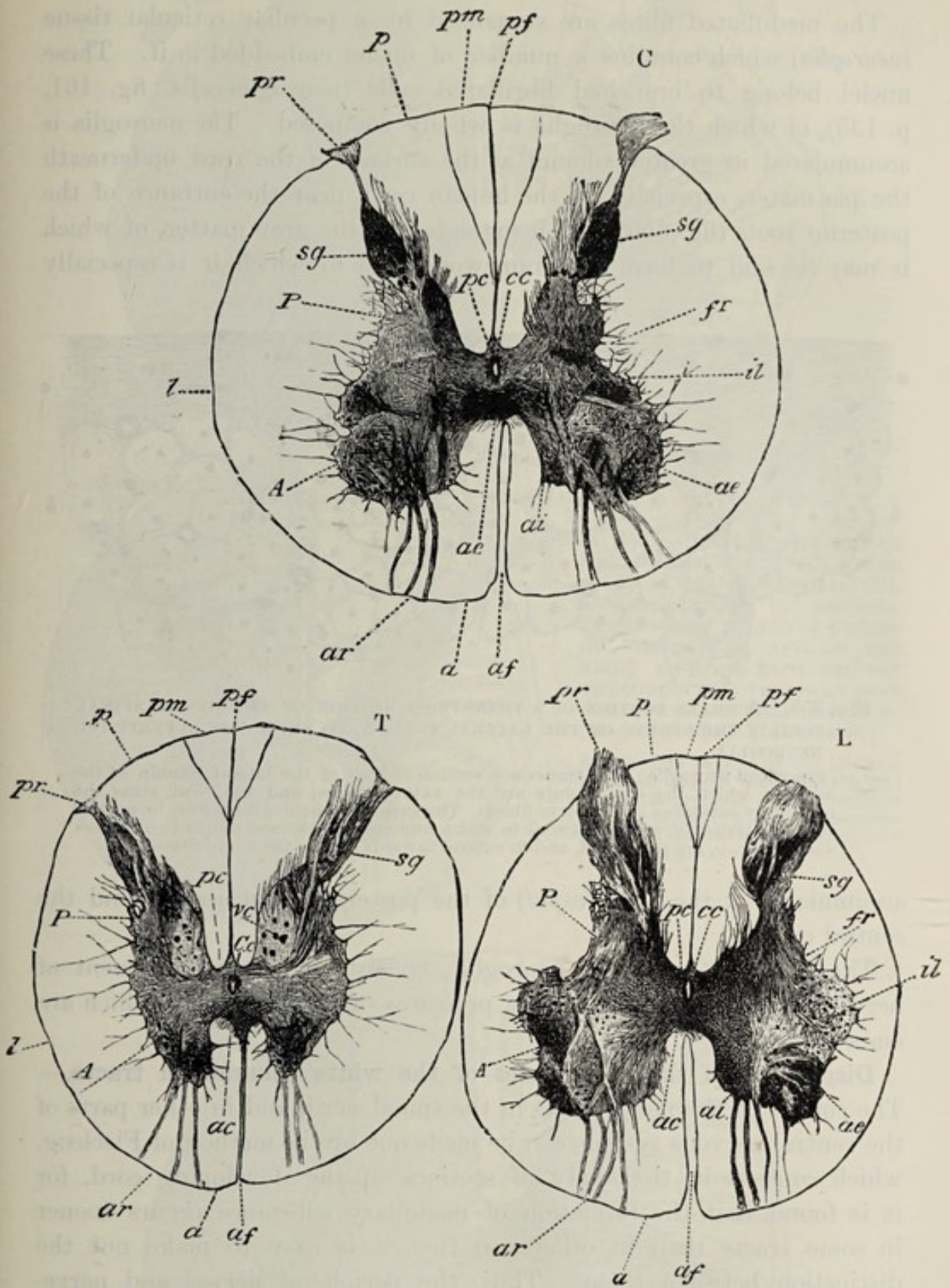


FIG. 354.—TRANSVERSE SECTIONS OF MONKEY'S SPINAL CORD. (Bevan Lewis.)[1]

C, from the cervical region; T, from the thoracic region; L, from the lumbar region.

A, anterior horn; *P*, posterior horn; *a*, anterior column; *l*, lateral column; *p*, posterior column; *ac*, anterior commissure; *ae*, *ai*, external and internal cell-groups of anterior horn; *af*, anterior median fissure; *ar*, anterior roots; *cc*, central canal; *fr*, formatio reticularis; *il*, lateral group of cells; *vc*, vesicular column of Clarke; *pc*, posterior commissure; *pf*, posterior median fissure; *pm*, postero-mesial column; *pr*, posterior roots; *sg*, substantia gelatinosa.

[1]Taken by permission of the author from Ferrier's *Functions of the Brain*.

The medullated fibres are supported by a peculiar reticular tissue (*neuroglia*) which contains a number of nuclei embedded in it. These nuclei belong to branched fibrillated cells (neuroglia-cells, fig. 161, p. 135), of which the neuroglia is wholly composed. The neuroglia is accumulated in greater amount at the surface of the cord underneath the pia mater, especially, in the human cord, near the entrance of the posterior roots (fig. 355), and it extends into the grey matter, of which it may be said to form the framework, and in which it is especially

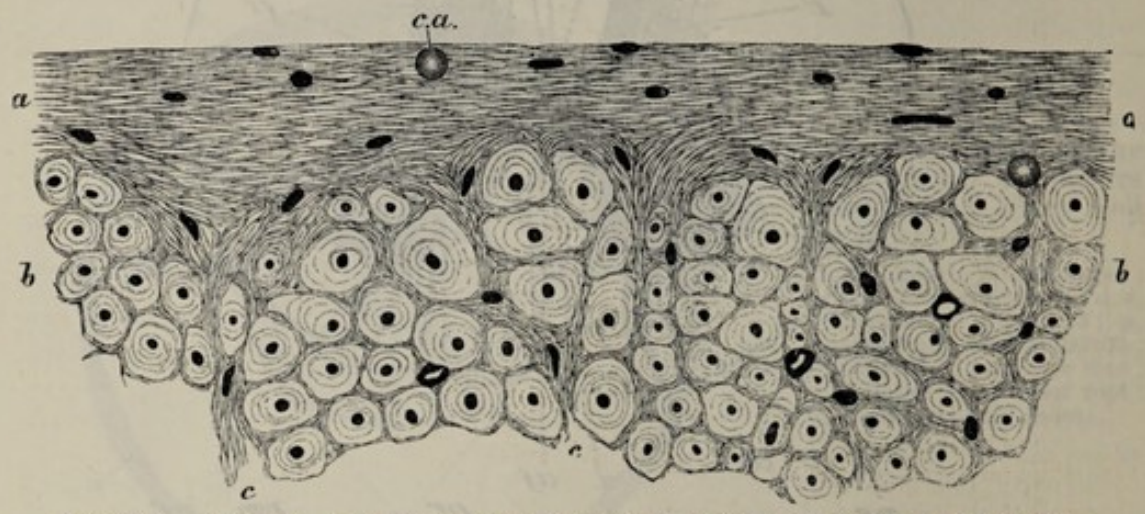


FIG. 355.—A SMALL PORTION OF A TRANSVERSE SECTION OF THE HUMAN SPINAL CORD IN THE REGION OF THE LATERAL COLUMN, TO SHOW THE SUPERFICIAL NEUROGLIA.

a, *a*, superficial neuroglia; *b*, *b*, transverse section of part of the lateral column of the cord, in which the dark points are the axis-cylinders, and the clear areas the medullary substance of the nerve-fibres. The superficial neuroglia is seen to exhibit the appearance of a fine feltwork in which numerous nuclei and one or two *corpora amylacea*, *c.a.*, are embedded, and to extend inwards among the nerve-fibres.

accumulated at the apex (*caput*) of the posterior horn and around the central canal.

The *grey matter*, besides neuroglia, consists of an interlacement of nerve-fibres and of the branching processes of the nerve-cells which are embedded in it.

Disposition of the nerve-fibres of the white columns in tracts.—The course of the nerve-tracts in the spinal cord, and in other parts of the central nervous system, can be made out by the method of Flechsig, which consists in the study of sections of the developing cord, for it is found that the formation of medullary substance occurs sooner in some tracts than in others, so that it is easy to make out the distinction between them. Thus, the peripheral nerves and nerve-roots become myelinated in the first half of the fifth month of fœtal life, and, of the tracts of the spinal cord, those of Burdach and Goll are the first to be myelinated, then the tracts of Flechsig and Gowers, all of these being sensory or centripetally conducting, while the pyramidal tracts, which are motor or centrifugally conducting, do not

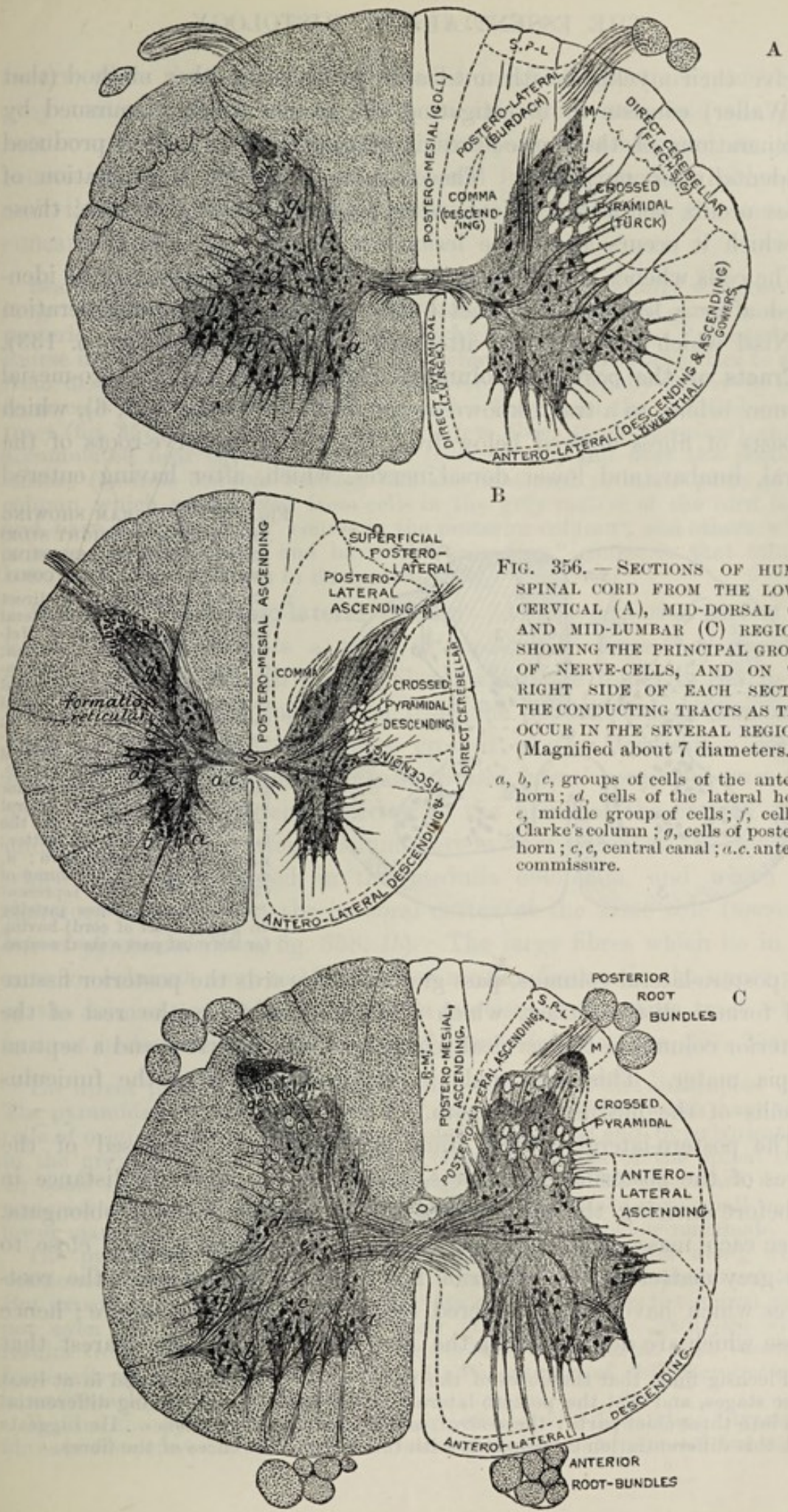


FIG. 356. — SECTIONS OF HUMAN SPINAL CORD FROM THE LOWER CERVICAL (A), MID-DORSAL (B), AND MID-LUMBAR (C) REGIONS, SHOWING THE PRINCIPAL GROUPS OF NERVE-CELLS, AND ON THE RIGHT SIDE OF EACH SECTION THE CONDUCTING TRACTS AS THEY OCCUR IN THE SEVERAL REGIONS. (Magnified about 7 diameters.)

a, *b*, *c*, groups of cells of the anterior horn; *d*, cells of the lateral horn; *e*, middle group of cells; *f*, cells of Clarke's column; *g*, cells of posterior horn; *c*, *c*, central canal; *a.c.* anterior commissure.

receive their myelin sheath until after birth.[1] Another method (that of Waller) consists in investigating the course which is pursued by degenerations of the nerve-fibres in consequence of lesions produced accidentally or purposely. Those tracts in which degeneration of fibres occurs below the lesion are termed "descending" tracts; those in which it occurs above the lesion are termed "ascending."

The cells whence the fibres of any tract arise can frequently be identified after a lesion of the tract by the chromatolysis or degeneration of Nissl which they undergo after section of their axons (see p. 133).

Tracts of the posterior column.—The fibres of the postero-mesial column belong to a tract, known as the *tract of Goll* (fig. 357, 6), which consists of fibres derived below from the posterior nerve-roots of the sacral, lumbar, and lower dorsal nerves, which, after having entered

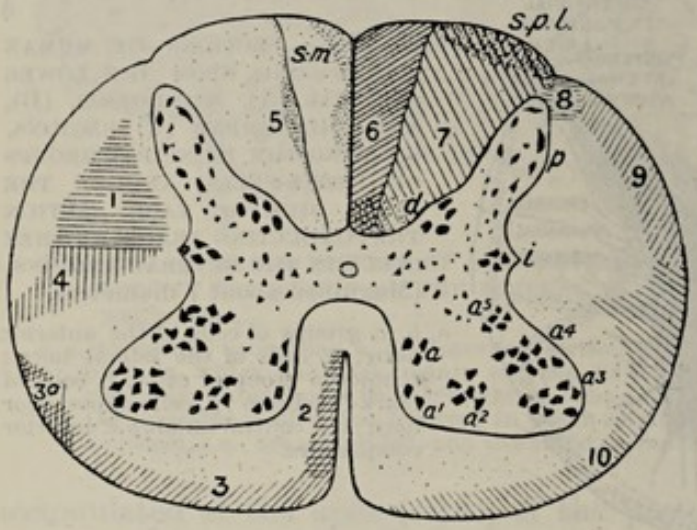


FIG. 357.—DIAGRAM SHOWING THE ASCENDING (RIGHT SIDE) AND DESCENDING (LEFT SIDE) TRACTS IN THE SPINAL CORD.

1, Crossed pyramidal; 2, direct pyramidal; 3, antero-lateral descending; 3*a*, bundle of Helweg; 4, prepyramidal; 5, comma; 6, postero-mesial; 7, postero-lateral; 8, marginal; 9, dorsal cerebellar; 10, antero-lateral ascending or ventral cerebellar; *s-m*, septo-marginal; *s.p.l.*, superficial postero-lateral fibres (dorsal root-zone of Flechsig); *a* to a^5, groups of cells in the anterior horn; *i*, intermedio-lateral group or cell-column in the lateral part of the grey matter; *p*, cells of posterior horn; *d*, dorsal nucleus or cell-column of Clarke. The dots represent "endogenous" fibres (arising in grey matter of cord) having for the most part a short course.

the postero-lateral columns, pass gradually towards the posterior fissure and form a distinct tract, which is marked off from the rest of the posterior column in the cervical region by a slight furrow and a septum of pia mater. This tract ends in the gray matter of the funiculus gracilis of the medulla oblongata.

The postero-lateral column (*tract of Burdach*) is composed of the fibres of the posterior nerve-roots, which run for a certain distance in it before entering the grey matter of the cord or medulla oblongata. Since each mass of posterior root-bundles enters the column close to the grey matter of the posterior horn it, as it were, pushes the root-fibres which have already entered nearer to the median fissure; hence those which are derived from the lowest nerve-roots are nearest that

[1] Flechsig finds that the fibres of the posterior roots are myelinated in at least three stages, and that the postero-lateral tract shows a corresponding differentiation into three chief parts; the *ventral, middle and dorsal root-zones*. He suggests that this differentiation corresponds with functional differences of the fibres.

fissure, while those which are derived from the highest are nearest the grey matter. Many of the fibres of this tract pass into the grey matter of the cord, either immediately on entering or in their course upwards; the rest are continued into the medulla oblongata and there end by arborizing amongst the cells of the nucleus cuneatus.

Besides the tracts of Burdach and Goll, which are wholly composed of long "ascending" fibres having their cells of origin in the ganglia on the posterior roots, there are a few fibres which have a shorter "descending" course in the posterior column and are believed by some authorities to arise from descending branches of the posterior root-fibres, by others to arise from cells in the grey matter of the cord. They form the so-called *comma* tract (fig. 357, 5). There are besides a few fibres (*septo-marginal*), chiefly accumulated near the median fissure (*oval bundle*) and near the posterior surface (*median triangle bundle*), but also scattered in other parts of the column, which are derived from cells in the grey matter of the cord itself, and have a "descending" course in the posterior column; and others which arise in the grey matter and have an "ascending" course in that column, being specially numerous in its ventral part.

Tracts of the antero-lateral column.—At the posterior part of the lateral column there is a tract of moderately large "descending" fibres, intermingled with smaller fibres, which are found to run in the lateral column of the spinal cord from the opposite side of the brain, after having for the most part crossed at the decussation of the pyramids of the medulla oblongata (*crossed lateral pyramidal tract*, figs. 357, *1*; 358, *1a*). Intermingled with the fibres of the crossed pyramidal tract in the lateral column are a few fibres of the pyramid which have not crossed in the medulla oblongata, and which are therefore derived from the cerebral cortex of the same side (*uncrossed lateral pyramidal fibres*, fig. 358, *1b*). The large fibres which lie in the anterior columns next to the anterior median fissure, in the upper part of the human cord, also belong to a portion of the same tract which has not undergone decussation (*direct pyramidal tract*, figs. 357, 358, *2*).

The direct pyramidal tract is only found in man and the anthropoid apes. The pyramidal tracts are composed of "descending" fibres, which have their cells of origin in the cerebral cortex (motor region) and end by arborisations in the grey matter at the base of the posterior cornua of the spinal cord. In some rodents (rat, mouse, guinea-pig) the pyramidal tracts are in the posterior columns of the cord. The pyramidal tracts are very small in the lower mammals, and are not found at all in vertebrates below mammals.

The pyramidal tracts are generally regarded as the paths along which volitional impulses are conveyed from the cerebral cortex to the spinal cord. But experiments have shown that they are not the only cortico-spinal paths nor even the most important in many animals, for the paralysis which results from their section is soon recovered from, whereas that resulting from section of the anterior column and adjacent part of the lateral column is more marked and permanent.

Besides the pyramidal tracts there are two other "descending" tracts of fibres in the antero-lateral column. One of these (the *antero-lateral descending*

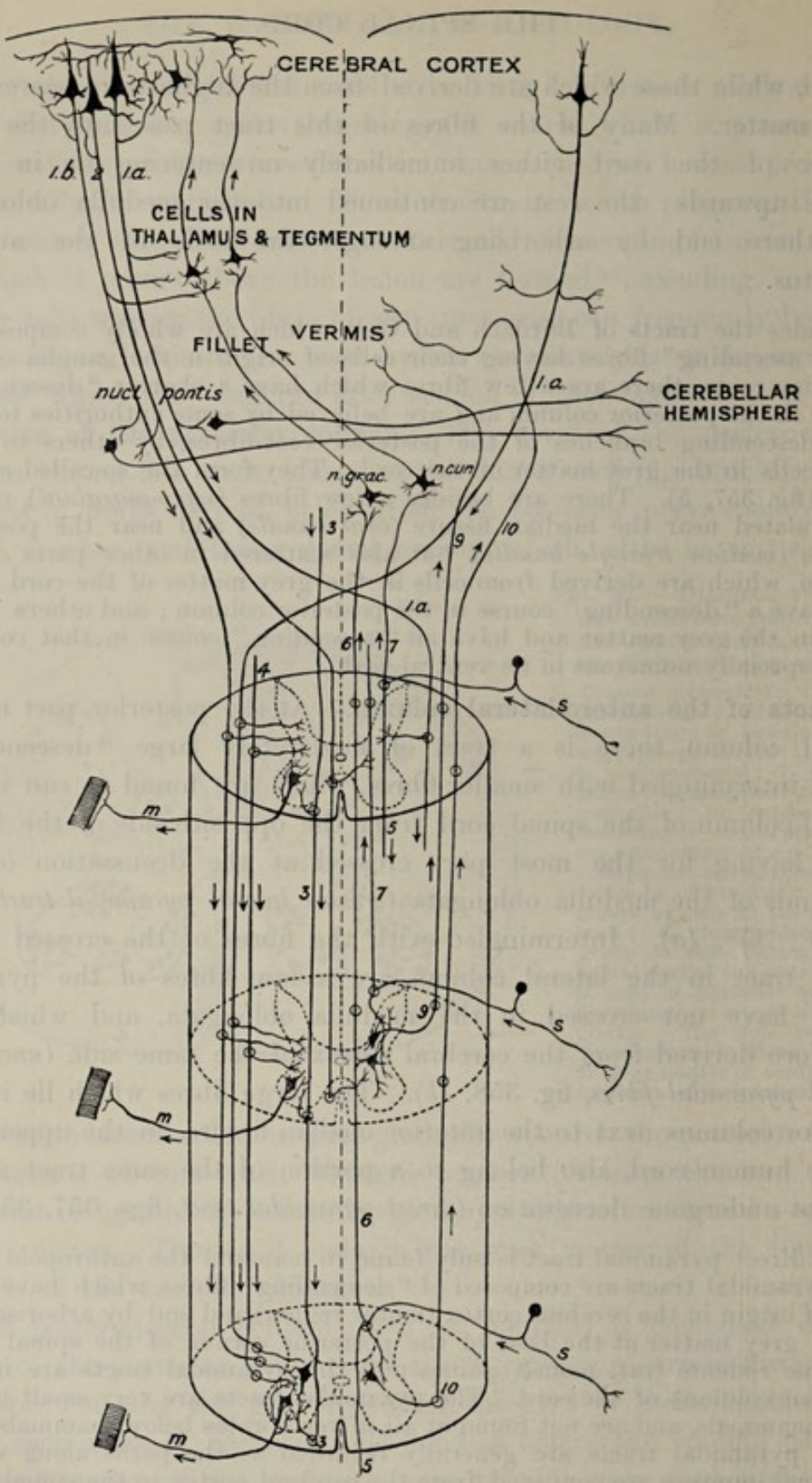


FIG. 358.—DIAGRAM SHOWING THE COURSE, ORIGIN, AND TERMINATION OF THE FIBRES OF THE PRINCIPAL TRACTS OF THE WHITE MATTER OF THE SPINAL CORD. (The numbers in this diagram refer to fibres of the tracts shown with corresponding numbers in fig. 357.)

"Descending" tracts:—*1a*, a fibre of the crossed pyramidal tract; *1b*, an uncrossed fibre of the pyramidal tract passing to the lateral column of the same side; *2*, a fibre of the direct pyramidal tract; *3*, a fibre of the antero-lateral descending tract; *4*, a fibre of the prepyramidal tract; *5*, a fibre of the comma tract. "Ascending" tracts:—*6*, a fibre of the postero-mesial tract; *7*, fibres of the postero-lateral tract; *9*, one belonging to the dorsal cerebellar; *10*, a fibre of the ascending antero-lateral or ventral cerebellar tract.

tract or *tract of Loewenthal*, figs. 357, 358, *3*) lies on the side of the anterior median fissure, and extends along the margin of the cord in the "root" zone, even reaching the anterior part of the lateral column. These fibres are continued down, partly from the posterior longitudinal bundle of the medulla oblongata and pons Varolii, partly from other sources higher up which will be afterwards referred to. They end by arborisations in the anterior horn. (Similar arborisations pass from the posterior longitudinal bundle to the nuclei of the motor cranial nerves.) It is possible that these fibres of the antero-lateral descending tract constitute the second path for volitional impulses, which has just been referred to.

But there is another "descending" tract in the lateral column just in front of the crossed pyramidal to which this function has also been ascribed. This is termed the *prepyramidal tract* (figs. 357, 358, *4*); its fibres end by arborising in the grey matter of the middle of the crescent; the situation of its cells of origin is not certain, but it is believed to be in the mid-brain. The tract in question is there known as *Monakow's bundle*; it will be again noticed later on.

Lastly a small triangular group of "descending" fibres traceable from the neighbourhood of the olive in the medulla oblongata, and passing down the cervical cord in the anterior part of the lateral column (fig. 357, 3*a*), (the exact origin and destination of the fibres is unknown) is termed the *bundle of Helweg*.

In the lateral column there are also two *ascending* tracts. One of these is only distinct in the cervical and dorsal regions. Here it lies external to the crossed pyramidal tract, and consists of large fibres which are derived from the cells of Clarke's column (fig. 356, *f*) and pass up into the cerebellum (*direct or dorsal cerebellar tract* or *tract of Flechsig*, fig. 356; figs. 357, 358, *9*). The other one, situated more anteriorly, lies in front of the crossed pyramidal and direct cerebellar tracts in the lumbar region; while in the dorsal and cervical regions it forms a narrow band of fibres curving round close to the external surface of the cord, and extending even into the anterior column. This is the *antero-lateral or ventral cerebellar tract* or *tract of Gowers* (figs. 357, 358, *10*). Its fibres are intermingled with those of the antero-lateral descending tract. Both these ascending tracts are connected with the vermis of the cerebellum, the tract of Gowers passing to that organ over and along with the superior cerebellar peduncle, whilst the dorso-lateral enters with the inferior peduncle. According to v. Gehuchten the tract of Gowers gives off a few fibres to enter the opposite cerebellar hemisphere by the middle peduncle. Lastly, there is another small tract of fibres undergoing degeneration above the point of section, marked M in fig. 356. This is the *marginal bundle* of Lissauer, and is formed by fine fibres from the posterior roots. Other portions of the antero-lateral columns near the grey matter are differentiated by the method of Flechsig, but their function is not known. They are probably short tracts uniting adjacent portions of the grey matter of the cord.

Disposition of the nerve-cells in the grey matter.—The nerve-cells which are scattered through the grey matter are in part disposed in

definite groups. Thus there are several groups of large multipolar nerve-cells in the anterior horn in the cervical and lumbar enlarge-

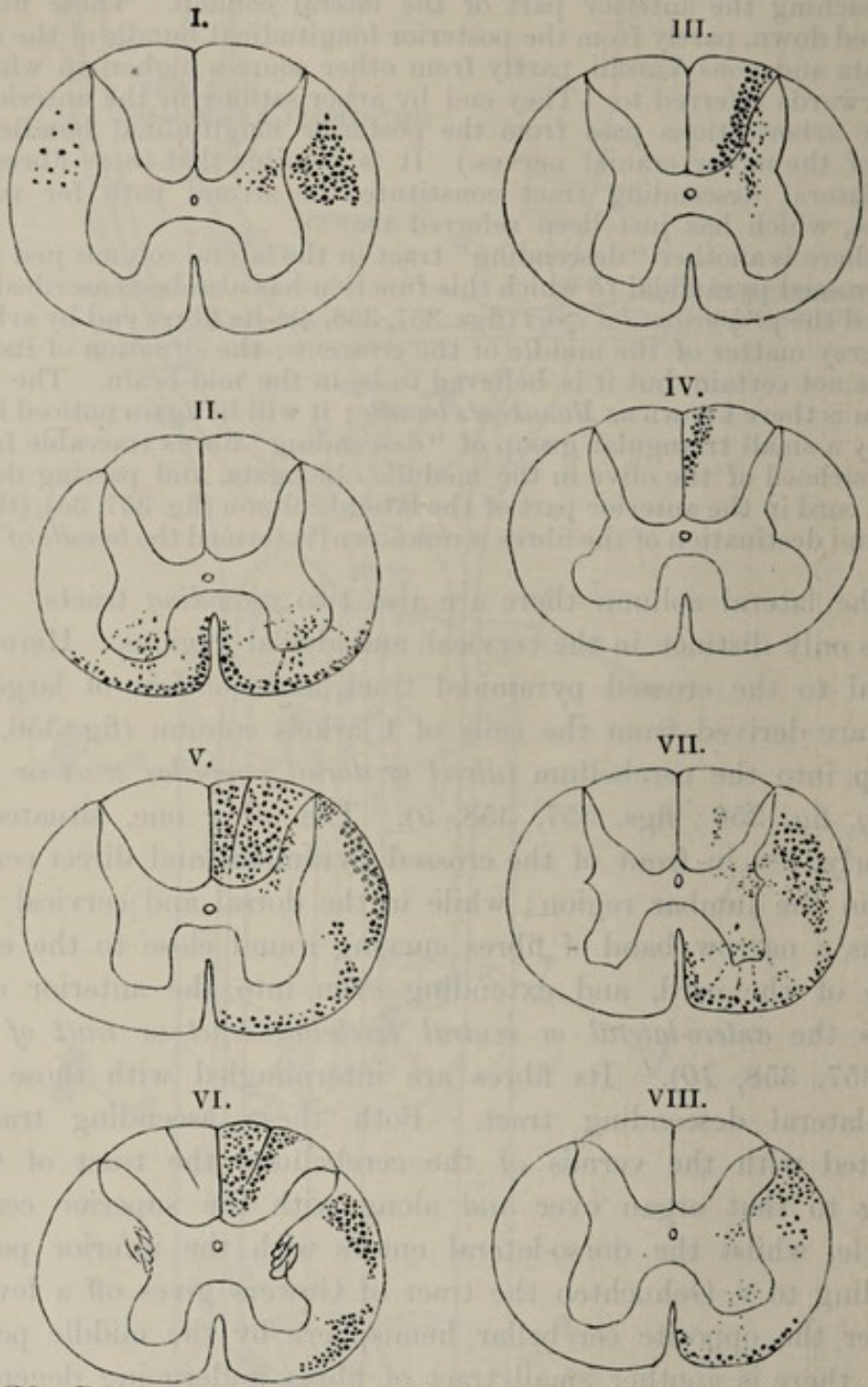


FIG. 359.—DIAGRAM OF SECTIONS OF THE SPINAL CORD OF THE MONKEY SHOWING THE POSITION OF DEGENERATED TRACTS OF NERVE-FIBRES AFTER SPECIFIC LESIONS OF THE CORD ITSELF, THE EFFERENT NERVE-ROOTS AND OF THE MOTOR REGION OF THE CEREBRAL CORTEX. (The degenerations are shown by the method of Marchi.)

I. Degenerations resulting from extirpation of the motor area of the cortex of the left cerebral hemisphere.

II. Degenerations produced by section of the posterior longitudinal bundle in the upper part of the medulla oblongata.

III. and IV. Result of section of posterior roots of the first, second, and third lumbar nerves on the right side. Section III. is from the segment of cord between the last thoracic and first lumbar roots; section IV. from the same cord in the cervical region.

V. to VIII. Degenerations resulting from (right) semi-section of the cord in the upper thoracic region. V. is taken a short distance above the level of section; VI., higher up the cord (cervical region); VII., a little below the level of section; VIII., lumbar region.

ments (fig. 357), although in other regions of the cord the number of groups in this situation is reduced to two, a mesial and a lateral. The larger groups in the enlargements correspond with segments of the limb; thus there appear to be groups associated with foot, leg, and thigh, and with hand, arm, and shoulder movements respectively.

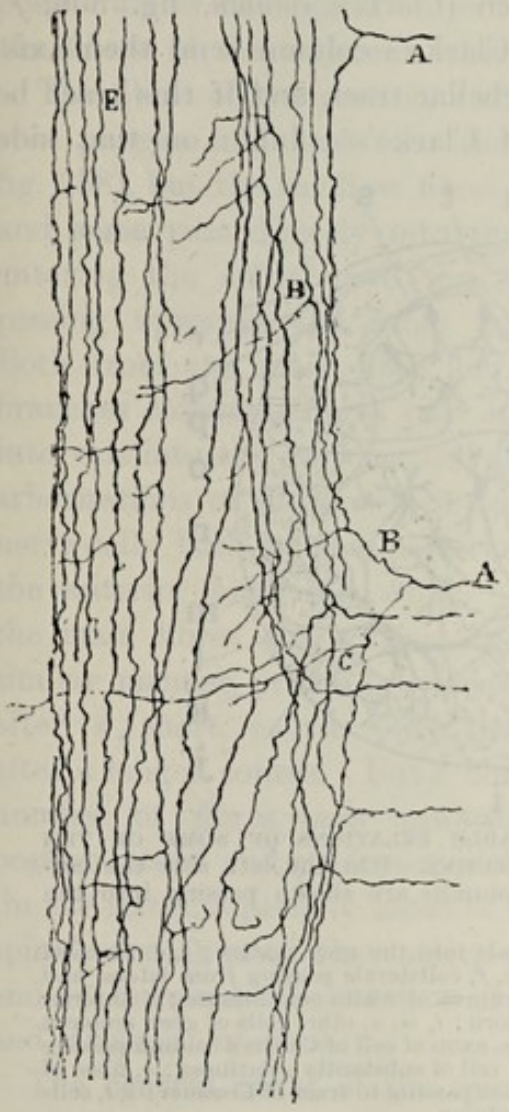


FIG. 360.—FROM A LONGITUDINAL SECTION OF SPINAL CORD, SHOWING THE ENTRANCE OF POSTERIOR ROOT-FIBRES. (S. Ramón y Cajal.)

A, A, fibres entering the postero-lateral column, and bifurcating into an ascending and descending division; B, C, collaterals passing from them into the grey matter; E, other fibres of the posterior white columns also giving off collaterals.

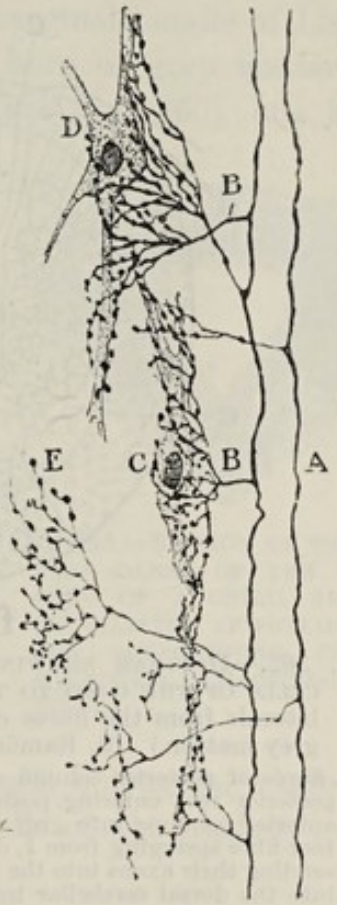


FIG. 361.—ARBORISATION OF COLLATERALS FROM THE POSTERIOR ROOT-FIBRES AROUND CELLS IN THE POSTERIOR HORN OF GREY MATTER. (S. Ramón y Cajal.)

A, fibres of posterior column derived from posterior root; B, collaterals; C, D, nerve-cells in grey matter surrounded by the arborisations of the collaterals; E, an arborisation shown separately.

But in the case of the diaphragm there is a special cell-group or cell-column in the cervical cord (anterior horn) from which the fibres of the phrenic nerve arise, so that in this case a cell-group is set apart for a special muscle. The axis-cylinder processes mostly pass out into the anterior nerve-roots (fig. 358, *m*; fig. 362, *k*), but a few send their

axons to the anterior column of the opposite side through the white commissure (fig. 362, *m*) or the anterior or lateral column of the same side (*l*, *n*). It is noteworthy that in birds a few cells of the anterior horn send their axons into the posterior roots. A well-marked group of large rounded nerve-cells, best marked in the thoracic region, lies at the base of the posterior horn (*Clarke's column*, fig. 356, *f*; fig. 357, *d*; fig. 362, *u*). The cells of Clarke's column send their axis-cylinder processes into the dorsal cerebellar tract, and if this tract be cut experimentally, the large cells of Clarke's column on that side

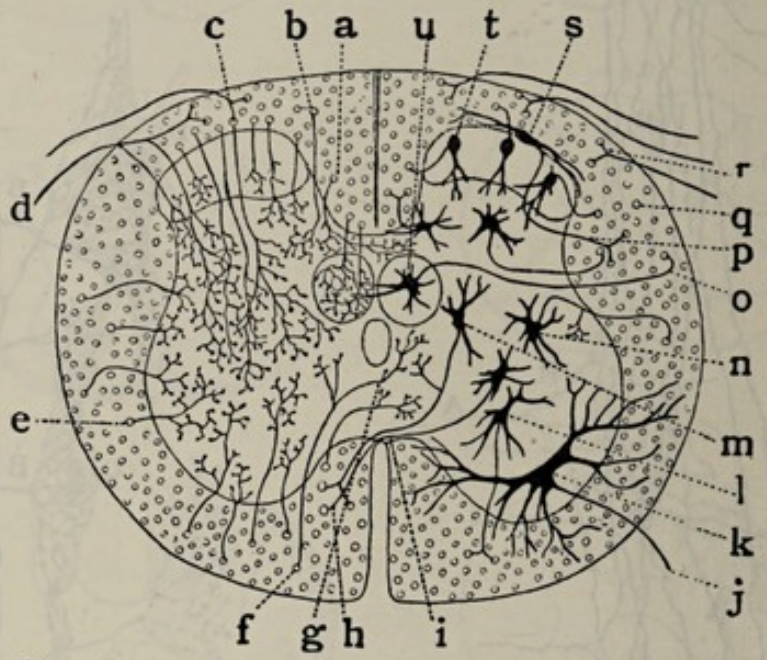


FIG. 362.—DIAGRAM SHOWING THE PROBABLE RELATIONS OF SOME OF THE CELLS OF THE CORD TO THE WHITE COLUMNS. (On the left side the collaterals from the fibres of the white columns are shown passing into the grey matter.) (S. Ramón y Cajal.)

a, *b*, fibres of posterior column sending collaterals into the grey matter; *c*, *d*, fibres of posterior root entering posterior column; *e*, *f*, collaterals passing from lateral and anterior columns into grey matter; *g*, *h*, *i*, fibres of white commissure; *j*, anterior root-fibre springing from *k*, cell of anterior horn; *l*, *m*, *n*, other cells of grey crescent sending their axons into the white matter; *o*, axon of cell of Clarke's column passing into the dorsal cerebellar tract; *p*, axon of cell of substantia gelatinosa; *q*, fibre of dorsal cerebellar tract; *r*, fibre of posterior root passing to tract of Lissauer; *s*, *t*, cells of substantia gelatinosa; *u*, cell of Clarke's column.

below the section undergo Nissl degeneration and eventually atrophy. There are, however, a few small cells with short axons in Clarke's column which do not undergo this change. Another group is seen on the outer side of the grey matter lying in a projection which is sometimes known as the lateral horn (*lateral cell-column*, fig. 356, *d*; 357, *i*). This is most distinct in the upper dorsal and lower cervical regions. Another group (*middle cell-column*) lies in the middle of the crescent (fig. 356, *e*). The cells of the posterior horn (*g*) are very numerous but are not collected into special groups.

The cells which send their axons into the adjacent parts of the white columns and not into any definite tract are sometimes termed the "cells of the white columns."

Connection of nerve-roots with spinal cord.—The *anterior roots* leave the anterior horn in a number of bundles. Most of their fibres are directly continued from the nerve-cells there.[1] On the other hand, these cells are surrounded by an interlacement of ramified nerve-endings, which are derived from various sources, especially from collaterals of the posterior root-fibres (see below), and from those of the fibres of the adjacent white columns.

The fibres of the *posterior roots* originate in the cells of the posterior root ganglia and pass into the postero-lateral column (see diagram, fig. 358), but the smallest fibres enter the marginal bundle of Lissauer, and some pass directly into the posterior horn of grey matter. On entering the spinal cord the fibres bifurcate (fig. 360), one branch passing upwards, the other downwards. Both from the main fibre and from its branches collateral fibres pass at frequent intervals into the grey matter, and end in arborisations of fibrils which envelop the nerve-cells both of the posterior and of the anterior horn (fig. 361). Many of the main fibres also ultimately end in a similar manner in the grey matter, some after a short course only, but others after a longer course. But a considerable number of fibres pass upwards in the postero-lateral and postero-mesial columns (in the latter, especially those of the lower spinal nerves), until they arrive at the medulla oblongata, where they end in terminal arborisations around the cells of the nucleus gracilis and nucleus cuneatus.

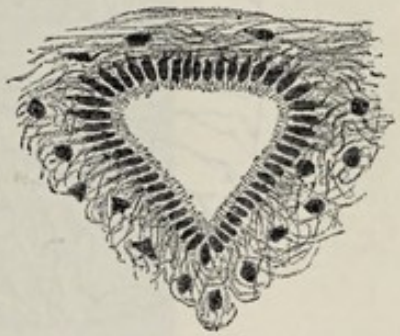


FIG. 363.—SECTION OF THE CENTRAL CANAL OF THE SPINAL CORD OF A CHILD, SHOWING ITS CILIATED EPITHELIUM AND THE SURROUNDING CENTRAL NEUROGLIA. (Moderately magnified.)

The **central canal** of the spinal cord is lined by columnar ciliated epithelium-cells, which are surrounded by a quantity of neuroglia. The cells are best seen in the spinal cord of animals and in the child (fig. 363); in the human adult they have frequently become proliferated, and their cilia are no longer visible. In the early embryo their fixed extremities extend through the whole thickness of the cord to reach the pia mater (fig. 364). This condition is permanent in the cord of many of the lower vertebrata.

Characters of the spinal cord in the several regions (figs. 354, 356).—In the *cervical region* the white matter, especially that of the lateral columns, occurs in largest proportion. The grey matter in the cervical

[1] According to Golgi, the anterior nerve-roots are derived in part from cells in the posterior horn, and by no means exclusively, although mainly, from the anterior horn cells.

enlargement is in considerable amount, and it encroaches especially in the upper part of the region in the form of a network upon the adjacent part of the lateral white column. The anterior horns are thick and the posterior slender. The postero-mesial column is distinctly marked off.

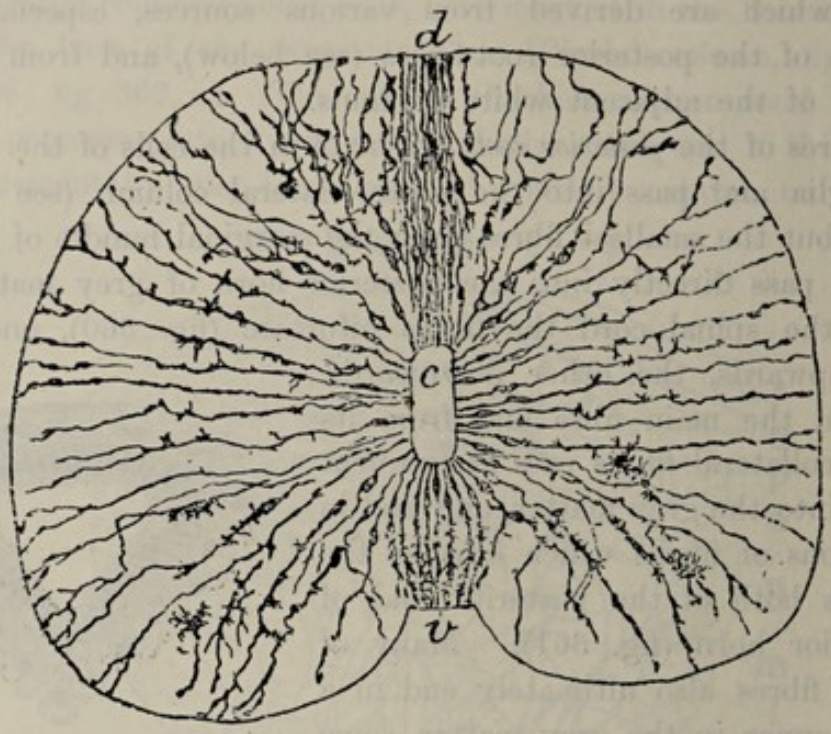


FIG. 364.—SECTION OF SPINAL CORD OF EMBRYO CHICK, SHOWING NEUROGLIA FIBRES PROLONGED FROM THE EPITHELIUM OF THE CENTRAL CANAL. (S. Ramón y Cajal.)

d, dorsal; *v*, ventral surface; *c*, central canal from which the neuroglia cells and fibres are seen to radiate to the periphery of the cord. Some detached neuroglia cells are also represented.

In the *dorsal region* the grey matter is small in amount, and both horns are slender. The whole cord is smaller in diameter than either in the cervical or lumbar region. The columns of nerve-cells known as Clarke's column and the intermedio-lateral tract are well marked.

In the *lumbar region* the crescents of grey matter are very thick, and the white substance, especially the lateral columns, relatively small in amount. The isthmus lies nearly in the centre of the cord, whereas in the cervical and dorsal regions it is nearer the anterior surface.

In the part of the spinal cord from which the *sacral* and *coccygeal* nerve-roots take origin the grey matter largely preponderates, the crescents form thick irregular masses, and the grey isthmus is also of considerable thickness.

Blood-vessels of the spinal cord.—The blood-supply of the grey matter is derived mainly from a series of arterioles, which come off from the mesially-situated anterior spinal artery, pass into the anterior median fissure, and at the bottom of this divide each into two branches, one for the grey matter of each lateral half of the cord (fig. 365).

In the grey matter is a very close capillary plexus which is supplied not alone by the vessels just mentioned, but also by small arterioles, which converge from the small arteries of the pia mater, passing through the white matter, and supplying this as they pass through it.

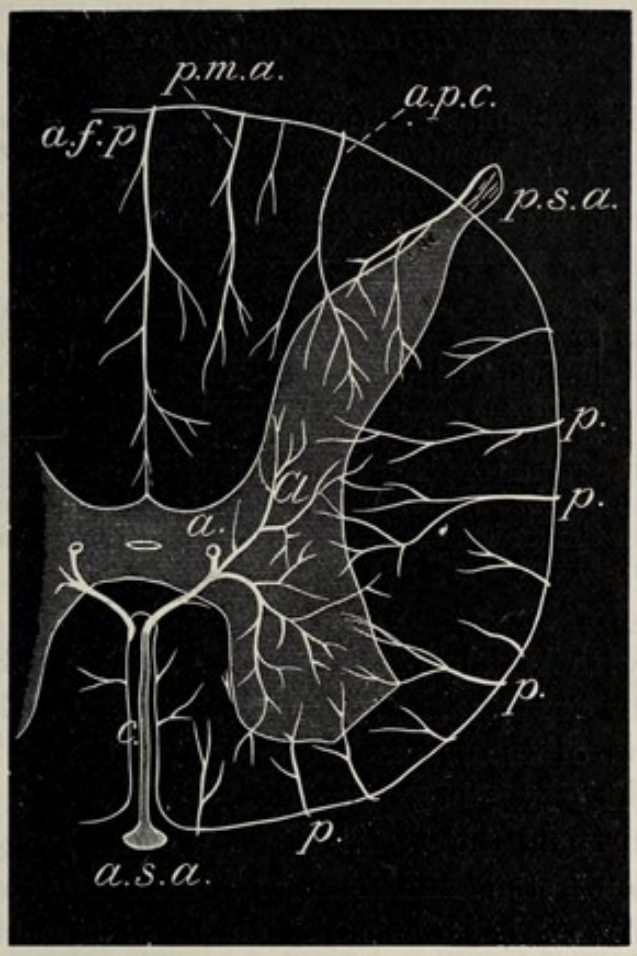


FIG. 365.—SEMIDIAGRAMMATIC REPRESENTATION OF THE ARTERIES OF THE CORD. (After Obersteiner.)

a.s.a., anterior spinal; *c*, a branch in the grey matter; *a*, an anastomotic arteriole in the grey matter: *Cl*, branch to Clarke's column; *a.f.p.*, artery of posterior fissure; *p.m.a.*, postero-mesial; *a.p.c.*, artery to posterior horn; *p.s.a.*, branch from posterior spinal to substantia gelatinosa; *p*, *p*, *p*, peripheral arterioles destined chiefly for white matter.

These arterioles are branches of the above-mentioned anterior spinal artery and of the posterior spinal arteries (which run on each side along the line of the posterior roots). The capillary plexus of the white matter is far less dense than that of the grey matter. It forms longitudinal meshes.

The veins of the spinal cord accompany the arteries. Two longitudinal venous vessels, accompanying corresponding anastomotic arterioles, are seen, one on either side of the central canal, in most transverse sections of the cord.

LESSON XL.

THE MEDULLA OBLONGATA.

SECTIONS of the medulla oblongata (made in the same way as with the spinal cord): (*a*) at the level of the decussation of the pyramids, (*b*) just above the decussation, (*c*) opposite the middle of the olivary body, and (*d*) either through the uppermost part of the olivary body, or just above it.

The brain consists of three great morphological divisions associated with the three primary cerebral vesicles of the embryo; they are termed respectively the hind-brain, mid-brain, and fore-brain.

The hind-brain is formed of the parts around the fourth ventricle, viz., the medulla oblongata or spinal bulb, and above this the pons Varolii with the cerebellum; the region of the corpora quadrigemina forms the mid-brain; whilst all parts above that region, and centering around the third ventricle, including the optic thalami, the corpora striata, and the cerebral hemispheres, constitute the fore-brain.

The structure of the **medulla oblongata** or **spinal bulb** can best be made out by the study of a series of sections taken from below upwards, and by tracing in these the changes which occur in the constituent parts of the spinal cord, taking note at the same time of any parts which may be superadded.

A section through the *region of the decussation of the pyramdis* (fig. 366) has much the same form as a section through the upper part of the spinal cord, and most of the structures of the cord can be easily recognised. A considerable alteration of the grey matter is, however, produced by the passage of the large bundles of the crossed pyramidal tract (*p*) from the lateral column of the spinal cord on each side through the root of the anterior horn and across the anterior median fissure to the opposite anterior column of the medulla oblongata, where, together with the fibres of the direct pyramidal tract, they constitute the prominent mass of white fibres which is seen on the front of the bulb, on each side of the middle line, and which is known as the *pyramid*. By this passage of fibres through the grey matter the tip of the anterior horn (*a*) is cut off from the rest and becomes pushed as it were to the side; in sections a little higher up it appears as an isolated mass of grey matter which is known as the *lateral nucleus* (fig. 367, *n.l.*). Between this and the pyramid the prominence of the *olive* is also beginning to appear.

The **pyramids** (or anterior pyramids) of the medulla oblongata are a direct downward continuation of fibres which originate in the motor

(Rolandic) region of the cerebral cortex, and which can be traced from the axons of large cells in the grey matter of that cortex through the white matter of the hemisphere, through the middle third or more of the internal capsule and crusta, through the pyramid bundles of the pons Varolii and into these structures (pyramids) of the bulb. As we have just seen they pass at the lower limit of the bulb chiefly to

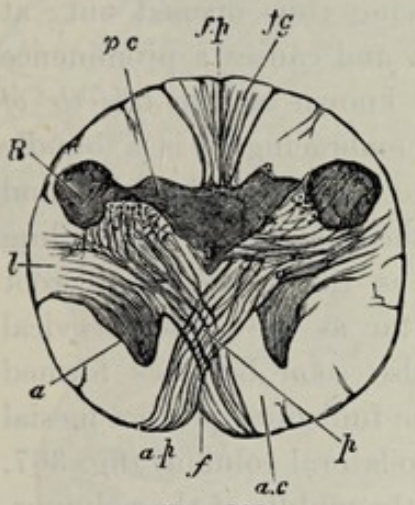


FIG. 366.

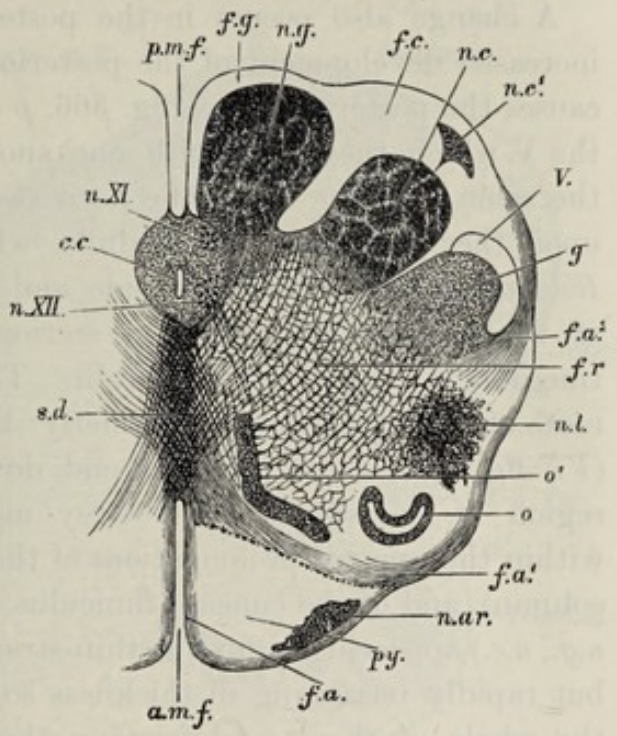


FIG. 367.

FIG. 366.—SECTION OF THE MEDULLA OBLONGATA AT THE MIDDLE OF THE DECUSSATION OF THE PYRAMIDS. $\frac{3}{1}$. (Lockhart-Clarke.)

f, anterior; *f.p.*, posterior fissure; *a.p.*, pyramid; *a*, remains of part of anterior cornu, separated by the crossing bundles from the rest of the grey matter; *l*, continuation of lateral column of cord; *R*, continuation of substantia gelatinosa of Rolando; *p.c.*, continuation of posterior cornu of grey matter; *f.g.*, funiculus gracilis.

FIG. 367.—SECTION OF THE MEDULLA OBLONGATA IN THE REGION OF THE SUPERIOR PYRAMIDAL DECUSSATION. $\frac{4}{1}$. (Schwalbe.)

a.m.f., anterior median fissure; *f.a.*, superficial arciform fibres emerging from the fissure; *py.*, pyramid; *n.a.r.*, nucleus of the arciform fibres; *f.a.'*, deep arciform fibres becoming superficial; *o*, lower end of olivary nucleus; *o'*, accessory olivary nucleus; *n.l.*, nucleus lateralis; *f.r.*, formatio reticularis; *f.a.²*, arciform fibres proceeding from formatio reticularis; *g*, substantia gelatinosa of Rolando; *V.*, so-called ascending root of fifth nerve, really descending; *n.c.*, nucleus cuneatus; *n.c.'*, external cuneate nucleus; *f.c.*, funiculus cuneatus; *n.g.*, nucleus gracilis; *f.g.* funiculus gracilis; *p.m.f.*, posterior median fissure; *c.c.*, central canal surrounded by grey matter, in which are, *n.XI.*, nucleus of the spinal accessory; and *n.XII.*, nucleus of the hypoglossal; *s.d.*, supra-pyramidal decussation (decussation of fillet).

the opposite or crossed lateral column of the cord, but partly to the lateral column of the same side, and, in man and anthropoid apes, partly to the anterior column (fig. 358). They collectively constitute the *pyramidal tract*, which is smaller in the medulla oblongata than in the pons Varolii, since many of its fibres terminate in the pons.

It is not a little remarkable that although the fibres of the pyramidal tract give off numerous collaterals to the grey matter of the cerebral cortex,

the basal ganglia of the cerebrum, the substantia nigra of the mid-brain, the nuclei pontis of the pons Varolii, and the base of the posterior horn of the spinal cord, no collaterals are seen to leave them in their course through the medulla oblongata, except a very few to the olivary nuclei. Various observers have described collaterals and terminations of the pyramidal fibres as passing to the motor nuclei of the cranial nerves and to the anterior horns of the spinal cord, but statements to this effect, although current in most text-books, have not been substantiated by recent investigations.

A change also occurs in the posterior horn in consequence of the increased development of the posterior column of white matter. This causes the posterior horns (fig. 366, *p c*) to be pushed towards the side, the V which they form with one another being thus opened out; at the same time the tip of the horn swells out and causes a prominence upon the surface of the medulla, which is known as the *tubercle of Rolando* (*R*). On its outer side and partly embracing it is a bundle of white fibres seen in every section of the medulla oblongata, and traceable up to the pons Varolii. This is the inferior or descending root of the fifth nerve—formerly known as the "ascending" root (*V.*, fig. 367). Its fibres extend down as far as the upper cervical region of the spinal cord. Grey matter also soon becomes formed within the upward prolongations of the gracile funiculus (postero-mesial column), and of the cuneate funiculus (postero-lateral column) (fig. 367, *n.g.*, *n.c.*) appearing at first as thin strands in the middle of the columns, but rapidly increasing in thickness so as eventually to occupy almost the whole of them, and forming the *nucleus gracilis* and the *nucleus cuneatus* respectively.

It is in these nuclei that the fibres of Goll's and Burdach's tracts, which are continued up from the posterior columns of the spinal cord, find their ultimate ending in complicated arborisations amongst the cells of the nuclei. These do not, however, receive all the ascending branches of the posterior root fibres, for a considerable number of these have already disappeared by entering the grey matter of the cord, in which they apparently also end by arborisation amongst its cells. The cells of the nucleus gracilis and nucleus cuneatus are small or of moderate size with long dendrons. Their axons pass as internal arcuate fibres through the reticular formation into the inter-olivary layer, cross the median raphe dorsal to the pyramids (fig. 367, *s.d.*), and then turn upwards towards the higher parts of the brain constituting the *tract of the fillet*. This tract, which in its lowest part is thus formed by the nerve fibres which belong to the second relay (or second neurones) of the sensory spinal path, is reinforced in the higher regions of the medulla oblongata and in the pons by fibres derived from cells of the sensory nuclei of the cranial nerves.

The continuation of the *central canal* of the spinal cord is still seen in

the lower medulla oblongata (fig. 367, *c.c.*), but it comes nearer to the posterior surface. The grey matter which surrounds it contains two well-marked groups of nerve-cells; the anterior (ventral) of these is the lower part of the *nucleus of the hypoglossal* or twelfth nerve (*n. XII.*), the posterior (dorsal), with smaller cells, that of the *vago-accessory* or eleventh (*n. XI.*). But most of the grey matter of the crescent becomes

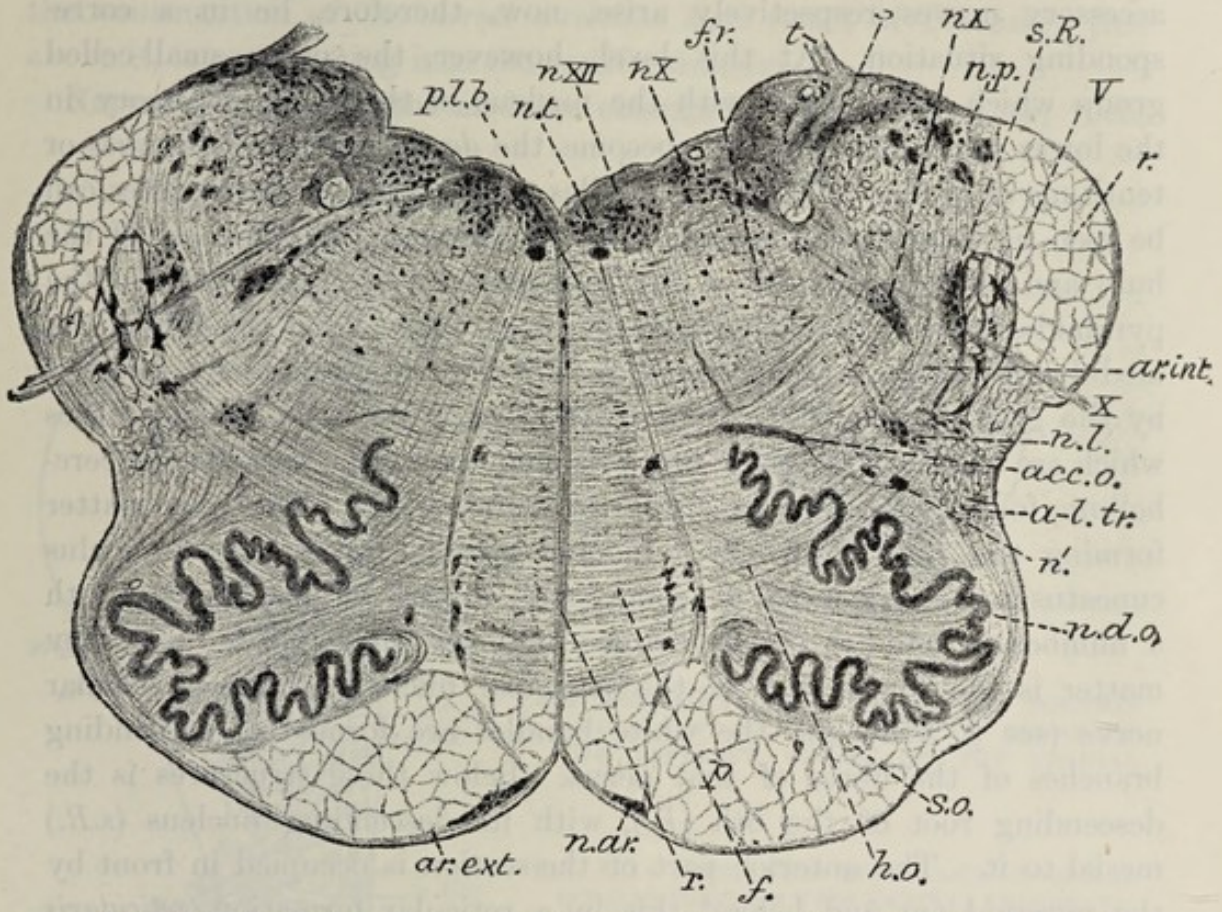


FIG. 368.—SECTION ACROSS THE MEDULLA OBLONGATA AT ABOUT THE MIDDLE OF THE OLIVARY BODY. (Magnified 5 diameters.)

r, raphe; *f*, fillet; *ar.ext.*, fibræ arcuatæ externæ; *n.ar.*, nucleus arcuatus; *py*, pyramid; *n.d.o.*, nucleus dentatus olivæ; *h.o.*, hilum olivæ; *s.o.*, siliqua olivæ; *acc.o.*, oliva accessoria; *n.l.*, nucleus lateralis; *n'*, portions of grey matter containing large cells, perhaps detached from the nucleus lateralis; *a-l.tr.*, antero-lateral ascending tract; *X.*, tenth nerve issuing from side of bulb; *ar.int.*, fibræ arcuatæ internæ; *V.*, descending root of fifth nerve; *s.R.*, substantia gelatinosa Rolandi; *r.*, corpus restiforme; *n'X.*, ventral nucleus of tenth nerve (nucleus ambiguus); *n.p.*, nucleus posterior; *s*, fasciculus solitarius (descending root of *X.* and *IX.* nerves); *t*, tænia (attachment of ependymal roof of fourth ventricle); *f.r.* formatio reticularis; *n.X.*, dorsal vago-accessory nucleus; *nXII.*, upper part of nucleus of twelfth nerve; *n.t.*, nucleus of funiculus teres; *p.l.b.*, posterior or dorsal longitudinal bundle.

broken up, by the passage of bundles of nerve-fibres through it, into a *reticular formation* (*f.r.*) the production of which is already foreshadowed in the upper part of the spinal cord. Instead of the comparatively narrow isthmus which joins the two halves of the spinal cord, a broad *raphe* now makes its appearance; this is formed of obliquely and antero-posteriorly coursing fibres, together with some grey matter containing nerve-cells.

In the section at *about the middle of the olive* (fig. 368), it will

be seen that a marked change has been produced in the form of the medulla oblongata and the arrangement of its grey matter, by the opening out of the central canal into the fourth ventricle. This causes the grey matter which lower down surrounded the central canal to be now spread out at the floor of that ventricle, and the collections of nerve-cells from which the hypoglossal and spinal accessory nerves respectively arise, now, therefore, lie in a corresponding situation. At this level, however, the outer small-celled group which corresponds with the nucleus of the spinal accessory in the lower part of the bulb has become the *dorsal nucleus of the vagus* or tenth nerve (*n.X.*). The nerve-bundles of the roots of these nerves can be seen in some of the sections coursing through the thickness of the bulb and emerging, those of the hypoglossal (*XII.*) just outside the pyramids, those of the spinal accessory and vagus (*X.*) at the side of the medulla oblongata. The posterior part of the section is chiefly occupied by the grey matter of the floor of the fourth ventricle, and by fibres which are passing obliquely upwards and outwards towards the cerebellum, forming its inferior crus (*restiform body*, *r.*). The grey matter forming the nucleus of the funiculus gracilis and of the funiculus cuneatus is here replaced by some small masses of grey matter with a number of bundles of nerve-fibres amongst them (*n.p.*). The grey matter is the lower part of the principal nucleus of the vestibular nerve (see p. 318), and the white bundles are formed of descending branches of the fibres of that nerve. Below these structures is the descending root of the 5th (*V.*), with its descending nucleus (*s.R.*) mesial to it. The anterior part of the section is occupied in front by the pyramid (*p*), and behind this by a reticular formation (*reticularis alba*), composed of longitudinally coursing bundles of fibres belonging mainly to the tract of the *fillet* (*f.*), interlaced with and reinforced by fibres that are passing obliquely from the opposite side, through the raphe, towards the nuclei of the posterior columns and restiform body (fig. 368, *ar. int.*). The middle portion of the section consists for the most part of a similar reticular formation (*f.r.*), but with more grey matter and nerve-cells (*reticularis grisea*). Laterally there is developed within the olive a peculiar wavy lamina of grey matter containing a large number of nerve-cells; this is the *dentate nucleus of the olive* (*n.d.o.*). The lamina is incomplete at its mesial aspect (*hilum olivæ*, fig. 368, *h.o.*), and here a large number of fibres issue, and passing through the raphe course as inner arcuate fibres to the opposite restiform body, and thus to the cerebellum. Some, however, turn sharply round and course below the dentate nucleus, forming an investment and capsule to it (*siliqua olivæ*, fig. 368, *s.o.*), and

pass towards the restiform body of the same side, but the main connection of the olivary nucleus is with the cerebellar hemisphere of the opposite side. The olives receive numerous collaterals from the neighbouring white columns, including a few from the pyramids. Just dorsal, or dorso-lateral to the olive, is the continuation upwards of the *ventral cerebellar tract* (tract of Gowers, *a-l.tr.*) of the spinal cord; the continuation of the *dorsal cerebellar tract* (tract of Flechsig), just above it, is now passing into the restiform body.

Nerves arising from the medulla oblongata.—The 12th, 11th, 10th,

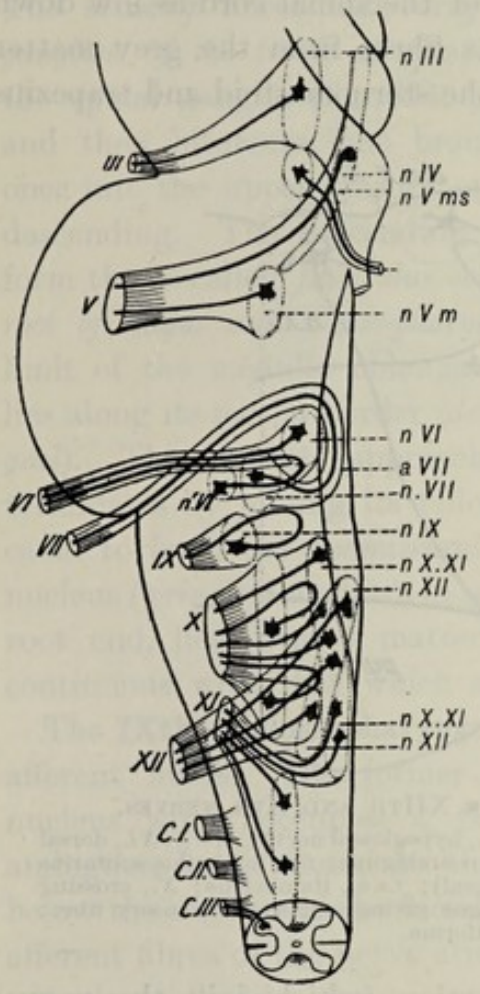


FIG. 369.

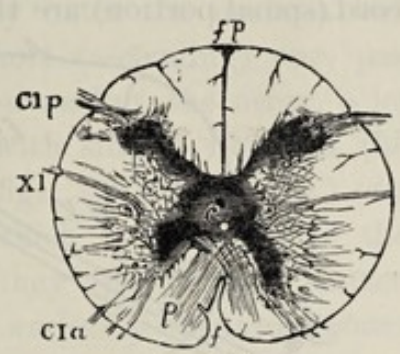


FIG. 370.

FIG. 369.—DIAGRAM SHOWING THE POSITION AND EXTENT OF THE NUCLEI OF ORIGIN OF THE EFFERENT FIBRES OF THE CRANIAL NERVES.

FIG. 370.—SECTION OF UPPER END OF SPINAL CORD AT JUNCTION WITH MEDULLA OBLONGATA, SHOWING THE ORIGIN OF ONE OF THE ROOTS OF THE SPINAL ACCESSORY NERVE. (Lockhart Clarke.)

c, central canal; *f*, anterior fissure; *fp*, posterior fissure; *p*, lower end of decussation of pyramids; *C1a*, *C1p*, roots of first cervical nerve; *XI*, spinal accessory root.

9th, and 8th nerves all take origin in the medulla oblongata, and their fibres may be seen emerging on either side, those of the 12th ventrally between the pyramid and olive, and those of the other three nerves in succession at the side of the medulla between the olive and restiform body.

The **XIIth** or **hypoglossal nerve** arises from a well-marked nucleus of large cells, similar to those of the anterior horn of the cord. This nucleus is situated:—in the lower part of the bulb, ventro-lateral to the central canal; in the upper part, near to the floor of the 4th

ventricle, close to the middle line (fig. 371, *nXII.*). None of the fibres cross to the opposite side; according to v. Gehuchten, this is true of all the cranial nerves, except a few fibres of the 3rd nerve and the whole of the 4th nerve. The hypoglossal nucleus extends throughout about the lower two-thirds of the bulb (fig. 369, *nXII.*). It receives many collaterals from adjacent sensory tracts in the reticular formation and from the descending sensory nuclei of the 5th, 9th, and 10th nerves, as well as from the posterior longitudinal bundle.

The **XIth nerve** or **spinal accessory** begins to take origin from cells in the lateral part of the anterior horn of the spinal cord as low down as the 4th cervical nerve (fig. 370). Its fibres from the grey matter of the cord (spinal portion) are those to the sternomastoid and trapezius

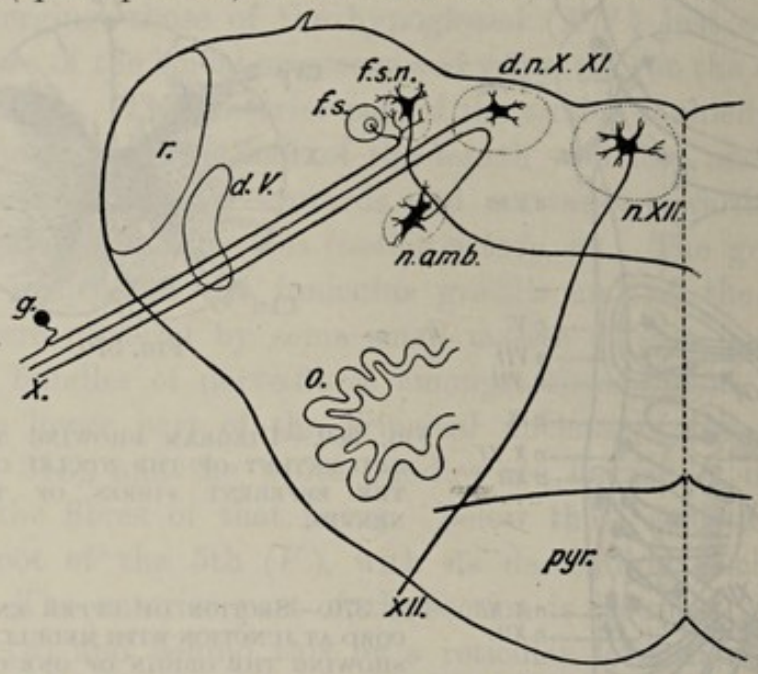


FIG. 371.—PLAN OF THE ORIGIN OF THE XIITH AND XTH NERVES.

pyr, pyramid; *n.XII.*, nucleus of hypoglossal; *XII.*, hypoglossal nerve; *d.n.X. XI.*, dorsal nucleus of vagus and accessory; *n.amb.*, nucleus ambiguus; *f.s.*, fasciculus solitarius (descending root of vagus and glosso-pharyngeal); *f.s.n.*, its nucleus; *X.*, crossing motor fibre of vagus; *g*, ganglion cell in vagus giving origin to a sensory fibre; *d.V.*, descending root of fifth; *c.r.*, corpus restiforme.

muscles. The fibres of the bulbar portion (which join the vagus) take origin in a nucleus of relatively small cells which lies dorso-laterally to the central canal of the medulla oblongata and behind the hypoglossal nucleus. This bulbar nucleus is continuous above with the dorsal nucleus of the vagus, and with it forms the *dorsal vago-spinal nucleus* (figs. 369, *nX. XI.*; 371, *d.n.X. XI.*). Its lower extent is nearly as far as the first cervical nerve; its upper part (vagal part) is in the floor of the 4th ventricle lateral to the hypoglossal nucleus, and extending nearly as far as the lower border of the pons. The 12th and 11th nerves are entirely efferent.

The **Xth nerve** or **vagus** (**pneumogastric**) contains both motor

(efferent) and sensory (afferent) fibres. The efferent fibres arise (1) from the upper part of the vago-spinal nucleus just described; (2) from a nucleus of grey matter containing large cells situated in the reticular formation (fig. 371, *n.amb.*). This nucleus begins near the lower limit of the bulb and extends nearly to the facial nucleus, which it resembles in general position: it is known as the *nucleus ambiguus* (*ventral* or *accessory nucleus of the Xth nerve*). The axons of its cells are directed at first backwards and inwards and then turn sharply round in the lateral direction to join the rest of the issuing fibres of the nerve. The sensory fibres take origin in the *ganglion of the root* and the *ganglion of the trunk* of the nerve from unipolar cells like those of the spinal ganglia (fig. 371, *g*). They enter the medulla oblongata, and then bifurcate, one branch, a short (ascending) one, passing at once into the upper sensory or *principal nucleus*, the other, a long one, descending. The descending fibres (with similar fibres of the IXth) form the so-called *fasciculus solitarius* (figs. 368, *s*; 371, *f.s.*) (*descending root of vagus and glosso-pharyngeal*), which is traceable to the lower limit of the medulla oblongata, and they end in grey matter which lies along its mesial border (*descending nucleus of vagus and glossopharyngeal*). This nucleus approaches the middle line as it descends, and terminates by joining its fellow of the opposite side over the central canal to form the *commissural nucleus* of Ramón. The upper sensory nucleus (*principal nucleus*), in which the short branches from the sensory root end, lies in grey matter near the floor of the ventricle, and is continuous with that which accompanies the fasciculus solitarius.

The **IXth** or **glossopharyngeal nerve** also contains both efferent and afferent fibres. The former have their cells of origin in a special nucleus which occupies a position similar to that of the nucleus ambiguus, but is mesial to the anterior end of that nucleus, and just below the nucleus of the facial (*motor nucleus of glossopharyngeal*). The afferent fibres of the nerve arise in the *jugular* and *petrosal ganglia* from unipolar cells like those of the spinal ganglia. Their central axons enter the medulla oblongata, and, like other sensory fibres, bifurcate into two branches, ascending and descending. These end, like those of the vagus, the descending by passing down in the fasciculus solitarius (extending to about one-third of its length), and ending by arborising in the grey matter accompanying it (*descending root and nucleus*), while the ascending branches pass nearly horizontally backwards and inwards to a nucleus (*principal nucleus*) beneath the inferior fovea of the ventricle which is continuous with the upper end of the nucleus of the descending root. The arrangement is almost exactly a counterpart of that of the vagus shown in the diagram given in fig. 371.

The **VIIIth nerve.**—A section taken *through the uppermost part of the olivary prominence* will still show very much the same form and structural arrangements as that just described. The *nucleus of the hypoglossal* (fig. 372, *n.XII.*) is still visible in the grey matter of the floor of the ventricle near the middle line, but the nerve which is now seen connected with the lateral part is the *eighth* or *auditory* (*VIII.*), the bundles of which, as they enter the bulb, embrace the inferior crus of the cerebellum (*corpus restiforme*, *c.r.*), which is now passing into that organ. The origin of the *eighth nerve* is thus subdivided

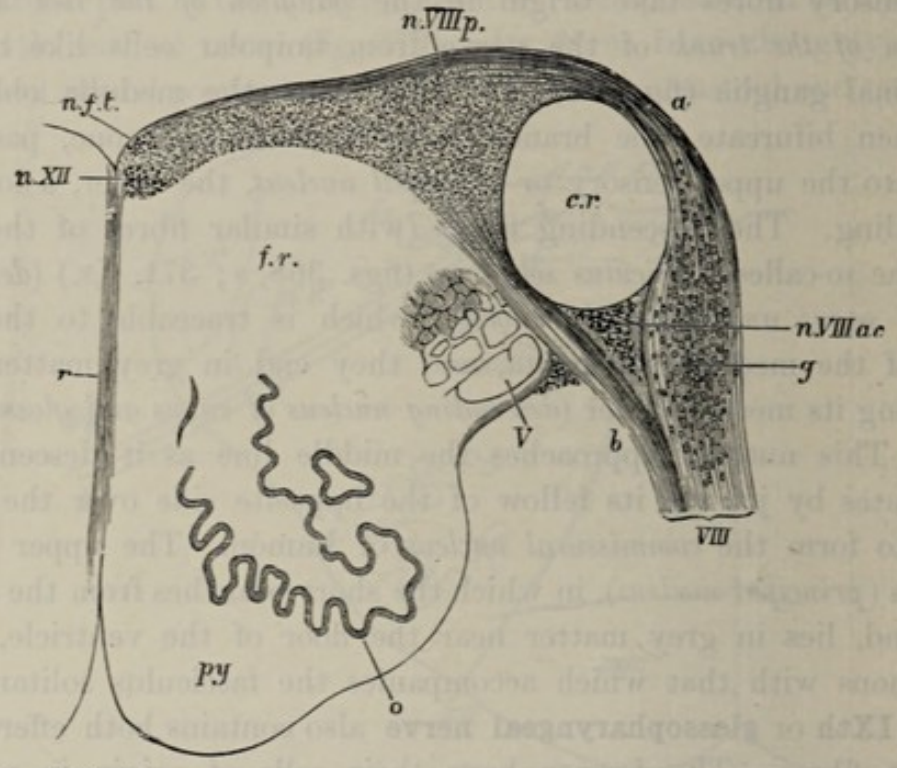


FIG. 372.—TRANSVERSE SECTION OF THE UPPER PART OF THE MEDULLA OBLONGATA. ¼. (Schwalbe.)

py, pyramid; *o*, olivary nucleus; *V*, descending root of the fifth nerve; *VIII.*, root of the auditory nerve, formed of two parts, *a*, cochlear, and *b*, vestibular, which inclose the restiform body, *c.r.*; *n.VIIIp.*, principal nucleus of the vestibular division; *n.VIIIac.*, accessory nucleus; *g*, ganglion of the dorsal root; *n.f.t.*, nucleus of the funiculus teres; *n.XII.*, nucleus of the hypoglossal; *r*, raphe; *f.r.*, reticular formation.

into two principal parts, known respectively as the *dorsal* or *cochlear* and the *ventral* or *vestibular* divisions (fig. 372).

The real origin of the nerve fibres in these roots is in the *ganglion of the cochlea* and the *ganglion of Scarpa* respectively. These ganglia, which are situated at the periphery within and near the internal ear, are composed of bipolar cells of which the peripheral axons end by ramifying amongst the cells of the auditory epithelium, and the central axons form the cochlear and the vestibular divisions of the auditory nerve and pass into the medulla oblongata in the manner here described.

The fibres of the *dorsal* or *cochlear division* bifurcate as they enter the medulla oblongata and pass partly to a mass of ganglion cells which is wedged in between the two roots and the restiform body, and

is known as the *accessory auditory nucleus* (fig. 372, *n.VIII.ac.*; 373, *n.acc.*), applying themselves with a peculiar form of terminal arborisation to the cells of this nucleus, partly over the restiform body to terminate in a prominent mass of grey matter which overlies that body and also extends to the lateral part of the floor of the fourth ventricle at its widest part (*tuberculum acusticum*). The cells of the tubercle have a peculiar spindle shape and are set vertically to the surface. They begin to appear in the root itself lying amongst the fibres of the nerve (fig. 372, *g*). Here they are sometimes spoken of as forming the "ganglion of the root."

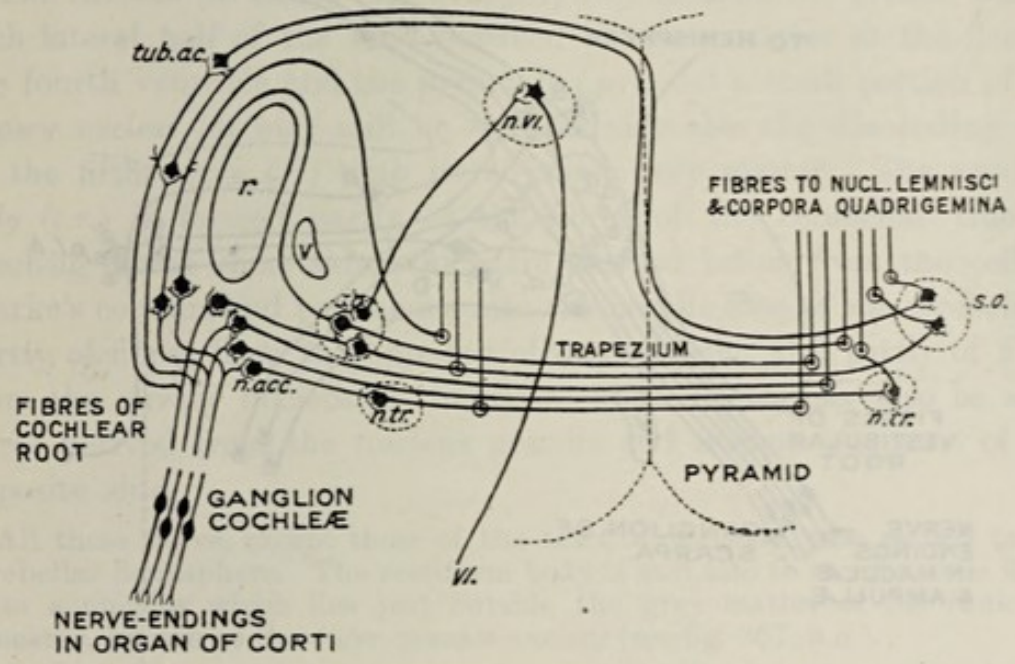


FIG. 373.—PLAN OF THE COURSE AND CONNECTIONS OF THE FIBRES FORMING THE COCHLEAR ROOT OF THE AUDITORY NERVE.

r., restiform body; *V.*, descending root of the fifth nerve; *tub.ac.*, tuberculum acusticum; *n.acc.*, accessory nucleus; *s.o.*, superior olive; *n.tr.*, nucleus of trapezium; *n.VI.*, nucleus of sixth nerve; *VI.*, issuing root fibre of sixth nerve.

These two nuclei, viz., the accessory nucleus and the acoustic tubercle, are the nuclei of ending of the cochlear fibres. From their nerve-cells new fibres arise which continue the auditory path centrally (see fig. 373). Those from the accessory nucleus enter the *trapezium*—which consists of transverse fibres running behind the pyramid bundles of the pons Varolii—and pass in it partly to the superior olive and trapezoid nucleus of the same side of the pons, but mostly to the corresponding structures on the opposite side, some ending in those nuclei, but others merely traversing them, giving off numerous collaterals to them and to certain other nuclei close by (see p. 321), and then turning upwards in the lateral part of the tract of the fillet to pass ultimately towards the inferior corpora quadrigemina; in tending towards these structures at the side of the mid-brain they form the *lateral fillet*, or *fillet of Reil*, which is there conspicuous. The fibres which arise in the acoustic tubercle pass for the most part over the floor of the fourth ventricle, where they are seen superficially as the *medullary striæ*, and, entering the raphe, traverse it from behind forwards, and then join the others from the accessory nucleus in their course to the superior olive and fillet. A few fibres are directed into the fillet of the same side as their cells of origin.

The accessory nucleus also receives fibres from the trapezium, which end by ramifying amongst its cells. These are perhaps derived from the accessory nucleus of the opposite side.

Both sets of fibres (from the accessory nucleus and tuberculum) give off collaterals near their origin from the cells, which terminate within these nuclei.

The *ventral* or *vestibular division* passes in between the restiform body and the descending root of the fifth (fig. 372), to enter a mass of grey matter containing for the most part cells of small size, which is termed the *principal nucleus* of the vestibular division (fig. 372, *n.VIII.p.*). Here

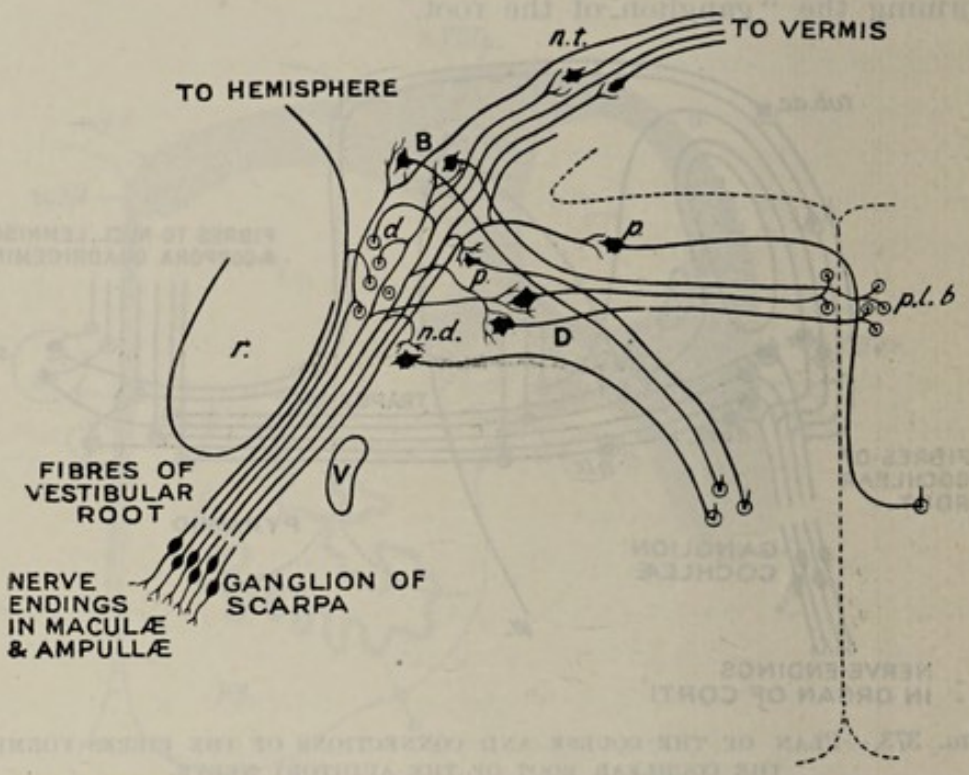


FIG. 374.—PLAN OF THE COURSE AND CONNECTIONS OF THE FIBRES FORMING THE VESTIBULAR ROOT OF THE AUDITORY NERVE.

r., restiform body; *V.*, descending root of fifth nerve; *p.*, principal nucleus of vestibular root; *d*, fibres of descending vestibular root; *n.d.*, a cell of the descending vestibular nucleus; *D*, nucleus of Deiters; *B*, nucleus of Bechterew; *n.t.*, nucleus tecti (fastigii) of the cerebellum; *p.l.b.*, posterior longitudinal bundle.

each of its fibres divides with a Y-shaped division into an ascending and a descending branch. The descending branches are collected into small bundles (*descending vestibular root*) which run downwards towards the lower part of the medulla oblongata, and gradually end by arborising around cells in the adjacent grey matter (*descending vestibular nucleus*), which is continued down from the principal nucleus. The ascending branches pass upwards on the inner side of the restiform body towards the cerebellum. In their course they give off numerous collaterals which arborise round the large cells of two nuclei which occur in this part of the medulla oblongata and pons near the outer part of the floor of the fourth ventricle. These two nuclei are

termed the *nucleus of Deiters* and the *nucleus of Bechterew* respectively (fig. 374).

The nucleus of Deiters is especially characterised by the large size of its cells and by the manner in which they are enveloped as by a basket-work with the ramifications of the collaterals in question. From these cells fibres arise which pass to the posterior longitudinal bundles of both sides : in these the fibres bifurcate, one branch passing upwards to the oculomotor nucleus and the other downwards, eventually reaching the anterior column of the spinal cord (antero-lateral descending tract) and terminating by arborisations amongst the cells of the anterior horn (see p. 301). The fibres which originate in the nucleus of Bechterew pass into the reticular formation and become longitudinal, but their destination is not certainly known.

The *reticular formation* (fig. 372, *f.r.*) still occupies the greater part of each lateral half of the bulb between the grey matter at the floor of the fourth ventricle and the pyramids (*py*), and a small portion of the *olivary nucleus* (*o*) may still be seen, as may also the descending root of the fifth nerve (*V*) with its adjacent grey matter. The *restiform body* (*c.r.*) is formed partly of the fibres of the cerebellar tract of Flechsig of the same side, which are derived below from the cells of Clarke's column, and pass above into the middle lobe of the cerebellum, partly of fibres from the opposite olivary nucleus, and partly of fibres from the olivary nucleus of the same side. There may also be some fibres derived from the nucleus gracilis and nucleus cuneatus of the opposite side.

All these fibres, except those of the tract of Flechsig, pass mainly to the cerebellar hemisphere. The restiform body is said also to receive some fibres from a nucleus which lies just outside the grey matter of the funiculus cuneatus, known as the *outer cuneate nucleus* (see fig. 367, *n.c'.*).

The *floor of the fourth ventricle* is covered by a layer of ciliated epithelium-cells, continuous below with those lining the central canal, and above, through the Sylvian aqueduct, with the epithelium of the third and lateral ventricles. The epithelium rests upon, and the prolonged extremities of its cells assist in forming, a layer of neuroglia known as the *ependyma* of the ventricle. The fourth ventricle is roofed over by a thin layer of pia mater, with projecting choroid plexuses, the under surface of which is covered by a thin epithelial layer continuous at each side with the ciliated epithelium of the floor. The roof becomes somewhat thickened as it is continued into the ependymal layer of the floor of the ventricle ; this thickened part (*tænia* or *ligula*, fig. 368, *t*), is often left attached when the thin epithelial roof is removed along with the pia-mater which covers it.

LESSON XLI.

THE PONS VAROLII AND MESENCEPHALON.

1. Sections through the lower, middle, and upper parts of the pons Varolii.

2. Sections across the region of the corpora quadrigemina, one at the level of the inferior, the other at the level of the superior, pair.

In all the above sections sketch under a low power the general arrangement of the grey and white matter, inserting the positions of the chief groups of nerve-cells.

[The tissue is hardened and the sections are prepared, stained, and mounted in the same way as the spinal cord and medulla oblongata.]

Pons Varolii.

Sections through the *pons Varolii* (figs. 375, 378) show very much the same arrangement of grey and white matter as that which is met with at the upper part of the medulla oblongata, but the general appearance of the sections is much modified by the presence of a large number of transversely coursing bundles of nerve-fibres, most of which are passing to or from the hemispheres of the cerebellum (fibres of middle peduncle of cerebellum). Intermingled with these bundles is a considerable amount of grey matter (*nuclei pontis*) from the cells of which many of the fibres of the middle peduncle of the opposite side appear to be derived, while other of these fibres arise in the hemisphere and passing to the raphe become lost amongst the cells of the opposite nucleus pontis; some of them may pass to the reticular formation, there becoming longitudinal. Amongst the cells of the nuclei pontis many fibres and collaterals of the pyramidal tract end and the cortico-pontine fibres also probably terminate here. The continuation of the pyramids of the medulla (*py*) is embedded between these transverse bundles, but the pyramid bundles of the pons are much larger than the pyramids of the medulla oblongata, and in addition to fibres of the pyramidal tract proper (cortico-spinal system) derived from the Rolandic area of the cortex, they are largely composed (especially the postero-lateral bundles) of fibres (cortico-pontine system) connecting other regions of the cortex with this part of the hind brain. The pyramidal bundles are separated from the reticular formation by deeper transverse fibres, which belong to a different system from those of the middle peduncle. They form what has already been

studied as the *trapezium* (figs. 373, 375); a collection of fibres which forms part of the central auditory path, and some of which appear to be commissural between the auditory nuclei of the two sides. The fibres of the trapezium traverse a collection of nerve-cells which lies mesial and ventral to the superior olivary nucleus, and is known as the *nucleus of the trapezium* (fig. 373, *n.tr*). The olivary nucleus is no longer seen, but there are one or two small collections of grey matter,

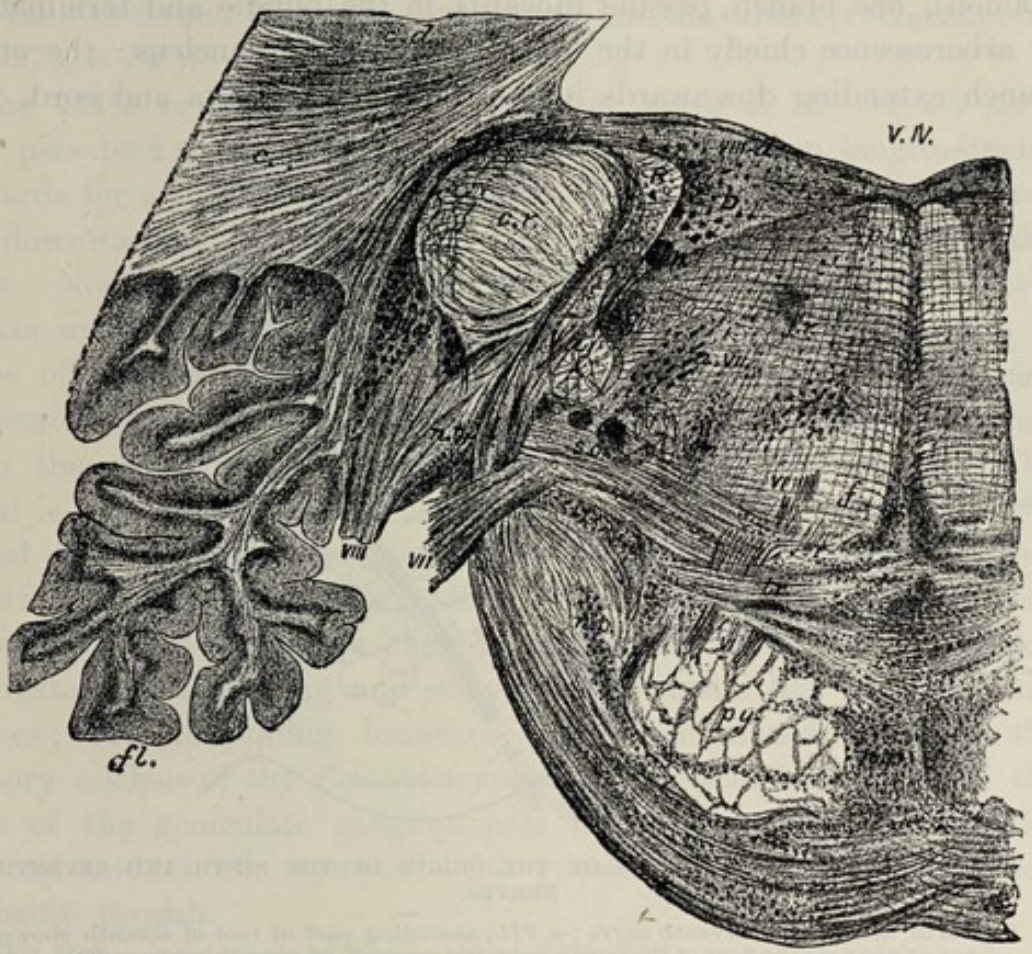


FIG. 375.—TRANSVERSE SECTION THROUGH THE LOWERMOST PART OF THE PONS VAROLII. $\frac{4}{1}$. (From a photograph.)

v.IV., fourth ventricle; *c*, white matter of cerebellar hemisphere; *c.d.*, corpus dentatum; *fl.*, flocculus; *c.r.*, corpus restiforme; *R*, bundle of Roller, composed of the descending branches of the vestibular nerve; *D*, nucleus of Deiters; *VIII.*, issuing root of auditory nerve; *VIII.d.*, principal nucleus of the vestibular nerve nucleus; *VIII.v.*, nucleus of cochlear portion; *tr.*, trapezium; *n.tr.*, its nucleus; *f*, fillet; *p.l.b.*, posterior longitudinal bundle; *f.r.*, formatio reticularis; *n*, *n'*, *n''*, various nuclei within it; *V.a.*, descending root of fifth nerve; *s.g.*, substantia gelatinosa; *s.o.*, superior olive; *VII.*, issuing root of facial nerve; *n.VII.*, its nucleus; *VI.*, root-bundles of sixth nerve; *py*, pyramid bundles; *n.p.*, nuclei pontis.

more conspicuous in some animals than in man, which lie in the ventral part of the reticular formation, and are known as the *superior olivary nucleus* (*o.s.*), the *preolivary nucleus*, and the *semilunar nucleus* (Ramón y Cajal). All these, as well as the nucleus of the trapezium itself, are connected with the fibres of the trapezium which form the central auditory path, some of these fibres either ending in the nuclei in question or giving off to them numerous collaterals; whilst from

the cells of the nuclei axons pass into the trapezium or into the adjacent lateral part of the fillet (see p. 317). The *nucleus of Deiters*, which begins to appear in the upper part of the medulla oblongata (p. 319), extends into the pons Varolii, where it lies near the floor of the fourth ventricle, a little mesial to the restiform body (*D*, fig. 375). The nerve-fibres connected with its cells pass towards the middle line and enter the *posterior longitudinal bundle*. Here they divide (Ramón), one branch passing upwards in the bundle and terminating by arborescence chiefly in the opposite oculomotor nucleus: the other branch extending downwards in the medulla oblongata and cord. In

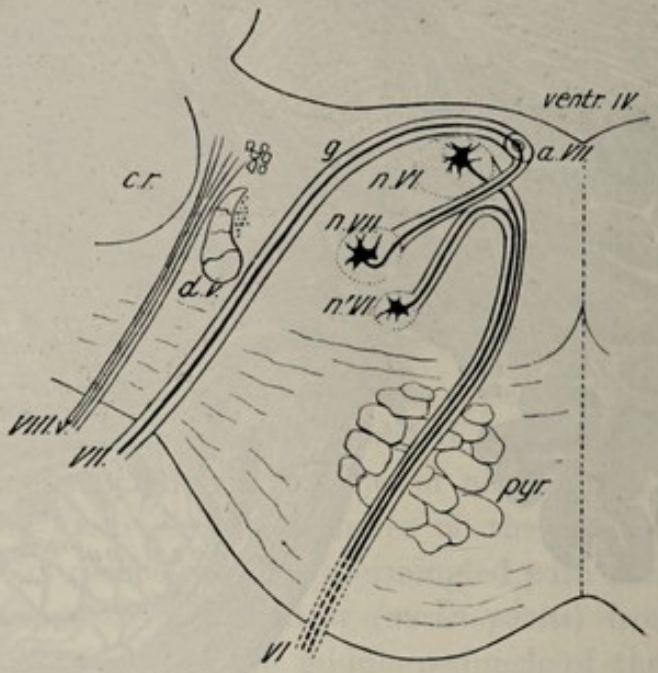


FIG. 376.—PLAN (TRANSVERSE) OF THE ORIGIN OF THE SIXTH AND SEVENTH NERVES.

VI., sixth nerve; *VII.*, seventh nerve; *a.VII.*, ascending part of root of seventh shown cut across near the floor of the fourth ventricle; *g*, germ of seventh nerve-root; *n.VI.*, chief nucleus of the sixth nerve; *n.VI.*, accessory nucleus of sixth; *n.VII.*, nucleus of seventh; *d.V.*, descending root of fifth; *pyr*, pyramid bundles; *VIII.v.*, vestibular root of eighth nerve.

the spinal cord they are found in the antero-lateral descending tract; fibres from each nucleus of Deiters occur in both of these tracts (E. H. Fraser). They terminate by arborescence in the anterior horn of grey matter.

The nerves which take origin from the grey matter of this region are part of the *eighth*, the *seventh*, the *sixth*, and somewhat higher up the *fifth* cranial nerves (see figs. 369, 373, 374, 376, 377). Of these the eighth (already considered) and fifth are connected with groups of nerve-cells which occupy the grey matter opposite the external border of the floor of the ventricle; the sixth with a nucleus which is also placed in the grey matter of the floor of the ventricle but nearer the middle

line, and the seventh with a special nucleus which lies in the formatio reticularis.

The VIth nerve (abducens).—The fibres of the *sixth nerve* (figs. 373, 376), which are purely motor, pass out from the mesial aspect of the nucleus and turn forwards; traversing the pyramid bundles they emerge at the lower margin of the pons. A few fibres are derived from a small *ventral nucleus* lying near the nucleus of the facial; these run at first backwards and then turn forwards to join the others (v. Gehuchten) (fig. 376, *n' VI.*).

The VIIth or **facial nerve.**—The motor fibres of the *seventh nerve* first pass backwards to the floor of the ventricle, then longitudinally upwards for a short distance (figs. 369, 376), and finally bend forwards and downwards to emerge between the transverse fibres at the side of the pons. None of its fibres are derived from the nucleus of the sixth, as has sometimes been supposed. As it curves over this nucleus it gives off a bundle of fine fibres which cross the raphe, but their destination is unknown. The nucleus of the facial receives collaterals from the adjacent sensory tracts in the formatio reticularis. The facial is not a purely motor nerve, but has a ganglion upon it of the spinal type (*geniculate ganglion*) from which fibres arise which pass centrally into the pars intermedia of Wrisberg which enters the pons between the seventh and eighth nerves, and the fibres of which bifurcate into ascending and descending branches like other sensory nerves; the descending branches have been traced down to the sensory nucleus of the glossopharyngeal. The peripheral axons of the cells of the geniculate ganglion pass into the large and superficial petrosal and chorda tympani—the gustatory fibres of which they probably furnish.

The **Vth** or **trigeminal nerve** (figs. 377, 378) emerges at the side of the pons in two roots, a smaller motor and a larger sensory. The motor root is derived partly from fibres which arise in the upper part of the pons and lower part of the mesencephalon from large spherical nerve-cells lying at the side of the grey matter bounding the Sylvian aqueduct (*accessory* or *superior motor nucleus of fifth*, fig, 369, *nVms*), partly from the *motor nucleus proper* (figs. 369, *nVm*; 378, *mnV*) which lies in the grey matter at the lateral edge of the fourth ventricle. The fibres of the sensory root are derived from the cells of the Gasserian ganglion which are homologous with the cells of the spinal ganglia. These fibres of the sensory root when traced into the pons are found to bifurcate, the ascending branches ending in a mass of grey matter (*principal sensory nucleus of the fifth*, figs. 378, *p.s.n.V.*; 278, *n.V.*) lying just lateral to the motor nucleus, while the descending

branches trend downwards into the medulla oblongata where they form the descending or spinal root of the fifth (fig. 378, *d.s.V.*), and some even reach the upper part of the spinal cord. They lie immediately lateral to and in close connection with the substantia gelatinosa Rolandi which forms the *inferior sensory nucleus* (*d.s.n.V.*), and which is continued above into the principal nucleus. The substantia gelatinosa which forms the sensory nucleus of the fifth contains numerous nerve-cells, both small and large; many of the small cells are grouped into nest-like clusters (islands of Calleja). The axons of the larger cells

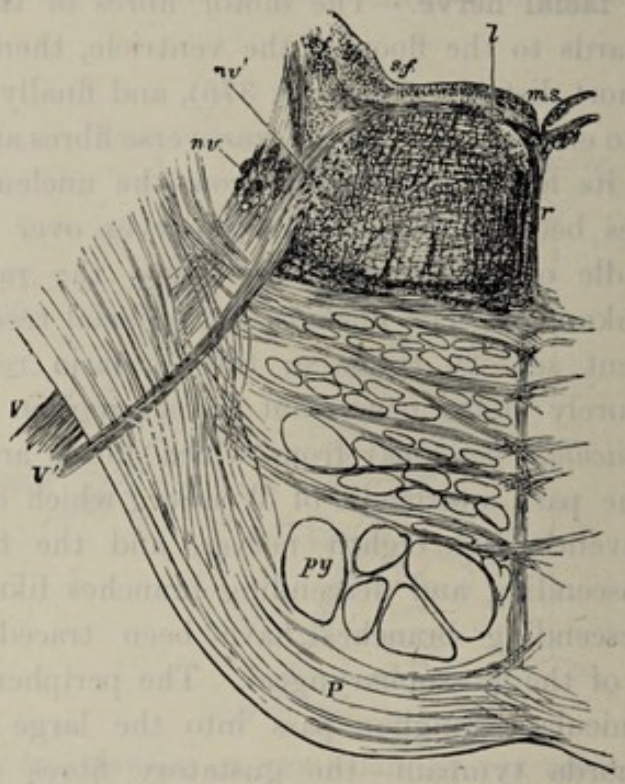


FIG. 377.—OBLIQUE SECTION OF THE PONS ALONG THE LINE OF EXIT TRAVERSED BY THE FIFTH NERVE. $\frac{8}{1}$.

The section passes through the lower part of the motor nucleus (*nv'*) from which a bundle of fibres of the motor root is seen passing, *V'*; a part of the upper sensory nucleus (*nv*) is also shown in the section in the form of a number of small isolated portions of grey matter. Amongst these are still a few bundles of the descending root, but most of these have already become diverted outwards to join and assist in forming the main or sensory root, *V*; *l*, small longitudinal bundle of fibres near the median sulcus (*m.s.*), passing outwards to join the root of the fifth nerve; *f.r.*, formatio reticularis; *r*, raphe; *s.f.*, substantia ferruginea.

pass for the most part across the raphe to the formatio reticularis of the opposite side where they reinforce the ascending fibres of the mesial fillet, but some ascend in the fillet of the same side, and others pass to a special ascending bundle of fibres which lies nearer the floor of the fourth ventricle.

Descending tracts in the pons and medulla oblongata.—Besides the *fibres of the pyramids*, which are much more numerous in the pons than in the medulla oblongata and which send numerous collaterals into the grey matter of the nuclei pontis, there are several tracts of

other fibres in the pons and medulla. One of these, which is very distinct, lies just ventral to the grey matter of the floor of the fourth ventricle, near the middle line; this is the *dorsal* or *posterior longitudinal bundle*; it appears to afford connection between Deiters' nucleus, the oculo-motor nucleus, the nucleus of the sixth, and the anterior horn cells of the spinal cord; it probably also receives fibres from the axons of the large cells of the formatio reticularis. This tract has already been referred to (pp. 319 and 322) and will be again noticed (p. 329).

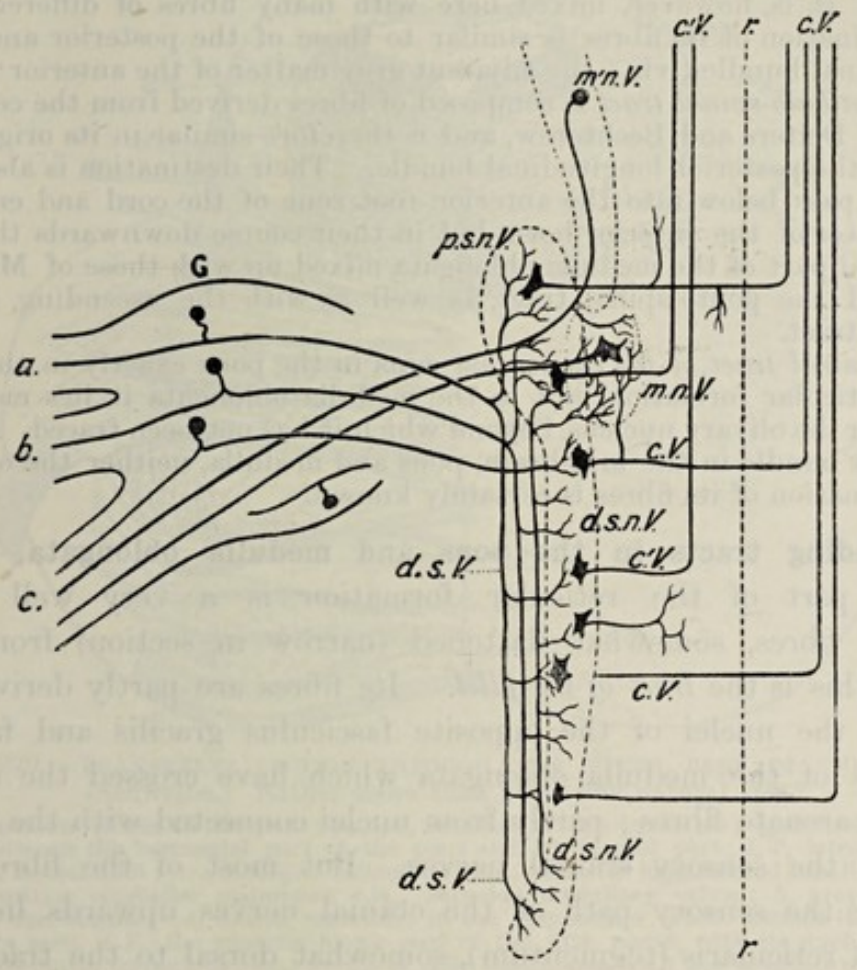


FIG. 378.—PLAN OF THE ORIGIN OF THE FIBRES OF THE FIFTH NERVE.

G, Gasserian ganglion; *a*, *b*, *c*, three divisions of the nerve; *m'.n.V.*, superior motor nucleus; *m.n.V.*, principal motor nucleus; *p.s.n.V.*, principal sensory nucleus; *d.s.n.V.*, descending sensory nucleus; *d.s.V.*, descending root; *cV.*, *c'V.*, central sensory tracts composed of fibres emanating from the sensory nuclei; *r*, plane of the raphe.

Other descending tracts in the pons which are not so distinctly marked in the normal condition, but which can be traced by the methods of Waller and Flechsig (see pp. 296, 298) are :—1. *Monakow's tract or bundle*; 2. *The ventral longitudinal bundle*; 3. *The ponto-spinal lateral tract*; 4. *The vestibulo-spinal tract*; 5. *The central tract of the tegmentum*. *Monakow's tract* has already been seen as the prepyramidal tract of the spinal cord (p. 301). Its fibres are said to arise from the cells of the red nucleus of the mid-brain of the opposite side, crossing the raphe in Forel's decussation (p. 330). In the upper part of the pons it is dorsal to the mesial fillet, but lower down lies at first mesial and still lower ventral to the descending root of the fifth, eventually passing into the lateral column of the cord.

The *ventral longitudinal bundle* consists of fibres which arise in the opposite superior quadrigeminal body ; these cross the raphe in Meynert's decussation (p. 330), and run down ventro-lateral to the posterior longitudinal bundle, giving off collaterals to the oculo-motor nuclei and the nuclei of the fourth and sixth nerves as it descends. Its fibres eventually mix with those of the posterior longitudinal bundle, and pass into the anterior column of the cord, joining the antero-lateral descending tract (p. 301).

The *ponto-spinal lateral tract* is formed of fibres which arise from the large cells of the reticular formation, and run down within the lateral area of this formation in the pons and medulla to reach the part of the lateral column of the cord which lies between the grey matter and the tracts of Monakow and Gowers. It is, however, mixed here with many fibres of different origin. The destination of its fibres is similar to those of the posterior and ventral longitudinal bundles, viz.: the adjacent grey matter of the anterior horn.

The *vestibulo-spinal tract* is composed of fibres derived from the cells of the nuclei of Deiters and Bechterew, and is therefore similar in its origin to the fibres of the posterior longitudinal bundle. Their destination is also similar for they pass below into the anterior root zone of the cord and end in the grey matter of the anterior horn, but in their course downwards they lie in the lateral part of the medulla oblongata mixed up with those of Monakow's tract and the ponto-spinal tract, as well as with the ascending fibres of Gowers' tract.

The *central tract of the tegmentum* runs in the pons exactly in the middle of the reticular formation, but in the medulla oblongata it lies more ventrally near the olivary nucleus, beyond which it has not been traced. Although a distinct bundle in the mid-brain, pons and medulla, neither the origin nor the destination of its fibres is certainly known.

Ascending tracts in the pons and medulla oblongata.—In the ventral part of the reticular formation is a very well marked tract of fibres, somewhat flattened (narrow in section) from above down ; this is the *tract of the fillet.* Its fibres are partly derived from cells in the nuclei of the opposite fasciculus gracilis and fasciculus cuneatus of the medulla oblongata which have crossed the raphe as internal arcuate fibres ; partly from nuclei connected with the terminations of the sensory cranial nerves. But most of the fibres which continue the sensory path of the cranial nerves upwards lie in the formatio reticularis (tegmentum), somewhat dorsal to the tract of the fillet, forming a homologous tract, less clearly defined, which runs up through the pons and mid-brain to terminate in the subthalamic region and in the optic thalamus (*central tract of the sensory cranial nerves*).

In the mid-brain the fillet splits up into three distinct bundles of fibres termed respectively the *lateral or lower*, the *upper*, and the *mesial fillet.* The fibres of the lateral fillet are seen at the side of the mesencephalon, and are traceable to the grey matter of the inferior corpora quadrigemina ; those of the upper fillet go partly to the superior corpora quadrigemina and partly to the tegmental region of the mesencephalon and thalamus ; while those of the mesial fillet pass to the side of the crusta and are continued up into the subthalamic region. Intermingled amongst the ascending fibres of the tract of the fillet, there are a certain number which degenerate below a section of the tract and are therefore descending (centrifugal).

At the upper part of the pons (fig. 379) the fourth ventricle narrows

considerably towards the Sylvian aqueduct, and behind and on either side of it two considerable masses of longitudinal white fibres make their appearance. These are the *superior peduncles of the cerebellum* (*s.c.p.*), and they tend as they pass upwards gradually to approach the middle line (fig. 380, A), across which in the region of the posterior pair of the corpora quadrigemina they pass, decussating with one another, to the formatio reticularis of the opposite side (figs. 381, 382).

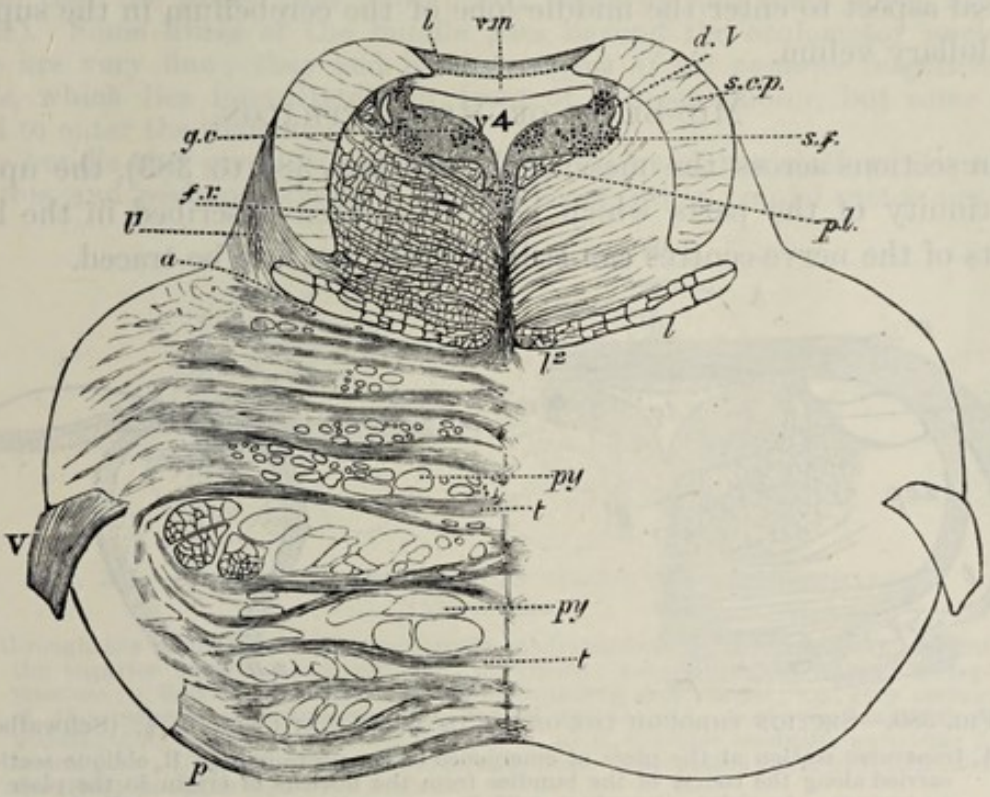


FIG. 379.—TRANSVERSE SECTION THROUGH THE UPPER PART OF THE PONS. (Schwalbe.) Rather more than twice the natural size.[1]

p, transverse fibres of the pons; *py*, *py*, bundles of the pyramids; *a*, boundary line between the tegmental part of the pons and its ventral part; *l*, *l'*, lateral fillet; l^2, mesial fillet; *f.r.*, formatio reticularis; *p.l.*, posterior longitudinal bundle; *s.c.p.*, superior cerebellar peduncle; *v.m.*, superior medullary velum; *b*, grey matter of the lingula; *v.4*, fourth ventricle; in the grey matter which bounds it laterally are seen, *d. V.*, the superior motor root of the fifth nerve, with its nucleus; *s.f.*, substantia ferruginea; *g.c.*, group of cells continuous with the so-called nucleus of the aqueduct.

The fibres of the superior cerebellar peduncles for the most part take origin in the cerebellum, emerging from its dentate nucleus, from the cells of which they are partly if not wholly derived. They cross the raphe in the mid-brain and terminate in the red nucleus of the tegmentum; but some of them give off a branch within the peduncle before crossing, and these branches are described by Cajal as forming a *descending cerebellar bundle* which passes downwards towards the medulla oblongata on the inner side of the descending root of the fifth, and gives off collaterals to the motor nucleus of the fifth, to the facial nucleus and perhaps to the nucleus ambiguus, as well as others to the reticularis grisea. There is also one bundle of fibres in the superior peduncle which are derived from cells in the thalamus and which pass downwards in the peduncle.

The *antero-lateral ascending tract* of the spinal cord is continued up

[1] The details of this and of several of the preceding figures are filled in under a somewhat higher magnifying power than that used for tracing the outlines.

in the lateral column of the medulla oblongata dorso-lateral to the olive and through the ventral part of the pons Varolii lateral to the pyramid bundles, but at about the level of the exit of the fifth nerve its fibres begin to pass obliquely towards the dorso-lateral part of the pons, where the superior cerebellar peduncle is emerging from the cerebellar hemisphere. The tract in question now curves over the lateral aspect of this peduncle, and then takes a sharp backward turn, passing over its dorsal aspect to enter the middle lobe of the cerebellum in the superior medullary velum.

Mid-Brain or Mesencephalon.

In sections across the mesencephalon (figs. 380 to 383), the upward continuity of the parts which have thus been described in the lower parts of the nerve-centres can still in great measure be traced.

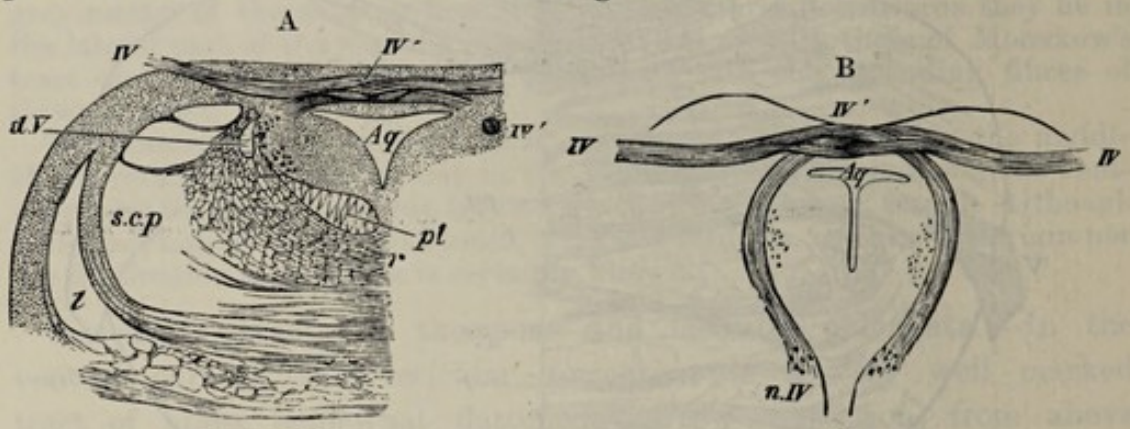


Fig. 380.—Section through the origin of the fourth nerve. $\frac{8}{1}$. (Schwalbe.)

A, transverse section at the place of emergence of the nerve-fibres. B, oblique section carried along the course of the bundles from the nucleus of origin to the place of emergence. *Aq*, Sylvian aqueduct, with its surrounding grey matter; *IV*, the nerve-bundles emerging; *IV'*, decussation of the nerves of the two sides; *IV''*, a bundle passing downwards by the side of the aqueduct to emerge a little lower down; *n.IV*, nucleus of the fourth nerve; *l*, lateral fillet; *s.c.p.*, superior cerebellar peduncle; *d.V*, superior motor root of the fifth nerve; *pl*, posterior longitudinal bundle; *r*, raphe.

The *Sylvian aqueduct* (fig. 382, *Sy*), with its lining of ciliated epithelium, represents the central canal of the cord and the fourth ventricle of the medulla oblongata. In the grey matter which surrounds it (*central grey matter*) there is seen in all sections of the region a group (column) of large nerve-cells (*oculomotor nucleus*) lying ventrally on each side of the middle line, close to the reticular formation. From the lower part of this column the root-bundles of the fourth nerve arise at the lower part of the mesencephalon and pass obliquely backwards and downwards around the central grey matter, decussating with those of the opposite side to emerge just above the pons Varolii (fig. 380). Higher up, the bundles of the third nerve spring from a continuation of the same nucleus (fig. 383, *n.III.*), and these pass forwards and downwards with a curved course through the reticular formation, to emerge at the mesial side of the crusta. According to v. Gehuchten

some of the fibres cross the middle line and emerge with the nerve of the opposite side.

Posterior longitudinal bundle.—This is well marked in the mid-brain, and gives off many collaterals and terminal fibres to the oculomotor nucleus which is immediately dorsal to it. The bundle largely, if not entirely, consists of nerve fibres derived from the cells of Deiters' nucleus (see p. 319), which on reaching the situation of the bundle, either on the same or on the opposite side, bifurcate, one branch ascending the other descending (or it may happen that the fibres pass unbranched, some up and some down in the bundle). Some fibres of the bundle pass beyond the oculomotor nucleus. These are very fine; they end in the *nucleus of the posterior longitudinal bundle*, which lies immediately in front of the oculomotor, but some are stated to enter the thalamus.

The bundle also gives collaterals to the nucleus of the sixth as it passes near this, and perhaps others to the nuclei of other cranial motor nerves.

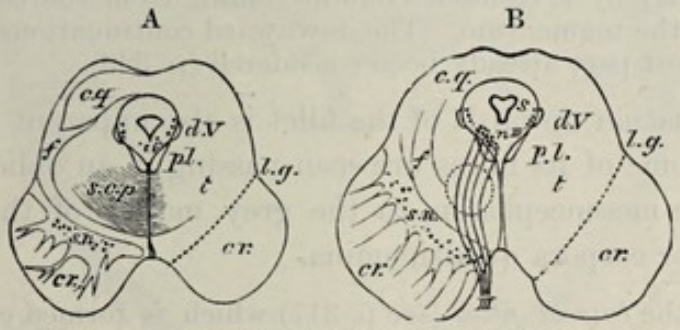


FIG. 381.—OUTLINE OF TWO SECTIONS ACROSS THE MESENCEPHALON. Natural size.

A, through the middle of the inferior corpora quadrigemina. B, through the middle of the superior corpora quadrigemina. *cr*, crusta; *s.n.*, substantia nigra; *t*, tegmentum; *s*, Sylvian aqueduct, with its surrounding grey matter; *c.q.*, grey matter of the corpora quadrigemina; *l.g.*, lateral groove; *p.l.*, posterior longitudinal bundle; *d.V.*, superior root of the fifth nerve; *s.c.p.*, superior cerebellar peduncle; *f*, lateral fillet; *III.*, third nerve; *n.III.*, its nucleus. The dotted circle in B indicates the situation of the tegmental nucleus.

Its descending fibres are eventually continued down the spinal cord in the antero-lateral descending tract, and give off collaterals to the anterior horn.

The posterior longitudinal bundle receives fibres from other sources than the cells of Deiters' nucleus, *e.g.* from the large cells of the sensory nucleus of the 5th, and from large cells in the reticular formation of the medulla oblongata, pons and mid-brain.

Tegmentum.—The reticular formation of the pons is continued up into the mesencephalon, and is here known as the *tegmentum*. It is composed as before of longitudinal and transverse bundles of fibres with much grey matter intermingled. The transverse fibres include the decussating fibres of the *superior peduncles of the cerebellum* (*s.c.p.*), which are derived from cells in the dentate nucleus of the cerebellum, and on reaching the opposite side bifurcate, their ascending branches becoming gradually lost amongst a number of nerve-cells which collectively constitute what is known as the *red nucleus* or *nucleus of the tegmentum*, whilst the descending branches turn downwards in the reticular formation (Ramón y Cajal) (see p. 327).

The cells of the red nucleus send their axons downwards and forwards. They are believed to form Monakow's bundle, which is continued below into the *pre-pyramidal tract* of the spinal cord. Other longitudinal fibres of the tegmentum are those of the *fasciculus retroflexus* lying mesially to the red nucleus and passing obliquely downwards and inwards from the ganglion of the habenula to the interpeduncular ganglion of the opposite side; those of *v. Gudden's bundle* from the corpora mammillaria; and the *ventral longitudinal bundle*, which passes lateral to the red nucleus and partly through it. But although the red nucleus receives many collaterals from this bundle its fibres are mainly derived, according to Held and Ramón, from cells in the grey matter of the opposite anterior corpus quadrigeminum, which send their axons sweeping round the central grey matter just central to the posterior longitudinal bundle to cross in the raphe, where they form the *fountain decussation of Meynert* (fig. 382, *d'*). This is not to be confounded with the *fountain decussation of Forel* (*d*), which lies nearer the ventral part of the tegmentum, and is partly formed by the intercrossing of Monakow's bundle and partly by v. Gudden's bundle coming from the corpora mammillaria to end in the tegmentum. The downward continuations of these tracts have for the most part already been considered (p. 326).

The continuation upwards of the fillet is also apparent in this part of the brain. Some of its fibres are seen passing in an oblique manner to the side of the mesencephalon, to the grey matter of the prominences of the posterior corpora quadrigemina.

This part is the *lateral fillet* (see p. 317) which is formed chiefly by fibres derived from the accessory auditory, the inferior olivary, and the trapezoid nuclei of the opposite side. In its course it traverses the *lateral fillet nucleus*, which consists of cells interpolated amongst its fibres (the greater number in the lower part near the superior olive), amongst which some of the fibres and many collaterals from them end. Their axons trend inwards towards the raphe. The rest of the fillet is continued upwards in the ventral part of the tegmentum (p. 326).

Crusta.—The pyramid bundles of the pons are traceable upwards on each side into the *crusta* or *pes pedunculi* (figs. 381, *cr.*, 382, 383, *p.p.*). This forms a mass of longitudinally coursing bundles of fibres lying on the ventral aspect of each half of the mesencephalon, and diverging above into the internal capsule of the cerebral hemisphere.

The fibres of the crusta are continued below into the so-called "pyramid bundles" of the pons—which however contain, as we have seen, many more fibres than those of the pyramidal tract. This is also therefore the case with the bundles of the crusta in which the pyramidal tract proper—composed of fibres emanating from the motor region of the cortex cerebri—is confined to the middle three-fifths, whilst the mesial fifth is mainly occupied by fibres passing from the frontal region of the brain to the pons; and the lateral fifth by fibres the origin and functions of which are not certainly known, although it is not improbable that they are connected directly or indirectly with the regions of the hemisphere behind the Rolandic area. In the extreme lateral and dorsal angle of the crusta is a bundle which is said to be derived from the mesial fillet, and to be composed of ascending fibres which are passing towards the cortex either directly or by way of the optic thalamus.

The crusta is separated from the tegmentum by a layer of grey matter (*s.n.*) containing a number of very deeply pigmented nerve-cells

(*substantia nigra*). The substantia nigra receives many collaterals from the adjacent pyramid bundles of the crusta. The crusta and tegmentum, together with the intervening substantia nigra, constitute the *cerebral peduncle* or *crus cerebri*.

Between the cerebral peduncles, just where they diverge from the mass of transverse fibres of the pons, is seen close to the ventral surface of the

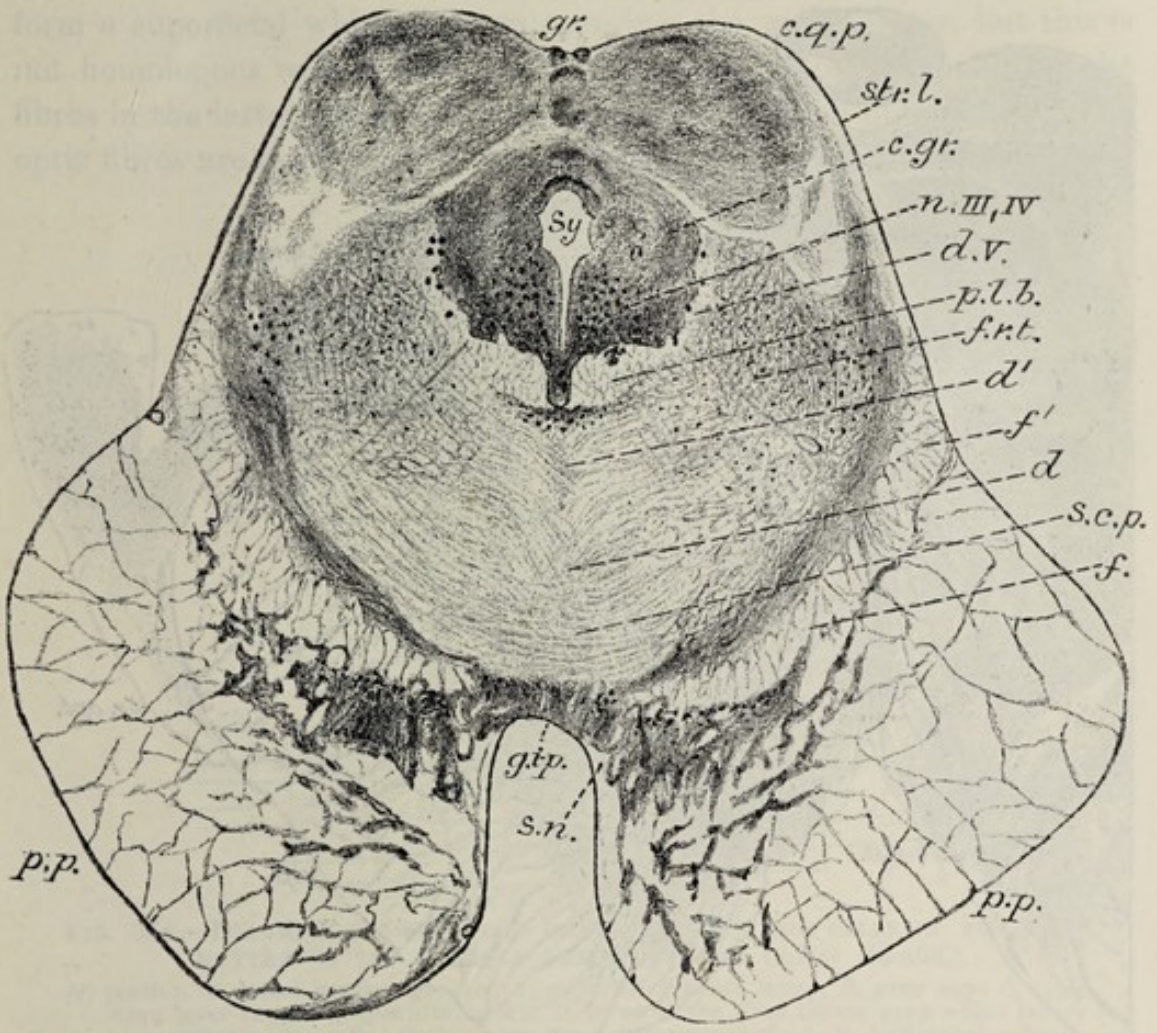


FIG. 382.—SECTION ACROSS THE MID-BRAIN THROUGH THE INFERIOR PAIR OF CORPORA QUADRIGEMINA. Magnified about 3½ diameters. (From a photograph.)

Sy., aqueduct of Sylvius; *c.gr.*, central grey matter of the aqueduct; *n.III.IV.*, group of cells forming part of the conjoined nucleus of the third and fourth nerves; *c.q.p.*, one of the posterior corpora quadrigemina; *gr*, median groove separating it from that of the opposite side; *str.l.*, stratum lemnisci (layer of the fillet), forming its superficial layer; *f*, upper fillet; *f'*, lateral fillet; d'. *V.*, accessory root of fifth nerve; *p.l.b.*, posterior longitudinal bundle; *f.r.t.*, formatio reticularis tegmenti; *d*, *d'*, decussating fibres of tegmenta (fountain-decussation of Meynert and Forel); *s.c.p.*, superior cerebellar peduncle; *p.p.*, pes pedunculi (crusta); *s.n.*, substantia nigra; *g.i.p.*, interpeduncular ganglion.

brain a small mass of grey matter containing a large number of small nerve cells with large and irregular dendrons, and axons which are directed dorsally into the tegmentum. This is the *interpeduncular ganglion* (fig 382, *g.i.p.*); it receives on either side the ending of the *fasciculus retroflexus* (*Meynert's bundle*), a bundle of fibres which comes from the *ganglion of the habenula*, a collection of nerve cells near the superior and mesial part of the thalamus, close to the commencement of the third ventricle (see fig. 404). These ganglia are both much better marked in many of the lower animals than in man.

The prominences of the **corpora quadrigemina** are formed mainly of grey matter containing numerous nerve-cells. From each a bundle of white fibres (*brachium*) passes upwards and forwards towards the geniculate bodies, eventually joining the optic tract of the same side. In the superior corpora quadrigemina four layers can be distinguished viz.: superficially, a thin white stratum containing a few horizontally

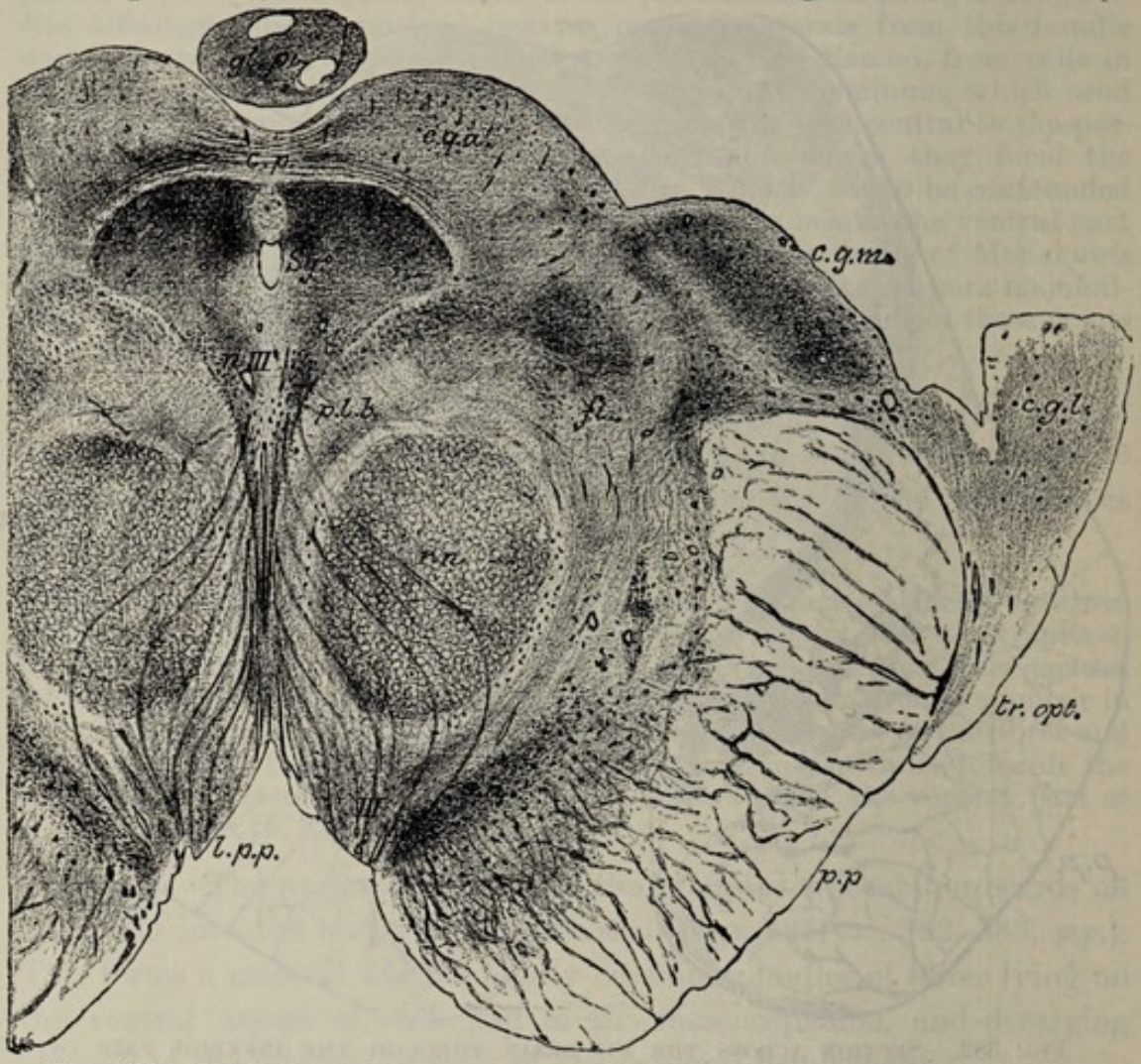


FIG. 383.—SECTION ACROSS THE MID-BRAIN THROUGH THE SUPERIOR CORPORA QUADRIGEMINA. Magnified about 3½ diameters. (From a photograph.)

c.p., posterior commissure of brain; *gl.pi.*, pineal gland; *c.q.a.*, grey matter of one of superior corpora quadrigemina; *c.g.m.*, mesial geniculate body; *c.g.l.*, lateral geniculate body; *tr.opt.*, optic tract; *p.p.*, crusta or pes pedunculi; *p.l.b.*, posterior longitudinal bundles; *fl*, upper fillet; *r.n.*, red nucleus; *III.*, issuing fibres of third nerve; *n.III.*, its nucleus; *l.p.p.*, locus perforatus posticus; *Sy*, Sylvian aqueduct.

disposed nerve-cells (fig. 384, A); next to this a grey cap (B) containing many and various nerve-cells, amongst which the terminations of the optic nerve (*h*, *h*) ramify; below this the optic nerve layer (C), which is formed of antero-posteriorly running fibres derived from the optic tract, and ending as we have just seen for the most part in the grey layer. This layer also contains nerve cells. Lastly there is a layer of tranversely disposed fibres (D) derived partly from the mesial fillet, but comprising many fibres which are derived from the cells of

the corpus quadrigeminum itself, with a number of large dendritic cells amongst the fibres. The superior corpora quadrigemina receive through their brachia, as has just been stated, many of the fibres of the optic tract, which in mammals enter the grey matter at the middle of its thickness and traverse it from before back, so that in transverse sections of the mid-brain they appear cut across. In birds they form a superficial white stratum covering the grey matter, but this is not homologous with the thin superficial stratum of mammals, for the fibres in the latter are not derived directly from the optic tract. The optic fibres are derived from nerve-cells in the retina, and as they pass

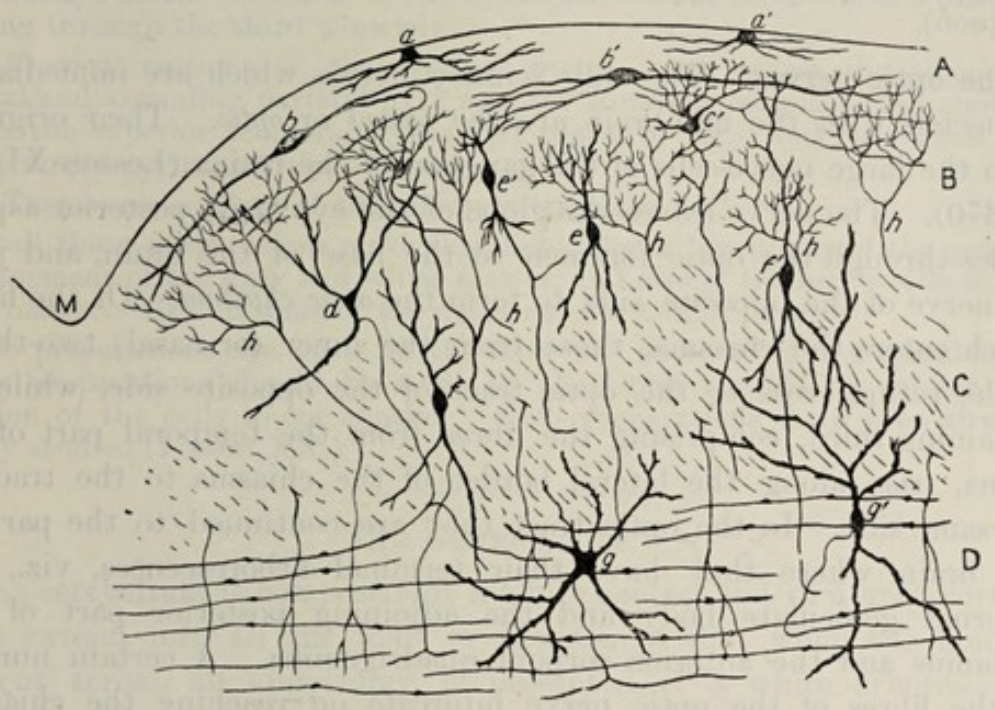


FIG. 384.—DIAGRAM SHOWING THE CHARACTERS OF THE CELLS IN THE GREY MATTER OF THE CORPORA QUADRIGEMINA. (After Ramón.)

M, portion of dorsal median groove; *A*, superficial white layer; *B*, grey cap; *C*, optic fibre layer (upper grey-white layer); *D*, layer of the fillet (lower grey-white layer). *a*, *a'*, marginal nerve cells: their axons are not represented; *b*, *b'*, horizontal spindle-shaped cells of Golgi's type II.; *d*, *d'*, small cells with much branched dendrons and an axon extending to the optic fibre layer: *e*, *e'*, spindle and stellate cells of the grey cap; *f*, *f'*, cells of the stratum optica, sending their axons into the stratum lemnisci; *g*, *g*, cells of the stratum lemnisci; *h*, *h*, fibres of the optic nerve layer ending in the grey and superficial white layers.

through the stratum opticum they turn into the grey matter (in a ventral direction in birds, in a dorsal direction in mammals) and end in arborisations amongst its cells. The cells of the grey matter are very various in form and size (fig. 384). Most of their axis-cylinder processes pass ventralwards. Their destination is not certainly known, but some appear to pass into Meynert's decussation to join the ventral longitudinal bundle of the opposite side (see p. 326); others to run down on the same side towards the pons Varolii, intermingled with the ascending fibres of the fillet, while others probably run in the tegmentum towards the thalamus.

All the nerve-fibres of the optic nerve and optic tract do not enter the corpora quadrigemina. Some pass into the lateral geniculate bodies and optic thalami to form arborisations there. On the other hand, axons from the cells of these structures pass to the cortex of the brain (occipital region).

From the grey matter of the corpora quadrigemina arcuate fibres issue and pass obliquely downwards into the ventral part of the mesencephalon encircling the central grey matter. These fibres intercross in the raphe where they constitute the *fountain-decussation of Meynert*, and after crossing constitute the main mass of the ventral longitudinal bundle. These are said to be continued into the antero-lateral columns of the spinal cord ; they give off collaterals to the motor nuclei of the eye-muscles.

In the cat, the anterior corpora quadrigemina receive a number of fibres from the pyramidal tract of the crusta of the same side, a few crossing over the aqueduct to the opposite corpora quadrigemina (Boyce, Sutherland Simpson).

The optic nerves.—The only sensory nerves which are immediately connected with the mid-brain are the *second* or *optic*. Their origin is from the large nerve-cells of the ganglion of the retina (Lesson XLIV., p. 370). The nerve leaves the globe of the eye at its posterior aspect, passes through the optic foramen to the base of the brain, and joins the nerve of the opposite side to form the *optic chiasma*. Of the fibres which enters the chiasma, those from the inner (or nasal) two-thirds of the retina cross to the optic tract of the opposite side, while the remaining third, comprising the fibres from the temporal part of the retina, pass along the lateral border of the chiasma to the tract of the same side. In the optic tract they are continued to the parts of the brain where they have their terminal arborescences, viz., the external geniculate body and the adjoining posterior part of the thalamus and the anterior corpora quadrigemina. A certain number of the fibres of the optic nerve bifurcate on reaching the chiasma, and the branches pass one into each optic tract (Ramón y Cajal).

The fibres which pass to the anterior corpora quadrigemina are much finer than those to the corpora geniculata. It is probable that the former furnish the path for reflex movements of the pupil, etc., and the latter the path for visual impressions, since the cells of the corpora geniculata are directly connected with the visual cortex in the occipital lobe, while no such direct connection obtains between that cortex and the anterior corpora quadrigemina.

The optic tracts and chiasma also contain the fibres of *v. Gudden's commissure* which connects the posterior corpora quadrigemina, but these fibres appear to have no relation to the visual function. There are also present in the optic nerve and tract a few fibres which originate in the nerve-centres—where is not known—and terminate in the retina.

Motor nerves.—The motor nerves arising from the mid-brain are the third and fourth. The position of their nuclei and their mode of exit have been already described (p. 328).

LESSON XLII.

STRUCTURE OF THE CEREBELLUM AND CEREBRUM.

1. Sections of the cerebellum vertical to the surface, (*a*) across the direction of the laminæ, (*b*) parallel with the laminæ.

2. Section across the whole of one hemisphere of the cerebrum of a monkey passing through the third ventricle.

3. Vertical sections of the cerebral cortex:—one across the ascending frontal and ascending parietal gyri, another from the occipital lobe, another across the superior temporal gyrus and island of Reil, and one across the hippocampal gyrus and hippocampus.

4. Transverse sections of the olfactory tract and bulb.

In all these preparations make sketches under a low power of the general arrangement of the grey and white matter, and also of the nerve-cells in the grey matter. Sketch some of the details under a high power.

The preparations are made in the same way as those of the spinal cord. Other preparations should be made by the Golgi method to exhibit the relation of the cells to one another. Such preparations have been already partly studied (Lesson XX.).

The Cerebellum.

The **cerebellum** is composed of a white centre, and of a grey cortex. Both extend into all the folds or laminæ, so that when the laminæ are cut across, an appearance is presented of a white arborescence covered superficially by grey matter. The white matter is in largest amount in the middle of each cerebellar hemisphere. There is here present a peculiar wavy lamina of grey matter, similar to that in the olivary body, and known as the *nucleus dentatus* (*n.d.*). Other isolated grey nuclei lie in the white matter of the middle lobe (fig. 385).

The grey matter of the cerebellum consists of two layers. The *inner* one (that next to the white centre) is composed of a large number of very small nerve-cells intermingled with a few larger ones and some neuroglia-cells (*granule layer*, fig. 386, *d*). The *outer one* is thicker, and is formed chiefly of fine nerve-fibres (fig. 387, A) with small nerve-cells scattered through it (*molecular layer*, fig. 386, *b*). Into its outer part processes of the pia mater conveying blood-vessels pass vertically, and there are also in this part a number of long tapering neuroglia-cells, somewhat like the Müllerian fibres of the retina (fig. 389, gl^3). Lying between the two layers of the grey matter is an incomplete stratum of large flask-shaped cells (*cells of Purkinje*, fig. 386, *c*). Each of these

gives off from its base a fine process (axon), which becomes the axis-cylinder of one of the medullated fibres of the white centre, while from the opposite pole of the cell large ramified processes (dendrons) extend into the superficial layer of the grey matter.

The dendrons of the cells of Purkinje spread out in planes transverse to the direction of the lamellæ of the organ, so that they present a different appearance according to whether the section is taken

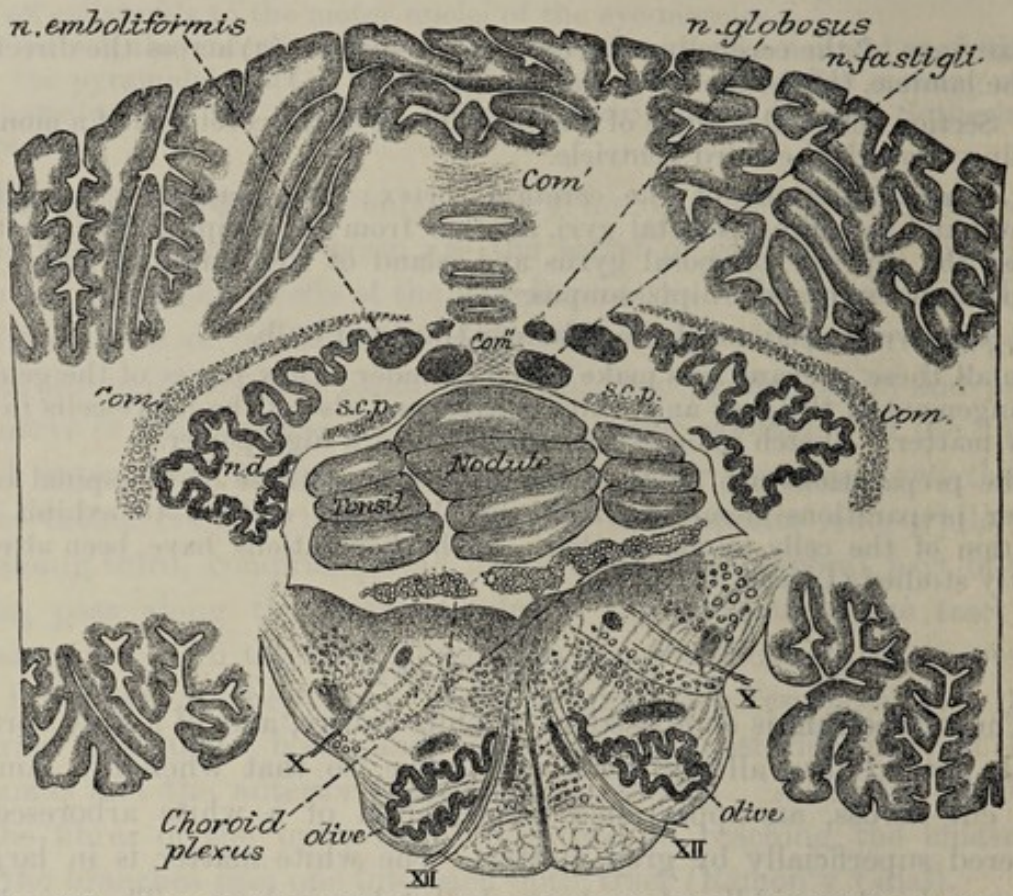


FIG. 385.—SECTION ACROSS THE CEREBELLUM AND MEDULLA OBLONGATA SHOWING THE POSITION OF THE NUCLEI IN THE WHITE CENTRE OF THE CEREBELLUM.

n.d., nucleus dentatus cerebelli; *s*, fibres derived from inferior peduncle: *s.c.p.*, fibres derived from superior peduncle; *com'*, *com''*, commissural fibres; *XII*, rootlet of hypoglossal nerve.

across the lamellæ or along them (compare fig. 387, I. and II.). These dendrons are invested at their attachment to the cell, and for some extent along their branchings, by basket-works formed by the terminal arborisations of certain fibres (*climbing or tendril fibres*) of the medullary centre (fig. 389, *cl.f.*). The body of the cell of Purkinje is further invested by a felt-work of fibrils formed by the arborisation of axis-cylinder processes of nerve-cells (*basket-cells*) in the outer layer of the grey matter (fig. 388; 389, *b*). Each cell has therefore a double investment of this nature, one covering the dendrons, the other the body of the cell and extending along the commencement of the axon.

The granules of the inner layer of grey matter are mostly small nerve-cells, each with a few dendrons penetrating amongst the other granules, and an axon which is directed between the cells of Purkinje into the outer layer. After penetrating a variable distance into this layer it bifurcates, and its two branches pass in opposite directions at

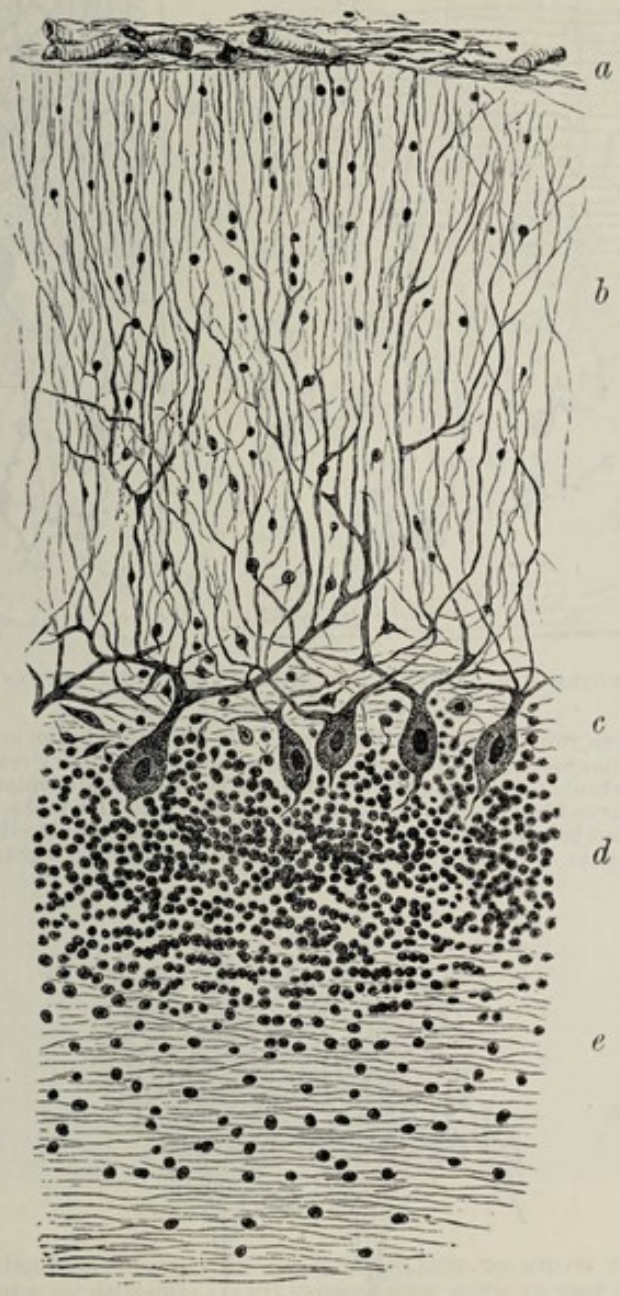


FIG. 386.—SECTION OF CORTEX OF CEREBELLUM. (Sankey.)
a, pia mater; *b*, external layer; *c*, layer of corpuscles of Purkinje; *d*, inner or granule layer; *e*, medullary centre.

right angles to the main stem, and parallel to the direction of the lamella (fig. 387, I.). What ultimately becomes of the branches is not known. In sections cut across the lamellæ the cut ends of these fibres give a finely punctated appearance to the outer layer (fig. 387, II.).

Some of the cells of the granule layer are far larger than the

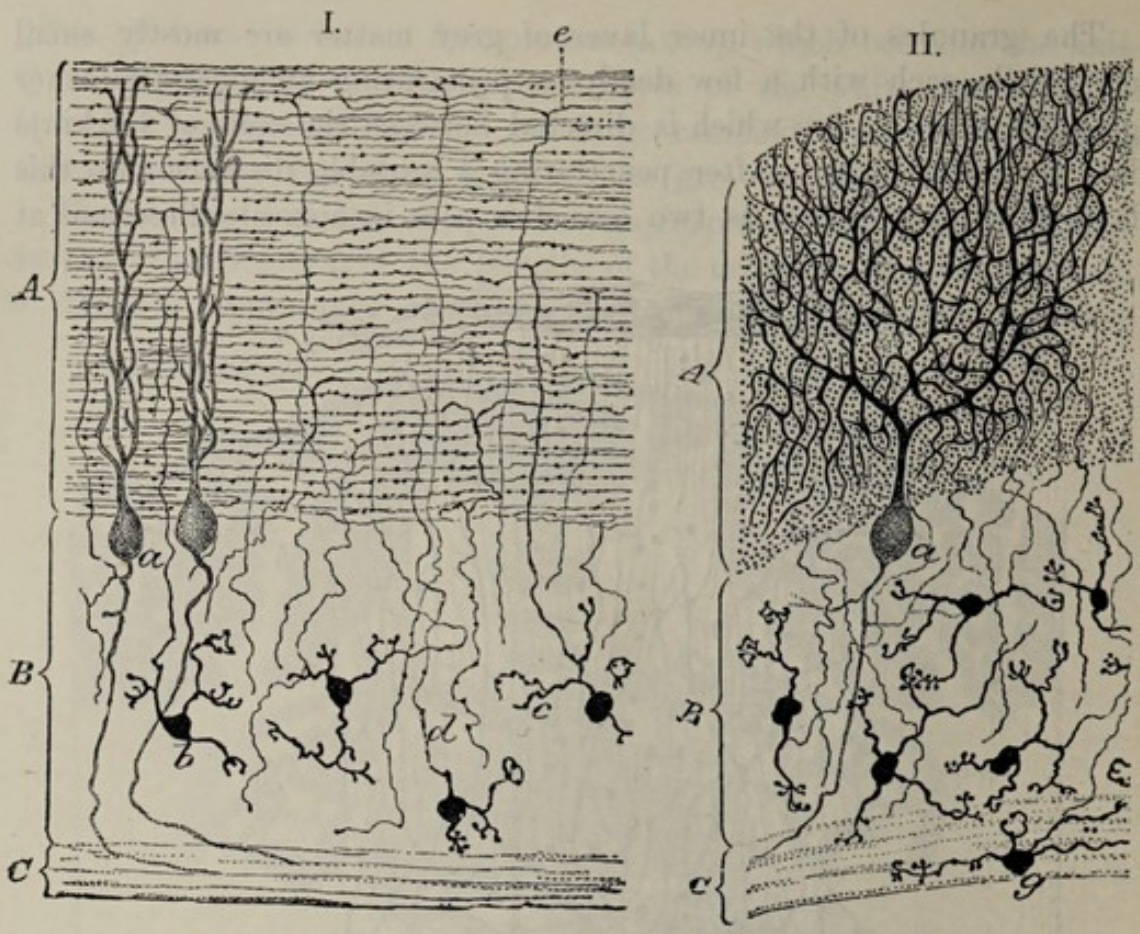


FIG. 387.—SECTIONS OF CORTEX CEREBELLI STAINED BY GOLGI'S METHOD. (Ramón y Cajal.)

I.—Section made in the direction of the lamina. II.—Section taken across the lamina. *A*, outer or molecular layer; *B*, inner or granule layer; *C*, medullary centre. *a*, corpuscle of Purkinje; *b*, small granules of inner layer; *c*, a protoplasmic process of a granule; *d*, nerve-fibre process of a granule passing into the molecular layer, where it bifurcates and becomes a longitudinal fibre (in II. these longitudinal fibres are cut across and appear as dots); *e*, bifurcation of another fibre; *g*, a granule lying in the white centre.

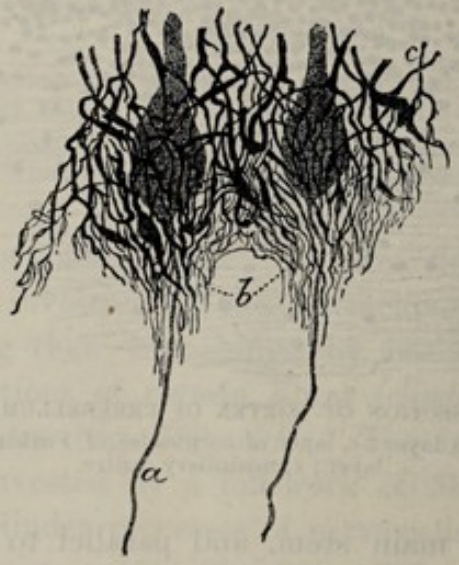


FIG. 388.—BASKET-WORK OF FIBRES AROUND TWO CELLS OF PURKINJE. (Ramón y Cajal.)

a, axis-cylinder or nerve-fibre process of one of the corpuscles of Purkinje; *b*, fibres prolonged over the beginning of the axis-cylinder process; *c*, branches of the nerve-fibre processes of cells of the molecular layer, felted together around the bodies of the corpuscles of Parkinje.

others, and send their much-branching axons amongst the smaller granules (*cells of Golgi*, fig. 389, G). Besides these, other large "granules" have been noticed by Ramón, occurring both in the granule-layer and in the white centre, with long axons passing into

FIG. 389.—DIAGRAMMATIC SECTION OF CEREBELLUM TO SHOW THE CHARACTERS AND RELATIONS OF THE CELLS AND FIBRES MET WITH IN THE SEVERAL LAYERS AS EXHIBITED BY THE CHROMATE OF SILVER METHOD. (After Kölliker.)

P, a cell of Purkinje; *G*, a cell of Golgi; *b*, a basket-cell; *m*, *m*, other cells of the molecular layer; *gr*, granules; *p*, a nerve fibre of the white substance derived from a Parkinje cell; *m.f.*, "moss"-fibres; *cl.f.*, a climbing fibre; gl^1, gl^2, gl^3, types of neuroglia cells.

the white matter of the cerebellum. These are, however, only rarely met with.

Ramifying amongst the cells of the granule layer are peculiar fibres derived from the white centre, and characterised by having pencils of fine short branches at intervals like tufts of moss (fig. 389, *mf*). These

have been termed by Ramón y Cajal the *moss-fibres*; they end partly in the granule layer, partly in the molecular layer.

The **peduncles of the cerebellum** have been already studied in connection with the medulla oblongata, pons and mid-brain. The *inferior peduncle* (restiform body) is wholly composed of ascending fibres derived from the dorsal cerebellar tract, from both olivary nuclei—but chiefly from that of the opposite side—and perhaps also from the nuclei of the gracile and cuneate funiculi, and from the nuclei of the sensory roots of the cranial nerves. Its fibres pass mainly to the vermis, crossing to the opposite side over the fourth ventricle, but before doing so they give off strong collaterals to the hemisphere of the same side. The *middle peduncle* is formed partly of fibres from the opposite nuclei pontis to the hemisphere, partly of fibres passing from the hemisphere of the cerebellum to the pons. The *superior peduncle* is formed of fibres which mostly take origin in the corpus dentatum cerebelli, but some are said to arise in the hemisphere and pass through this. It passes into the red nucleus of the opposite side. It is joined by the tract of Gowers as it issues from the hemisphere, and this runs back along its mesial border to the vermis.

Structure of the Cerebrum.

The grey matter of the **cerebral cortex** is described as if composed of a number of layers, but they are not sharply marked off from one another, and they vary in relative development in different regions of the cortex. The cells are for the most part of a pyramidal shape. The following layers were distinguished by Meynert as constant:

1. A peripheral stratum (*molecular* or *plexiform layer*) containing a few scattered nerve-cells and neuroglia-cells. In the most superficial part of this layer, immediately under the pia mater, is a thin stratum of medullated nerve-fibres, and besides these the layer contains a large number of fibres, many of which are ramified. They are largely derived from the dendrons of the deeper nerve-cells of the cortex. Intermingled with these fibres are a certain number of ramified nerve-cells, most of which have two (sometimes three) horizontally disposed axis-cylinder processes, all of which terminate by arborisation within the superficial layer (*cells of Ramón*) (figs. 390, 1; 391, *I*).

2. A layer of closely set small pyramidal nerve-cells, several deep (*layer of small pyramids*, 2).

3. A layer of medium-sized pyramidal cells less closely set, with small granule-like cells amongst them (*layer of medium-sized pyramids*, 3). The pyramidal cells are larger in the deeper parts of the layer and this is sometimes described as the layer of large pyramids.

4. A layer of small irregular cells (*granules* or *small stellate cells* or *polymorphous cells*, 4). In the motor region of the cortex, which in man is confined to parts of the frontal lobe, pyramidal cells of very large size (giant cells) lie amongst these polymorphous cells (which are here few in number), and are disposed in small clusters or "nests" (Betz,

Bevan Lewis) (fig. 394). The fibres of the pyramidal tract are believed to arise from these giant cells.

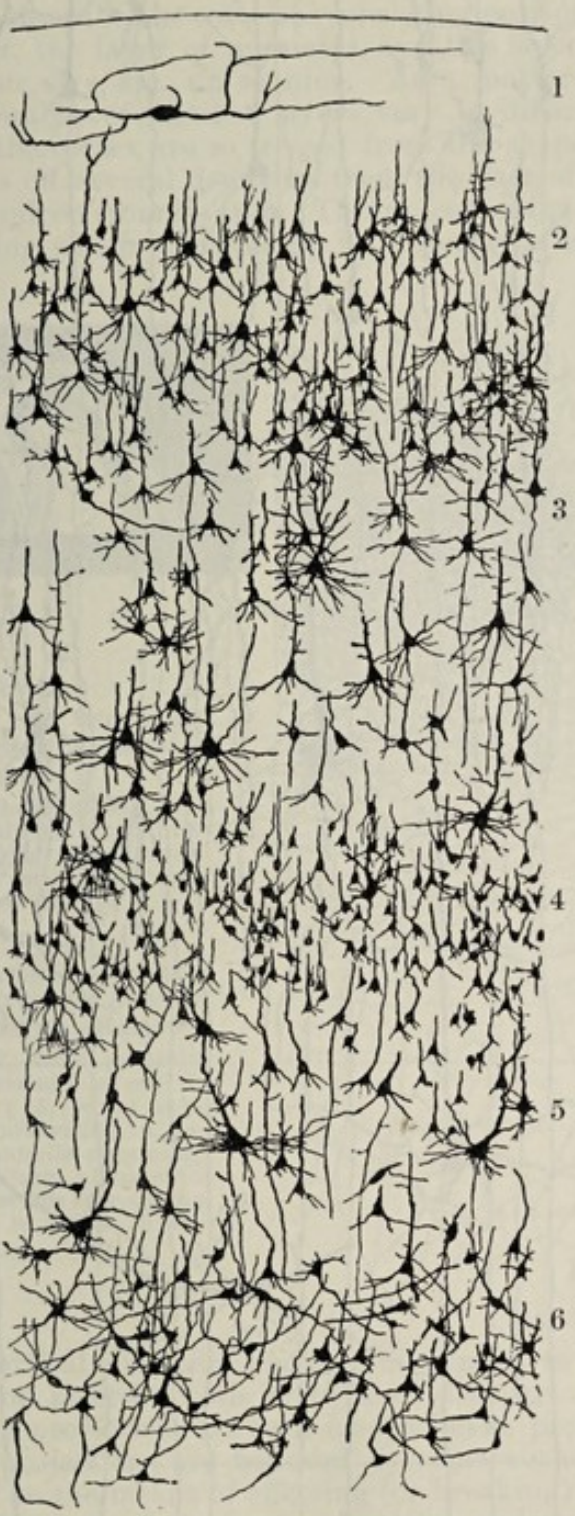


FIG. 390.—SECTION OF CEREBRAL CORTEX PREPARED BY THE GOLGI METHOD. (Modified from Kölliker.)

1, plexiform layer showing one of the cells of Ramón; 2, small pyramids; 3, larger pyramids; 4, polymorphous cells or "granules; 5, giant pyramids; 6, claustral layer.

5. A layer (fig. 390, 5) of small scattered cells, many of a fusiform shape. This layer lies next to the white centre. In the island of Reil it is considerably developed, and is separated from the rest of the grey

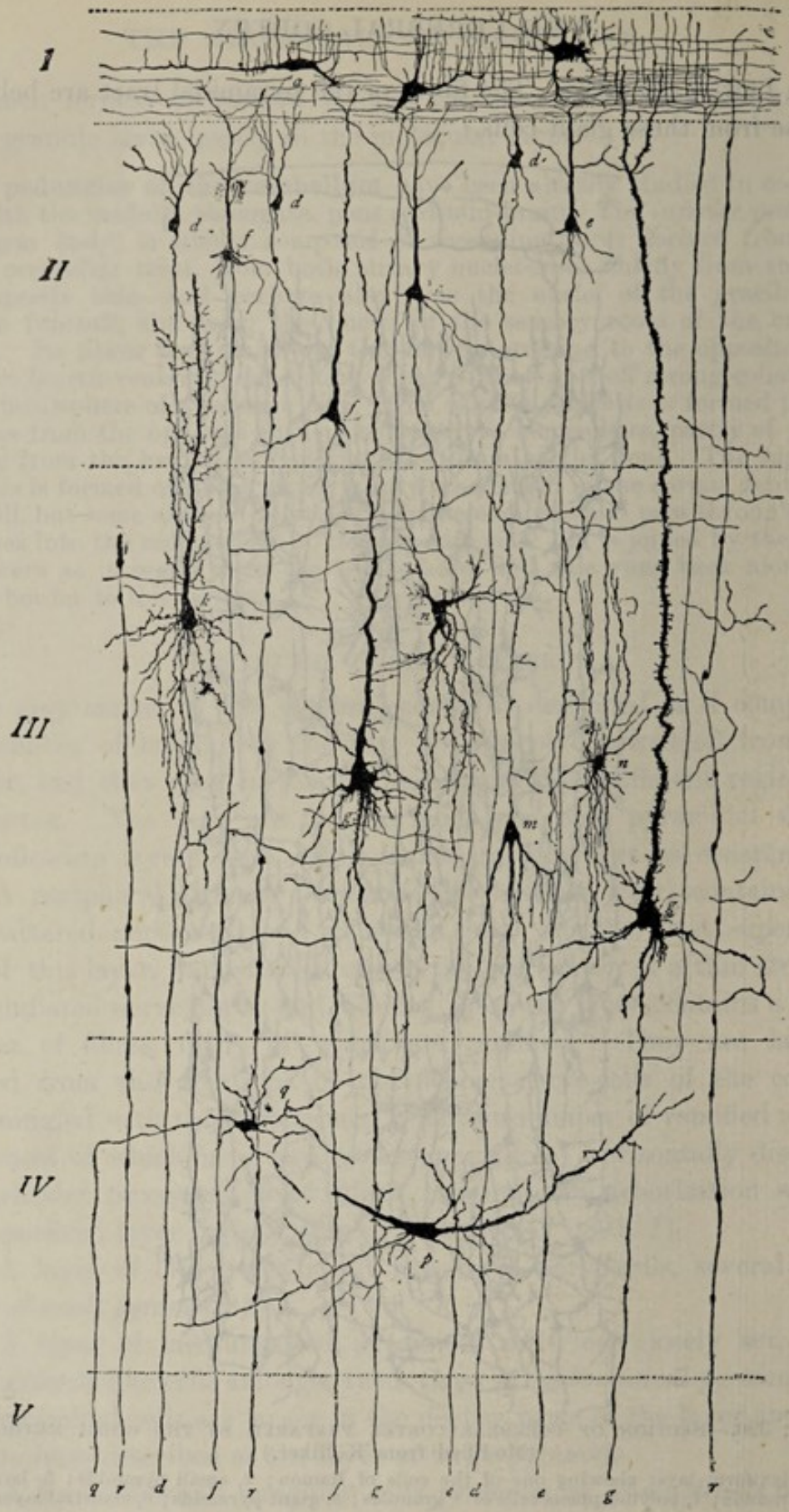


FIG. 391.—DIAGRAM SHOWING THE RELATIONS OF SOME OF THE CELLS IN THE CEREBRAL CORTEX. (Barker, after Starr, Strong and Leaming.)

I, plexiform layer with cells of Ramón; *II*, small (*d*, *e*) and middle sized (*f*) pyramids; *III*, large pyramids (*g*, *g*, *k*); also, *m*, cell with axon passing towards the surface, but soon ramifying; *n*, *n*, cell of Golgi's second type, with axon ramifying in the adjacent grey matter: one of these belongs to the kind termed by Ramón "double-brush" cells; *IV*, polymorphous cells, of which *p* has its axon passing peripherally and *q* its axon passing into the medullary centre, *V*, which contains also the axons of the pyramids.

matter by a layer of white substance. It is here known as the *claustrum*, and on that account the layer is sometimes termed the *claustral layer*.

Some authorities describe the cortex as consisting only of three layers, viz.: the molecular layer, the layer of pyramids, and the layer of polymorphous cells; others of four, five, etc., up to nine. As a matter of fact, the complexity and the number of distinct layers vary in different regions. The pyramidal cells of the cortex are so termed from the shape of the cell-body, which usually gives off several dendrons from the base of the pyramid and one large (shaft) dendron from its apex. This process extends to the plexiform layer, on approaching which it breaks up into numerous ramifications which

FIG. 392.

FIG. 392.—SECTIONS OF CEREBRAL CONVOLUTIONS. (After Baillarger.) (Natural size.)

a, from the neighbourhood of the calcarine fissure with only one white line clearly visible; *b*, ordinary type, with the superficial layer and outer and inner lines of Baillarger shown.

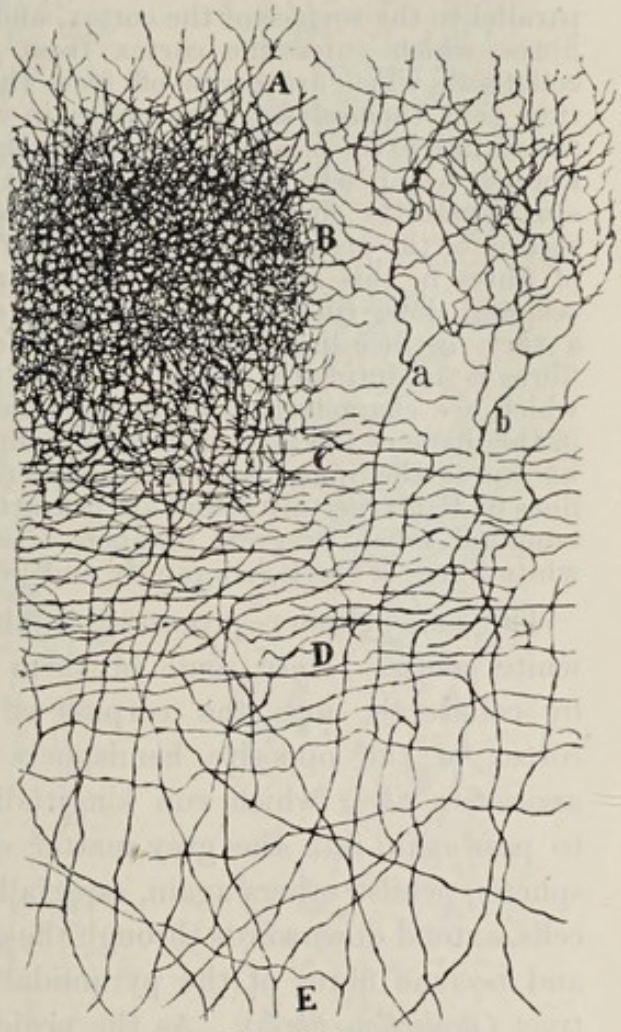


FIG. 393.

FIG. 393.—PREPARATION SHOWING SOME OF THE AFFERENT FIBRES OF THE "MOTOR" CORTEX. (Ramón.)

A, plexiform layer; *B*, small pyramid layer; *C*, middle pyramid layer; *D*, large pyramid layer; *E*, white substance; *a*, *b*, fibres arborizing in the layer of small and middle pyramids, amongst which they form, along with fibres derived from various sources, the dense plexus which is shown in the left half of the figure.

have a general vertical direction and extend almost to the outer surface. This apical dendron is beset, both in its undivided part and in its branches, by minute spinous projections (as seen in specimens prepared by the Golgi method). These projections are believed by some authors to be retractile (amœboid) and to be the means of effecting (or breaking) nervous connection with the other elements of the cortex, but the evidence for this is inconclusive. All the pyramidal cells have a single axon, which is usually directed towards the medullary centre, of which it forms one of the fibres; but the axon sometimes curves back and passes outwards, ending in arborisations in one of the other layers. Intermingled with the pyramids and polymorphous cells are two other kinds of cells, viz.: (1) cells with axis-cylinder process ramifying near the cell-body; those occur in all the layers (fig. 391, *n*), and (2) cells sending their axons towards the plexiform layer (Martinotti) (fig. 391, *m*); these are found chiefly in the deeper layers of the cortex.

From the white centre bundles of medullated nerve-fibres pass in vertical streaks through the deeper layers of the grey matter, to lose themselves amongst the pyramidal cells of the more superficial layers. Some of these fibres are continuous with the axis-cylinder processes of the pyramidal and polymorphous cells, and therefore take origin in the cortex; others are passing into the cortex to end amongst the cells of the several layers in free arborisations (fig. 393).

Besides these vertical strands of fibres there are others which lie in planes parallel to the surface of the cortex, and which are derived partly from the fibres which enter the cortex from the white matter, partly from the collaterals which are given off from the axis-cylinder processes of the cortical cells themselves. The planes in which these fibres occur are (1) near the surface in the plexiform (molecular) layer: this superficial stratum of white fibres is best marked in the hippocampal region. (2) in the layer of medium-sized pyramids: here the fibres give the appearance of a whitish line in the section of the grey matter (outer line of Baillarger). There is a dense plexus of fibres in this situation in certain regions of the cortex, especially the occipital lobe (in man especially near the calcarine fissure), producing a very distinct line known as the line of Gennari: the plexus of nerve-fibres is in intimate association with the large and small stellate cells which are characteristic of this region. (3) In most regions of the brain, in the plane of the layer of large pyramids, another white line is seen; this is known as the inner line of Baillarger. The planes in which these white lines of Baillarger are found are characterised, especially in the occipital and temporal lobes, by great numbers of small nerve-cells, amongst which the white fibres of the layers ramify and probably terminate.

The axis-cylinder processes of the pyramidal cells pass into the white centre. Here some of them are continued either directly or by collaterals into the corpus callosum, and through this to the cortex of the opposite hemisphere (*commissural fibres*); others join *association fibres* which run longitudinally or transversely, eventually to pass again into the grey matter of other parts of the same hemisphere; whilst others again, especially those of the largest pyramidal cells, extend downwards through the corona radiata and internal capsule, and become fibres of the pyramidal tract and of the cerebro-pontine tract (*projection fibres*). As the projection fibres pass through the grey and white matter of the hemisphere they give off collateral fibres to the adjacent grey matter, to the corpus callosum, and to the corpus striatum and optic thalamus, and some of them probably end in these masses of grey matter. According to Ramón y Cajal, in the brain of man as compared with the lower mammals, there is a marked preponderance of cells of Golgi's type II. (with short axis-cylinder ramifying near the cell-body). Such cells are most numerous in the granule layer and in the layer of small pyramids.

Special features of certain parts of the cortex.—There is, as already stated, a great amount of variation met with in the relative extent of development of the above layers. This is exemplified in the accompanying drawings

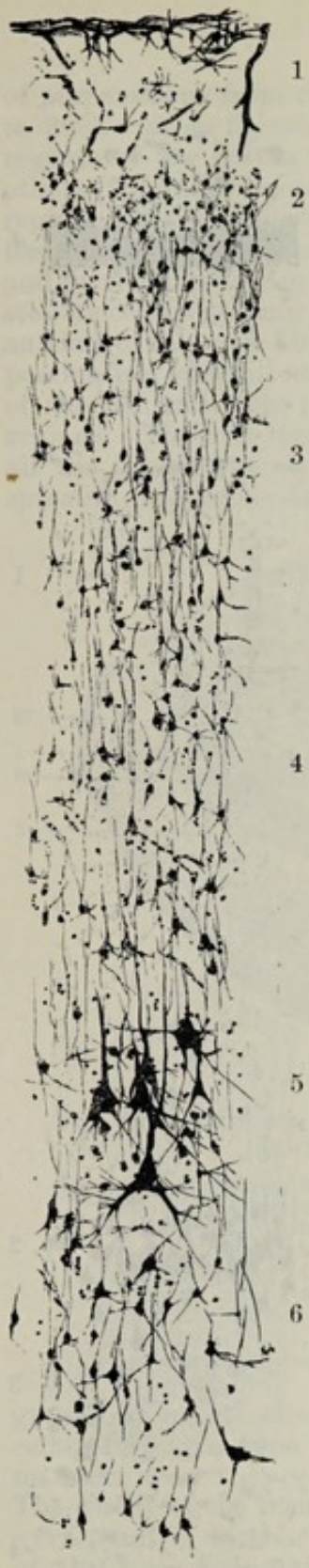


Fig. 394.

Fig. 395.

Fig. 396.

FIG. 394.—SECTION OF MOTOR CORTEX OF MONKEY'S BRAIN.

1, plexiform layer; 2, small pyramids; 3, middle pyramids; 4, larger pyramids; 5, giant pyramids with small stellate cells amongst them; 6, spindle-shaped and angular (polymorphous) cells.

FIG. 395.—SECTION OF FRONTAL CORTEX IN FRONT OF MOTOR AREA.

1, 2, 3, 4, as in fig. 394; 5, polymorphous cells.

FIG. 396.—SECTION OF TEMPORAL CORTEX.

1, plexiform layer; 2, small pyramids; 3, middle-sized pyramids; 4, small stellate cells; 5, large pyramids; 6, polymorphous cells.

FIG. 397.

FIG. 398.

FIG. 398.—SECTION OF GYRUS HIPPOCAMPI.

1, plexiform layer; 2, large stellate cells; 3, pyramids with small stellate cells interspersed amongst them.

FIG. 399.

FIG. 397.—SECTION OF CORTEX OF OCCIPITAL LOBE.

1, plexiform layer; 2, small pyramids; 3, middle pyramids; 4, large stellate cells; 5, 7, small stellate cells, amongst which are interspersed pyramids with ascending axons; 6, large pyramids; 8, spindle-shaped cells.

FIG. 399.—SECTION OF HIPPOCAMPUS MAJOR.

d, fascia dentata; 1, plexiform layer; 2, pyramids; 3, so-called stratum moleculare; 4, alveus.

Figs. 394 to 399 are taken by the author's permission from Ferrier's *Functions of the Brain*, 2nd edition. They are from preparations and drawings (from the monkey's brain) made by Mr. Bevan Lewis, and are magnified about 145 diameters.

of preparations from the monkey's cerebral cortex by Bevan Lewis (figs. 394 to 399). From these it will be seen that smaller-sized cells prevail in some regions of the cortex (occipital, temporal); larger and fewer cells occur in others (frontal, hippocampal), and groups of very large cells in the "motor" region. The occipital region (in man, the neighbourhood of the calcarine fissure) is especially characterised by the great numbers of small stellate cells and by the presence in the layer superficial to them of a stratum of very large stellate cells with long spreading dendrons: amongst these stellate cells (small and large) the optic fibres from the corpora geniculata externa ramify. A preponderance of small stellate cells is also seen, but to a less extent, in sections of the temporal lobe; to a still less extent in the prefrontal and parietal regions. The first temporal gyrus is characterised by the presence in nearly all the layers, but especially the deepest, of special large cells with widely-spreading dendrons and an axon passing towards the white substance but

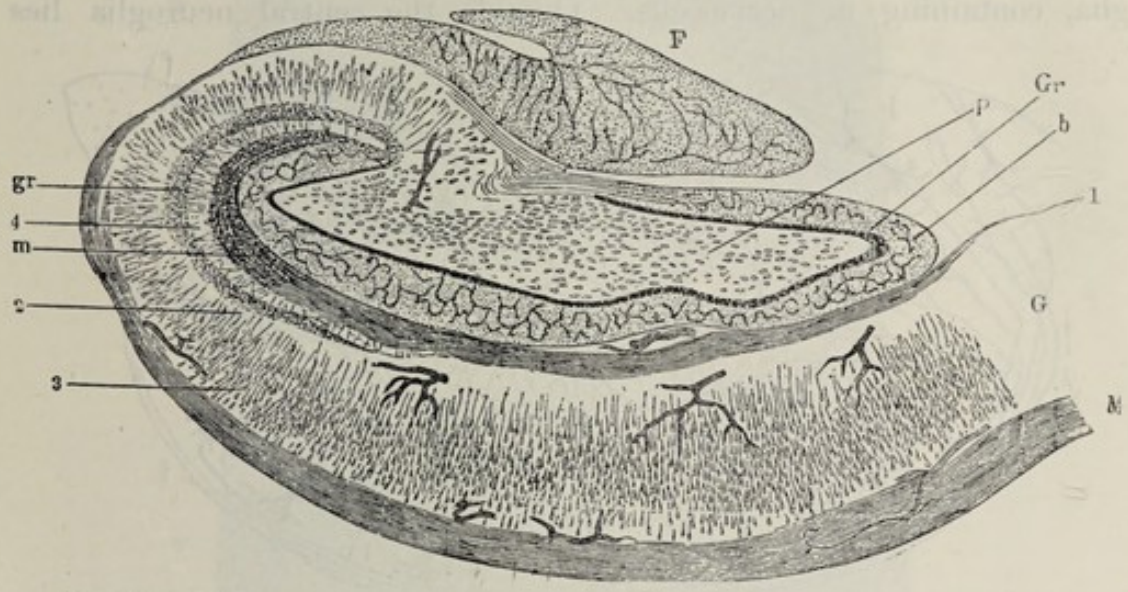


FIG. 400.—SECTION ACROSS THE HIPPOCAMPUS MAJOR, DENTATE FISSURE, DENTATE FASCIA AND FIMBRIA. (W. Krause.)

G, part of the gyrus hippocampi or uncinate convolution; just above it is the fascia dentata, or dentate convolution; between them is the dentate fissure; F, fimbria, composed of longitudinal fibres here cut across; M, medullary centre of the hippocampal gyrus prolonged around the hippocampus, as the so-called alveus, into the fimbria; 3, layer of large pyramidal cells; 2, their processes (stratum radiatum); 4, plexiform layer (stratum laciniosum); 1, superficial medullary lamina, involuted around the dentate fissure; *b*, plexiform layer of the fascia dentata; *p*, nerve-cells of fascia dentata; Gr, stratum granulosum of fascia dentata; *gr*, stratum granulosum of hippocampus major.

giving off many collaterals in the grey matter. There are also very many cells of Golgi's type II. with axis-cylinder ramifying in a most complex manner near the cell-body, mainly in a plane vertical to the surface. The cortex of the insula has special cells similar to those in the first temporal gyrus, and is further characterised by the peculiar spindle shape of many of the large pyramids. In the region of the hippocampus major (figs. 398, 399, 400) the cortex is simpler in structure than elsewhere, and in the hippocampus major itself, which is an infolded part of the cortex, the pyramids are reduced to a single layer of large cells lying in the deeper portion and sending their apical dendrons as long fibres into the plexiform layer. The plexiform layer and the superficial white stratum which overlies it are both very strongly marked, the plexiform layer having a distinctly reticular aspect, due partly to neuroglia cells partly to the arborescence of the dendrons of the pyramids: the plexiform layer is here termed *stratum laciniosum*; internal to it near the dentate gyrus is a layer of closely-packed

small cells termed *stratum granulosum*. The pyramidal cells lie close to the white layer known as the *alveus*. This is the part of the hippocampus seen within the ventricle, and represents the white matter of the hemisphere. The alveus is prolonged externally into the *fimbria*, in which its fibres become longitudinal in direction and continued into part of the fornix.

In the dentate gyrus (*fascia dentata*, figs. 400, 401) the pyramidal cells are arranged in an irregularly radiating manner, occupying the centre of the convolution, and surrounded by a ring of closely packed small cells (*stratum granulosum*). External to these is a thick plexiform layer, occupied by interlacing fibres (*stratum laciniosum*).

The **olfactory tract** is an outgrowth of the brain which was originally hollow, and remains so in many animals; but in man the cavity has become obliterated, and the centre is occupied by neuroglia, containing no nerve-cells. Outside the central neuroglia lies

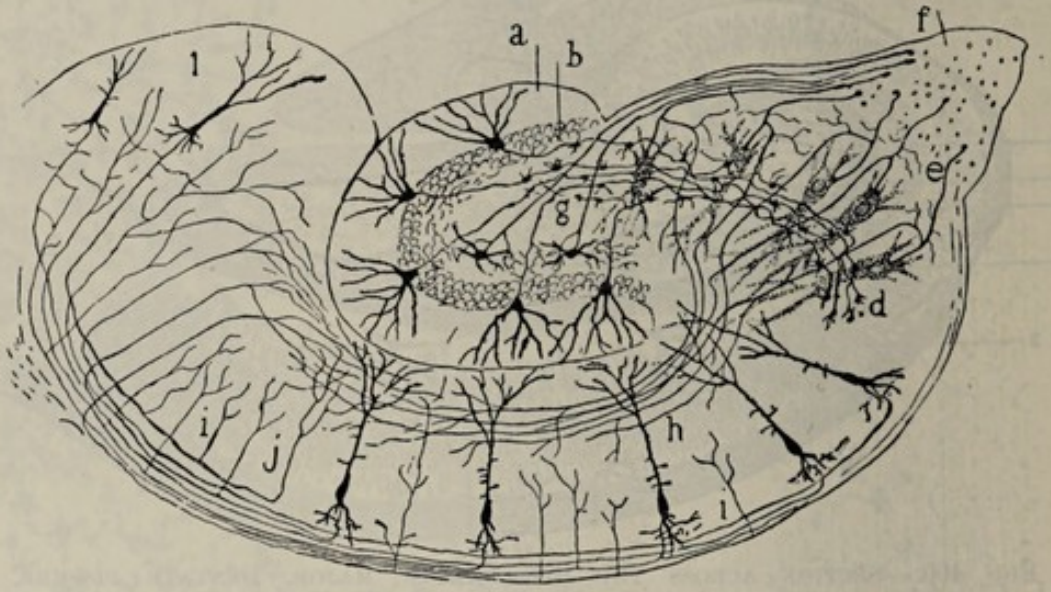


FIG. 401.—RELATIONS OF THE CELLS AND FIBRES OF THE HIPPOCAMPAL REGION, AS SHOWN BY THE GOLGI METHOD. (S. Ramón y Cajal.)

a, fascia dentata; *b*, its stratum granulosum; *d*, ending of axons of cells of fascia dentata amongst pyramid cells of hippocampus: *e*, axons of pyramid cells of hippocampus passing into fimbria, *f*, and giving off collaterals to superficial medullary lamina; *g*, pyramid cells of fascia dentata giving axons to fimbria; *h*, pyramid cells of hippocampus; *l*, pyramid cells of hippocampal gyrus; *i*, *j*, collaterals coming off from their axons.

the white or medullary substance, consisting of bundles of longitudinal white fibres. Most externally is a thin superficial layer of neuroglia.

The **olfactory bulb** (fig. 402) has a more complicated structure. Dorsally there is a flattened ring of longitudinal white bundles inclosing neuroglia (1, 2, 3), as in the olfactory tract, but below this ring several layers are recognised as follows:

1. A *white or medullary layer* (fig. 402, 4, 5), characterised by the presence of a large number of small cells ("granules") with reticulating bundles of medullated nerve-fibres running longitudinally between them.

2. A *layer of large nerve-cells* (6), with smaller ones intermingled,

the whole embedded in an interlacement of fibrils which are mostly derived from the cell-dendrons. From the shape of most of the large cells of this layer (fig. 403, *m.c.*) it has been termed the "mitral" layer. These cells send their axons upwards into the next layer, and they eventually become fibres of the olfactory tract and pass along this to the base of the brain, giving off numerous collaterals into the bulb as they pass backwards.

3. The *layer of olfactory glomeruli* (fig. 402, 7; fig. 403, *gl.*). This

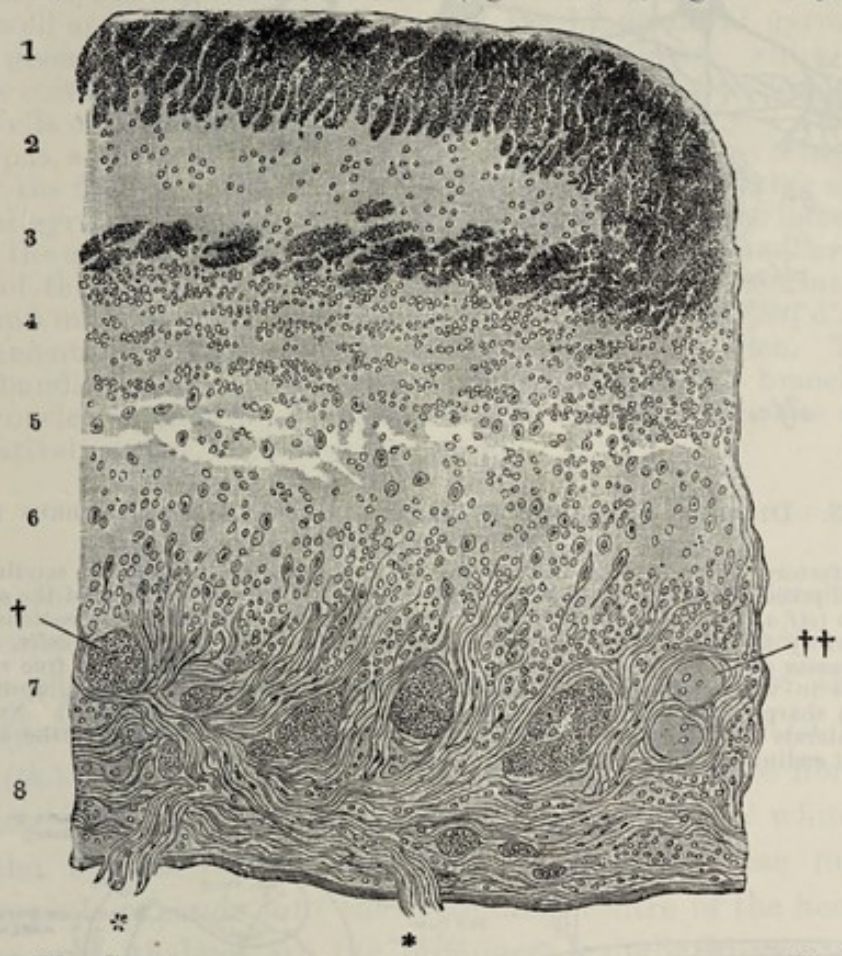


FIG. 402.—SECTION ACROSS A PART OF THE OLFACTORY BULB. (Henle.)

1, 3, bundles of very fine transversely cut nerve-fibres, forming the flattened medullary ring, inclosing the central neuroglia, 2: this ring is the anterior continuation of the olfactory tract; 5, white layer with numerous small cells (granules); 6, mitral-cell layer; 7, layer of olfactory glomeruli, †, ††; 8, layer of olfactory nerve-fibres, bundles of which are seen at * passing through the cribriform plate of the ethmoid bone.

consists of rounded nest-like interlacements of fibrils which are derived on the one hand from the terminal arborisations of the non-medullated fibres which form the subjacent layer, and on the other hand from arborisations of dendrons of the large "mitral" cells of the layer above. There are also a few small nerve-cells immediately external to and extending within the glomeruli (periglomerular cells). These belong to Golgi's type II., and appear to connect neighbouring glomeruli.

4. The *layer of olfactory nerve-fibres* (fig. 402, 8; fig. 403, *olf.n.*). These are all non-medullated, and are continued from the olfactory fibres of

the Schneiderian or olfactory mucous membrane of the nasal fossæ. In

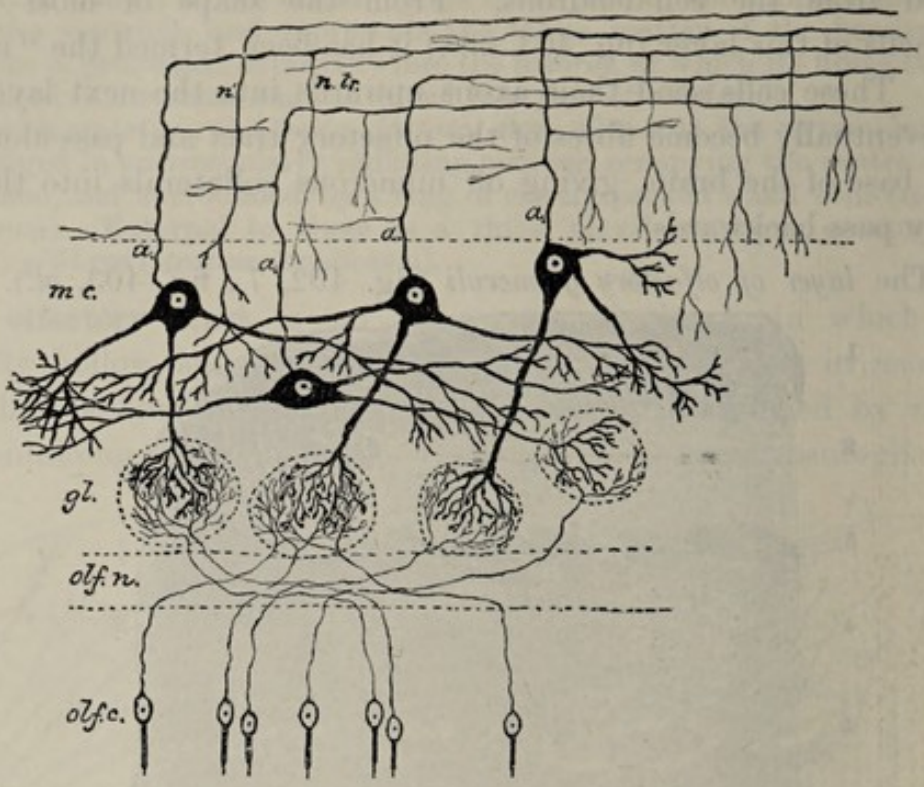


FIG. 403.—DIAGRAM TO SHOW THE RELATIONS OF CELLS AND FIBRES IN THE OLFACTORY BULB.

olf.c., olfactory cells of M. Schultze in the olfactory mucous membrane, sending their basal processes as non-medullated nerve-fibres into the deepest layer of the olfactory bulb (*olf.n.*); *gl*, olfactory glomeruli containing the terminal arborisations of the olfactory fibres and of processes from the mitral cells; *mc.*, mitral cells, sending processes down to the olfactory glomeruli, others laterally to end in free ramifications in the nerve-cell layer, and their axis-cylinder processes, *a*, *a*, upwards, to turn sharply backwards and become fibres of the olfactory tract (*n.tr.*). Numerous collaterals are seen coming off from these fibres; *n'*, a nerve-fibre of the olfactory tract ending in a free ramification in the olfactory bulb.

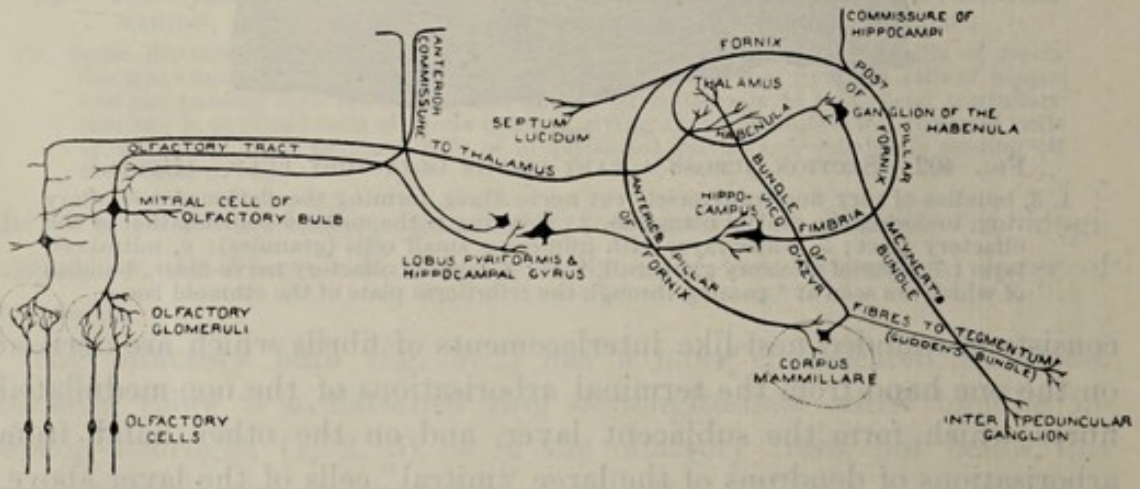


FIG. 404.—DIAGRAM OF THE OLFACTORY PATH IN THE BRAIN. To simplify the diagram the various divarications of the olfactory path have been represented by branchings of individual fibres, although in most cases the divarication is brought about by the turning aside of bundles of entire fibres.

this mucous membrane they take origin from the bipolar olfactory cells which are characteristic of the membrane (see Lesson XLV., fig.

440), and they end in arborisations within the olfactory glomeruli, where they come in contact with the arborisations of the mitral cells. The relations of the olfactory cells and fibres to the mitral cells, and the continuation of the axis-cylinders of the latter upwards and backwards in the olfactory tract, are shown in the accompanying diagrams (figs. 403, 404).

As is seen in fig. 404, the fibres of the olfactory tract pass to the hippocampal region of the brain, terminating by arborescence in the grey matter of the base of the olfactory lobe in the region of the anterior perforated space, as well as in that of the uncus and the hippocampal gyrus. Fibres are also given off from it to the anterior commissure, which probably pass to the corresponding structures on the other side of the brain. From the pyramid-cells of the hippocampal gyrus fibres pass to the grey matter of the hippocampus, and from the pyramid-cells of the hippocampus others proceed by way of the fimbria and fornix to the hippocampus of the other side, to the subcallosal gyrus and septum lucidum, to the ganglion of the habenula, and finally by the anterior pillar of the fornix to the corpora mammillaria. From the cells of the corpora mammillaria the olfactory path is continued to the anterior and inner part of the thalamus by the bundle of Vicq d'Azyr, and to the tegmentum of the mid-brain by the bundle of Gudden. The fibres of these bundles arise in common by single axons, which branch as they leave the nuclei, as shown in fig. 404: of the two branches, the ascending one is relatively coarse, the descending fine.

Basal Ganglia.

Besides the grey matter of the cerebral cortex the cerebral hemispheres conceal in the deeper parts certain other masses of grey substance (figs. 405, 406). The principal of these are the *corpus striatum* (*nucleus caudatus*, *n.c.*, and *nucleus lenticularis*, *n.l.*) and *optic thalamus* (*th.*). Between them run the bundles of white fibres which are passing upwards from the crus cerebri, forming a white lamina termed the *internal capsule*. Above the level of these nuclei the internal capsule expands into the medullary centre of the hemisphere. Below the optic thalami are the prominent ganglia known as *corpora albicantia* or *mammillaria*. Their relations to the olfactory path, thalamus, and tegmentum have been noticed above.

The **nucleus caudatus** of the corpus striatum is composed of a reddish-grey substance containing cells both with long and with short axis-cylinders; some of the former being very large. It receives fibres from the part of the internal capsule which separates it from the nucleus lenticularis, and next to the lateral ventricle it is covered by a thin layer of neuroglia (ependyma), and over this by the epithelium of the cavity.

The **nucleus lenticularis**, which corresponds in position internally with the island of Reil externally, is divided by two white laminæ into three zones. It is separated from the nucleus caudatus and optic

thalamus by the *internal capsule* (figs. 405, *c.i.*; 406, *i.c.*), which consists of the bundles of medullary fibres which are passing between the white centre of the hemisphere and the crus cerebri; it receives on its inner

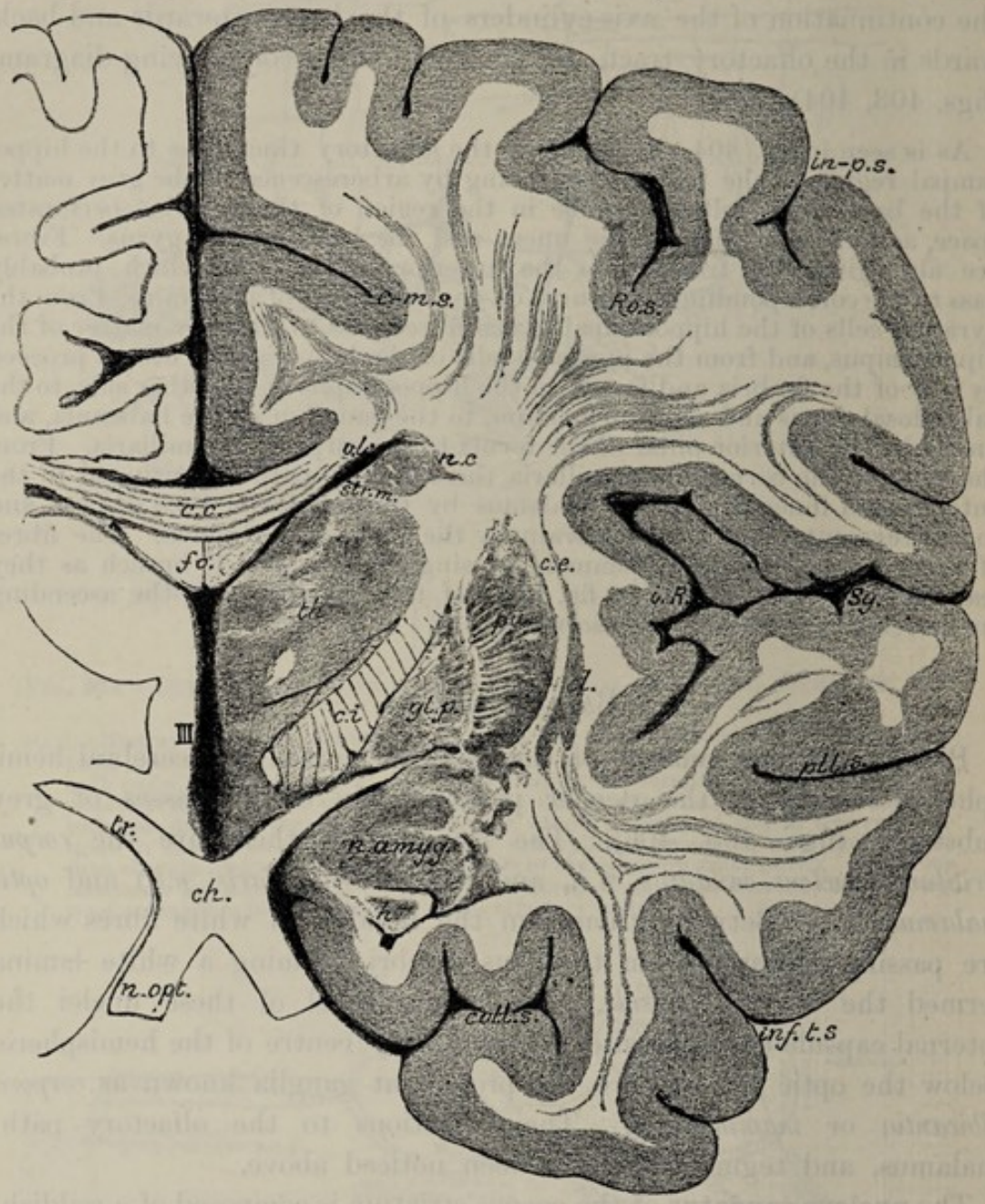


FIG. 405.—FRONTAL SECTION ACROSS THE RIGHT CEREBRAL HEMISPHERE TAKEN JUST BEHIND THE OPTIC CHIASMA.

c.c., corpus callosum; *c.e.*, external capsule, with *cl.*, claustrum; *i.R.*, island of Reil; *c.i.*, internal capsule; *fo.*, fornix; *gl.p.*, globus pallidus; *pu.*, putamen (parts of lenticular nucleus of corpus striatum); *n.c.*, nucleus caudatus of corpus striatum; *th.*, thalamus opticus; *str.m.*, medullary stria between this and nucleus caudatus; *n.amyg.*, nucleus amygdalæ; *h*, hippocampus major projecting into descending cornu of lateral ventricle; *v.l.*, body of lateral ventricle below corpus callosum; III., third ventricle; *n.opt.*, optic nerve; *tr.*, optic tract; *ch*, optic chiasma. The following sulci are also marked: *c-m.s.*, calloso-marginal; *Ro.s.*, Rolandic; *in-p.s.*, intra-parietal; *Sy.*, Sylvian; *pll.s.*, parallel; *inf.t.s.*, inferior temporal; *coll.s.*, collateral.

side many white fibres from the capsule, and these impart to it a radially striated aspect. Many of the nerve-cells of the nucleus lenticularis contain yellow pigment.

The **optic thalamus**, which lies at the side of the third ventricle and forms part of the floor of the lateral ventricle, is covered externally by a layer of white fibres, most marked next to the internal capsule. Fibres from the latter pass into the thalamus and serve to connect it with the hemisphere.

The grey matter of the thalamus (figs. 405, 406) is partially subdivided by an oblique white lamina into a smaller, mesial, and a larger

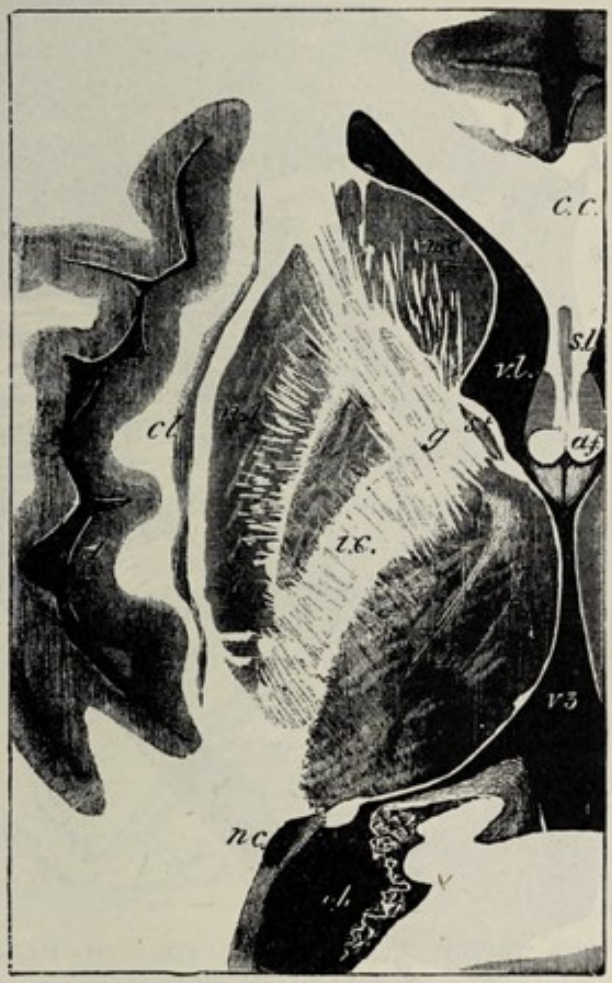


FIG. 406.—HORIZONTAL SECTION THROUGH THE OPTIC THALAMUS AND CORPUS STRIATUM. (Natural size.)

v.l., lateral ventricle, anterior cornu; *c.c.*, corpus callosum; *s.l.*, septum lucidum; *a.f.*, anterior pillars of the fornix; *v3*, third ventricle; *th.*, thalamus opticus; *s.t.*, stria medullaris; *n.c.*, nucleus caudatus, and *n.l.* nucleus lenticularis of the corpus striatum; *i.c.*, internal capsule; *g*, its angle or genu; *nc.*, tail of the nucleus caudatus appearing in the descending cornu of the lateral ventricle; *cl.*, claustrum; *I*, island of Reil.

lateral, nucleus; these contain a large number of small nerve-cells. Anteriorly another portion of grey matter is divided off in a similar way; this contains comparatively large nerve-cells.

From the cells of the thalamus nerve-fibres pass in every direction into the white matter of the hemisphere, and eventually to the cortex. From the outer part they tend especially into the occipital region, assisting to form the central visual tract which passes to the visual cortex. From the inner and deeper part they converge towards the subthalamic region and many are collected into the ansa lenticularis (see p. 355), by which they pass into

the nucleus lenticularis, while others enter the corona radiata and reach the cortex of the hemisphere. These fibres from the thalamus to the cortex probably form the third and last link in the chain of sensory neurones, the second being formed by the neurones of the tract of the fillet and the first by the sensory root-fibres.

Attached to the optic thalamus below and externally are the two *geniculate bodies* which at first sight appear to be both connected

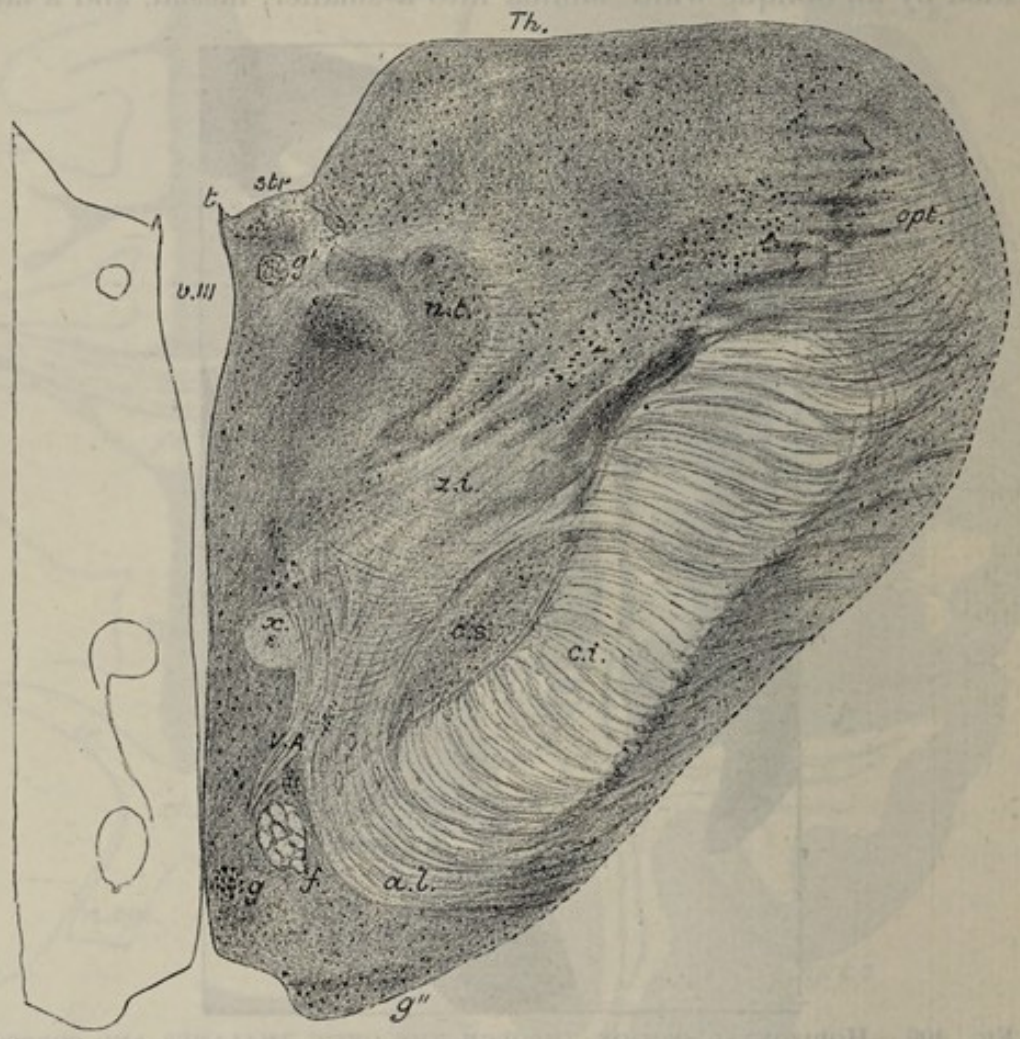


FIG. 407.—SECTION TAKEN OBLIQUELY THROUGH THE OPTIC THALAMUS AND INTERNAL CAPSULE SHOWING SOME OF THE STRANDS OF FIBRES OF THE SUB-THALAMUS. (Magnified 2½ diameters.)

Th., thalamus; *v.iii.*, third ventricle; *t.*, tænia, or attachment of epithelial roof of ventricle; *str.*, stria medullaris or habenula; *g'*, ganglion of the habenula; *n.t.*, mesial nucleus of thalamus; *opt.*, optic fibres passing into pulvinar of thalamus; *zi.*, tract of fibres emerging from thalamus and sweeping as the *ansa lenticularis* round the internal capsule, *c.i.*, to pass towards the lenticular nucleus; *c.s.*, corpus sub-thalamicum; *f.*, anterior pillar of fornix passing backwards to corpus mammillare; *V.A.*, bundle of Vicq d'Azyr, passing upwards and forwards from corpus mammillare into thalamus; *g*, group of nerve cells, perhaps extending forwards from those of the corpus mammillare; *x*, white bundle (? fasciculus retroflexus).

with the optic tract, although only the outer one directly receives fibres from the tract. Of the geniculate bodies the outer has a lamellated structure consisting of alternating layers of grey and white matter, the white layers being composed partly of the entering optic fibres and partly of fibres emerging and passing to the central optic

path, while the grey substance contains very numerous nerve-cells amongst which many of the fibres of the optic tract end in complex arborisations. From these cells axons arise and join a bundle of fibres which enters the white matter of the hemisphere above and along with the internal capsule, and passes to the visual area of the cortex (central visual tract). Some of the fibres from the corpus geniculatum externum, as they enter the visual tract, send a branch downwards towards the tegmentum.

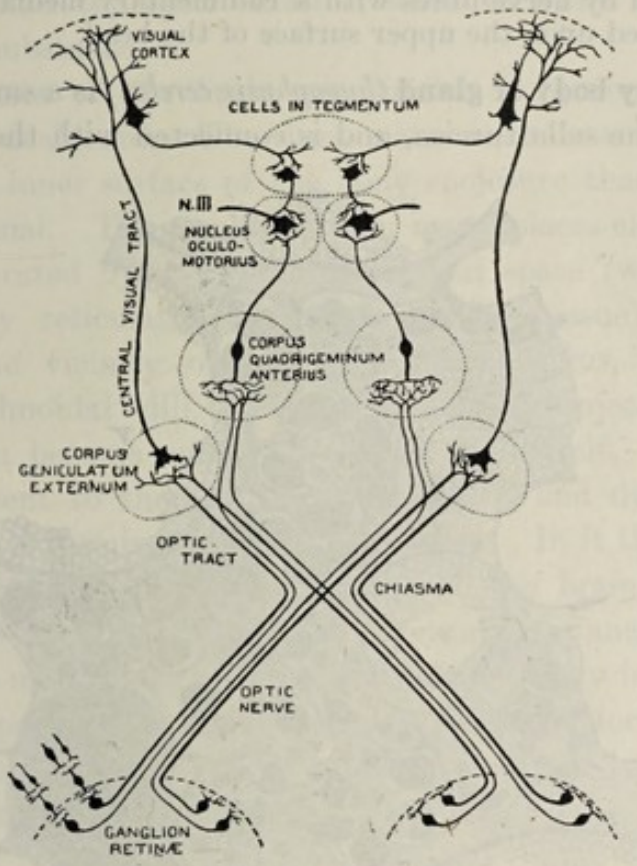


FIG. 408.—DIAGRAM TO SHOW THE PROBABLE COURSE AND RELATIONS OF THE OPTIC FIBRES.

The tegmentum of the crus cerebri is prolonged below the thalamus opticus, and between it and the internal capsule, into a mass of grey substance, with longitudinally and obliquely crossing white bundles, which is known under the name of *subthalamus* (fig. 407). Its deepest part contains a lens-shaped mass of grey matter prolonged forwards from the substantia nigra, known as the *corpus subthalamicum*. A mass of fibres from the thalamus sweeps round this and round the internal capsule passing towards the nucleus lenticularis; this is known as the *ansa lenticularis*.

The **pineal gland** (fig. 383, *gl.pi.*), which is developed in the roof of the third ventricle, is composed of a number of tubes and saccules lined and sometimes almost filled with epithelium, and containing deposits of

earthy salts (*brain-sand*). (Similar deposits may also occur in other parts of the brain.) The follicles are separated from one another by vascular connective tissue derived from the pia mater, and with the vessels are numerous nerve-fibres of sympathetic type (Ramón). No true nerve-cells can be seen, although there are a number of cells similar in general appearance to the "granules" of the cerebellum, but apparently without axons.

In the chameleon and some other reptiles, the pineal is better developed, and is connected by nerve-fibres with a rudimentary median eye of invertebrate type, placed upon the upper surface of the head.

The **pituitary body or gland** (*hypophysis cerebri*) is a small reddish mass which lies in the sella turcica, and is connected with the third ventricle

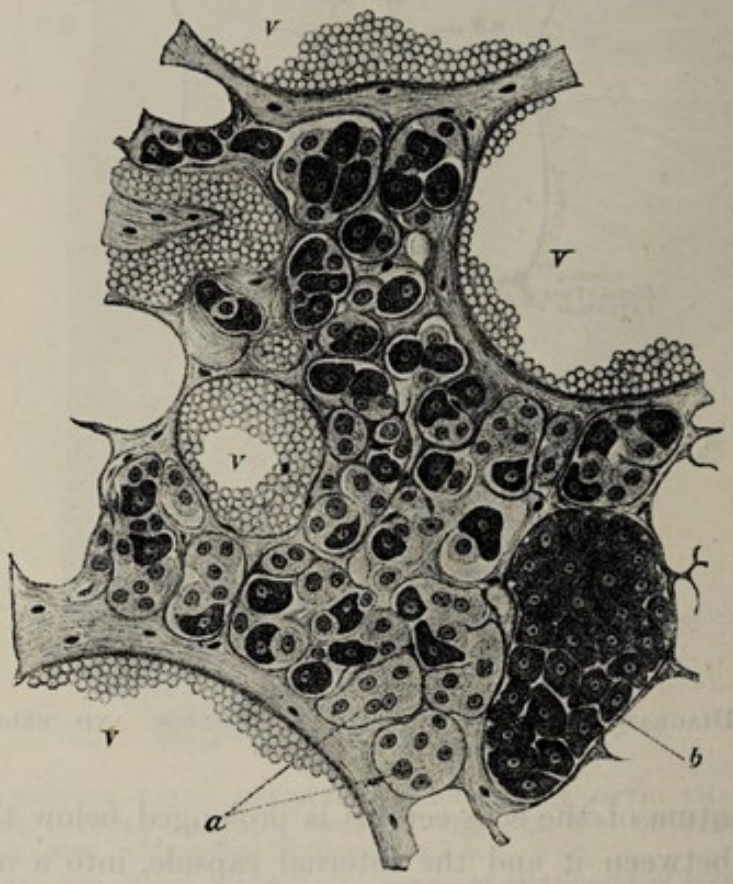


FIG. 409.—SECTION OF HYPOPHYSIS OF OX. (Dunham, from Dostoiewsky.)
V.V., veins; *a*, cell-columns containing clear cells; *b*, columns of darker granular cells. Other columns contain both kinds of cell.

by the infundibulum. It consists of two lobes, a large anterior and a smaller posterior. The *anterior lobe* is originally developed as a hollow protrusion of the buccal epithelium. It consists of a number of tubules, which are lined by epithelium and united by connective tissue. In some of the tubes the epithelium is ciliated, and occasionally a colloid substance is found in them, but for the most part the lumen of the tubules has become obliterated in the adult, and they present the

appearance of solid cell-masses between which are numerous large blood capillaries.

The *posterior lobe* of the pituitary body, which is developed from the floor of the third ventricle, consists chiefly of vascular connective tissue, but it also includes masses of cells of an epithelial character, which are at one part continuous with those of the anterior lobe. There are no cells in the adult of distinctly nervous character, but it receives many nerve fibres which arise from large cells in the grey matter just behind the optic chiasma, some of which penetrate into the glandular substance.

The **membranes of the brain** are similar in general structure to those of the spinal cord. The dura mater is, however, more closely adherent to the inner surface of the bony enclosure than is the case in the vertebral canal. The arachnoid is in many places close to the dura mater, and separated by a wide subarachnoid space (which is bridged across by finely reticulating bands of areolar tissue) from the pia mater. In the vicinity of the longitudinal sinus, small rounded elevations (arachnoidal villi, Pacchionian glands) project into the dura mater, and even become embedded in the skull itself. The pia mater is closely adherent to the surface of the brain, and dips into all the sulci, but without forming actual folds (Tuke). In it the blood-vessels ramify before passing into the substance of the brain, and they are accompanied, as they thus enter the cerebral substance, by prolongations of the pia mater, which do not, however, closely invest them, but leave a clear space around each vessel, presumably for the passage of lymph (perivascular space). The capillary network is much closer in the grey than in the white matter.

LESSONS XLIII. AND XLIV.

STRUCTURE OF THE EYELIDS AND OF THE PARTS OF THE EYEBALL.

LESSON XLIII.

1. SECTIONS of the eyelid vertical to its surfaces and transverse to its long axis.

Notice the long sacculated Meibomian glands lying in dense connective tissue close to the conjunctival surface, their ducts opening at the margin of the lid. External to these the small fibres of the orbicularis palpebrarum cut across; a few of the fibres of the muscle lie on the conjunctival side of the duct. A short distance from the Meibomian gland may be observed a tolerably large sebaceous gland; outside this again are the eyelashes. In the skin covering the outer surface of the eyelid a few small hairs may be seen. At the attached part of the eyelid are some bundles of involuntary muscular fibres cut longitudinally in the section, and in the upper eyelid the fibrous attachment of the elevator muscle may be observed attached to the dense connective tissue.

Make a general sketch under a low power.

2. Sections through the posterior part of an eyeball. These sections will show the relative thickness of the several coats and the layers of which each coat is formed. Sections which pass through the point of entrance of the optic nerve will also exhibit the manner in which the nerve-fibres pierce the several coats to reach the inner surface of the retina. The modifications which are found in the neighbourhood of the yellow spot may also be made out if sections through this are made; but they must be taken from the human eye, or from that of the monkey.

3. Sections of the anterior half of an eyeball. These sections should pass through the middle of the cornea. The lens may be left *in situ*, but this renders the preparation of the sections and the mounting of them difficult on account of the extreme hardness which is imparted to the lens-tissue by alcohol.[1]

In these sections make a general sketch under a low power, showing the relations of the several parts one with another; and study carefully, and sketch in detail, the layers of the cornea, the junction of the cornea and sclerotic, the ciliary muscle, the muscular tissue of the iris, the mode of suspension of the lens, and the pars ciliaris retinæ.

4. Mount in glycerine thin tangential sections of a cornea stained with chloride of gold by Cohnheim's method; if from the frog, the cornea can be torn with fine forceps into thin lamellæ, which are mounted whole. Sketch three or four of the connective-tissue cells (corneal corpuscles). The arrangement and distribution of the nerve-fibres and their termination amongst the epithelium-cells as shown in chloride of gold preparations have been already studied (Lesson XXI., p. 147).

[1] The celloidin method of embedding is well adapted for preparations of this kind (see Appendix).

5. Mount in xylol balsam sections of a cornea which has been stained with nitrate of silver. Notice the branched cell-spaces corresponding with the connective-tissue cells of the last preparation.

[This preparation is best made by rubbing the surface of the cornea with lunar caustic after scraping off the epithelium with a scalpel. After ten minutes (by which time the nitrate of silver will have penetrated the thickness of the cornea) the eye is washed with distilled water, and exposed to the light. When brown, tangential sections may be made, for which purpose the stained cornea may be hardened in spirit.]

LESSON XLIV.

1. Remove the sclerotic from the anterior part of an eye which has been preserved in Müller's fluid, and tear off thin shreds from the surface of the choroid, including amongst them portions of the ciliary muscle. Stain the shreds with hæmatoxylin and mount them in glycerine. Sketch the branched pigment-cells, the elastic network, the mode of attachment of the fibres of the ciliary muscle, etc.

2. Injected preparation of choroid and iris. Mount in xylol balsam portions of the choroid coat and iris from an eye (preferably of an albino rabbit), the blood-vessels of which have been filled with coloured injection. Make sketches showing the arrangement of the capillaries and veins.

3. Teased preparation of human retina. Break up with needles in a drop of glycerine a minute fragment of retina which has been placed in 1 per cent. osmic acid solution for two hours, and has subsequently been kept in dilute glycerine. Complete the separation of the retinal elements by tapping the cover-glass. Draw carefully under a high power some of the isolated elements—*e.g.* the rods and cones with their attached fibres and nuclei, the inner granules, the ganglion-cells, the fibres of Müller, hexagonal pigment-cells, etc. In some of the fragments the arrangement of the elements in the retinal layers may be made out even better than in actual sections.[1]

Measure the length and diameter of some of the cones, the length of the cone-fibres, and the diameter of some of the outer and inner nuclei.

4. Teased preparation of frog's retina. To be prepared in the same way as 3. Notice the very large rods, their outer segments breaking up into disks, and the relatively small cones. Also the pigment extending between the rods, the distance varying according as the eye has been kept in the dark or in the light. A fresh frog-retina should also be teased in salt solution.

5. Sections of retina of ox or dog, which have been prepared by Golgi's method. A curled-up piece of fresh retina is placed in osmium-bichromate mixture and is subsequently treated with nitrate of silver solution.[2]

6. Teased preparation of lens. Separate in water the fibres of a crystalline lens which has been macerated for some days in bichromate of potash or dilute formol solution. Sketch some of the fibres, together and separate.

The **eyelids** (fig. 410) are covered externally by the skin, and internally or posteriorly by a mucous membrane, the *conjunctiva*, which is reflected from over the globe of the eye. They are composed in the main of connective tissue, which is dense and fibrous under the conjunctiva, where it forms what is known as the *tarsus*.

[1] The distribution of the nerve-fibres and cell-processes within the retina can only be made out satisfactorily by the employment of Golgi's silver chromate method (see § 5).

[2] See Appendix.

Embedded in the tarsus is a row of long sebaceous glands (the *Meibomiam glands*, *f*), the ducts of which open at the edge of the eyelid. The rest of the thickness of the eyelid is composed of a somewhat loose connective tissue, and contains the bundles of the *orbicularis* muscle (*b*). In the upper eyelid the *levator palpebræ* is inserted

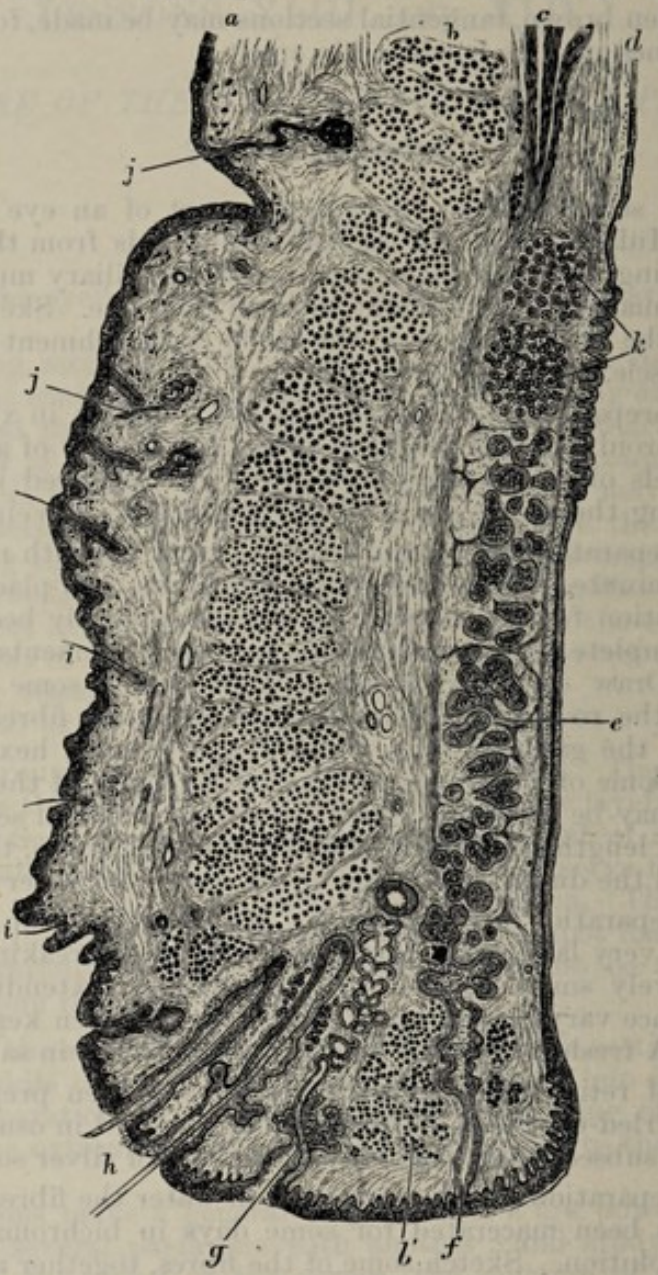


FIG. 410.—VERTICAL SECTION THROUGH THE UPPER EYELID. (Waldeyer.) (Magnified.)

a, skin; *b*, orbicularis; *b'*, ciliary bundle; *c*, involuntary muscle of eyelid; *d*, conjunctiva; *e*, tarsus with Meibomian gland; *f*, duct of the gland; *g*, sebaceous gland near eyelashes; *h*, eyelashes; *i*, small hairs in outer skin; *j*, sweat-glands; *k*, posterior tarsal glands.

into the tarsus by a fibrous expansion, and some bundles of involuntary muscle are also present near the attachment of the eyelid. The skin has the usual structure; it contains small sweat-glands, and the follicles of small hairs, and, in addition, at the edge of the eyelid, the large hair-follicles from which the eyelashes grow. The epithelium

of the conjunctiva palpebræ is columnar, passing at the edge of the lid into the stratified epithelium of the skin ; it also becomes stratified in the part which is reflected over the globe of the eye. The nerves of the conjunctiva terminate for the most part in end-bulbs, which in man are spheroidal, and formed chiefly of a small mass of polyhedral cells ; but in the calf and most animals they are elliptical (see Lesson XXI.).

The **lacrymal gland** may be briefly mentioned in connection with the eyelid. It is a compound racemose gland, yielding a watery secretion. Its alveoli are lined by columnar cells, which are normally filled with granules, but, after profuse secretion, these disappear, and

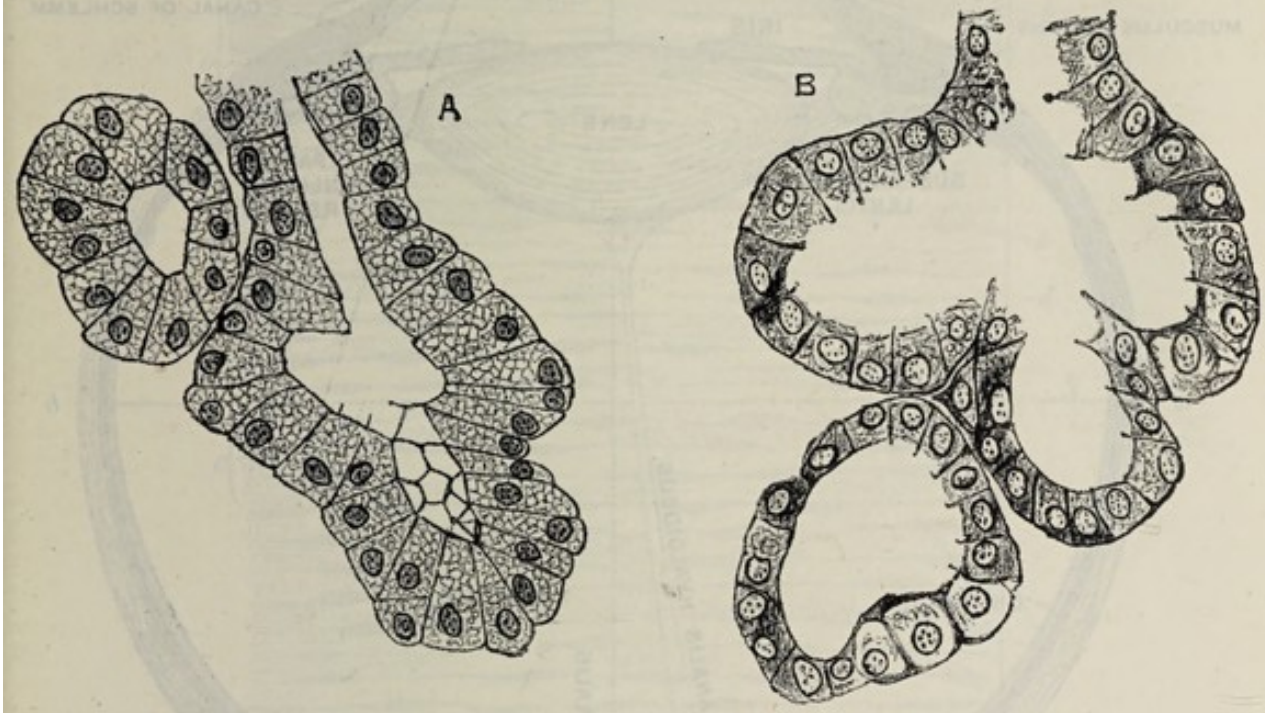


FIG. 411.—SECTIONS OF LACRYMAL GLAND OF DOG, SHOWING PARTS OF TWO OR THREE ALVEOLI.
A, resting ; B, after copious secretion produced by pilocarpine.

the cells become much shorter and smaller (fig. 411, A, B). Its ducts, of which there are several, open at the upper fold of the conjunctiva, near its outer extremity.

The **globe of the eye** (fig. 412) is inclosed by three coats, the cornea-sclerotic, choroid (with the iris), and retina. It is filled by the vitreous and aqueous humours and the crystalline lens which lies between them.

The **sclerotic coat** is composed of dense fibrous tissue, the bundles of which are intimately interlaced. It is thickest at the back of the eyeball. It is covered externally with a lymphatic epithelium, while internally it is lined by a layer of connective tissue containing pigment-cells, which give it a brown appearance (*lamina fusca*). At the entrance of the optic nerve the sclerotic is prolonged into the sheath of that

nerve, the bundles of which, piercing the coat, give a sieve-like aspect to the part (*lamina cribrosa*, fig. 424, L.).

The **cornea** (fig. 413) consists of the following layers (enumerated from before back):

1. A *stratified epithelium* continuous with the epithelium of the conjunctiva (1).

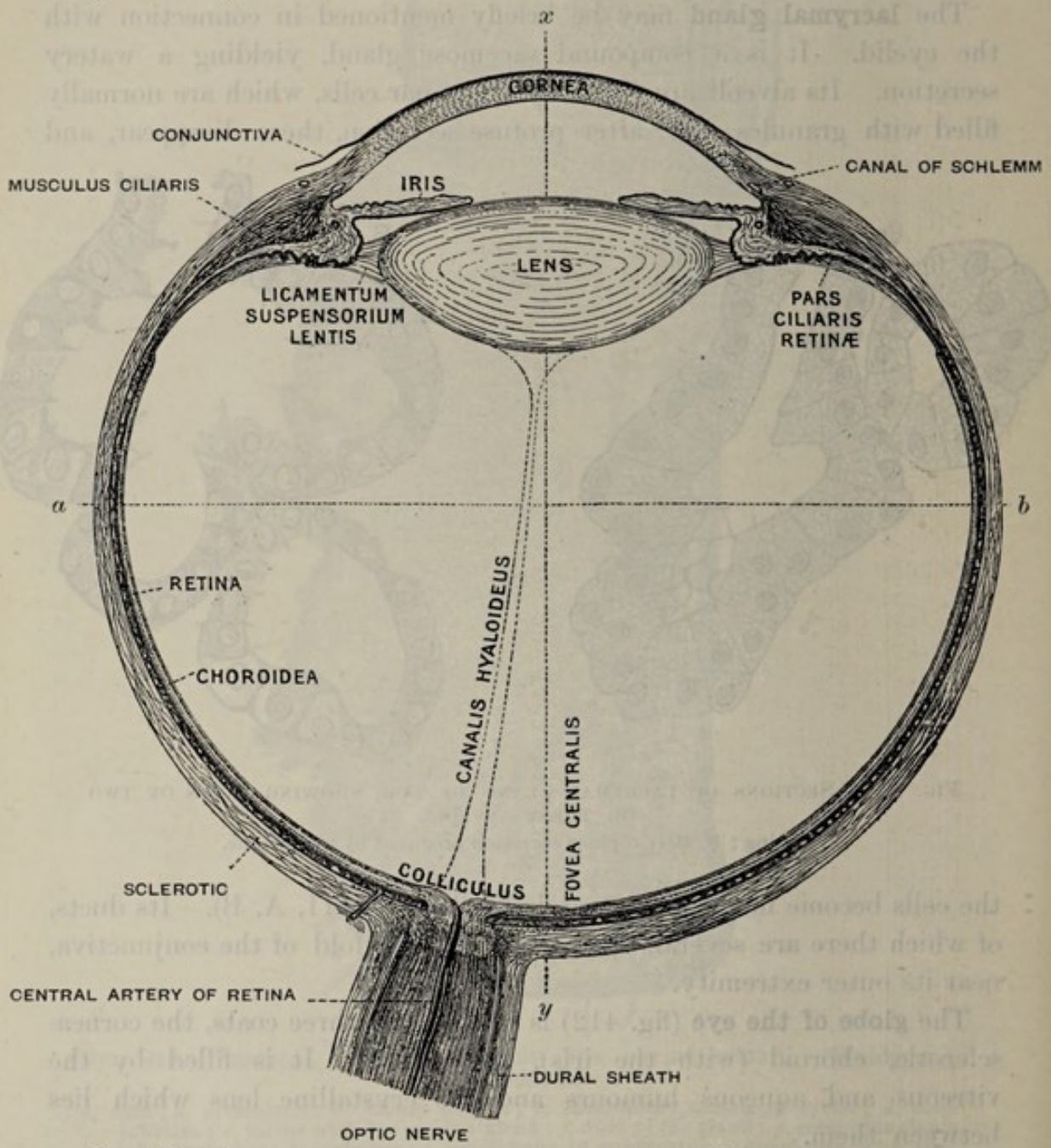


FIG. 412.—DIAGRAM OF A SECTION THROUGH THE (RIGHT) HUMAN EYE PASSING HORIZONTALLY NEARLY THROUGH THE MIDDLE. (Magnified about 4 diameters.)

a, *b*, equator; *x*, *y*, optic axis.

2. A thin lamina of homogeneous connective tissue (*membrane of Bowman*), upon which the deepest cells of the epithelium rest (2).

3. A thick layer of fibrous connective tissue which forms the *proper*

substance of the cornea (3). This is continuous laterally with the tissue of the sclerotic. It is composed of bundles of white fibres arranged

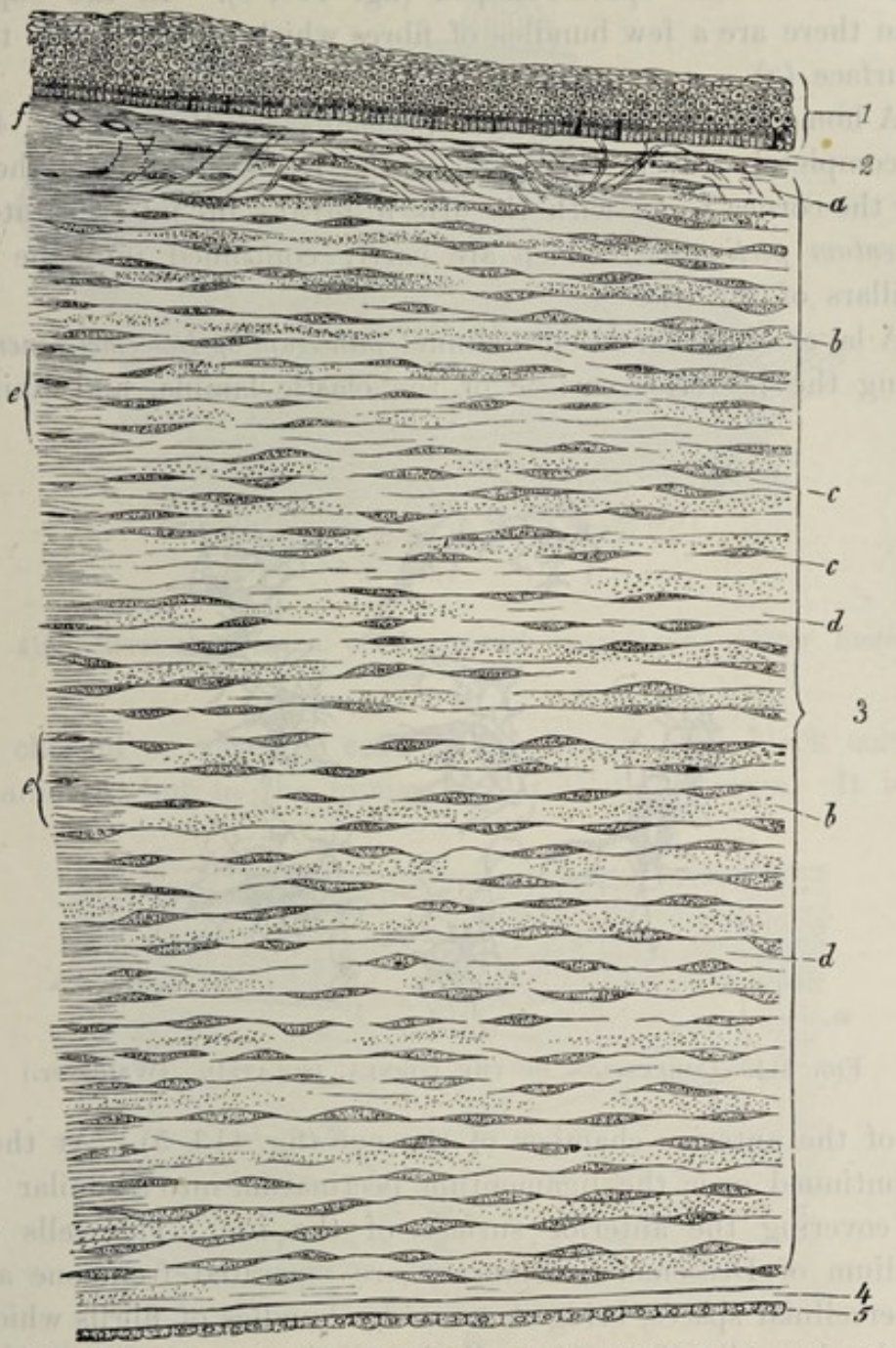


FIG. 413.—VERTICAL SECTION OF HUMAN CORNEA FROM NEAR THE MARGIN. (Waldeyer.) (Magnified.)

1, epithelium; *2*, anterior homogeneous lamina; *3*, substantia propria corneæ; *4*, posterior homogeneous (elastic) lamina; *5*, epithelium of the anterior chamber; *a*, oblique fibres in the anterior layer of the substantia propria; *b*, lamellæ, with their fibres cut across, producing a dotted appearance; *c*, corneal corpuscles appearing fusiform in section; *d*, lamellæ with the fibres cut longitudinally; *e*, transition to the sclerotic, with more distinct fibrillation, and surmounted by a thicker epithelium; *f*, small blood-vessels cut across near the margin of the cornea.

in regular laminæ, the direction of the fibres crossing one another at right angles in the alternate laminæ. Between the laminæ lie flattened connective-tissue corpuscles (fig. 414), which are branched and united

by their processes into a continuous network; there is of course a corresponding network of cell-spaces. In vertical sections the cells appear narrow and spindle-shaped (fig. 413, *c*). In the superficial laminæ there are a few bundles of fibres which run obliquely towards the surface (*a*).

4. A homogeneous elastic layer (*membrane of Descemet*, fig. 413, 4). This completely covers the back of the cornea, but near the angle which the cornea forms with the iris it breaks up into separate fibres (*ligamentum pectinatum*) which are partly continued into the iris as the pillars of the iris.

5. A layer of pavement-epithelium (*epithelium of Descemet's membrane*) covering the posterior surface of the elastic lamina, and lining the

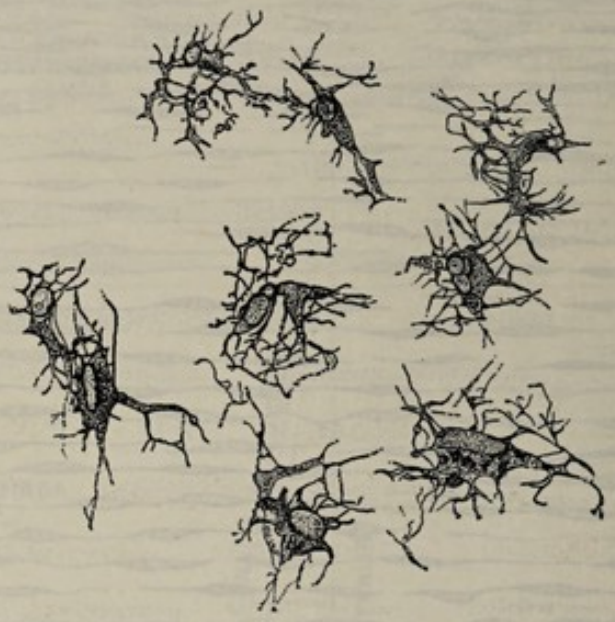


FIG. 414.—CORPUSCLES OF THE CORNEA, ISOLATED. (Waldeyer.)

front of the anterior chamber of the eye (fig. 413, 5). At the sides it is continued over the ligamentum pectinatum into a similar epithelium, covering the anterior surface of the iris. The cells of the epithelium of Descemet's membrane are separated from one another by intercellular spaces, bridged across by bundles of fibrils which pass through the cells (fig. 415). Each cell has a peculiar basket-like reticulum close to the nucleus: perhaps a modified centrosome.

The nerves of the cornea pass in from the periphery, losing their medullary sheath as they enter the corneal substance. They form a primary plexus in the substantia propria, a secondary or sub-epithelial plexus immediately under the epithelium which covers the anterior surface, and a terminal plexus of fine fibrils which pass from the sub-epithelial plexus in pencil-like tufts and become lost between the epithelium-cells (see also Lesson XXI.). There are no

blood-vessels or lymphatics in the cornea, although they come close up to its margin.

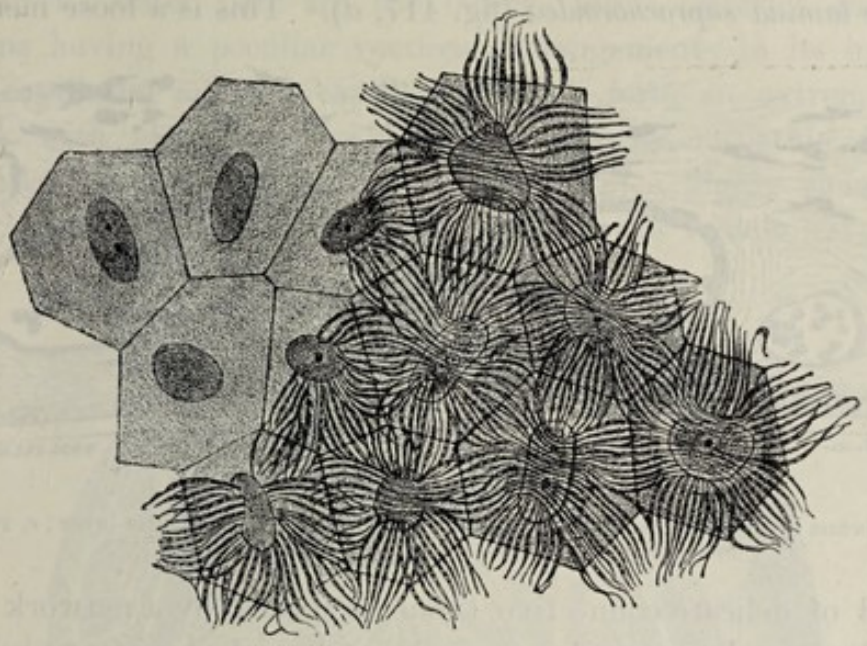


FIG. 415.—EPITHELIUM-CELLS OF DESCEMET'S MEMBRANE. (After Smirnow and Nuël.)

The **choroid** or **vascular coat** of the eye is of a black colour in many animals, but in the human eye it is dark brown. It is com-

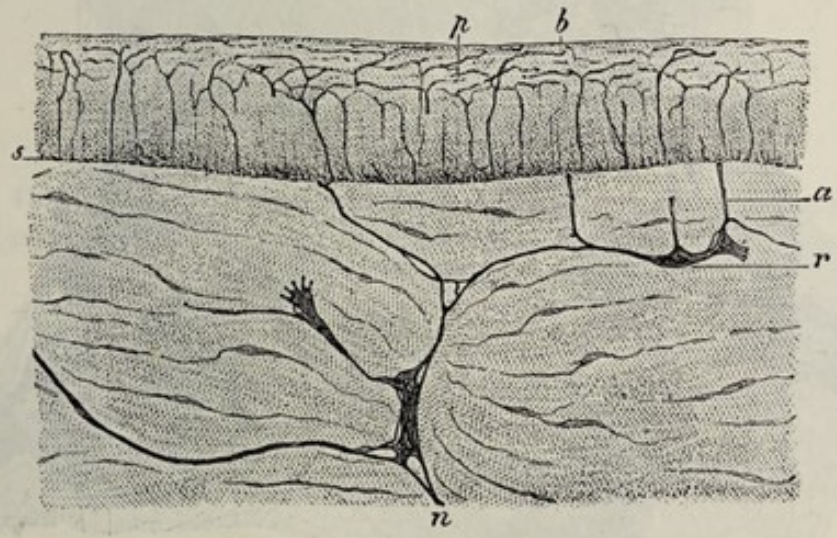


FIG. 416.—NERVES OF CORNEA AS SEEN IN VERTICAL SECTION. (Ranvier.)

n, *r*, primary plexus in connective tissue of cornea; *a*, branch passing to subepithelial plexus, *s*; *p*, intra-epithelial plexus; *b*, terminations of fibrils.

posed of connective tissue, the cells of which are large and filled with pigment (figs. 417, 418). It contains in its inner layer a close network of blood-vessels, and in its anterior part the involuntary muscular fibres of the ciliary muscle, which pass backwards from their origin at the junction of the cornea and sclerotic, to be inserted

into the choroid. The choroid is separable into the following layers (enumerated from without in):—

1. The *lamina suprachoroidea* (fig. 417, *d*). This is a loose membrane

FIG. 417.—SECTION OF CHOROID. (Cadiat.)

a, membrane of Bruch: the chorio-capillaris is just above it; *b*, vascular layer; *c*, vessels with blood-corpuscles; *d*, lamina suprachoroidea.

composed of delicate connective tissue pervaded by a network of fine elastic fibres, and containing many large branched pigment-cells and lymph-corpuscles (fig. 418). It is covered superficially by a lymphatic

FIG. 418.—A SMALL PORTION OF THE LAMINA SUPRACHOROIDEA. (Highly magnified.)

p, pigment-cells; *f*, elastic fibres; *n*, nuclei of endothelial cells (the outlines of the cells are not indicated); *l*, lymph-cells.

endothelium, and is separated from the lamina fusca of the sclerotic by a cleft-like lymphatic space which is bridged across here and there by the passage of vessels and nerves, and by bands of connective tissue.

2. The *vascular layer* of the choroid (fig. 417, *b*), which resembles the suprachoroidea in structure, but contains the blood-vessels of the coat. In its outer part are the larger vessels (arteries and veins), the veins having a peculiar vorticose arrangement; in its inner part (chorio-capillaris) are the capillaries, which form an extremely close network with elongated meshes, the capillaries radiating from the extremities of the small arteries and veins in a highly characteristic manner (fig. 419). In the ciliary processes the vessels have for the

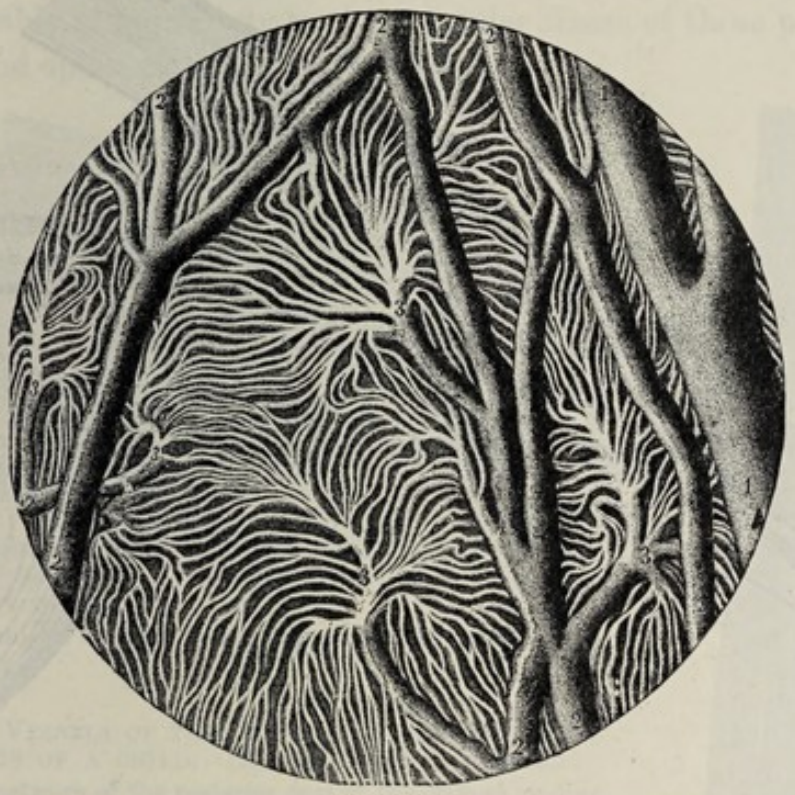


FIG. 419.—INJECTED BLOOD-VESSELS OF THE CHOROID COAT. (Sappey.)
1, one of the larger veins; 2, small anastomosing vessels; 3, branches dividing into the smallest vessels.

most part a longitudinal direction, but there are numerous convoluted transversely disposed capillaries uniting the longitudinal vessels (fig. 422, *d*).

Lining the inner surface of the choroid is a thin transparent membrane known as the *membrane of Bruch* (fig. 417, *a*).

The *ciliary muscle* consists of involuntary muscular bundles which arise at the corneo-sclerotic junction, and pass meridionally backwards to be inserted into the choroid (fig. 420, *M*). Many of the deeper-seated bundles take an oblique direction, and these pass gradually into others which run circularly around the circumference of the iris, and on a level with the ciliary processes. This set of circularly arranged bundles constitutes the *circular ciliary muscle* of H. Müller (*Mu.*); it is most marked in hypermetropic eyes.

The **iris** is that part of the vascular coat of the eye which extends in front of the lens. It is continuous with the choroid and has a similar structure, but its pigment-cells often contain variously coloured pigment. Besides the delicate connective tissue with numerous elastic fibres and blood-vessels of which it is chiefly composed, it contains two sets of plain muscular fibres. The one set forms the

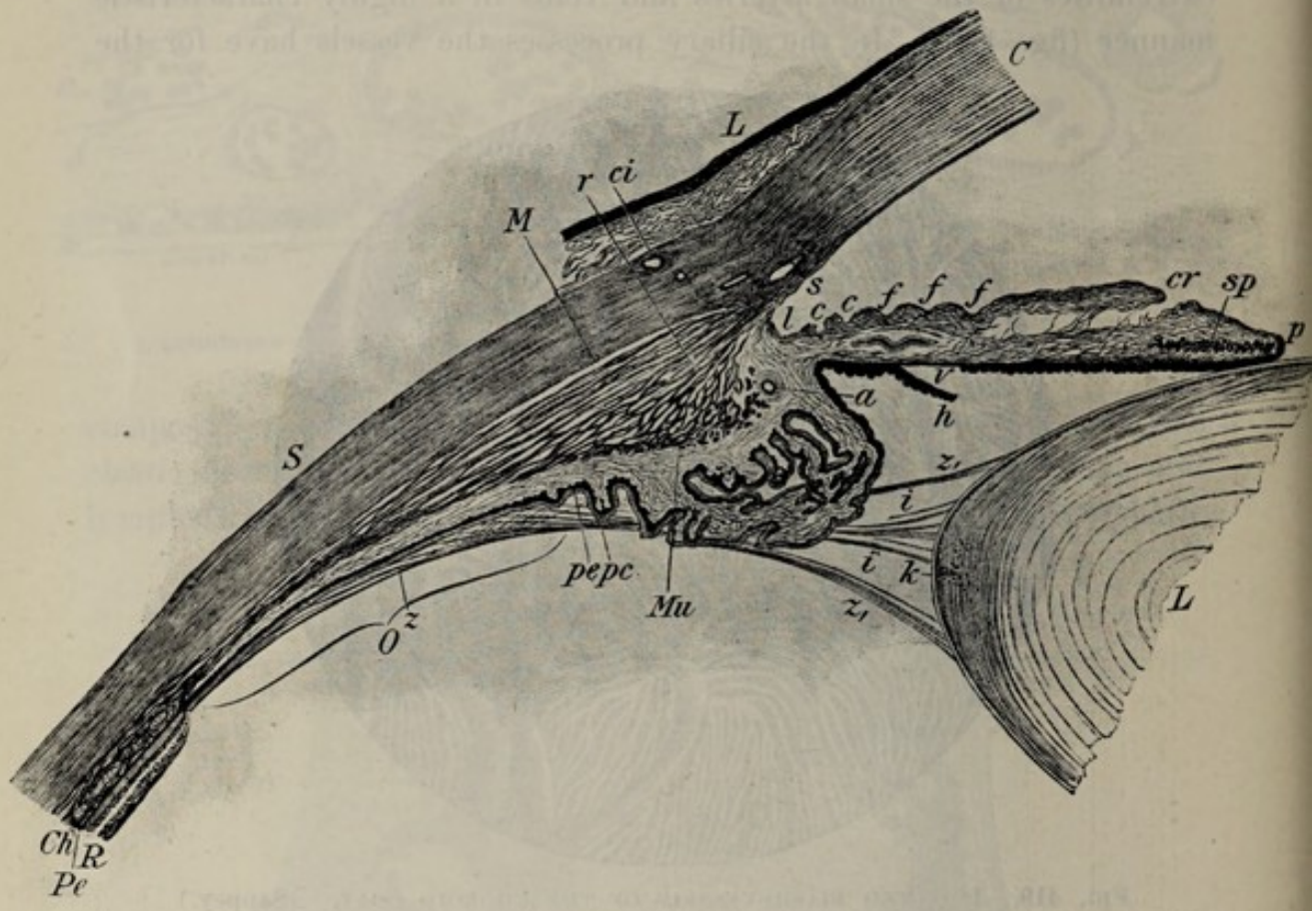


FIG. 420.—SECTION THROUGH THE CILIARY PART OF THE EYE, INCLUDING PART OF THE CORNEA, THE ORA SERRATA, THE IRIS AND THE EDGE OF THE LENS WITH ITS SUSPENSORY LIGAMENT. (Fuchs.)

C, cornea; *S*, sclerotic; *Ch*, choroid; *R*, retina; *Pe*, its pigmented epithelium; *o*, ora serrata (termination of retina); *O*, pars ciliaris: this is continued over the choroid process, *P*; *p.e.*, *p.c.*, pigmented and non-pigmented layer of pars ciliaris; *L*, lens; *M*, ciliary muscle; *r*, its radiating (meridional) fibres passing from their origin at the corneo-sclerotic junction; *Mu*, circular ciliary muscle; *ci*, artery; *s*, vein (canal of Schlemm); *z*, fibres of zonula of Zinn passing between choroid processes into the suspensory ligament of the lens (*z'*, *i*); *l*, angle of anterior chamber; *sp*, sphincter pupillæ; *p*, edge of pupil; *h*, pigment epithelium of iris (accidentally detached at this point); *a*, artery at insertion of iris; *k*, capsule of lens.

sphincter muscle (figs. 420, *sp.*, 421, *a*), which encircles the pupil, the other set consists of a flattened layer of radiating fibres which extend from the attachment of the iris nearly to the pupil, lying close to the posterior surface and constituting the *dilatator* muscle (fig. 421, *b*).

The muscular tissue of the iris is stated to be developed from the epithelium of the back of the iris (Nussbaum, Szili).

The back of the iris is covered by a thick layer of pigmented epithelium (uvea) continuous with the epithelium of the pars ciliaris retinæ.

The blood-vessels of the iris converge towards the pupil (fig. 422, *e*). Near the pupil the small arteries form an anastomotic circle, from which capillaries arise and pass still nearer the pupil, around which they form a close capillary network.

A large number of nerve-fibres are distributed to the choroid and iris, probably going chiefly to the muscular tissue of those parts (ciliary muscle and sphincter and dilator iridis).

FIG. 421.—SEGMENT OF THE IRIS, SEEN FROM THE POSTERIOR SURFACE AFTER REMOVAL OF THE UVEAL PIGMENT. (Iwanoff.)

a, sphincter muscle ; *b*, dilator muscle of the pupil.

FIG. 422.—VESSELS OF THE CHOROID, CILIARY PROCESSES AND IRIS OF A CHILD. (Arnold.) (10 diameters.)

a, capillary network of the posterior part of the choroid, ending at *b*, the ora serrata ; *c*, arteries of the corona ciliaris, supplying the ciliary processes, *d*, and passing into the iris, *e* ; *f*, the capillary network close to the papillary margin of the iris.

The **retina** consists of the eight layers shown in the accompanying figure (fig. 423), numbered as they occur from within out.

The inner surface of the retina, which is smooth, rests upon the hyaloid membrane of the vitreous humour. It is formed of the united bases of the fibres of Müller, which will be afterwards described.

The *layer of nerve-fibres* is formed by the expansion of the optic nerve after it has passed through the coats of the eye (fig. 424). At its entrance it forms a slight eminence (*colliculus nervi optici*). The nerve-fibres lose their medullary sheath on reaching the retina. Most are connected with (derived from) the cells of the ganglionic or optic nerve-cell layer (fig. 425), but some (centrifugal) fibres pass through the ganglionic and molecular layers to form a terminal arborisation in the inner nuclear layer (fig. 426). The layer of nerve-fibres becomes gradually thinner in the anterior part of the retina.

The *layer of optic nerve-cells*, or *ganglionic layer*, is composed of nerve-cells somewhat like the cells of Purkinje of the cerebellum but varying in size, although those of large size are prevalent in most parts of the retina. On the other hand, in the yellow spot, smaller nerve-cells are met with, and they may here lie several deep. These nerve-cells have

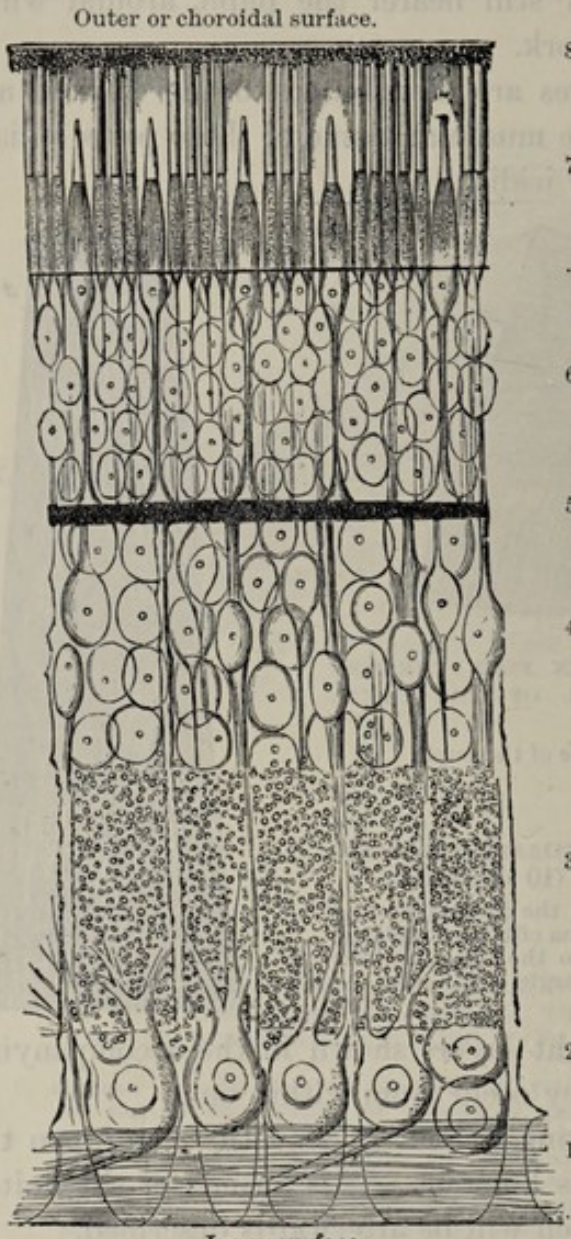


FIG. 423.—DIAGRAMMATIC SECTION OF THE HUMAN RETINA. (M. Schultze.

a fine axis-cylinder process prolonged into a fibre of the layer just noticed, and a thick branching process, the ramifications of which terminate in the next layer in flattened arborisations at different levels (fig. 427, A, B, C).

The *inner synapse layer* or *inner molecular layer* is comparatively thick, and has an appearance very like parts of the grey matter of the nerve-centres. A few nuclei are scattered through it, and it is occupied by

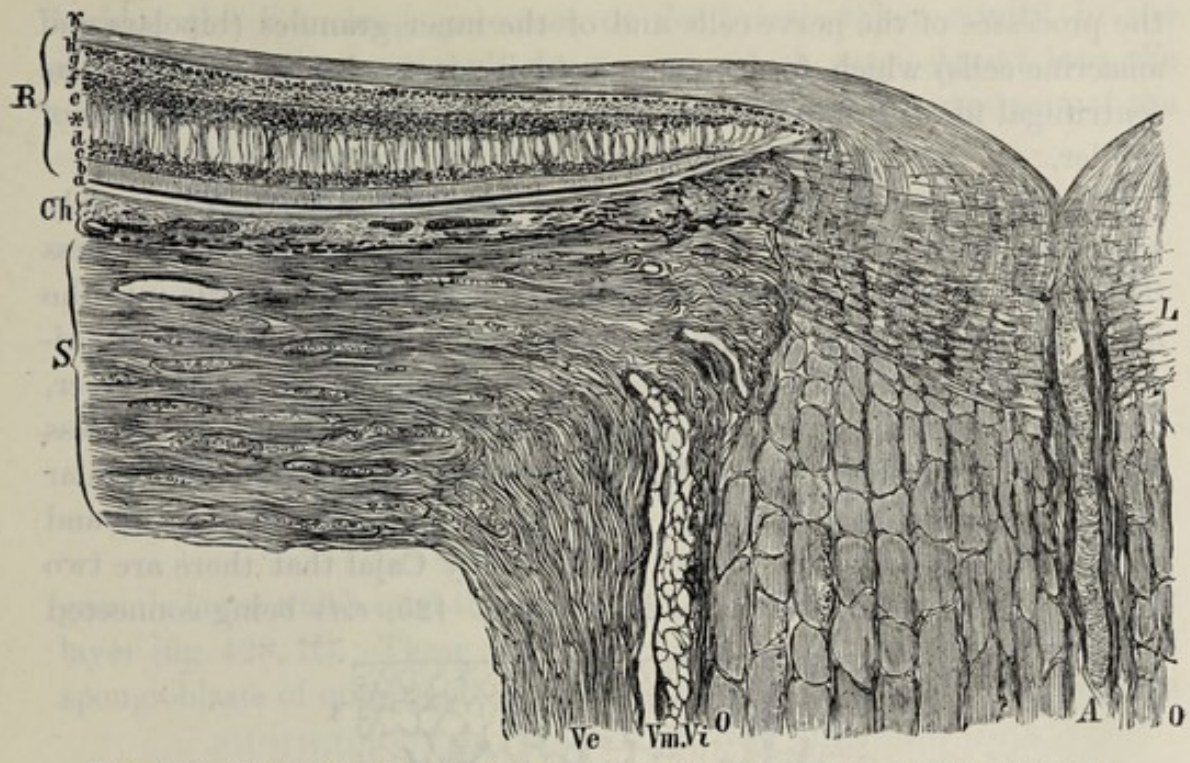


FIG. 424.—SECTION THROUGH THE COATS OF THE EYEBALL AT THE POINT OF ENTRANCE OF THE OPTIC NERVE. (Toldt.)

Ve, dural sheath; *Vm*, arachnoidal sheath, and *Vi*, pia-matral sheath of the optic nerve, with lymphatic spaces between them; *O*, *O*, funiculi of the nerve; *L*, lamina cribrosa *A*, central artery; *S*, sclerotic; *Ch*, choroid; *R*, retina. The small letters refer to the various parts of the retina, *b* being the layer of rods and cones, and *i* that of nerve-fibres.

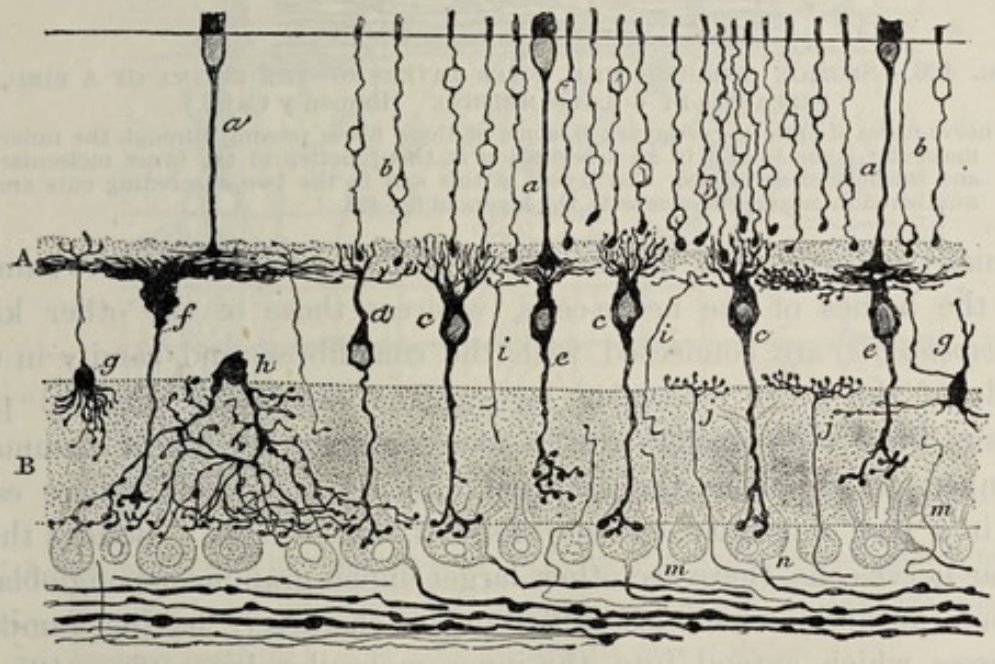


FIG. 425.—SECTION OF DOG'S RETINA, GOLGI METHOD. (S. Ramón y Cajal.)

a, cone-fibre; *b*, rod-fibre and nucleus; *c*, *d*, bipolar cells (inner granules) with vertical ramifications of their outer processes or dendrons: in the centre of the ramification lie the enlarged ends of rod-fibres; *e*, other bipolars with flattened ramifications abutting against ramified ends of cone-fibres; *f*, large bipolar with flattened ramification; *g*, inner granule-cell sending an axon towards the rod and cone-fibres; *h*, amacrine cell with diffuse arborisation of its processes in inner molecular layer; *i*, *j*, *m*, nerve-fibrils passing respectively to outer molecular, inner nuclear, and inner molecular layers; *n*, ganglionic cells.

the processes of the nerve-cells and of the inner granules (bipolars and amacrine cells) which form synapses in it; it is also traversed by the centrifugal fibres from the optic nerve layer, as well as by the fibres of Müller.

The *inner granule layer* (also termed *inner nuclear layer*) is mainly composed of bipolar nerve-cells containing large nuclei. A process (the axon) of each of these cells (fig. 425) extends inwards into the inner molecular layer where it spreads out into a terminal arborisation. These arborisations occur at different levels in the layer, forming synapses with the optic nerve-cells. Another process (dendron) is directed outwards, and arborises in the outer molecular layer, where it forms synapses with the terminations of the rod and cone-fibres. It has been shown by Ramón y Cajal that there are two kinds of bipolars, one kind (*rod-bipolars*, fig. 425, *c.d*) being connected

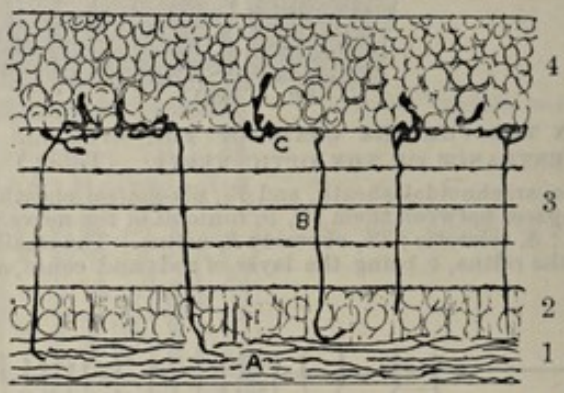


FIG. 426.—SECTION THROUGH THE INNER LAYERS OF THE RETINA OF A BIRD, PREPARED BY GOLGI'S METHOD. (Ramón y Cajal.)

A, nerve-fibres of optic nerve layer; B, some of these fibres passing through the inner molecular layer to end in an arborisation at the junction of the inner molecular and inner nuclear layers. The layers in this and in the two succeeding cuts are numbered in correspondence with the layers in fig. 423.

externally with the rods of the retina, and passing inwards to ramify over the bodies of the nerve-cells, whereas those of the other kind (*cone-bipolars*, *e*) are connected with the cone-fibres, and ramify in the middle of the inner molecular layer. The outwardly directed processes of these cone-bipolars are, in some animals, but not in mammals, continued on as far as the external limiting membrane, where each ends in a free extremity (*fibre of Landolt*, fig. 428, E). Besides these bipolar nerve-cells, there are other larger inner granules (spongioblasts of some authors) which are different in character, having ramified processes which extend into the inner molecular layer (figs. 425, *h*; 428, A, B, C), in which the bodies of these cells are often partly embedded. The cells in question have been regarded as of the nature of neuroglia-cells, but according to Ramón they are probably all nerve-cells. He has termed them *amacrine-cells*, from the fact that they are destitute of a long process; but some have been noticed to give off,

besides the branching processes or dendrons, which ramify in the molecular layer, an axis-cylinder process which may extend into the nerve-fibre layer. There are also some cells in the outer part of the

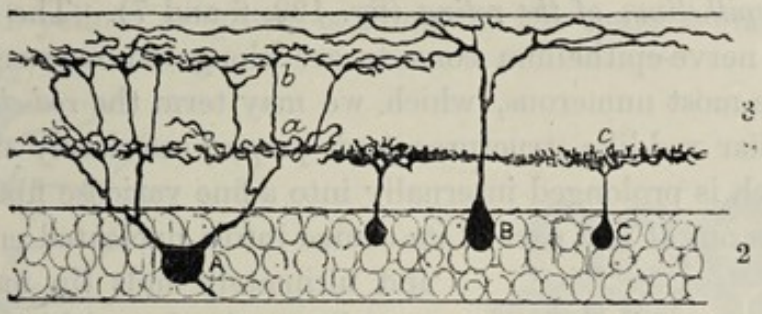


FIG. 427.—SECTION ACROSS THE MOLECULAR AND GANGLIONIC LAYERS OF BIRD'S RETINA, PREPARED BY GOLGI'S METHOD. (Ramón y Cajal.)

Three or four ganglionic cells, A, B, C, and the terminal arborisations of their dendrons, *a*, *b*, *c*, in the molecular layer, are shown.

granule layer which send their processes entirely into the outer molecular layer (fig. 428, H). These are the *horizontal-cells* of Ramón (also termed spongioblasts of outer molecular layer by some authors). The fibres of

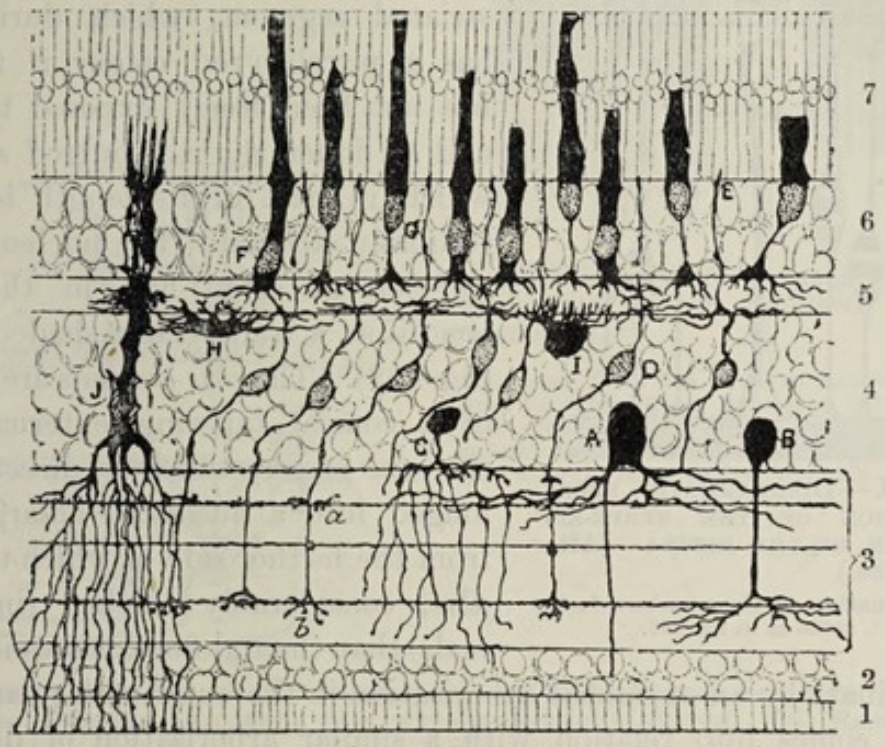


FIG. 428.—SECTION OF BIRD'S RETINA, PREPARED BY GOLGI'S METHOD. (Ramón y Cajal.)

A, large nerve-cell of inner nuclear layer; B, C, amacrine cells; D, small bipolar nerve-cells with one process, ramifying in the inner molecular layer and the other one ramifying in the outer molecular layer, and extending (E) as far as the rods and cones as a fibre of Landolt; F, G, rod- and cone-nuclei respectively; H, I, cells with dendrons ramifying in outer molecular layer; J, fibre of Müller.

Müller have nucleated enlargements (fig. 428, J) in the inner nuclear layer.

The *outer molecular layer* is thin, and is composed mainly of the arborisations of the inner granules, of the rod and cone-fibres, and of the horizontal cells (figs. 425, 428), which all form synapses in this layer.

The *outer nuclear layer* and the *layer of rods and cones* are composed of elements which are continuous through the two layers, and they should properly, therefore, be described as one. It has been termed the *sensory epithelium of the retina* (fig. 429, 6 and 7). The elements of which this nerve-epithelium consists are elongated nerve-cells of two kinds. The most numerous, which we may term the *rod-elements*, consist of peculiar rod-like structures (*rods proper*) set closely side by side, each of which is prolonged internally into a fine varicose fibre (*rod-fibre*) which swells out at one part of its course into a nucleated enlargement, and ultimately ends (in mammals) in a minute knob within the outer molecular layer, where it is embedded in the ramifications of the dendrons of the rod-bipolars. The rod proper consists of two segments, an outer cylindrical and transversely striated segment, which during life has a purplish-red colour if the eye has not been freely exposed to light, and an inner slightly bulged segment which in part of its length is longitudinally striated. The nucleus of the rod-element often has, in the fresh condition, a transversely shaded aspect (fig. 429). The *cone-elements* are formed of a conical tapering external part, the *cone proper*, which is directly prolonged into a nucleated enlargement, from the farther side of which the *cone-fibre*, considerably thicker (in mammals) than the rod-fibre, passes inwards, to terminate by an expanded arborisation in the outer molecular layer; here it comes into relation with a similar arborisation of dendrons of a cone-bipolar. The cone proper, like the rod, is formed of two segments, the outer of which, much the smaller, is transversely striated, the inner, bulged segment being longitudinally striated. The inner ends of the rod and cone-fibres, as already stated, form synapses with the peripheral arborisations of the bipolars, and through the latter elements and their synapses in the inner molecular layer a connection is brought about with the nerve-cells and nerve-fibres of the innermost layers. The connection of the retinal elements with one another and through the optic fibres with the central nervous

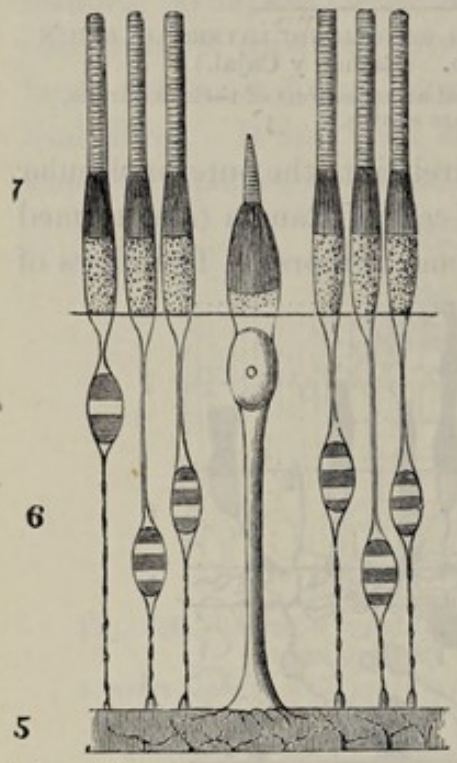


FIG. 429. — DIAGRAMMATIC REPRESENTATION OF THE NERVE-EPITHELIUM OF THE RETINA. (After Schwalbe.)

The designation of the numbers is the same as in fig. 353.

system (superior corpora quadrigemina and external geniculate bodies) is shown diagrammatically in fig. 430 (see also fig. 408).

In birds, reptiles, and amphibia, a small oil-globule, often brightly coloured red, yellow, or green, is found in the inner segment of each

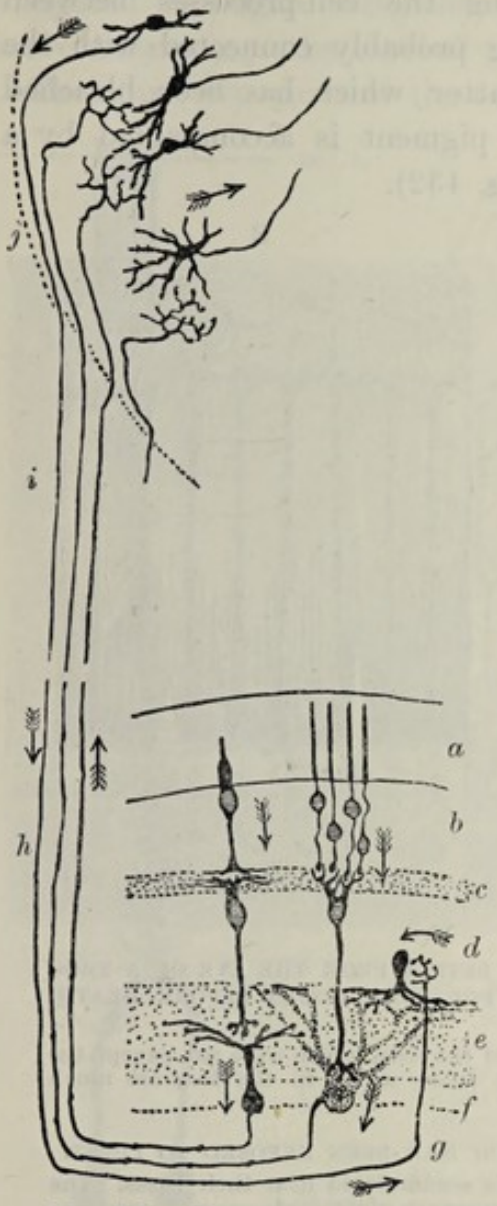


FIG. 430.—DIAGRAM OF THE CONNECTIONS OF THE RETINAL ELEMENTS WITH ONE ANOTHER AND WITH THE CENTRAL NERVOUS SYSTEM. (S. Ramón y Cajal.)

a to *g*, layers of retina; *a*, rods and cones; *b*, outer nuclear layer; *c*, outer molecular layer; *d*, inner nuclear layer; *e*, inner molecular layer; *f*, nerve-cells giving origin to fibres of optic nerve; *g*, *h*, *i*, a centrifugally conducting fibre, with a terminal arborescence in the retina; *j*, grey matter of corpus geniculatum or corpus quadrigeminum.

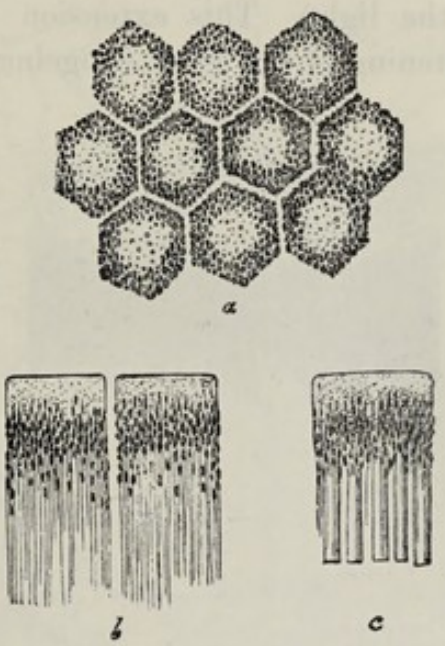


FIG. 431.—PIGMENTED EPITHELIUM OF THE HUMAN RETINA. (M. Schultze.) (Highly magnified.)

a, cells seen from the outer surface with clear lines of intercellular substance between; *b*, two cells seen in profile with fine offsets extending inwards; *c*, a cell still in connection with the outer ends of the rods.

cone. Other variations of structure are met with in different animals.

The cones are most numerous at the back of the retina; they are fewer in number, and the rods are proportionally more numerous towards the anterior part.

The *pigmentary layer* forms the most external part of the retina. It consists of hexagonal epithelium-cells (fig. 431), which are smooth

externally where they rest against the choroid, but are prolonged internally into fine filaments which extend between the rods. The pigment-granules, many of which are in the form of minute crystals, lie in the inner part of the cell, and after prolonged exposure to light they are found extending along the cell-processes between the rods (Kühne), their function being probably connected with the restoration of the purple colouring matter which has been bleached by the light. This extension of the pigment is accompanied by a shortening of the cones (Engelmann) (fig. 432).

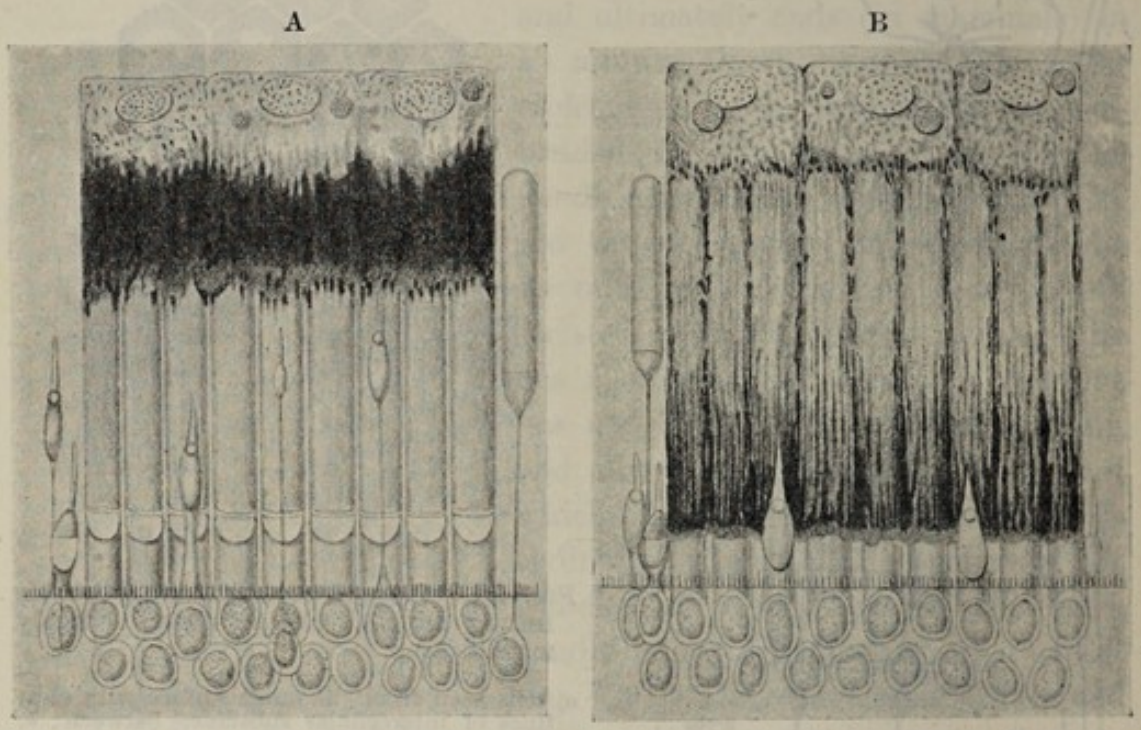


FIG. 432.—A. PART OF A SECTION OF THE RETINA FROM THE EYE OF A FROG WHICH HAD BEEN KEPT IN THE DARK FOR SOME HOURS BEFORE DEATH. (v. Genderen-Stort.)

The pigment is collected towards the outer ends of the rods, which were red, except the outer detached rod, which was green. The cones, which in the frog are much smaller than the rods, are mostly elongated.

B. A SIMILAR SECTION FROM A FROG WHICH HAD BEEN EXPOSED TO LIGHT.

The pigment is extended between the rods, and is accumulated near their bases. The rods were colourless. All the cones are contracted.

Fibres of Müller.—The fibres of Müller (fig. 428, *J*, and fig. 433) are long stiff cells which pass through several of the retinal layers. Commencing at the inner surface of the retina by expanded bases which unite with one another to form the so-called internal limiting membrane (fig. 434), they pass through all the layers in succession, until they reach the outer granule layer. Here they branch and expand into a sort of honeycomb tissue which serves to support the fibres and nuclei of the rod- and cone-elements. At the bases of the rods and cones, this sustentacular tissue ceases, being here bounded by a distinct margin which has been called the external limiting

membrane (fig. 433, *m.e.l.*), but delicate sheaths pass from it around the bases of the rods and cones. Each Müllerian fibre, as it passes through the inner granule layer, has a nucleated enlargement (*n*), indicating the cell-nature of the fibre. The fibres of Müller represent elongated neuroglia cells, such as are found in some parts of the nerve-centres, *e.g.* the cerebellum (see fig. 389, gl^3).

There are two parts of the retina which call for special description.

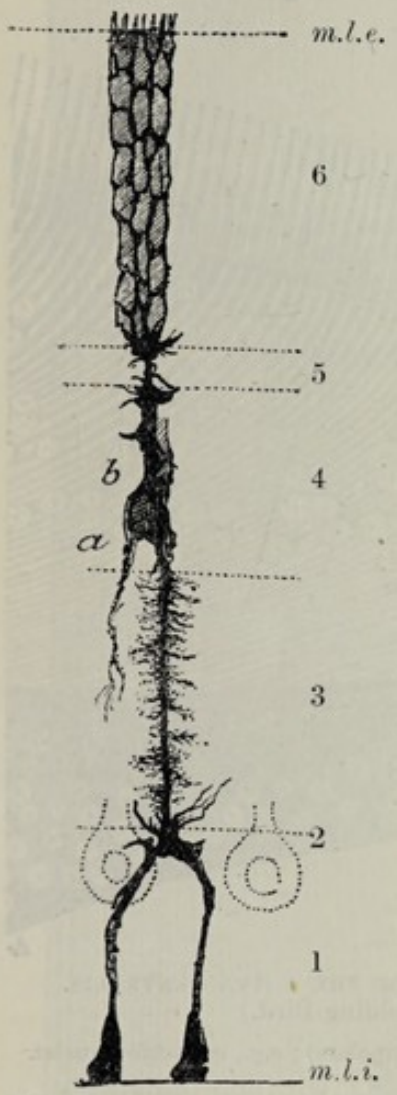


FIG. 433.

FIG. 434.

FIG. 433.—A FIBRE OF MÜLLER FROM THE DOG'S RETINA, GOLGI METHOD. (Ramón y Cajal.)

1, nerve-fibre layer; 2, nerve-cell layer; 3, inner molecular layer; 4, inner granule layer; 5, outer molecular layer; 6, outer granule layer; *b*, nucleus of the fibre; *a*, a process extending into inner molecular layer; *m.l.i.*, membrana limitans interna; *m.l.e.*, membrana limitans externa.

FIG. 434.—INTERNAL LIMITING MEMBRANE OF RETINA TREATED WITH SILVER NITRATE, SHOWING THE OUTLINES OF THE BASES OF THE FIBRES OF MULLER. (G. Retzius.)

The **macula lutea** (**yellow spot**), with its **central fovea**, is the part of the retina which is immediately concerned in direct vision. It is characterised firstly by its greater thickness (except at the middle of the fovea), secondly by the large number of its ganglion-cells, which are rounded or conical, and thirdly by the large number of cones it contains as compared with the rods. In the central fovea itself (fig. 435) there are no rods, and the cones are very long and slender, measuring not more than 2μ in diameter; all the other layers become gradually thinned down almost to com-

plete disappearance, so that the middle of the central fovea is the thinnest part of the retina. Since there are few rods, the outer granule layer loses in great measure its appearance of being composed of closely packed nuclei, and the cone-fibres are very distinct. The direction of these fibres is oblique in this part of the retina.

The pigmentary layer is thickened over the fovea, and there is also a thickening in the choroid coat here, due to a large accumulation of capillary vessels.

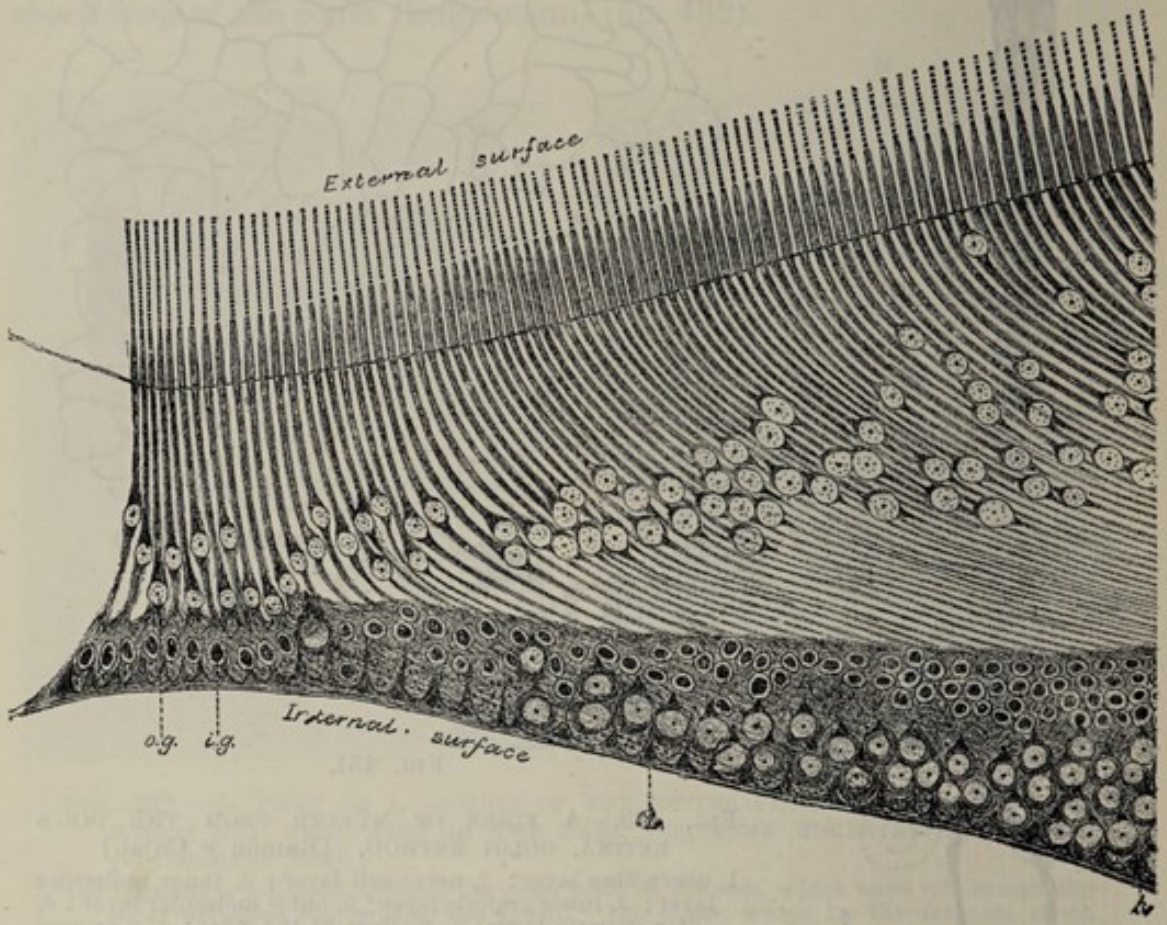


FIG. 435.—SECTION THROUGH THE CENTRAL PART OF THE FOVEA CENTRALIS. $\frac{350}{1}$. (From a preparation by C. H. Golding-Bird.)

M, bases of Müllerian fibres; *i.g.*, nuclei of inner granules (bipolars); *o.g.*, cone-fibre nuclei.

The **pars ciliaris retinæ,** which commences at the *ora serrata*, where the retina proper abruptly ends, is composed of two epithelial layers (fig. 436), and has no nervous structures. Of the two layers, the external is a thick stratum of pigmented epithelium formed of rounded cells and continuous with the pigmentary layer of the retina on the one hand, and with the uvea of the iris on the other; the inner is a layer of columnar cells, each containing an oval nucleus. They probably represent the Müllerian fibres of the retina.

The retina contains but few blood-vessels. The central artery enters and the vein leaves it in the middle of the optic nerve. The larger vessels ramify in the nerve-fibre layer, and there are capillary

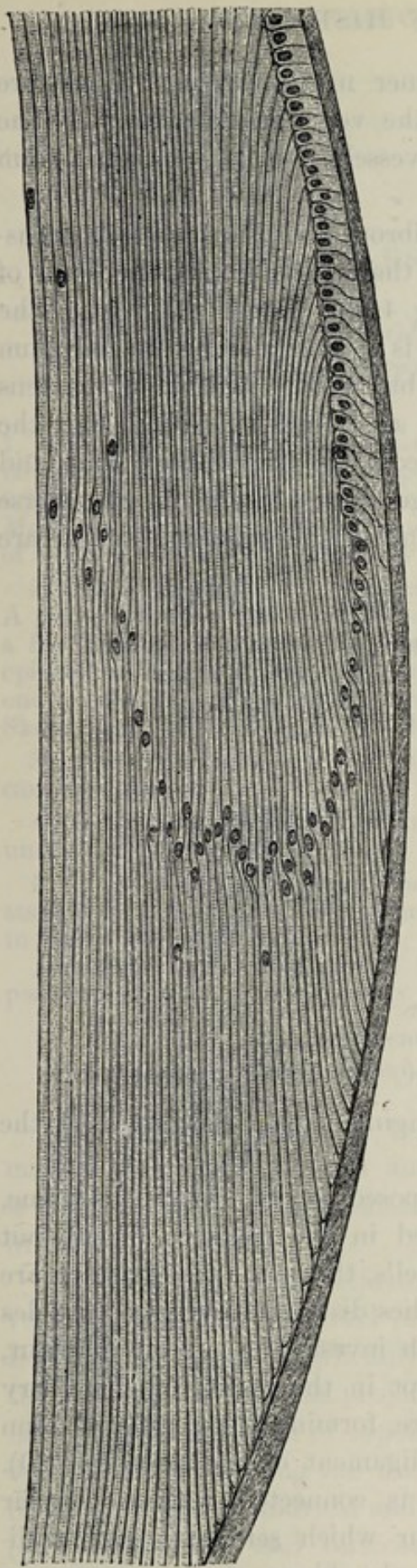


FIG. 437.—SECTION THROUGH THE MARGIN OF THE RABBIT'S LENS, SHOWING THE TRANSITION OF THE EPITHELIUM OF THE CAPSULE INTO THE LENS-FIBRES. (Babuchin.)

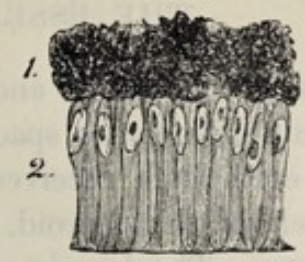


FIG. 436.—A SMALL PORTION OF THE CILIARY PART OF THE RETINA. (Kölliker.) 350 diameters.

1, pigment-cells; *2*, columnar-cells.

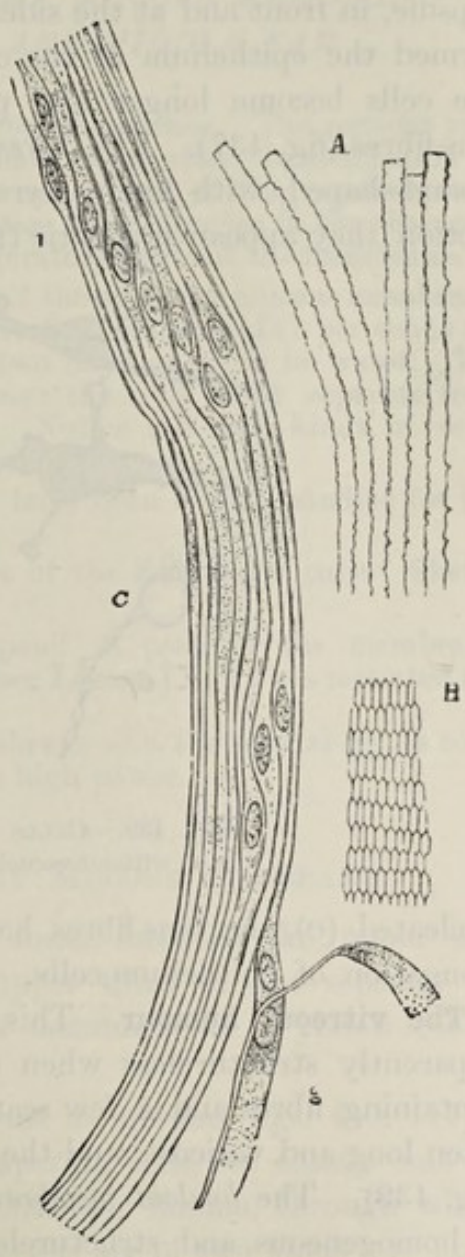


FIG. 438.—FIBRES OF THE CRYSTALLINE LENS. (350 diameters.)

A, longitudinal view of the fibres of the lens from the ox, showing the serrated edges. B, transverse section of the fibres of the lens from the human eye. C, longitudinal view of a few of the fibres from the equatorial region of the human lens. Most of the fibres in C are seen edgeways, and, towards 1, present the swellings and nuclei of the 'nuclear zone'; at 2, the flattened sides of two fibres are seen. (A and B from Kölliker; C from Henle.)

networks in this layer and in the inner nuclear layer. There are perivascular lymphatic spaces around the veins and capillaries. The sensory epithelium receives no blood-vessels, but is nourished from the vessels of the choroid.

The lens.—The lens is a laminated fibrous body inclosed by a transparent elastic capsule to which, around the circumference, the fibres of the suspensory ligament are attached (fig. 420). Immediately within the capsule, in front and at the sides, there is a layer of cubical epithelium termed the epithelium of the capsule, but at the margin of the lens the cells become longer and pass by a gradual transition into the lens-fibres (fig. 437). The *fibres* which compose the lens are long and riband-shaped, with finely serrated edges (fig. 438, A); in transverse section they appear prismatic (B). Many of the superficial fibres are

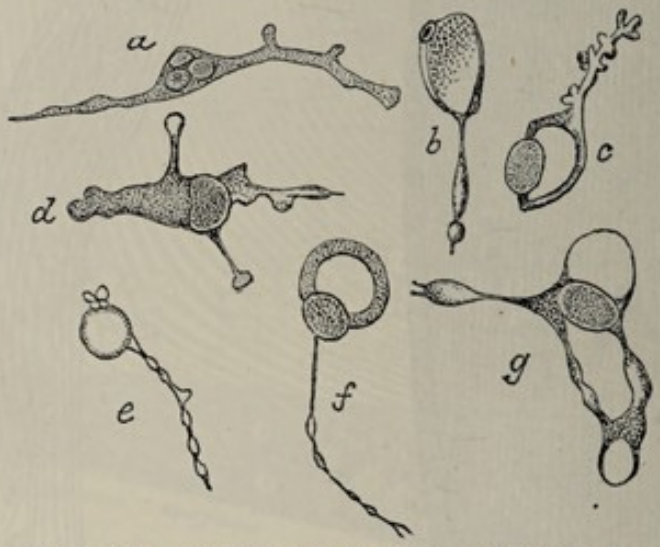


FIG. 439.—CELLS OF VITREOUS. (Schwalbe.)
a, *d*, without vacuoles; *b*, *c*, *e*, *f*, *g*, with vacuoles.

nucleated (C), the lens-fibres having originally been developed by the elongation of epithelium-cells.

The vitreous humour.—This is composed of soft gelatinous tissue, apparently structureless when examined in the fresh condition, but containing fibres and a few scattered cells, the processes of which are often long and varicose, and the cell-bodies distended by large vacuoles (fig. 439). The *hyaloid membrane*, which invests the vitreous humour, is homogeneous and structureless except in the region of the ciliary processes, where it is fibrous in structure, forming the zonule of Zinn and spreading out into the suspensory ligament of the lens (fig. 420). This part of the hyaloid membrane is connected with a circular fibrous portion of the vitreous humour which serves to give additional firmness to the attachment of the fibres of the suspensory ligament of the lens (Anderson Stuart).

LESSON XLV.

STRUCTURE OF THE OLFACTORY MUCOUS MEMBRANE AND OF THE EXTERNAL AND MIDDLE EAR.

1. Vertical sections of the olfactory mucous membrane. The sections may be carried either across the upper turbinate bone, after decalcification in 0·2 per cent. chromic acid, or across the upper part of the nasal septum. Make a sketch under the low power. Notice the difference in the character of the epithelium in the olfactory and respiratory parts of the membrane.

2. Teased preparation of the epithelium of the olfactory mucous membrane. A piece of the membrane is placed quite fresh in osmic acid (1 per cent.) for a few hours, and is then macerated for two days or more in water. The epithelium is broken up in dilute glycerine; the cells easily separate from one another on tapping the cover-glass. Notice the two kinds of cells. Sketch some of the cells under a high power.[1]

3. Sections of the external ear (these have been already studied for the cartilage, Lesson XII.).

4. Sections across the cartilaginous part of the Eustachian tube. Sketch under the low power.

5. Preparation of the membrana tympani. A piece of the membrane, stained with magenta and gentian violet (see Lesson IX. § 2), is mounted flat in Canada balsam.

Determine the composition of the membrane—*i.e.* the several layers composing it—by focussing carefully with the high power.

Structure of the Olfactory Mucous Membrane.

The **olfactory region** of the nasal fossæ includes the upper and middle turbinate processes and the upper third of the septum. It is covered by a soft vascular mucous membrane of a yellow colour in man.

The *epithelium* of the olfactory mucous membrane (figs. 440, 441) is very thick and is composed of long tapering cells, set closely side by side and bounded superficially by a cuticular lamina, through which the free ends of the cells project. The cells are of two kinds: 1. Long narrow spindle-shaped or bipolar nerve-cells consisting of a larger part or body (*b*), containing the nucleus, and of two processes or poles, one (*c*) straight and cylindrical and extending to the free surface, the other (*d*) very delicate and varicose, looking not unlike a nerve-fibril and extending down towards the corium. The position of the nuclear

[1] The connection of the olfactory cells with the olfactory nerve-fibres is displayed in embryos, the method of Golgi being employed.

enlargement varies, and with it the relative length of the two processes. The distal or free process terminates in a small clear projection, which passes beyond the cuticular membrane; in amphibia, reptiles, and birds, and perhaps also in mammals, it bears fine stiff hairlike filaments. The proximal or varicose process becomes lost amongst the plexus of olfactory nerve-fibrils at the base of the epithelium; it is connected with one of the fibrils, and ultimately passes through the cribriform plate of the ethmoid to end in an arborisation within one of the olfactory glomeruli (see diagram, fig. 403, p. 350). These cells

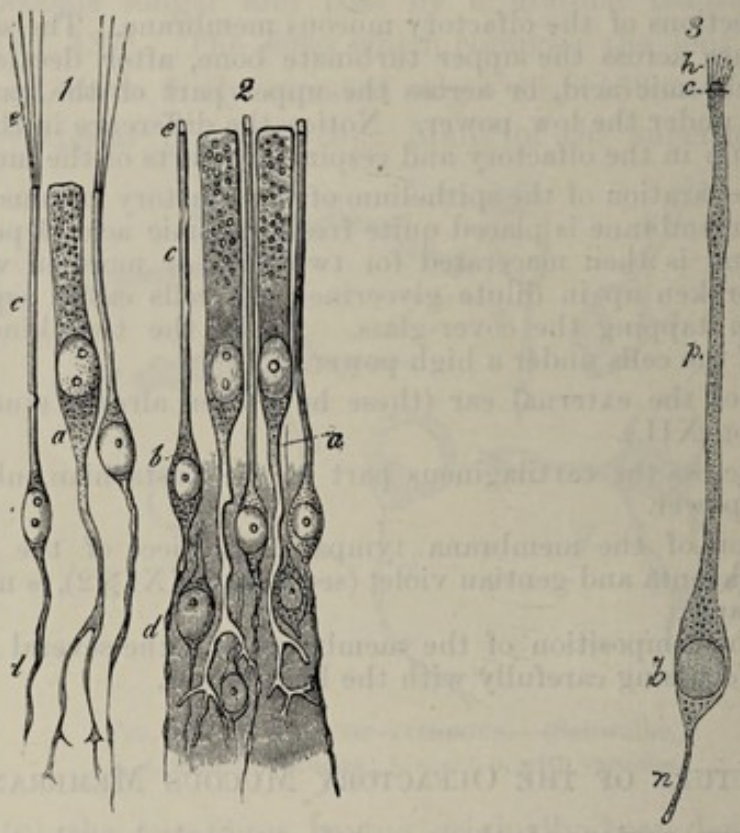


FIG. 440.—CELLS AND TERMINAL NERVE-FIBRES OF THE OLFACTORY REGION. (Highly magnified.)

1, from the frog; *2* and *3*, from man. In *1* and *2*:—*a*, epithelial cell, extending deeply into a ramified process; *b*, olfactory cells; *c*, their peripheral rods; *e*, the extremities of these, seen in *1* to be prolonged into fine hairs; *d*, their central filaments. In *3*:—*h*, hairlets; *c*, free border of cell; *p*, peripheral process; *b*, body of cell; *n*, nerve-fibre. *1* and *2* from M. Schultze; *3* from v. Brunn.

have been termed the *olfactory cells*. 2. Long columnar epithelium-cells (*a*), with comparatively broad cylindrical nucleated cell-bodies placed next to the free surface, and long, forked, and branching tail-like processes extending down to the corium. These are regarded not as sensory epithelium-cells, but merely as serving to support the proper olfactory cells. They are the *columnar* or *sustentacular cells*. 3. Tapering cells are present, at least in some animals, in the deeper part of the epithelium. They rest by their bases upon the corium, and project between the other cells, which they assist to support.

The *corium* of the olfactory mucous membrane is also very thick (fig. 441). It contains numerous blood-vessels, bundles of the olfactory nerve-fibres (which are non-medullated), and a large number of serous glands known as *Bowman's glands* (*b*), which open upon the surface by ducts which pass between the epithelium-cells.

Structure of the Auditory Organ.

The **external ear** proper (*pinna*) is composed of elastic fibro-cartilage, invested by a thin closely adherent skin. The skin is covered by small hairs, and connected with these are the usual sebaceous follicles. In some parts—*e.g.* the lobule—there is a considerable amount of adipose tissue; and voluntary muscular fibres are in places attached to the cartilage, and may therefore be seen in sections of the ear.

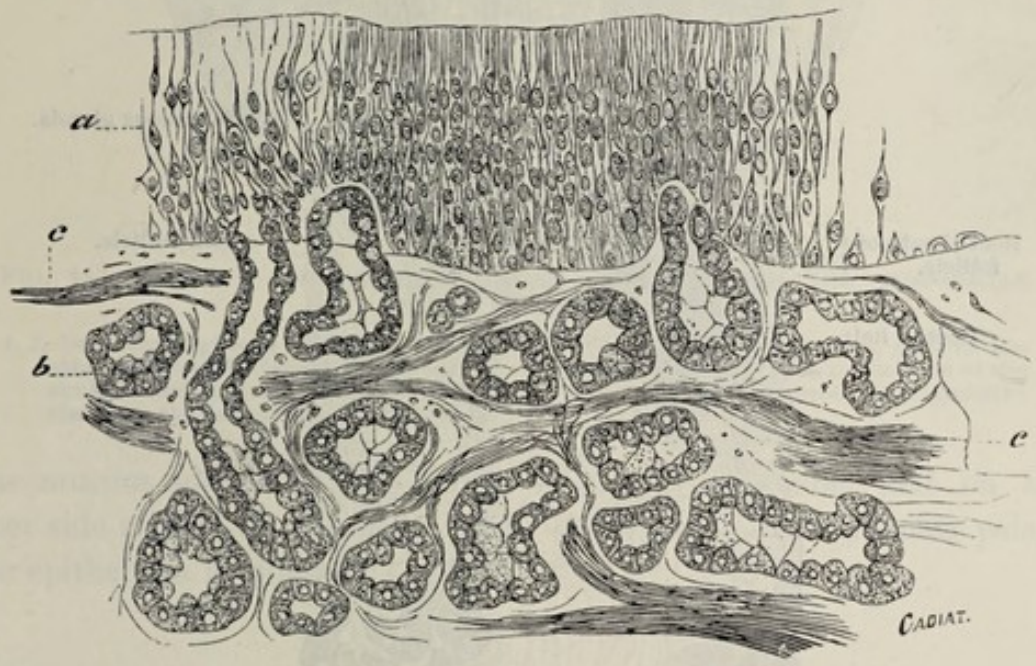


Fig. 441.—Section of olfactory mucous membrane. (Cadiat.)
a, epithelium; *b*, glands of Bowman; *c*, nerve-bundles.

The **external auditory meatus** is a canal formed partly of cartilage continuous with that of the pinna, partly of bone. It is lined by a prolongation of the skin and is closed by the membrana tympani, over which the skin is prolonged as a very thin layer. Near the orifice the skin has hairs and sebaceous glands, and the meatus is also provided throughout the cartilaginous part with small convoluted tubular glands of a brownish-yellow colour, which yield a waxy secretion (*ceruminous glands*). They appear to represent modified sweat-glands. They are represented in fig. 442.

The **tympanum** is lined by a mucous membrane which is continuous through the Eustachian tube with the mucous membrane of the

pharynx; it is also prolonged into the mastoid cells. The epithelium is columnar and ciliated in some parts, but in others—*e.g.* roof, promontory, ossicles, and membrana tympani—it is a pavement-epithelium.

The **membrani tympani** is a thin membrane formed of fibrous bundles which radiate from a central depression (umbo). Within

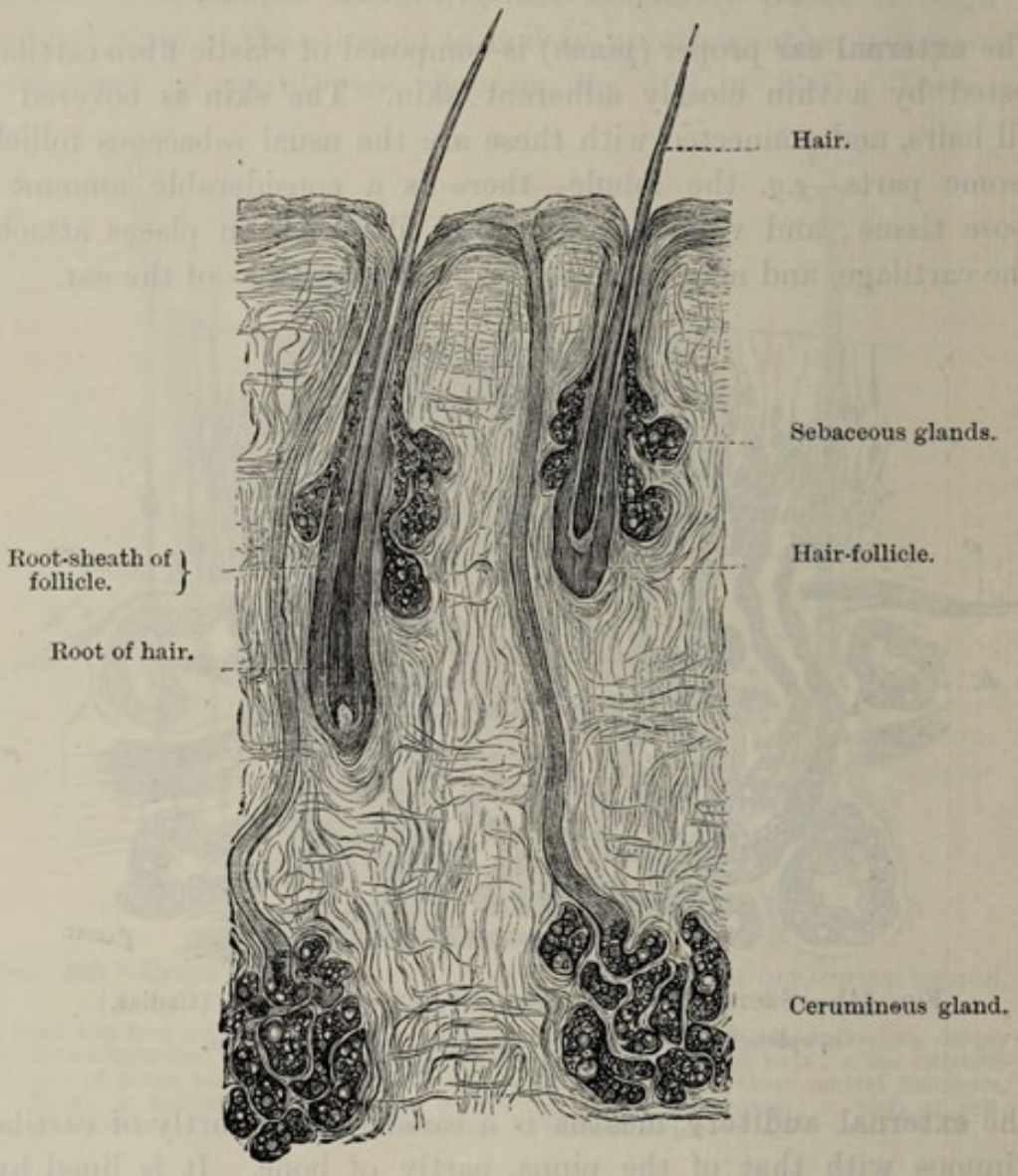


FIG. 442.—CERUMINOUS GLANDS AND HAIRS OF THE EXTERNAL EAR. (Grüber.)

the radial fibres are a few annular bundles. Covering the fibrous membrane externally is a thin layer continuous with the skin of the meatus; covering it internally is another thin layer, derived from the mucous membrane of the tympanic cavity. Blood-vessels and lymphatics are distributed to the membrane chiefly in the cutaneous and mucous layers.

The **Eustachian tube** is the canal leading from the tympanum to

the pharynx. It is formed of bone near the tympanum, but below, near the pharynx, it is bounded partly by a bent piece of cartilage (fig. 443, 1, 2), partly by fibrous tissue. The latter contains nume-

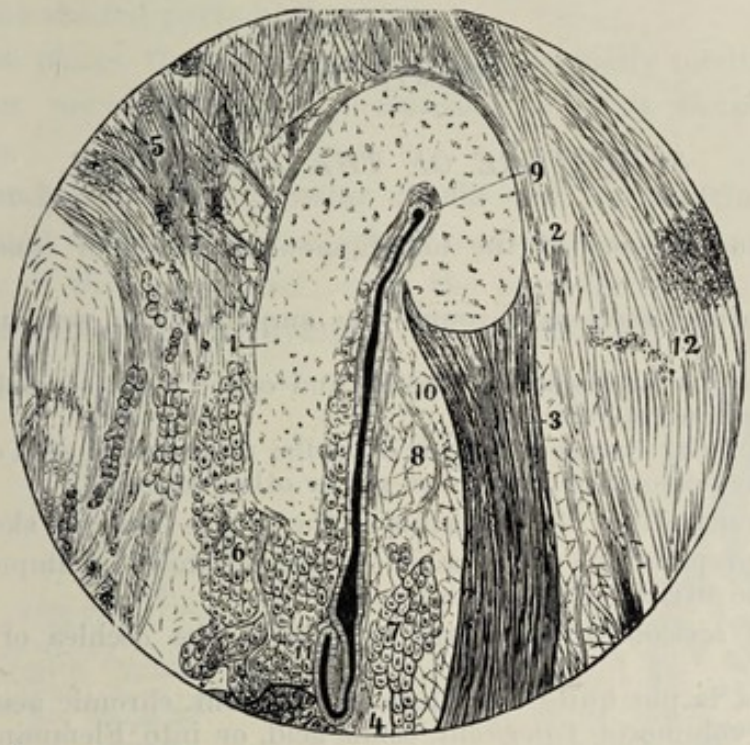


FIG. 443.—SECTION ACROSS THE CARTILAGINOUS PART OF THE EUSTACHIAN TUBE. (Rüdinger.)

1, *2*, bent cartilaginous plate; *3*, musc. dilatator tubæ; to the left of *4*, part of the attachment of the levator palati muscle; *5*, tissue uniting the tube to the base of the skull; *6* and *7*, mucous glands; *8*, *10*, fat; *9* to *11*, lumen of the tube; *12*, connective tissue on the lateral aspect of the tube.

rous mucous glands (6, 7), which open into the tube, and on the outer side a band of muscular tissue (3) which joins the tensor palati. The epithelium is ciliated.

LESSON XLVI.

STRUCTURE OF THE LABYRINTH.

1. Sections across one of the membranous semicircular canals of a fish (skate).

2. Longitudinal sections through the ampulla of a semicircular canal (skate).

1 and 2 may be hardened in chromic and osmic acid (see below under 5) and embedded in celloidin.

The semicircular canals and their ampullæ may also be seen cut across in sections of the petrosal of the guinea-pig or other mammal.

3. Golgi preparations of the macula of the utricle from the skate.

4. Teased preparations of the auditory epithelium of an ampulla or of the macula of the utricle, from the skate.

5. Vertical sections through the middle of the cochlea of a mammal (guinea-pig).

The cochlea is put quite fresh into 0·2 per cent. chromic acid containing one-fifth its volume of 1 per cent. osmic acid, or into Flemming's solution. The decalcification can be hastened by the use of the phloroglucin-nitric acid fluid.[1] When decalcified, the preparation is well washed, and then placed in spirit.

In preparing sections of the above three preparations it is advisable, in order that the epithelium should be kept in position, to embed in celloidin. If the paraffin method of embedding be used, the sections are fixed to the slide by an adhesive process. The organ should preferably be stained in bulk.

6. Teased preparations of the epithelium of the organ of Corti from the guinea-pig.

Both 4 and 6 are made from osmic preparations.

Make sketches from all these preparations under the high power.[2]

The **labyrinth**, which is the essential part of the auditory organ, consists of a complex membranous tube lined by epithelium and filled with endolymph, contained within a bony tube—the osseous labyrinth—of corresponding complexity of shape (figs. 444, 445). The membranous labyrinth does not wholly fill the bony cavity ; the rest of the space is occupied by perilymph. The membranous labyrinth (fig. 444) is composed of the *utricle* (*u*), and the three *semicircular canals*—each with an enlargement or ampulla which opens into it—the *saccule* (*s*), and the *canal of the cochlea* (*c.c.*).

[1] See Appendix.

[2] For the methods of obtaining the various parts of the labyrinth for microscopical examination, the reader is referred to the author's *Course of Practical Histology*.

The branches of the auditory nerve pass to certain parts only of the membranous labyrinth, viz. the maculæ of the utricle and saccule, the cristæ of the ampullæ, and along the whole length of the canal of the cochlea (the shaded parts in fig. 444).

At these places the lining epithelium is specially modified to form a sensory or nerve-epithelium; elsewhere it is a simple pavement-epithelium.

The **membranous semicircular canals** and the **utricle** and **saccule** are composed of fibrous tissue, which is adherent along one side to the endosteum of the bony canal; from the opposite side bands of fibrous tissue pass across the perilymph. Within the fibrous membrane is a

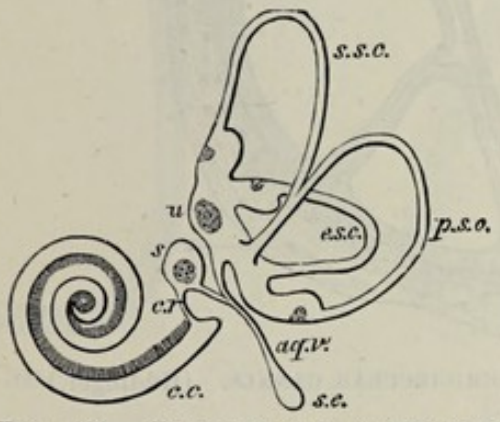


FIG. 444.—PLAN OF THE RIGHT MEMBRANOUS LABYRINTH VIEWED FROM THE MESIAL ASPECT. $\frac{2\frac{1}{2}}{1}$.

u, utricle, with its macula and *s.s.c.*, *p.s.c.*, and *e.s.c.*, the three semicircular canals with their ampullæ; *s*, saccule; *aq.v.*, aquæductus vestibuli; *s.c.*, saccus endolymphaticus; *c.r.*, canalis reuniens; *c.c.*, canal of the cochlea.

FIG. 445.—VIEW OF THE INTERIOR OF THE LEFT OSSEOUS LABYRINTH.

The bony wall of the labyrinth is removed superiorly and externally. 1, fovea hemielliptica; 2, fovea hemisphærica; 3, common opening of the superior and posterior semicircular canals; 4, opening of the aqueduct of the vestibule; 5, the superior, 6, the posterior, and, 7, the external semicircular canals; 8, spiral tube of the cochlea; 9, scala tympani; 10, scala vestibuli.

thick clear tunica propria, which, in the semicircular canals, forms papilliform elevations in the interior of the tube (figs. 446, 447).

The places of entrance of the nerve-fibres are marked in the ampullæ by a transverse, inwardly projecting ridge (*crista*), in the saccule and utricle by a thickening of the tunica propria (*macula*). The epithelium at these places is formed of columnar cells (fig. 448), which are surmounted by long, stiff, tapering hairs (*auditory hairs*, fig. 448, *h*), and around these *hair-cells* the axis-cylinders of the nerve-fibres ramify (fig. 450); they are therefore—like the gustatory cells of the taste-buds—sensory epithelium cells. Between them are a number of thin and somewhat rigid nucleated cells (*fibre-cells* of Retzius), which rest upon the basement-membrane, and are connected at their free extremity with a cuticular membrane, through which the auditory hairs project.

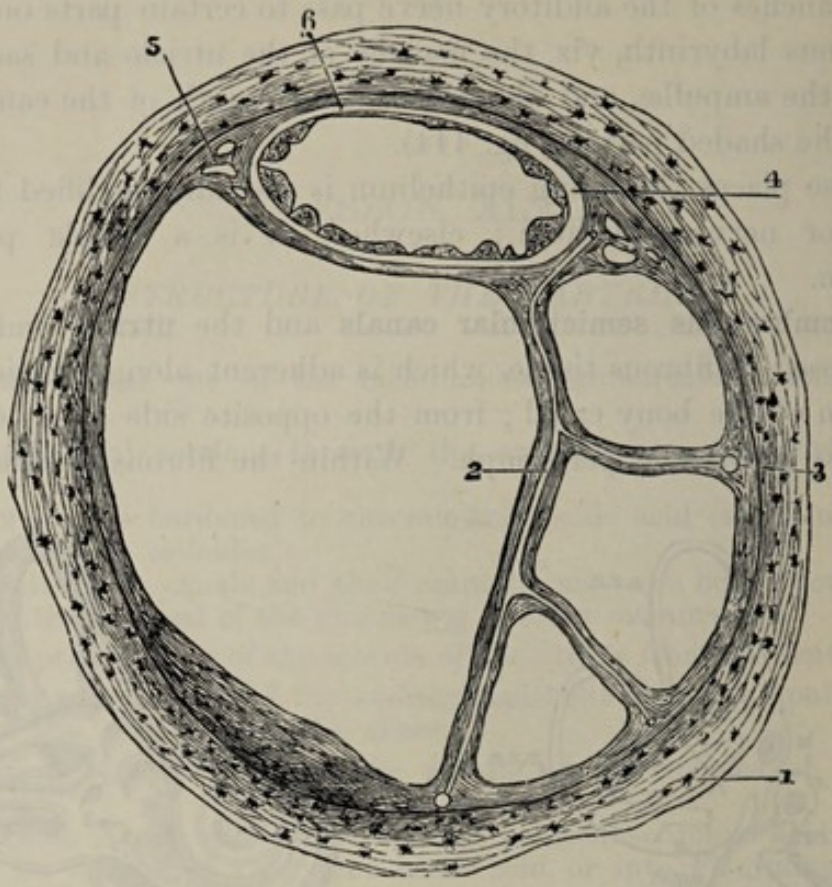


FIG. 446.—SECTION OF ONE OF THE HUMAN SEMICIRCULAR CANALS. (Rüdinger.) (Magnified.)

1, osseous wall; 2, fibrous bands with included blood-vessels, united at 3 with the periosteum; 4, membranous canal with its three layers; 5, short fibrous bands (with intervening spaces) uniting the membranous canal firmly to the periosteum; 6, union of its outermost layer with the periosteum.

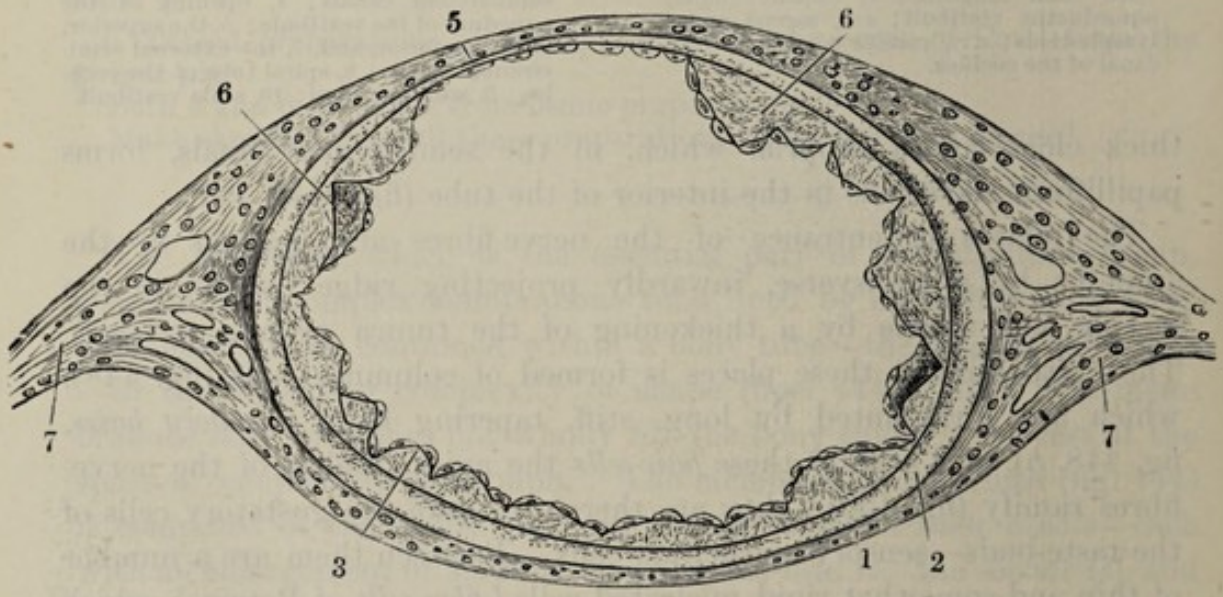


FIG. 447.—SECTION OF MEMBRANOUS SEMICIRCULAR CANAL. (Rüdinger.) (More magnified.)

1, outer fibrous layer; 2, tunica propria; 3, 6, papilliform projections with epithelial covering; 5, fixed side of the canal, with very thin tunica propria without papillæ; 7, fibrous bands passing to periosteum.

The auditory hairs do not jut freely into the endolymph, but into a soft mucus-like substance, of a dome-like form in the ampullæ (*cupula*

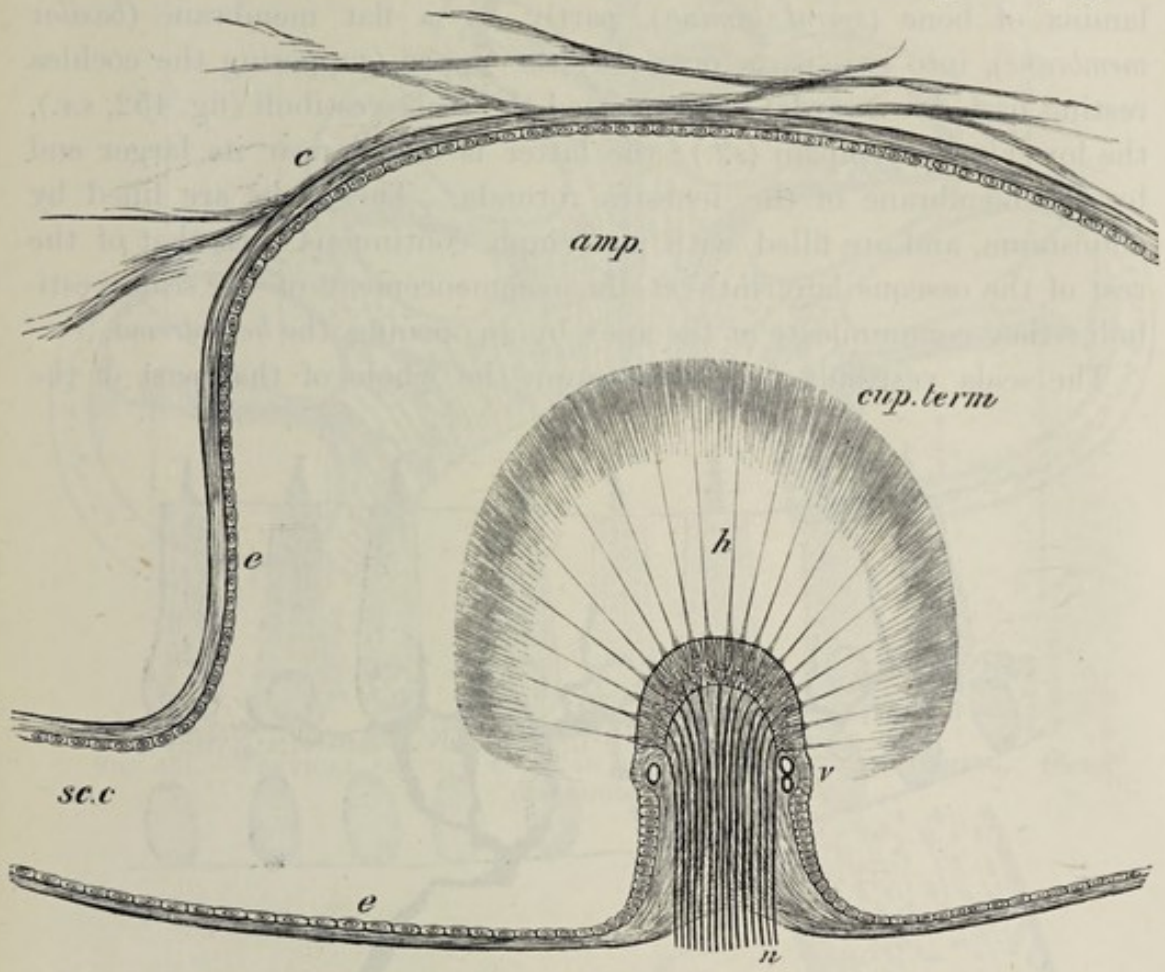


FIG. 448.—LONGITUDINAL SECTION OF AN AMPULLA THROUGH THE CRISTA ACUSTICA (SEMIDIAGRAMMATIC).

amp., cavity of the ampulla; *sc.c.*, semicircular canal opening out of it; *c*, connective tissue attached to the wall of the membranous ampulla and traversing the perilymph; *e*, *e*, flattened epithelium of ampulla; *h*, auditory hairs projecting from the columnar cells of the auditory epithelium into the cupula, *cup.term*; *v*, blood-vessels; *n*, nerve-fibres entering the base of the crista and passing into the columnar cells.

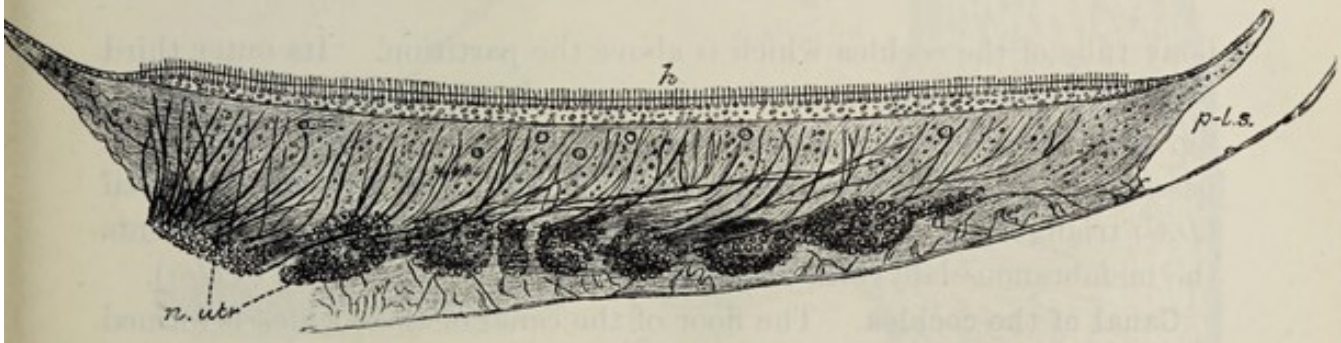


FIG. 449.—SECTION OF MACULA OF UTRICLE, MAN. (G. Retzius.)

n. utr, bundles of the utricular branch of the vestibular part of the eighth nerve; *h*, auditory hairs; *p.l.s.* perilymphatic space.

terminalis, fig. 488), and which in the saccule and utricle has a mass of calcareous particles (*otoliths*) embedded in it.

The **cochlea** consists of a bony tube coiled spirally around an axis

which is known as the *columella* (fig. 451). The tube is divided longitudinally by a partition which is formed partly by a projecting lamina of bone (*spiral lamina*), partly by a flat membrane (*basilar membrane*), into two parts or *scalæ*; the upper (supposing the cochlea resting base downwards) being termed the scala vestibuli (fig. 452, *s.v.*), the lower scala tympani (*s.t.*); the latter is closed near its larger end by the membrane of the fenestra rotunda. The scalæ are lined by endosteum, and are filled with perilymph, continuous with that of the rest of the osseous labyrinth at the commencement of the scala vestibuli; they communicate at the apex by an opening, the *helicotrema*.

The scala vestibuli does not occupy the whole of that part of the

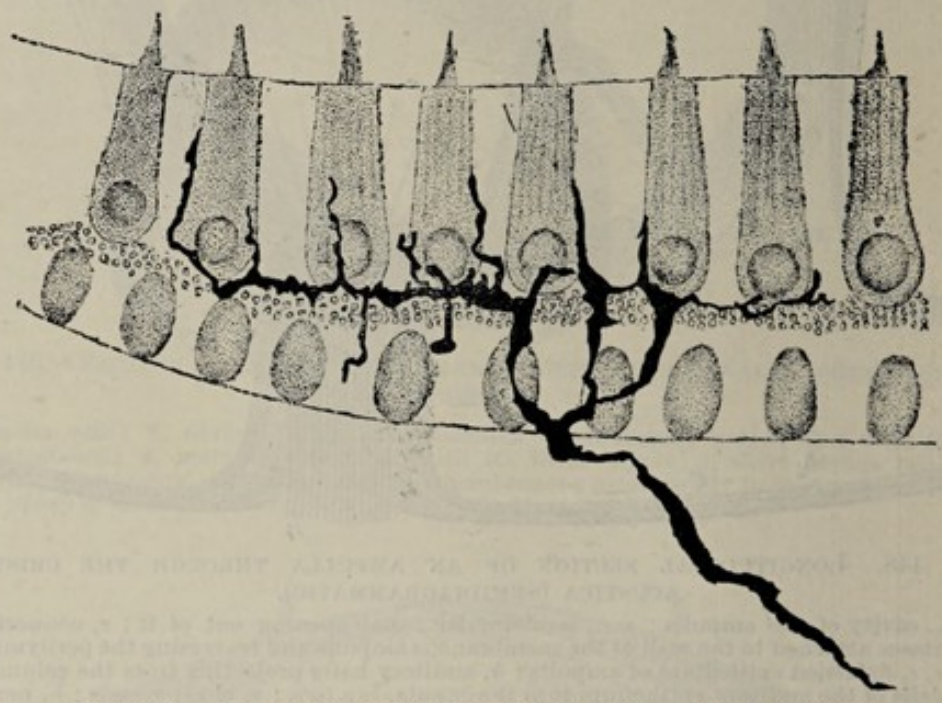


FIG. 450.—NERVE TERMINATIONS IN MACULA. GOLGI METHOD. (Barker, from Lenhossék.)

bony tube of the cochlea which is above the partition. Its outer third is cut off by a delicate connective-tissue membrane (*membrane of Reissner*, fig. 452, *R*), which springs from near the end of the spiral lamina, and passes upwards and outwards to the outer wall, thus separating a canal (*D.C*) triangular in section, which is lined by epithelium, and represents the membranous labyrinth of the cochlea (*duct or canal of the cochlea*).

Canal of the cochlea.—The floor of the canal of the cochlea is formed (1) of the extremity of the spiral lamina, which is thickened above by a peculiar kind of connective tissue, forming an overhanging projection known as the *limbus* (fig. 452, *l*); (2) of the basilar membrane (*b.m.*), which stretches across from the end of the bony lamina to the outer wall, and is attached to this by a projection of reticular connective tissue termed the *spiral ligament* (*l.sp*).

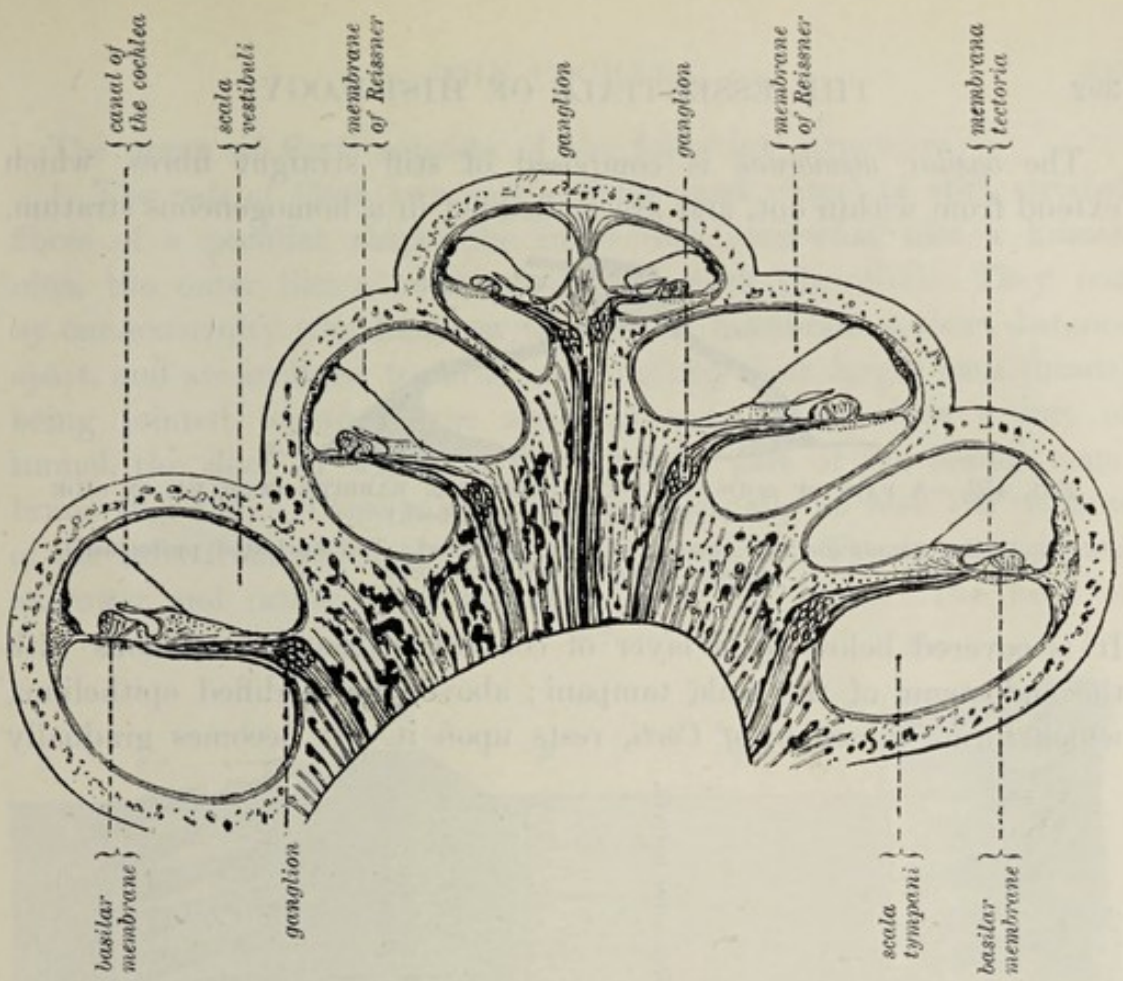


FIG. 451.—VERTICAL SECTION THROUGH THE MIDDLE OF THE COCHLEA. (Semi-diagrammatic.)

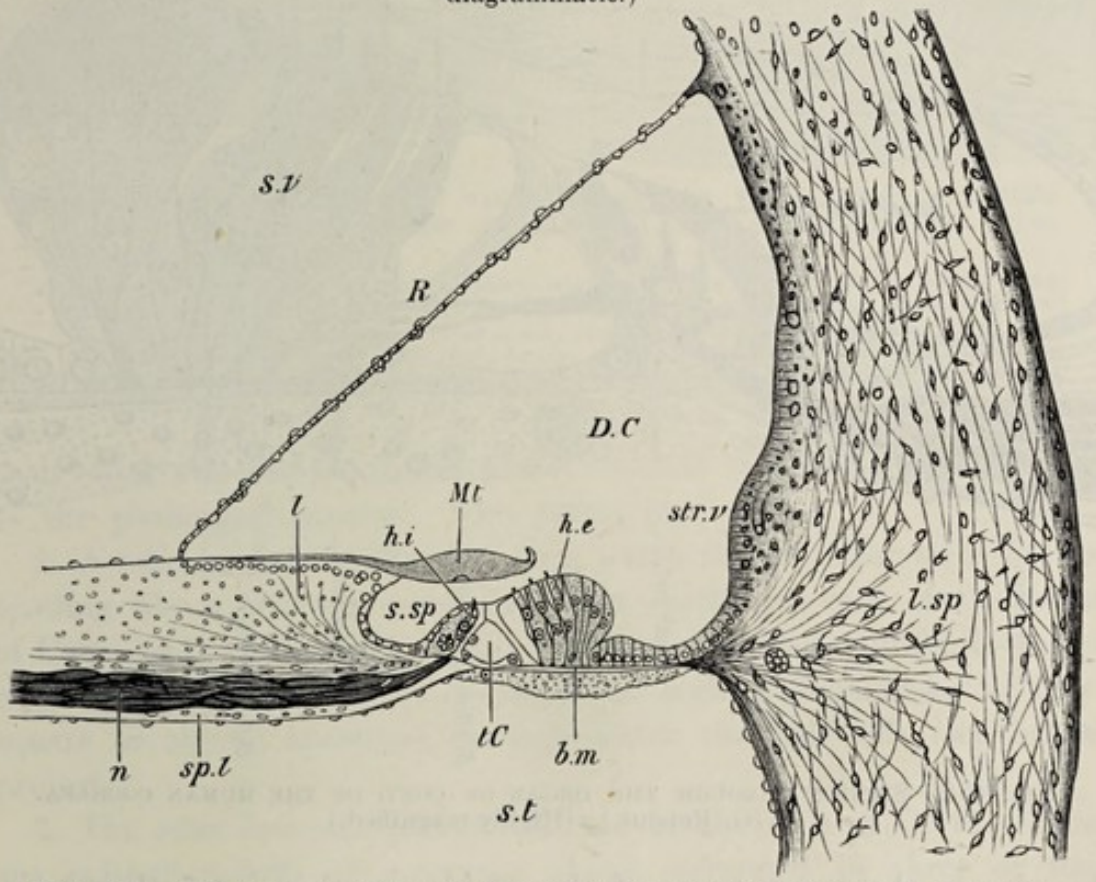


FIG. 452.—VERTICAL SECTION OF THE FIRST TURN OF THE HUMAN COCHLEA. (G. Retzius.)

s.v, scala vestibuli; *s.t*, scala tympani; *D.C*, canal of the cochlea; *sp.l*, spiral lamina; *n*, nerve-fibres; *l.sp*, spiral ligament; *str.v*, stria vascularis; *s.sp*, spiral groove; *R*, section of Reissner's membrane; *l*, limbus laminæ spiralis; *Mt*, membrana tectoria; *tC*, tunnel of Corti; *b.m*, basilar membrane; *h.i*, *h.e*, internal and external hair-cells.

The *basilar membrane* is composed of stiff straight fibres, which extend from within out, and are embedded in a homogeneous stratum.

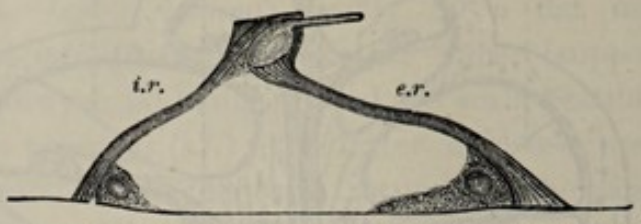


FIG. 453.—A PAIR OF RODS OF CORTI, FROM THE RABBIT'S COCHLEA, IN SIDE VIEW. (Highly magnified.)

b, *b*, basilar membrane; *i.r.*, inner rod; *e.r.*, outer rod. The nucleated protoplasmic masses at the feet are also shown.

It is covered below by a layer of connective tissue continuous with the endosteum of the scala tampani; above, the modified epithelium, which forms the *organ of Corti*, rests upon it. It becomes gradually

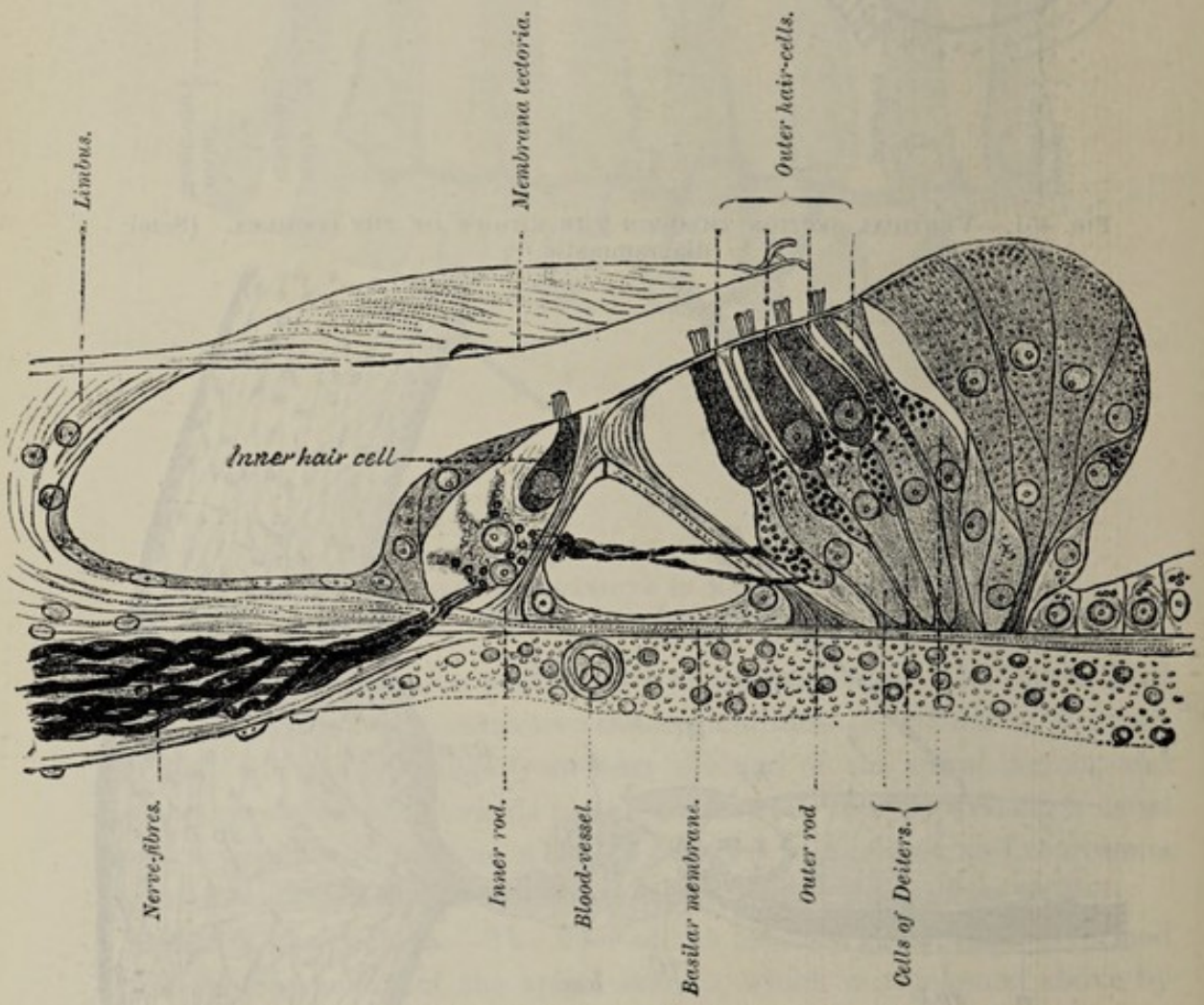


FIG. 454.—SECTION THROUGH THE ORGAN OF CORTI OF THE HUMAN COCHLEA. (G. Retzius.) (Highly magnified.)

broader in the upper turns of the cochlea (rather more than twice as broad in the uppermost as in the lowermost turn), and its constituent fibres become therefore gradually longer.

The **organ of Corti** consists of the following structures:

1. The *rods of Corti*, two series (inner and outer) of stiff, striated fibres of a peculiar shape, the inner rods somewhat like a human ulna, the outer like a swan's head and neck (fig. 453). They rest by one extremity (the foot) on the basilar membrane a short distance apart, and are inclined towards one another, their larger ends (heads) being jointed together; the series of rods thus inclose a sort of tunnel, the floor of which is formed by a part of the basilar membrane (fig. 455). Close to their feet may usually be seen the remains of the cells from which they have been formed. The inner rods are narrower and rather more numerous than the outer. The head of

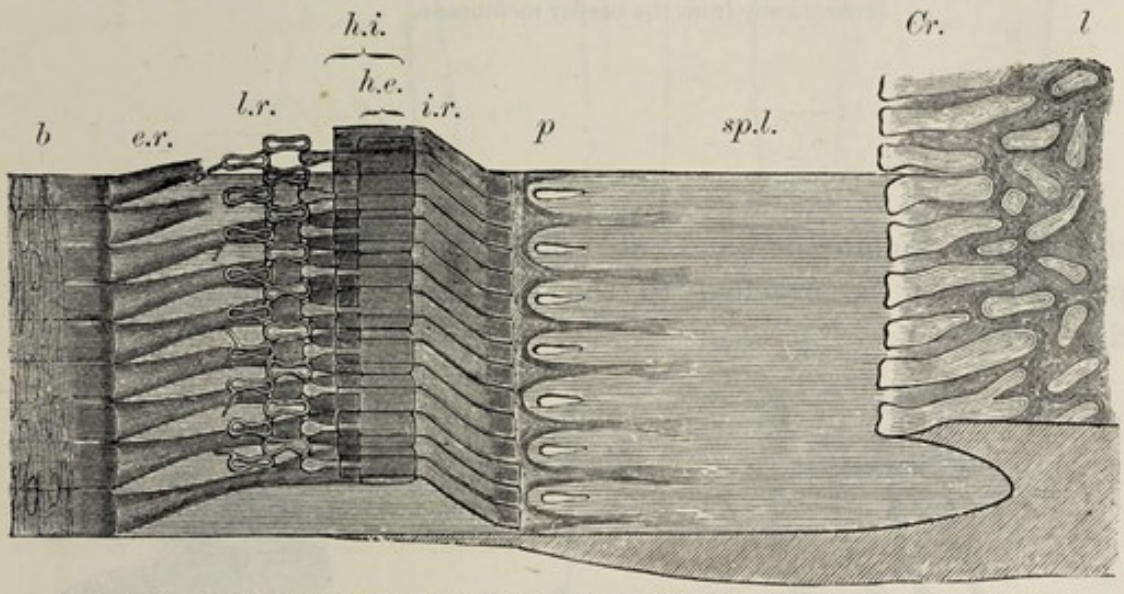


FIG. 455.—SEMI-DIAGRAMMATIC VIEW OF PART OF THE BASILAR MEMBRANE AND TUNNEL OF CORTI OF THE RABBIT, FROM ABOVE AND THE SIDE. (Much magnified.)

l, limbus; *Cr*, extremity or crest of limbus with tooth-like projections; *b*, basilar membrane; *sp.l.*, spiral lamina with, *p*, perforations for transmission of nerve-fibres; *i.r.*, fifteen of the inner rods of Corti; *h.i.*, their flattened heads seen from above; *e.r.*, nine outer rods of Corti; *h.e.*, their heads, with the phalangeal processes extending outward from them and forming, with the two rows of phalanges, the lamina reticularis, *l.r.*

each outer rod has a process which extends outwards and is known as the phalangeal process. This forms part of—

2. A *reticular lamina* (fig. 455, *l.r.*), which is a cuticular structure extending like a wire-net over the outer epithelium-cells of the organ of Corti, and is composed of two or three series of stiff fiddle-shaped rings (*phalanges*) cemented together in such a manner as to leave square or oblong apertures through which the hair-cells (see below) project.

3. The *outer hair-cells* placed external to the rods of Corti. These are epithelium-cells of columnar shape, arranged in three or four series (fig. 454). The free extremity of the cell is surmounted by a bundle of short *auditory hairs*, and projects through one of the

apertures in the reticular lamina; the fixed extremity is prolonged into a stiff cuticular process (fig. 456, *p*), which is attached to the basilar membrane. Between them are other supporting cells which are tapered in the same manner, but rest by their larger end upon

FIG. 456.—AN OUTER HAIR-CELL IN CONNECTION WITH ITS BASILAR PROCESS. From the guinea-pig. (Highly magnified.)

Two auditory hairs have remained attached to the cell; *b*, bulged lower end of cell; *p*, basilar process, protoplasmic above, but becoming cuticular below, and slightly expanded at the extremity, *f*, which is broken away from the basilar membrane.

the basilar membrane, and are prolonged above into a cuticular process which is attached to the reticular lamina (*cells of Deiters*, figs. 454, 457).

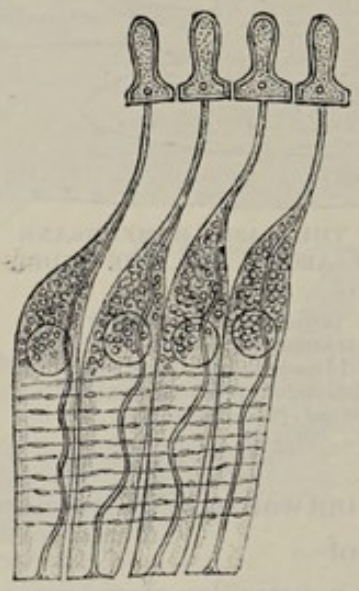


FIG. 457.

FIG. 458.

FIG. 457.—FOUR CELLS OF DEITERS FROM THE RABBIT. (After G. Retzius.) (Highly magnified.)

The varicose lines are spirally-running nerve-fibrils. The phalangeal processes are attached above to a portion of the lamina reticularis.

FIG. 458.—GENERAL VIEW OF THE MODE OF DISTRIBUTION OF THE COCHLEAR NERVE, ALL THE OTHER PARTS HAVING BEEN REMOVED. (Arnold.)

4. The *inner hair-cells* (fig. 454), placed internal to the rods of Corti. They form a single series of columnar cells surmounted by auditory hairs, lying in close apposition to the inner rods.

The remaining epithelium-cells have no important characteristics. They are long and columnar next to the outer hair-cells, but soon diminish in size, becoming cubical, and in this form they are continued over the outer wall of the cochlear canal. Here they cover a very vascular membrane (*stria vascularis*, fig. 452, *str.v.*), which is frequently pigmented; its capillary blood-vessels penetrate between

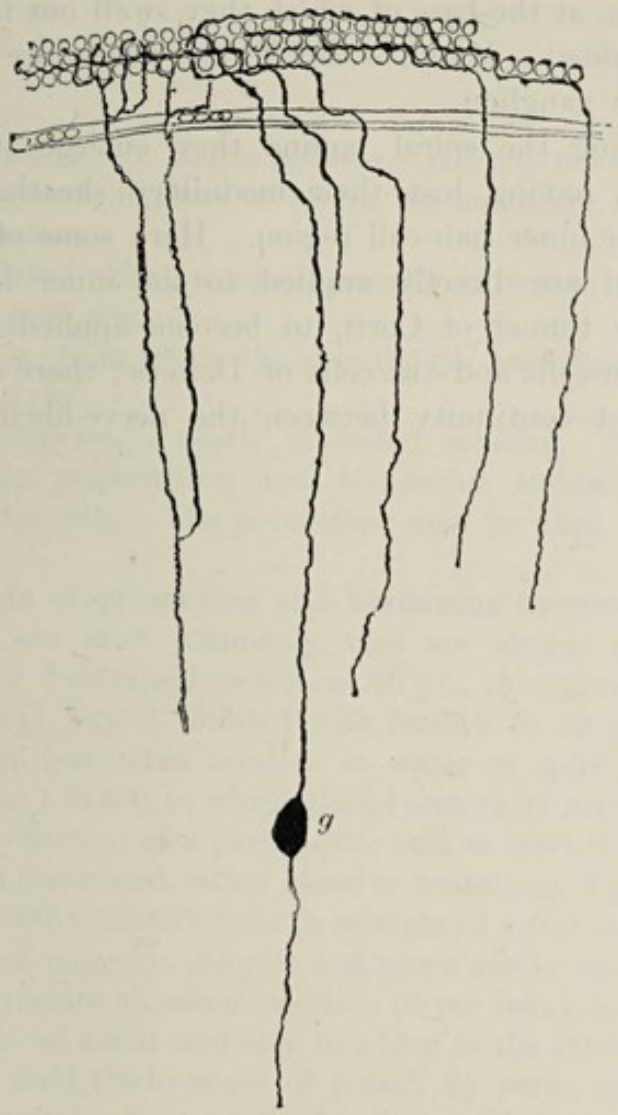


FIG. 459.—ENDING OF SOME OF THE FIBRES OF THE COCHLEAR NERVE AMONGST THE HAIR-CELLS. (G. Retzius.)

This preparation is made by Golgi's method, and is viewed from above. *g*, a cell belonging to the spiral ganglion.

the epithelium-cells. Internal to the inner hair-cells the epithelium also soon becomes cubical; it is prolonged in this form over the limbus of the spiral lamina. The epithelium of Reissner's membrane is of the pavement variety.

The *membrana tectoria* (figs. 452, 454) is a soft, fibrillated structure, which is attached along the upper surface of the limbus, and lies like a pad over the organ of Corti. It thins out towards the distal margin, here becoming somewhat reticular, and, according to Retzius,

it is attached to the lamina reticularis. In sections it usually appears raised a short distance above the auditory hairs, but it is probable that it always rests upon them during life.

The fibres of the cochlear branch of the auditory nerve enter the base of the columella, and run in canals through its substance (fig. 451), being gradually deflected outwards as they pass upwards into the spiral lamina, at the base of which they swell out into a ganglionic cord (*spiral ganglion*). Many, if not all the fibres, are connected with the cells of this ganglion.

After traversing the spiral lamina they emerge in bundles, and the fibres then, having lost their medullary sheath, pass into the epithelium of the inner hair-cell region. Here some of them course at right angles and are directly applied to the inner hair-cells, whilst others cross the tunnel of Corti, to become applied in like manner to the outer hair-cells and the cells of Deiters; there does not appear to be any direct continuity between the nerve-fibrils and the cell-substance.

APPENDIX.

Mounting solutions:—1. *Saline solution.*—A 0·6 to 0·9 per cent. solution of common salt is used in place of serum for mounting fresh tissues for immediate examination.

2. *Glycerine*, diluted with an equal quantity of water. The cover-glass may be fixed by gold size.

3. *Canada balsam*, from which the volatile oils have been driven off by heat, dissolved in xylol.

4. *Acetate of potassium*, a nearly saturated solution. This is the best medium for osmic preparations and for iodine stained liver, showing glycogen within the cells. The cover-glass may be fixed by soluble glass or by gold size.

General methods of preserving and hardening tissues and organs.—The fluids which are most commonly used are alcohol (75 per cent. to absolute); Carnoy's fluid (absolute alcohol 60 c.c., chloroform 30 c.c. glacial acetic acid 10 c.c.); formol (diluted with from 9 to 99 parts of water); corrosive sublimate (saturated solution in water or spirit); chromic acid solution (1 in 200 to 1 in 500, to which glacial acetic acid may advantageously be added in the proportion of 2 parts acetic acid to 1000 chromic solution); picric acid solution (saturated, either alone or containing 2 parts of nitric or sulphuric acid to 1000); Mann's fluid (a mixture of equal parts of saturated aqueous solutions of mercuric chloride and picric acid); osmic acid solution (1 per cent.); bichromate of potash solution (3 per cent.), to which for more rapid hardening glacial acetic acid may be added to the extent of 5 per cent. or less; Müller's fluid (bichromate of potash 2½ parts, sulphate of soda 1 part, water 100 parts); Zenker's fluid (which is Müller's fluid containing 5 parts per cent. of mercuric chloride, to which 5 c.c. of acetic acid is added at the time of use); and mixtures of Müller's fluid and osmic acid 1 per cent. in varying proportions.

It is best, if possible, to inject the fluid used for hardening into the blood-vessels after washing them out with warm normal saline; if this is not possible, very small pieces of tissue should be taken, and always a considerable amount of the hardening fluid.

The fluid of most universal application is formol. This is a 40 per cent. solution of formaldehyde. Mixed in the proportion of 2 to 5 parts formol to 100 water, it penetrates readily and hardens quickly.

For preserving the structure of cells and nuclei, one of the best fixing

fluids is that recommended by Flemming. This consists of 15 vols. of 1 per cent. chromic acid, 4 vols. of 2 per cent. osmic acid, and 1 vol. glacial acetic acid. It is sometimes diluted with from two to five times its bulk of water before use. Three or four days is generally sufficient. The tissue should be washed for several hours in running water after hardening, and then placed in alcohol. Carnoy's fluid is also excellent for cell-structure and mitotic changes, and very rapid in its action.

Tissues to be hardened in alcohol are usually placed at once in strong methylated spirit, or, better, in absolute alcohol, but for some tissues it is best to begin with 50 per cent. alcohol, and pass the pieces through successive grades of 75 per cent., 95 per cent., into absolute alcohol, leaving them a few hours in each. They are ready for cutting as soon as they are dehydrated, but as a rule they may be left indefinitely in alcohol without deterioration. Organs which contain much fibrous tissue, such as the skin and tendons, should not go into stronger alcohol than about 80 or 90 per cent. ; otherwise they become too hard to cut. Alcohol is generally used after the other fixing reagents, partly to complete the hardening, partly on account of its dehydrating property, since previous to embedding in paraffin all trace of water must be eliminated from the tissue. If mercuric chloride be used for hardening, tincture of iodine must be added to the alcohols subsequently used (except the final alcohol), to get rid of the excess of sublimate. Mercuric chloride in alcohol (saturated solution) is one of the most rapid fixing and hardening reagents, and may be used if sections are desired within a very short time. It can also be used in place of alcohol and ether mixture for fixing blood films (Lesson II., § 5), in which case it may be saturated with eosin, and used for fixing and staining at the same time. An immersion of 5 minutes is sufficient.

Many tissues can be instantly hardened by being plunged for a minute into boiling water and then placed in alcohol : this is not, however, a good method for glandular organs.

For tissues that are to be hardened in chromic acid an immersion of from 7 to 14 days is generally necessary ; they may then, after washing for some hours or days in tap-water, be placed in alcohol for preservation and to complete the process of hardening. The spirit should be changed once or twice.

Organs placed in bichromate of potash or Müller's fluid are ready for section in a fortnight or three weeks ; they may, however, be left for a much longer time in those fluids without deterioration.

With picric acid the hardening process is generally complete in 2 or 3 days ; the organs may then be transferred to spirit, which ought to be frequently changed.

The hardening of the brain and spinal cord in Müller's fluid takes from 3 weeks to as many months. It can be hastened by warmth, and by the addition of acetic acid, or by placing small pieces in Marchi's solution (see below), after they have been a week or 10 days in Müller's fluid.

Tissues containing calcareous matter, *e.g.* bone and tooth, may be rapidly decalcified in a solution made by dissolving, with the aid of heat, 1 grm.

phloroglucin in 10 c.c. nitric acid, and filling up to 100 c.c. with water, to which more nitric acid may be added if desired. For decalcifying more slowly a 1 to 5 per cent. solution of nitric acid in water or alcohol, a saturated solution of picric acid containing a superabundance of crystals, or a 1 per cent. solution of chromic acid may be employed.

Embedding of hardened tissues, and preparation of sections.—Sections are most advantageously made with some form of microtome. It is generally needful to support the hardened tissue whilst it is being cut, and with this object it is embedded in some substance which is applied to it in the fluid condition and becomes solid on standing. The embedding substance can either simply inclose the tissue, or the tissue may be soaked in it: the latter method is the one most commonly employed.

The embedding substance chiefly used is paraffin of 50° C. melting point.

Embedding in paraffin.—Before being soaked in melted paraffin, the piece of tissue may be stained; it is then dehydrated by a series of alcohols (50 per cent., 75 per cent., 95 per cent.) finishing up with absolute alcohol, and soaked in cedar-wood oil, xylol, or chloroform. It is now transferred to molten paraffin, which should not be too hot, and is soaked in this for one or several hours, according to thickness. It is then placed in a mould or in a watch-glass which has been smeared with glycerine, and is covered with molten paraffin which is allowed to cool quickly. A square block of the paraffin containing the tissue is then fixed in the desired position on the microtome, thin sections are cut and fixed to a slide (see below), the paraffin dissolved out by turpentine or xylol, and the sections mounted.

If it be desired to cut a riband of successive sections, and the paraffin used proves too hard for this purpose, a paraffin of lower melting point (40° C.) is smeared over the opposite sides of the block; the sections then adhere together as they are cut.

Preparation of frozen sections.—The bichromate solutions and formol are the best fluids to use for preserving tissues which are to be frozen in place of being embedded. The tissue requires to be soaked in gum-water before being placed upon the freezing microtome. A thin syrup of either gum arabic or dextrin may be used.

Embedding in celloidin.—The piece to be embedded is dehydrated by alcohol, and is then placed over night in a solution of celloidin in alcohol and ether similar to ordinary collodion, and afterwards in collodion of double strength. After 24 hours more it is removed from the celloidin (collodion) and placed upon a metal holder which is adapted to be fixed in the microtome when the celloidin has been hardened. When the celloidin is set by evaporation of its ether the holder is plunged in alcohol (85 per cent.), and after a few hours sections may be cut with a knife wetted with spirit of the same strength. The sections are placed in 95 per cent. alcohol; and passed through cedar-wood oil or bergamot oil into xylol balsam. They must not go into clove-oil, nor into absolute alcohol. The advantage of the method is that the celloidin, which is quite transparent, need not be got rid of in mounting the sections, and serves to keep the parts of a section together: it is thus very useful for friable tissues or for large sections. The

tissue may either be stained in bulk before embedding, or the sections may be stained.

Microtomes.—A section-cutting apparatus or microtome is essential for histological work. Several kinds are made, but those which are most generally useful are the Cathcart microtome for freezing ; the rocking microtome of the Cambridge Scientific Instrument Company, and the tripod microtome for objects which have been embedded in paraffin ; and the sliding microtome for celloidin-embedded tissues. The action of the rocker is automatic ; that is to say, every to-and-fro movement of the handle, H, not only cuts a section of the tissue of definite thickness, but also moves the paraffin block forwards in readiness for the next section. And by employing a rectangular block of paraffin of the proper consistency, a long series of

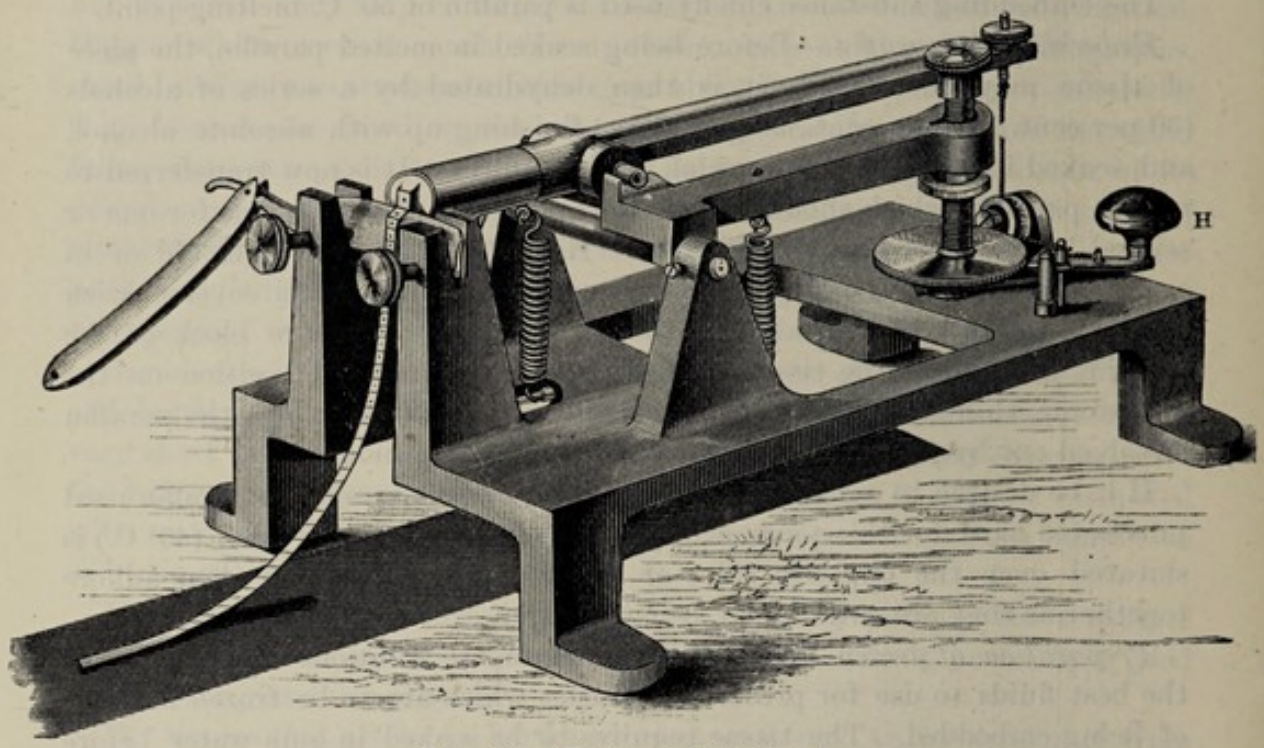


FIG. 460.—ROCKING MICROTOME.

sections of the same object, of equal thickness, can be obtained and made to adhere together in a riband (as shown in fig. 460). The sections can be kept in series by the employment of some adhesive method of mounting the riband. Other good automatic microtomes are those designed by Minot and Delepine, but they are more complicated and expensive.

The tripod microtome is a simple and efficient little instrument, and has the advantage of being very inexpensive. It consists of a metal frame (fig. 461) in which the razor is fixed, provided with a micrometer screw by which the height of the razor-edge is adjusted. The paraffin block containing the tissue is fixed by the aid of heat on a flat piece of glass over which the tripod slides. The razor-edge is lowered after each successive section.

In the Cathcart freezing microtome (fig. 462) the tissue, after being soaked in gum-water, is placed on a metal plate and frozen by playing an ether-spray on the under surface of the plate. The plate is moved upwards by a finely cut screw, and the knife or plane used to cut the sections is guided over the

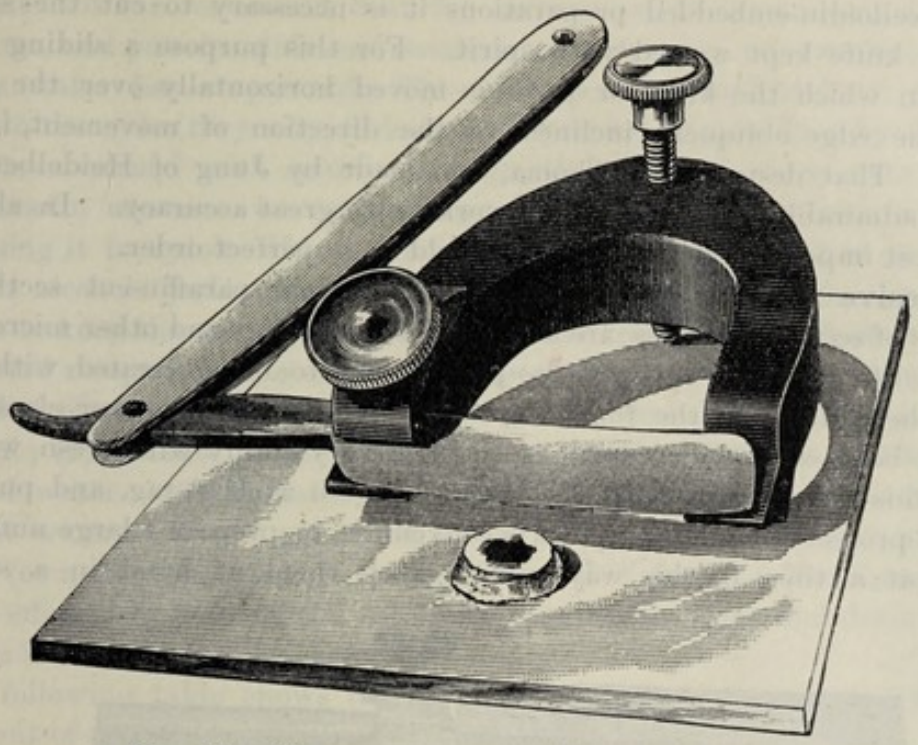


FIG. 461.—TRIPOD MICROTOME. (Birch's pattern.)

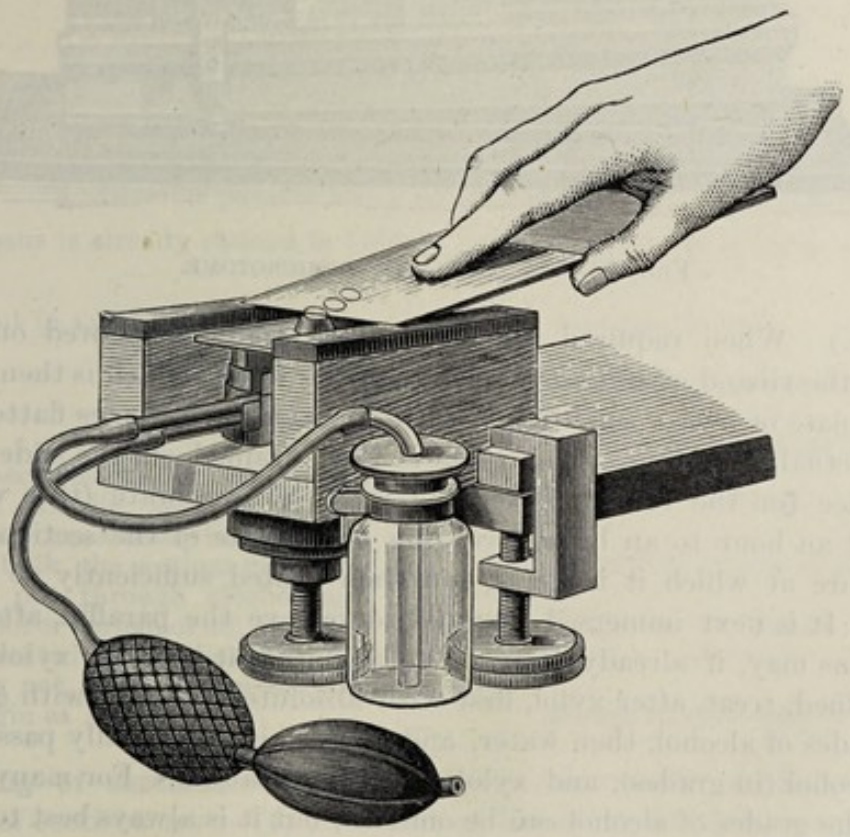


FIG. 462.—CATHCART FREEZING MICROTOME.

plate by passing over glass slips. In using the freezing microtome, especially for the nervous system, it is important not to freeze the tissue too hard, or the section will roll up like an ice-wafer.

For celloidin-embedded preparations it is necessary to cut the sections with a knife kept wetted with spirit. For this purpose a sliding microtome, in which the knife or razor is moved horizontally over the tissue, with the edge obliquely inclined to the direction of movement, is most useful. That designed by Thoma, and made by Jung of Heidelberg (fig. 463) is admirably constructed, and works with great accuracy. In all cases it is most important that the knife should be in perfect order.

Adhesive methods of mounting.—Individual paraffin-cut sections or ribands of sections, such as are cut with the rocking and other microtomes, are fixed to a slide or cover-glass—preliminary to being treated with stains and other fluids—in the following way:—The slide (or cover-glass), after having been carefully cleaned, is smeared very thinly with fresh white of egg: this can be done with the finger or with a clean rag, and put aside to dry, protected from dust. (It is convenient to prepare a large number of slides at a time in this way, and to keep them at hand in a suitable

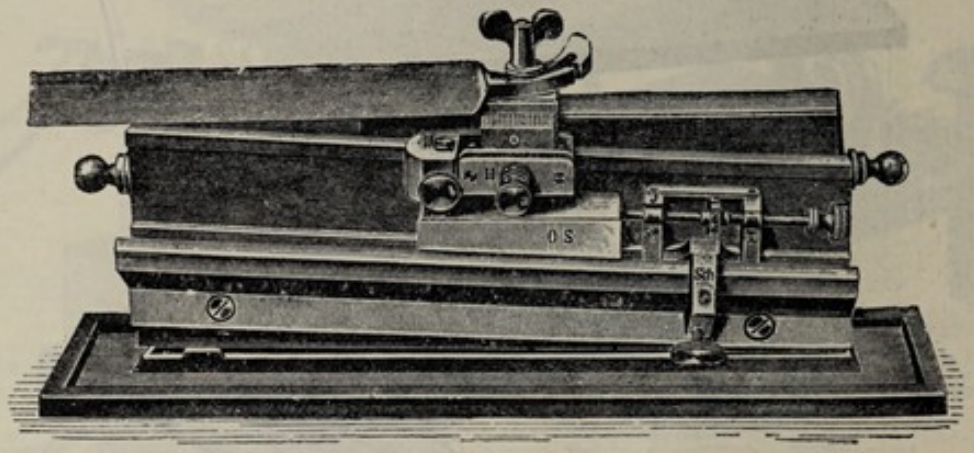


FIG. 463.—INCLINED PLANE MICROTOME.

receptacle.) When required for use a little water is poured on to the slide and the riband of sections is placed on the water, which is then warmed on a hot plate or over a small flame until the paraffin becomes flattened out, without actually melting. The water is then drained off, the slide put in a warm place for the remainder of the water to evaporate (this will take from half an hour to an hour according to the size of the section and the temperature at which it is kept), and then heated sufficiently to melt the paraffin. It is next immersed in xylol to remove the paraffin, after which the sections may, if already stained, be mounted at once in xylol balsam; if not stained, treat, after xylol, first with absolute and then with gradually lower grades of alcohol, then water, and then stain, and finally pass through water, alcohol (in grades), and xylol, into xylol balsam. For many sections some of the grades of alcohol can be omitted, but it is always best to place in 50 p.c. between water and absolute alcohol.

A simpler method, but one which, in most cases, answers the purpose perfectly well, is to place the riband or the individual sections cut from paraffin on the surface of water in a basin, just sufficiently warm to flatten out the paraffin, but not to melt it, then pass a perfectly clean slide under

the surface of the water and float the sections on to it; remove, drain off the water, and put the slide and sections aside for one or more hours until all the water has evaporated. The sections are found to have adhered firmly to the slide (they may, if desired, be yet more firmly fixed by drawing a brush moistened with solution of celloidin in oil of cloves over them). The paraffin can now be removed by washing the slide with xylol or immersing it in xylol. If not previously stained they can then be passed through alcohols and stained and mounted as just described. It is convenient to keep the several solutions which are required in cylindrical tubes or grooved receptacles, in a regular row upon the working table, and transfer the slide from one to the other in succession. Thus such a series would be (1) xylol; (2) absolute alcohol; (3) 75 p.c. alcohol; (4) 50 p.c. alcohol; (5) distilled water; (6) hæmatoxylin staining solution; (7) tap water; (8) distilled water; (9) 50 p.c. alcohol; (10) 75 p.c. alcohol; (11) absolute alcohol (or methylated spirit); (12) xylol (or oil of cloves). The changes can also be effected by pouring the solutions over the sections and draining off, but this is less satisfactory.

The following table shows the methods which may be adopted for the treatment of paraffin-cut sections or ribands of sections:

1. Place on a slide or cover-glass in a drop of tap-water: the glass may previously have been smeared with egg-white: warm gently.
2. Drain off water and allow to dry *completely*.
3. Warm until paraffin is just melted.
4. Dissolve paraffin away with xylol.

If tissue is already stained in bulk.

Mount in xylol balsam.

For sections cut by the *freezing* or *celloidin methods*, if the tissue has already been stained in bulk, the sections need only be put through alcohol and xylol or bergamot oil, and then mounted in xylol balsam. If it has not already been stained, begin at No. 7.

If tissue is not already stained.

5. Absolute alcohol.
6. Descending grades of alcohol.
7. Stain (*e.g.* hæmatoxylin).
8. Water.
9. Ascending grades of alcohol.
10. Xylol or bergamot oil or clove-oil.

Mount in xylol balsam.

Staining of sections.—The fluids most commonly employed for the staining of sections are:—(1) Solutions of hæmatoxylin and alum; (2) solutions of carmine with or without alum; (3) certain aniline dyes. The time of immersion in the staining fluid varies according to the strength of the fluid and the mode by which the tissue has been hardened. The necessity of staining sections may be avoided if the tissue is stained in bulk before embedding. For this purpose a piece of tissue is left to stain for 24 hours or

more in a moderately diluted hæmatoxylin solution or in carmalum or borax carmine. The excess of stain, if any, is removed from the sections upon the slide (after they have been cleared of paraffin in the usual way by immersion in xylol) by treating them with 50 p.c. alcohol containing 1 to 10 parts per 1000 of hydrochloric acid. The sections are then thoroughly washed with tap-water, dehydrated by alcohol, and passed through clove-oil or xylol into xylol balsam. For some purposes (*e.g.* the study of ossifying cartilage) an alcoholic solution of magenta is useful for staining in bulk; from this the tissue goes direct into a small quantity of oil of cloves, and after being soaked with this it is passed through xylol into molten paraffin. Sections may also be stained whilst still infiltrated with paraffin by floating them on to the surface of the staining solution, which may be gently warmed (but not enough to melt the paraffin). They generally require far longer exposure to the stain. The subsequent treatment is quite simple, for they need only be transferred to water, floated on to a slide, allowed to dry, and mounted in xylol balsam.

The following are some of the principal staining solutions and methods of staining for special purposes :—

1. *Delafield's hæmatoxylin.*—To 150 cubic centimetres of a saturated solution of alum in water add 4 cubic centimetres of a saturated solution of hæmatoxylin in alcohol. Let the mixture stand 8 days, then decant, and add 25 cubic centimetres of glycerine, and 25 cubic centimetres of methylic alcohol. The solution must stand a few days before it is ready for use.

To stain sections add a few drops of this solution to a watch-glassful of *distilled* water. If overstained the excess of colour can be removed by alcohol containing 1 per cent. nitric or hydrochloric acid. With long keeping this solution becomes red instead of blue; a trace of ammonia will restore the blue colour.

2. *Ehrlich's hæmatoxylin.*—Dissolve 2 grammes hæmatoxylin in 100 cubic centimetres alcohol; add 100 cubic centimetres water, 100 cubic centimetres glycerine, and 10 cubic centimetres glacial acetic acid: add alum to saturation. This solution will keep almost indefinitely: it is valuable for staining in bulk, as it does not easily overstain. For staining sections it is best to dilute the solution either with distilled water or with 30 per cent. alcohol. After the sections have been stained they must be thoroughly washed with tap-water. This develops the blue colour of the hæmatoxylin.

3. *Kultschitzky's hæmatoxylin.*—Dissolve 1 gramme hæmatoxylin in a little alcohol, and add to it 100 cubic centimetres of a 2 per cent. solution of acetic acid. This solution is valuable for staining sections of the nervous system (see Weigert-Pal process).

4. *Hæmalum.*—Hæmatoxylin-alum solutions acquire their colouring properties only as the hæmatoxylin on keeping becomes converted into hæmateïn. The latter substance may, therefore, as recommended by Mayer be used advantageously in place of hæmatoxylin if the stain is required immediately. The following mode of preparing the solution may be adopted :—Dissolve 50 grammes of ammonia alum in 1 litre of water, and 1 gramme of hæmateïn in 100 c.c. of rectified spirit. Add the hæmateïn solu-

tion gradually to the alum. The mixture is ready for staining at once, either as it is or diluted with distilled water. A small piece of thymol or a little carbolic acid should be added to prevent the growth of moulds.

5. *Eosin.*—A 1 per cent. solution in water (or a saturated solution in 75 per cent. alcohol) may be used. This is rarely employed alone, but in conjunction with hæmatoxylin forms a valuable *ground* stain. The sections are first stained deeply with hæmatoxylin and rinsed with water. They are then stained with the eosin solution, passed through 75 per cent. alcohol, and then through strong spirit—which is allowed to dissolve out some but not all of the eosin stain—into clove-oil: they are finally mounted in xylol balsam.

Eosin stains hæmoglobin of an orange red colour; so that the blood corpuscles are well shown by it when fixing fluids have been employed which do not remove the hæmoglobin from them (such as mercuric chloride and bichromate of potash).

6. *R. Heidenhain's method.*—After hardening in alcohol, or in saturated solution of picric acid and then in alcohol, place the tissue from 12 to 14 hours in a $\frac{1}{3}$ per cent. watery solution of hæmatoxylin, and then from 12 to 24 hours more in a $\frac{1}{2}$ per cent. solution of yellow chromate of potash. Now place in alcohol, pass through xylol, and embed in paraffin.

7. *M. Heidenhain's method.*—Harden in sublimate, followed by alcohol; fix sections to slide by water method; treat with iodised alcohol; transfer to 2·5 per cent. solution of sulphate (or tartrate) of iron and ammonia and leave 4 to 8 hours; rinse with distilled water; place in 0·5 per cent. pure hæmatoxylin in water from 12 to 18 hours and leave overnight; wash with water; differentiate in the iron and ammonia solution until nearly decolorised; wash for 15 minutes in tap-water; dehydrate and mount in the usual way. This method is especially adapted for exhibiting the centrosomes of cells. It is also used for retiform tissue (p. 57).

8. *Carmalum* (Mayer).—Useful either for sections or bulk-staining. If the sections are subsequently passed through alcohol containing picric acid in solution a double stain is produced.

Carminic acid, - - - - - - - -	1 gramme.
Ammonia alum, - - - - - - - -	10 grammes.
Distilled water, - - - - - - - -	200 c.c.

Boil together, allow to cool and filter. Add thymol or a little carbolic acid to prevent the growth of moulds.

9. *Carminate of ammonia.*—Prepared by dissolving carmine in ammonia and allowing the excess of ammonia to escape by slow evaporation. The salt should be allowed to dry and be dissolved in water as required.

10. *Picric acid.*—A saturated solution of picric acid in spirit may be used as a second stain after hæmatoxylin or carmine. Any excess of picric acid is dissolved out by rinsing with strong spirit. This form of double stain is valuable for exhibiting keratinised tissues and muscle fibres.

11. *Picro-carminate of ammonia* (*picro-carmine*, Ranvier).—To a saturated solution of picric acid add a strong solution of carmine in ammonia, until a

precipitate begins to form. Evaporate on the water bath (or, better, allow it to evaporate spontaneously) to one half its bulk; add a little carbolic acid to prevent the growth of moulds; filter from the sediment.

12. *Bourne's picro-carmine.*—"Add 5 c.c. of ammonia to 2 grammes carmine in a bottle capable of containing about 250 c.c. Stopper, shake, and put aside till next day. Add slowly, shaking the while, 200 c.c. of a saturated solution of picric acid in distilled water. Put aside till next day. Add slowly, constantly stirring, 11 c.c. of 5 per cent. acetic acid. Put aside till next day. Filter; to the filtrate add four drops of ammonia, put back in the stoppered bottle" (Langley).

13. *Borax-carmine.*—Dissolve 4 grammes borax and 3 grammes carmine in 100 cubic centimetres of warm water. After 3 days add 100 cubic centimetres of 70 per cent. alcohol, let stand 2 days and filter. This solution improves on keeping. It is useful for staining in bulk.

After staining with borax-carmine, the tissue should be placed in 70 per cent. alcohol containing 5 drops of hydrochloric acid to 100 cubic centimetres.

14. *Aniline dyes.*—These are used either in aqueous solution (which may contain 0·01 per cent. of caustic potash) or in water shaken up with aniline oil, and it is usual to overstain a tissue with them, and subsequently to decolorise with absolute alcohol containing $\frac{1}{3}$ its bulk of aniline oil (from which the sections can pass directly into xylol) or with acid-alcohol (1 to 10 per 1000 hydrochloric acid) followed by absolute alcohol and this by xylol. Those most employed are the "basic" dyes—methyl-blue, methylene-blue, gentian-violet, toluidin-blue, saffranin and vesuvin; and the "acid" dyes—erythrosin, acid magenta or acid fuchsin, and orange G. A double stain is obtained by combining eosin with methyl-blue or toluidin-blue, the sections being first stained for 10 minutes in 1 per cent. aqueous eosin and then, after rinsing with water, for 20 minutes in 1 per cent. of the blue solution, after which they are decolorised by absolute alcohol or absolute alcohol and aniline oil. The decolorisation is arrested by xylol. A triple stain may be got, by the Ehrlich-Biondi fluid, formed by mixing together aqueous solution of orange G., acid-fuchsin, and methyl-green in certain proportions.[1]

15. *Magenta.*—A 1 p.c. solution in 50 per cent. alcohol (to which 1 drop of 1 p.c. alcoholic solution of gentian-violet may be added per cubic centimetre), is the best stain for connective tissue (see p. 57). For developing bone and tooth and for lymphatic gland a 1 per cent. solution of magenta in 95 per cent. alcohol may advantageously be used. The piece of tissue is left for several days in the magenta solution and is then placed direct in a small quantity of clove-oil for a few hours, after which it is transferred to xylol and embedded in paraffin in the usual way.

16. *Orcein.*—Dissolve 1 gramme orcein in 100 c.c. absolute alcohol containing 1 c.c. hydrochloric acid. Place the sections in some of this solution in a watch-glass and warm slightly, allowing the fluid to nearly evaporate to dryness. Dehydrate in alcohol, which removes the excess of stain;

[1] See *Course of Practical Histology*, p. 23.

pass through xylol into balsam. This stains especially the elastic fibres.

17. *Flemming's method for karyokinetic nuclei.*—This is especially valuable for staining cell-nuclei in mitosis. The tissue elements having been fixed by picric acid, by sublimate, by dilute chromic and acetic acid, by Flemming's solution, or by Carnoy's fluid, small shreds or thin sections are placed for 2 days in saturated alcoholic solution of saffranin, mixed with an equal amount of aniline-water. They are then washed with distilled water and decolorised in aniline alcohol or in alcohol containing 1 per 1000 hydrochloric acid until the colour is washed out from everything except the nuclei. They are then again rinsed in water and placed in saturated aqueous solution of gentian violet for 2 hours, washed again in distilled water, decolorised with aniline alcohol until only the nuclei are left stained, then transferred to bergamot oil or xylol, and from this are mounted in xylol balsam. Gentian violet and several other aniline colours may be employed in place of saffranin from the first. Delafield's hæmatoxylin (followed by acid), or Ehrlich's hæmatoxylin also stain the mitotic figures well.

18. *Marchi's solution.*—This is a mixture of Müller's fluid (2 parts) with 1 per cent. osmic acid (1 part). It is of value for staining nerve-fibres in the earlier stages of degeneration, before sclerosis sets in (especially a few days after the establishment of a lesion). All the degenerated medullated fibres are stained black, whilst the rest of the section remains almost unstained. It is best to put thin pieces of the brain or cord to be investigated singly into a large quantity of the solution (after previously hardening for 10 days in Müller's fluid), and to leave them in it for a week or more; but if necessary sections can be stained; in this case the process is more complicated.[1] In either case they are fixed on a slide and mounted by the usual process in xylol balsam.

19. *Weigert-Pal method.*—This method is chiefly used for the central nervous system. By it all medullated nerve-fibres are stained dark, while the grey matter and any sclerosed tracts of white matter are left uncoloured. The following modification of the original method can be recommended: Pieces which have been hardened in Müller's fluid and afterwards kept a short time in alcohol (without washing in water) are embedded in celloidin, and sections are cut as thin as possible. Or sections may be made by the freezing method direct from Müller's fluid, if the tissue is first soaked in gum-water for a few hours. In either case they are placed in water, and from this are transferred to Marchi's fluid (see above, § 18), in which they are left for a few hours. They are then again washed in water and transferred to Kulschitzky's hæmatoxylin (see above, § 3). In this they are left overnight, by which time they will be completely black. After again washing in water they are ready to be bleached. This is accomplished by Pal's methods as follows: Place the overstained sections, first in $\frac{1}{4}$ per cent. solution of potassic permanganate for five minutes; rinse with water and transfer to Pal's solution (sulphite of soda 1 gramme, oxalic acid 1 gramme, distilled water 200 cubic centimetres), in which the actual bleaching takes place.

[1] See Hamilton, *Brain*, 1897, p. 180.

They are usually sufficiently differentiated in a few minutes: if not, they can be left longer in the solution without detriment. If after half an hour they are not differentiated enough, they must be put again (after washing) into the permanganate for some minutes, and then again into Pal's solution. After differentiation they are passed through water, alcohol (with or without eosin), and oil of bergamot (or xylol), to be mounted in xylol balsam. The advantages which this modification has over the original methods are (1) the very finest medullated fibres are brought to view with great surety; (2) the staining of the fibres is jet black, and offers a strong contrast to the colourless grey matter; (3) the sections are easily seen and lifted out of the acid hæmatoxylin, which has very little colour; (4) it is difficult to over-bleach the sections; (5) the stain is remarkably permanent.

As a modification of the above, Bolton recommends to harden with formol, place the sections for a few minutes in 1 per cent. osmic acid, stain for 2 hours in acid logwood at 40° C., and then proceed with the bleaching process.

20. *Staining with chloride of gold.*—*α. Cohnheim's method.*—Place the fresh tissue for from 30 to 60 minutes in a ½ per cent. solution of chloride of gold; then wash and transfer to a large quantity of water faintly acidulated with acetic acid. Keep for 2 or 3 days in the light in a warm place. This answers very well for the cornea. If it be principally desired to stain the nerve-fibrils within the epithelium, the cornea may be transferred after 24 hours (the outlines of the larger nerves should be just apparent to the naked eye) to a mixture of glycerine (1 part) and water (2 parts), and left in this for 24 hours more (Klein.)

β. Löwit's method.—Place small pieces of the fresh tissue in a mixture of 1 part of formic acid to 2 to 4 parts of water for ½ to 1 minute; then in 1 per cent. chloride of gold solution for 10 to 15 minutes; then back again into the formic acid mixture for 24 hours, and into pure formic acid for 24 hours more. After removal from the gold, and whilst in the acid, the tissue must be kept in the dark.

γ. Ranvier's method.—Immerse in lemon-juice for 5 to 10 minutes, then wash with water and place in 1 per cent. gold chloride solution for 20 minutes. Then treat either as in Cohnheim's or as in Löwit's method.

21. *Staining with nitrate of silver.*—Wash the fresh tissue with distilled water; immerse in ½ to 1 per cent. nitrate of silver solution for from 1 to 5 minutes; rinse with distilled water and expose to bright sunlight either in water, 70 per cent. alcohol, or glycerine. The tissue, which is generally a thin membrane, may either be mounted in glycerine, or it may be spread out flat in water on a slide, the water drained off, the tissue allowed to dry completely, and then xylol balsam added. This method is used to exhibit endothelium, and generally to stain intercellular substance.

22. *Golgi's chromate of silver methods.*—These are chiefly employed for investigating the relations of cells and fibres in the central nervous system. Two methods are mostly used, as follows:

α. Very small pieces of the tissue which has been hardened for some

weeks in 3 p.c. bichromate of potash or Müller's fluid are placed for half an hour in the dark in 0·75 per cent. nitrate of silver solution, and are then transferred for 24 hours or more to a fresh quantity of the same solution (to which a trace of formic acid may be added). They may then be placed in 96 per cent. alcohol (half an hour), and sections, which need not be thin, are cut either from celloidin with a microtome or with the free hand after embedding (but not soaking) with paraffin. The sections are mounted in xylol balsam, which is allowed to dry on the slide: they must not be covered with a cover-glass, but the balsam must remain exposed to the air.

β. Instead of being slowly hardened in bichromate, the tissue is placed at once in very small pieces in a mixture of bichromate and osmic (3 parts of Müller's fluid to 1 of osmic acid). In this it remains from 1 to 8 days, a piece being transferred each day to 0·75 per cent. silver nitrate. The subsequent procedure is the same as described under *α*. For some organs it is found advantageous to repeat the process, replacing them for a day or two in the osmic-bichromate mixture after silver nitrate and then putting them back into silver nitrate (Ramón's double method). This method is not only more rapid, but is more sure in its results.

23. *Ehrlich's methylene-blue method.*—This method is one of great value for exhibiting nerve-terminations, and in some cases the relations of nerve-cells and fibres in the central nervous system. For its application the tissue must be living: it is therefore best applied by injecting a solution of methylene-blue (1 part to 100 of warm saline solution) into a vein in an anæsthetised mammal, until the whole blood is of a bluish colour; or through the vessels of the part to be investigated, immediately after killing an animal. But good results can also be obtained by immersing small pieces of freshly-excised living tissue in a less concentrated solution (0·1 per cent.), or, in the case of the central nervous system, by dusting the methylene-blue powder over a freshly-cut surface, allowing some time for it to penetrate, and then treating it with picrate of ammonia and Bethe's solution (see below). In either case the tissue should be freely exposed to air; the blue colour then appears in the nerve-cells and axis-cylinders, even to their finest ramifications. It does not however remain, but after a time fades from them while other tissues become coloured. To fix the stain the tissue is taken at the moment that the nerve-fibres are most distinctly seen and placed for an hour or two in saturated solution of picrate of ammonia, after which the preparation can be mounted in glycerine containing picrate of ammonia. But to allow of sections being made from it for mounting in balsam, it must, subsequently to the treatment with picrate of ammonia, be placed for some hours in Bethe's fluid, viz.:

Molybdate of ammonia,	1 gramme.
Chromic acid 2 per cent. solution,	10 c.c.
Distilled water,	10 c.c.
Hydrochloric acid,	1 drop.

This renders the colour insoluble in alcohol.

24. *Sihler's method of staining nerve-endings in muscle and blood-vessels.*—Macerate the tissue for 18 hours in the following solution :

Ordinary acetic acid,	1 part.
Glycerine,	1 part.
1 per cent. chloral hydrate solution,	6 parts.

From this transfer to glycerine for from 1 to 2 hours ; then unravel somewhat with needles and place for from 3 to 10 days in the following :

Ehrlich's hæmatoxylin,	1 part.
Glycerine,	1 part.
1 per cent. chloral hydrate solution,	6 parts.

It may then be kept for any desired time in glycerine, which should be changed several times.

Preparations are made by careful dissociation with needles. If overstained they may be differentiated by acetic acid until the dark blue colour is changed to violet. The muscle spindles (p. 148) are said to be well shown by this method.

25. *Nissl's method of staining the chromatic granules in nerve-cells.*—This is a method of overstaining with methylene blue and subsequent differentiation with alcohol (see § 14). Nissl recommended 90 per cent. alcohol as the hardening agent, but both formol and corrosive sublimate followed by alcohol are better. Toluidin-blue (Mann) may be used in place of methylene-blue. The sections may first be stained with 1 per cent. aqueous solution of eosin, and then, after rinsing in water, with 1 p.c. methylene-blue solution : they are best differentiated in aniline alcohol. The effect of heating the solutions to about 70° C is to accelerate and accentuate the staining, which will then take only a few minutes.

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μ = micromillimetre = $\frac{1}{1000}$ millimetre