A SYSTEM OF
HUMAN ANATOMY.

INCLUDING ITS

MEDICAL AND SURGICAL RELATIONS.

BY

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SECTION I.—HISTOLOGY.

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ALLEN'S

HUMAN ANATOMY.

HISTOLOGY.

CONTENTS.

HUMAN ANATOMY.

HISTOLOGY.

HUMAN ANATOMY,

INCLUDING ITS

MEDICAL AND SURGICAL RELATIONS.

INTRODUCTION.

IT is the design of this book to present the facts of human anatomy in the manner best suited to the requirements of the student and the practitioner of medicine. The author believes that such a book is needed, inasmuch as no treatise, as far as he knows, contains, in addition to the text descriptive of the subject, a systematic presentation of such anatomical facts as can be applied to practice.

Works on anatomy may be placed in two groups: those written by scientists which have no special application of any kind, and those written by surgeons which have a decided leaning to surgical application. The model for the latter group originated in Europe, where the line is sharply drawn between surgical and medical practice. It requires but little discernment to detect the faulty plan upon which both these varieties of books are constructed. The scientist necessarily lacks clinical knowledge and sympathy; the surgeon lacks interest in all but one class of subjects. A book which will be at once accurate in statement and concise in terms; which will be an acceptable expression of the present state of the science of anatomy; which will exclude nothing that can be made applicable to the medical art, and which will thus embrace all of surgical importance, while omitting nothing of value to clinical medicine—would appear to have an excuse for existence in a country where most surgeons are general practitioners, and where there are few general practitioners who have no interest in surgery.

The author may be allowed to say that, in the performance of his self-imposed task, nothing has been hastily or inconsiderately undertaken. He has been actuated throughout by a sincere desire to produce a useful book. He has subordinated all other tendencies and notions to this end. In occasionally attempting a method of treatment of a subject somewhat different from the one usually accepted, he has not departed from established ways of teaching for the sake of appearing to be original, but for good reasons, as he trusts will appear when the reader compares the text with that of other books on anatomy. The plan adopted is one necessarily encyclopedic. The author has gleaned his materials from every source accessible to him, and, so far from fearing a charge of plagiarism, he will be glad to have the instances noted in which he has had the good taste to appropriate an occasional apt phrase or striking adjective. There is doubtless a greater degree of indebtedness due English works than the author is aware of, since the powerful impressions they have made on his mind must remain unconsciously to influence his style.

By way of introduction to the essential features of the volume, the attention of the reader is invited to the kinds of knowledge of the human body the physician demands.

In the first place, the physician demands an exact acquaintance with the form and construction of the organs of the body. But, inasmuch as an anatomical fact is of little use unless the range of the application of the fact is known, the due connection between the normal condition of an organ and the variation in the condition of that organ within the limits of health will

receive proper attention. Accordingly, the typical description of each organ will be followed by a brief statement of "variations."

In the second place, the physician demands a knowledge of the relations of the parts. This information it is necessary to possess in performing operations and in explaining signs or symptoms. Anatomical relations may be interpreted to be the mutual disposition of those parts which occupy the same neighborhood. The local value of relation has been enforced by the surgeon whose accurate knowledge of each special region is held by him to be of great importance; but the general practitioner cannot appreciate the necessity of keeping up ever refreshened impressions of these regions. The anatomical relations he needs are determined at the examination of the sick, or at the autopsy. While parts in a given region may hold both surgical and medical relations, this need not of necessity be the case. In many instances the medical relations involve parts remote from one another and separated by one or more topographical regions. The former will receive the name of the *topographical* or the *direct* relation; and the latter the *clinical* or the *indirect* relation.

In the third place, the physician needs some account of the uses of the organs. This subject overlaps physiological anatomy. That much only will be succinctly given as may be said properly to illustrate the subject from an anatomical point of view, and at the same time to be free from controversy.

In the fourth place, the physician must have a true conception of the nature and general behavior of morbid processes, and of the manner in which such processes are modified by locality. His comprehension of the changes due to diseased action in a given place must be fairly proportional to his knowledge of the normal anatomy of that place. This subject, which will receive the name of *localization of diseased action*, will be illustrated for the most part by concise statements of recorded cases, in which the essential feature of each case will be emphasized and the bearing it has on the subject treated of clearly shown. The material in these sections is capable of being used by the student in two ways: first, in bringing forcibly to his mind the value of the facts themselves, since cases similar to those quoted may occur to himself after graduation; and, secondly, in lightening the task of remembering important though otherwise uninviting details. In a word, anatomy may thus be made—what unfortunately it rarely is—an *interesting study*.

In presenting anatomical features in explanation of given lesions, or of signs, or symptoms, care has been taken to give the sources of the statements made. It is hoped that the original papers or volumes containing such statements will be consulted whenever this is practicable.

May not a yet more important use be made of these cases? May not a series of such abridgments be available in assisting the practitioner in detecting the significance of obscure conditions in relation to which the underlying facts are anatomical? Should these questions be answered affirmatively, this book, it is hoped, will take a place among the physician's volumes of daily reference. In order to assist in the attainment of this object a copious index of diseases and injuries, in addition to the index of subjects, will be appended.

Among other matters, the book will be found to contain an elaborate description of the tissues; an account of the normal development of the body; a section on the nature and varieties of monstrosities; a section on the method of conducting post-mortem examinations; and a section on the study of the superficies of the body taken as a guide to the position of the deeper structures. These will appear in their appropriate places, duly subordinated to the design of presenting a text essentially anatomical.

DEFINITIONS.

ANATOMY is the science that treats of the enumeration of organized bodies, and the description of their structure.

HUMAN ANATOMY treats of the anatomy of man.

COMPARATIVE ANATOMY, as usually understood, treats of the anatomy of all animals excepting man. In a better sense, Comparative Anatomy includes the form and structure of animals as related among themselves rather than as related to man. The term may be also used in speaking of the anatomy of the different races of mankind as compared with one another.

DESCRIPTIVE OR SYSTEMIC ANATOMY treats of the body as classified by its tissues or organs. Thus, the bones, the muscles, the bloodvessels, the viscera, etc., are severally distinct from one another. Descriptive Anatomy is opposed to Topographical or Regional Anatomy. In this subdivision the body is divided by the relations of its parts to one another into a number of more or less arbitrarily defined regions. Surgical Anatomy is a term often used to designate that branch of topographical anatomy which treats of regions of special importance in the study of surgical operations and of the effects of injury. Medical Anatomy is of similar import to the foregoing, but refers chiefly to the relations of parts as specially considered by the student of clinical conditions as distinguished from surgical.

GENERAL ANATOMY treats of the composition and general relations of the tissues and organs. Thus, by the general anatomy of bone are understood, first, the composition of the fibrous tissue, the cartilage, and the salts contained in the bone; secondly, the relations that these hold one to another; and, thirdly, the consideration of similar structures or ingredients in allied tissues. The study of the ultimate elements of structure, as resolvable by the microscope, has led authors of late years to speak of this branch of general anatomy as Histology or Microscopical Anatomy. In like manner, the chemical analysis of tissue is treated of under the head of Zoo-chemistry, or Physiological Chemistry.

General Anatomy is opposed to Special Anatomy, which deals with the elucidation of a single part. Comparative anatomists apply this term to the structure of a single animal when no comparison is entered upon. In this sense human anatomy itself is a Special Anatomy.

MORPHOLOGICAL ANATOMY, or Morphology, is the science of organic form, and treats of homologies and the comprehensive relations of parts, especially those relations indicating zoological affinity. It is often inexactly spoken of as Philosophical or Transcendental Anatomy. It is opposed to Teleological Anatomy, or Teleology, which treats of the adaptations of parts or organs to certain final specific uses.

PHYSIOLOGICAL ANATOMY includes the consideration of the functions of organs, but in a more general sense than teleology. There is no sharply-defined line separating physiological anatomy from physiology or physics. The physiological anatomy of the eye is at once its physiology, which, in turn, can be explained only by reference to the principles of physics as applied to vision.

MORBID ANATOMY is the science which treats of the variations in the normal anatomy as determined by diseased action. It is conventionally held to include congenital defects, or gross variations in structure: but these subjects are best included under the head of TERATOLOGY.

PRACTICAL ANATOMY is a term much in use to embrace the special kinds of printed directions best suited to those engaged in dissecting, together with the methods of making anatomical preparations, etc. It may also be said to include the study of human anatomy by dissection in contradistinction to the

study of human anatomy as a branch of general knowledge.

FŒTAL ANATOMY, or EMBRYOLOGY, treats of the origin and formation of the organs in the embryo. As it is naturally considered in connection with the physiological anatomy of the organs of generation, it is often included under the head of Physiology.

DESCRIPTIVE ANATOMY.—Its divisions are as follows:—

The Bones, or Osteology.
" Joints, or Arthrology.
" Muscles, or Myology.
" Bloodvessels, or Angeiology.
" Viscera, or Splanchnology.
" Nerves, or Neurology.
" Special Senses.

ANATOMICAL NOMENCLATURE.

In this book the word *distal* (following Barclay) will be understood to refer to a point away from the centre of the body; and the word *proximal* to a point toward the centre. For example, the trochlea of the humerus is at the distal extremity of the bone, while the head is at the proximal extremity. The word *central* also refers to a portion of a nerve or vessel which is connected with the centre of the system to which the part treated of belongs. The remaining portion, as opposed to the central, is called *peripheral*. In the case of the bloodvessels the central end is often spoken of as *cardiac*.

When the axis of the body or a limb is understood, the words *median* and *lateral* are often used in describing parts. *Median* means near or related to the axis (median line). *Lateral* means near or related to the surface or periphery, as distinct from median. "Inner" and "outer," "internal" and "external," are words very generally employed in the same sense as median and lateral. They are less exact, however, since they are also used to denote a central in opposition to a peripheral part, as in the contents of a section.

Median and lateral are synonymous with *visceral* (splanchnic) and *parietal*, in describing surfaces of the pleura, pericardium, peritoneum, etc.

A *longitudinal* section is a section cut parallel to the longitudinal axis of the body or limb. It may be made from before backward, when it is called the *sagittal* section (vertico-longitudinal), because it is parallel to the sagittal suture of the cranium; or it may be made from side to side, when it is called *frontal* (vertico-transverse), because it is parallel to the frontal suture of the cranium.[1] The frontal section is, of course, perpendicular to the sagittal section. Some writers restrict the term longitudinal to the sagittal section, in which case the frontal becomes to it a dextro-sinistral transverse. It is in this sense that Charcot uses the latter term. The frontal section of the cranium and contents becomes a true transverse section of the brain, owing to the angulation of the brain with the axis of the trunk. But a frontal section of the spinal cord is a longitudinal section, since it is parallel to the axis of the trunk. With the exercise of a little care in the use of these terms, no confusion need occur.

A *transverse* section is a section cut perpendicular to the longitudinal axis. Thus a transverse section of a limb is perpendicular to the axis of the limb.

A *vertical* section can be opposed only to a transverse as the author defines the word, and may include both the frontal and the sagittal. The term should be restricted to sections made with direct reference to the study in which the vertical position of the part is of importance.

The term *horizontal* is sometimes used to express a section made parallel to the plane on which the organ or approximate parts rest. Thus, one can speak of a horizontal section of the brain and of a horizontal semicircular canal, because these are parallel (or approximately so) to the plane of the base of the skull.

In a transverse section of the parts confined in that portion of the trunk, neck, or head which contains the large vessels Owen has named the structures in relation to the position of the central nervous system and aorta. Let it be supposed that it is desired to describe the parts in a transverse section of the thorax; then the structures *above* the body of the vertebra become *neural*, and those *below* the body become *hemal*, since the former are near the central nervous system as expressed here in the section, and the latter are near the aorta. In the same way the section of the

[1] The terms sagittal and frontal are in general use among German writers. That they relate to the disposition of the cranial sutures is an assumption of the writer. He cannot give the authority for their first employment.

vertebral canal becomes the neural space, and the cavity of the thorax the hemal space. Anything *toward* the neural space becomes neurad; and anything *toward* the hemal space becomes hemad, etc.

Ventral and *dorsal* are terms nearly equal in value to those just given. They more commonly relate to surfaces.

Huxley proposes the terms *epi-axial* and *hypo-axial* to designate the relation of parts to any given axis, either of the trunk or of the limbs. According to this method, the longissimus dorsi muscle is epi-axial to the axis of the spine, while the psoas muscle is hypo-axial to it. The biceps cubiti muscle is epi-axial, the triceps is hypo-axial, etc. In making these distinctions the body is assumed to be prone or supine. The terms *pre-axial* and *post-axial* may be substituted for the foregoing in studying a body, like that of man, in the erect position.

In the naming of organs, it must be acknowledged that little order exists in the employment of terms. The terms are often inappropriate, cumbersome in form, and vague in meaning. They are as likely as not to be applied in a manner at variance with their legitimate use. Authors have multiplied terms to such a degree that there are but few structures which are designated by a single name; and since no custom has fixed the choice to be made in such synonymy, clinical writers are perhaps excusable in consulting their own convenience. Whenever practicable, the terminology used by clinical writers will be preferred throughout this treatise. Femurs will have "heads" and "necks," and convolutions will continue to "ascend" or "descend," as long as practical physicians employ these words in recording their cases. With a view of preventing confusion, the more common of the synonymous terms will be placed in brackets after those adopted by the author. The significance of anatomical terms not in general use is fully exhibited in works readily accessible to the student.

HISTOLOGY.

LYMPH.

OF all the tissues of the human frame, perhaps the lymph is the most important; it is certainly one of the most extensive. Possessing a volume nearly one-third that of the entire body, it surrounds every constituent of the connective framework, and is in close contact with the elementary parts of all organs. It is the ever-present medium of transportation from the highways of the blood to the cell-elements of the body, of the pabulum necessary to their life and function; it is the common carrier of the products both of elaboration and of waste of the great connective-tissue system; and it is the perennial stream, through whose agency the depuration of the blood, during its course in the capillaries, is balanced by a complementary accession.

The morphology of the lymph is all that concerns us in this place. Viewed from this standpoint, the lymph is one of the simplest tissues studied under the microscope; and it is for this reason that we have chosen to begin with it.

Under a high magnifying power, lymph is seen to consist, when freshly examined, of numbers of form-elements, imbedded usually in a clear, colorless, transparent, structureless substance of a fluid consistence (the lymph-plasma). These form-elements may readily change their relative positions in the surrounding medium, by means of currents in the latter, or by means of an individual power of locomotion which seems to be inherent in some. In structure, shape, and dimensions, these forms differ much among themselves, particularly in the warm-blooded animals; and their number in a given volume of the fluid medium, in which they are loosely suspended, varies greatly in different parts of the lymphatic system, according to the many circumstances which influence the density and chemical constitution of the lymph-plasma, as well as the activity of the form-elements themselves.

The great majority of these elements do not differ so much in the general plan of their construction, as in the proportions of their constituent parts. Before speaking particularly of this, however, it should be well understood, that in every collection of lymph there are present in the plasma forms in widely varying numbers representing three general classes of elements: (*a*) minute granules; (*b*) cells consisting of one or more nuclei, and a protoplasmic body; (*c*) forms more or less closely resembling red blood-corpuscles.

a. Minute granules.—There are always present in every 0.03937 cubic inch of the lymph numbers of particles, which, under a magnifying power of 500 or 600 diameters, present the form of very *minute granules;* they are somewhat spherical (sometimes angular), have a gray, opalescent appearance, and are in a state of constant agitation—thus exhibiting the so-called *Brownian movement.* It is the presence of these elementary particles in vast numbers which gives rise to the opalescence of chyle. A more detailed description of them will be given when the constitution of chyle is discussed. In the lymph their number varies greatly in different parts of the lymphatic system; it varies also from one time to another in collections made at the same point.

b. Lymph-corpuscles.—The *characteristic* form-element of the lymph is the so-called *lymph-corpuscle,* variously termed leucocyte, white-corpuscle, or wandering-cell.

Size.—The lymph-corpuscles vary much in dimensions. In warm-blooded animals their diameter ranges, in the thoracic duct, from $\frac{1}{5000}$ to $\frac{1}{2000}$ of an inch, while, in the lymph of the peritoneum, the size of

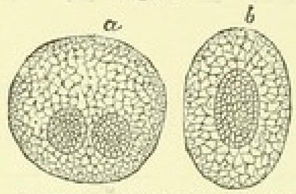
many cells may even reach $\frac{1}{1200}$ of an inch. Their mean diameter is generally less in the efferent than in the afferent vessels of the lymph-glands.

Number.—Their number in a given volume of the plasma has been found to vary quite as widely as their dimensions. Owing to several causes, particularly the viscosity (adhesiveness) of the corpuscles, the enumeration of these elements has always been accomplished with great difficulty, and consequently with much irregularity as to results. Notwithstanding this, however, the data obtained tend to establish, with considerable certainty, the following dicta: 1st. The number of lymph-corpuscles in any given volume of the plasma varies widely in different parts of the lymphatic system. 2d. In the efferent lymph-vessels of lymphatic glands and follicles they are much more numerous than in the afferent vessels of the same glands. 3d. They are usually much less numerous in the smaller than in the larger lymph-vessels of the same course. Indeed, in many locations, the small radicles of the peripheral lymph-capillaries are almost entirely free of lymph-corpuscles. 4th. The small lymph-spaces and lymph-capillaries of the tendons and aponeuroses contain almost none in health, while in the loose connective tissues lymph-corpuscles are much more abundantly present.

In the dog, lymph from the thoracic duct, at one observation, was found to contain 4800 globules per 0.03937 *c. i.*; at another time the number reached 7500 per 0.03937 *c. i.*, while the number of white corpuscles in the blood was 25000 per 0.03937 *c. i.* In the rabbit, the same observer (Ranvier) found in the thoracic duct 11300 per 0.03937 *c. i.*, whilst in the blood of the aorta only 7500 were enumerated.

Minute constitution.—Both nucleus and cell-body consist of a fine network of colorless albumenoid material, which incloses in its meshes a semi-fluid substance, usually also colorless. This network is visible only under very favorable conditions, generally after the action of certain reagents, yet it has been seen in other cells of the economy *in sitû natura* during the life of the animal. The nuclear portion of this network has been termed the intra-nuclear, while that of the surrounding cell-body has been named the intra-cellular network; the fibres of the two intercommunicate through the limiting membrane of the nucleus. The opalescent or finely-granular appearance of this and of the preceding class of white cells or lymph-corpuscles is entirely due to the optical effect of the fine fibres forming the network. Seen in optical transverse section these minute fibres appear as fine grayish granules, and at the nodal or crossing points, resemble dots of similar aspect, the minute intermediate spaces seeming more brilliant. It is this finely-mottled appearance which has suggested the use of the term "*finely granular*," universally employed in describing some cells, for in many healthy living cells there are really no granules to be found. *a*, Fig. 1, represents very fairly the networks already referred to. The drawing also very well shows the difference in the closeness of the two reticula. By reference to the figure it will be readily observed that the meshes of the intra-cellular network are much wider than those of the intra-nuclear reticulum. It can now be readily understood that the semblance of a granule or pseudo-nucleus in the cell-body, or of a spot or pseudo-nucleolus within the nucleus, may be produced by means of a condensation or contraction of this reticulum at any point.

Fig. 1.



a. White blood-corpuscle, showing an intra-cellular and an intra-nuclear reticulum. *b.* Elliptical colored blood-corpuscle, showing similar reticula. High power. (*Klein.*)

Varieties.—For convenience of description *lymph-corpuscles* may be divided into three classes—the extreme forms of each class, however, gradually shading off into those of the others—as follows:—

1. In every specimen of lymph there are to be found *small colorless corpuscles*, more or less spheroid in shape, composed of a single roundish nucleus, surrounded by an exceedingly small protoplasmic body. In their construction these small cells do not visibly differ from those of the next succeeding class, except in the relative proportion of nucleus to cell-body. They are present in numbers varying according to the location from which the lymph may be obtained. In the thoracic duct their number is about equal to the elements of the second class, while in the efferent lymph-vessels of lymphatic follicles or glands they are much more numerous, and in the afferent vessels of the same glands much less numerous than the larger lymph-corpuscles. In the lymph-glands themselves these small colorless corpuscles preponderate in the medullary portion, while, on the contrary, the larger cells far outnumber the smaller in the cortical portions. Because of the very small protoplasmic body of these cells they have frequently been described as free nuclei. Their diameter is often not more than $\frac{1}{5000}$ of an inch.

2. A *larger finely granular cell*, with one nucleus about the size of that of the preceding variety, or with two or more smaller ones, and with a surrounding cell-body of much greater extent, more or less spherical in outline when at rest, and composed of a

minute structure apparently identical with that of the preceding forms, may be considered to represent the second class of lymph-corpuscles. In the thoracic duct, and in the afferent vessels of lymph-glands, their diameter often reaches $\frac{1}{2500}$ of an inch, while in serous cavities it not infrequently measures $\frac{1}{1200}$ of an inch. The cell consists essentially of two parts, nucleus and cell-body. The nucleus, whether there be one or more contained within the body of the cell, is usually spheroid, vesicular, and possesses a limiting membrane of double contour. When single, the nucleus is about $\frac{1}{5000}$ of an inch in diameter. During life, the nucleus is, as a rule, invisible, being masked by the natural slight opalescence of the cellular body surrounding it.

3. The intra-cellular reticulum of the lymph-corpuscle may contain, in its meshes, besides a colorless hyaline semi-fluid substance, real collections of colored or highly refracting material—genuine *granules*. The cell is then called *a granular cell*. The size of these granular cells may equal or exceed the dimensions of the finely granular corpuscle, but they are present in the lymph in much fewer numbers than the latter. The granules are not distributed evenly throughout the cell, but may be more or less grouped in various portions. Their predilection is for the body of the cell. This is so strong, indeed, that when seen during life, light areas are often observed of considerable size wherein scarcely any granules are visible. These lighter areas generally correspond to the position of the nuclei when the cells are motionless.

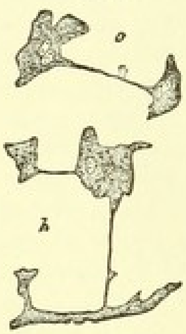
The lymph-corpuscle is destitute of an enveloping membrane. When living, its substance is soft and gelatinous, and extremely free to assume any shape which extraneous or inherent forces may direct. Living lymph-corpuscles, when removed from the animal which they inhabit, and observed under conditions of heat, surrounding fluids, gases, etc., which are as nearly as possible natural to them, evince their vitality in numerous ways, and for longer or shorter periods.

Movements.—Many of these are contractile, and when watched sufficiently long and close, exhibit various phenomena of an individual motion, which, when energetic and protracted, may ultimately result in cell-multiplication or locomotion. This contractility seems to reside in the fibres which constitute the reticulum, the fluid and the granules which may be suspended in it having only a secondary or passive motion. It appears also that the intra-cellular reticulum is usually much more powerfully active in the various movements of the cell than is the intra-nuclear network. Even a movement which accomplishes the division of the nucleus, but stops short of complete cell-division, may be effected almost entirely through the agency of the intra-cellular network. Yet the intra-nuclear network is by no means entirely passive. It possesses and exercises a measure of moving power, for certain reliable observers have seen spots or nucleoli move within the nucleus when the cell presented no other movements. During the contractions and expansions of the reticulum the fluid and the suspended particles contained in the meshes are set in motion, and currents more or less limited are thus produced. In this way suspended particles, whether elaborated in the cell or imported thither, may move from place to place, while the invisible contraction or expansion of the reticulum may have a location in the cell quite different from that of the movement of the visible particles.

The lymph-corpuscles of the second and third class are, *par excellence*, those cells of the lymph which exhibit active movements. The small colorless corpuscles, having only a very thin cell-body around the nucleus, and consequently a very small amount of intra-cellular network, as a rule, show very feeble movements, or none at all. When the fresh lymph of a batrachian or mammalian animal is, immediately after extraction, placed in a moist chamber and properly prepared for examination under a high power of the microscope, at first, the colorless corpuscles are, more or less, perfectly globular, and so opalescent that the nucleus cannot be seen. Presently, if the temperature of the lymph be kept sufficiently near that normal to the animal from which it has been taken, some of the *finely granular*, as well as many of the *granular* corpuscles are seen to put forth from one or more portions of their surface hyaline masses, which may persist indefinitely, or be at length withdrawn. These masses, at first hyaline, or, in the case of the granular corpuscles, free from granules, soon, in a greater or lesser part of their area, present the same optical appearance as does the body of the cell. They may then increase in size until perhaps half the volume of the cell has, so to speak, flowed into them. After or before this stage of alteration of form has been reached, one of two things may happen. The substance of the projection or bud may sink back again into the original body of the cell, which may then present its primary form, to be perchance subsequently altered again by similar manœuvres; or the remainder of the cell-substance may continue to pass into the projection, until the latter has completely absorbed the former. In the latter case, it is evident that the location of the cell has been changed. In

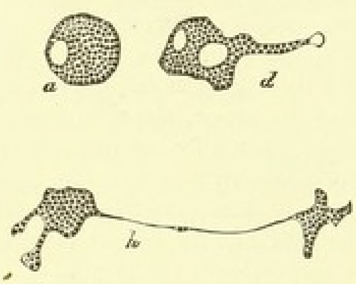
this manner the lymph-cells may slowly move from place to place. After a considerable portion of the substance of the cell has passed into a bud or projection, the two main masses may increase the distance between their centres by a lengthening out and thinning of the pedicle which unites them (see Fig. 2). Subsequently the newly-moulded mass may still flow back into the original cell, as before suggested, or it may draw the original or mother mass into it, or the two masses may continue to separate until the uniting bond becomes so fine that it breaks, when the two become independent individuals, each endowed with the characteristics of the original cell. This is one of the modes of multiplication which the student can readily follow. Instead of one such budding mass, two or more may sprout from the original cell-body, and experience the various changes already mentioned. Figs. 2 and 3 very fairly represent the out-

Fig. 2.



WHITE CORPUSCLES (OR LYMPH-CELLS) undergoing division, and active movements. High power. (*Carpenter.*)

Fig. 3.



A GRANULAR CORPUSCLE OF NEWT, showing changes undergone in fifteen minutes. High power. (*Klein.*)

lines which the finely granular and the coarsely granular corpuscles present at various stages of their alterations, although they are drawn from white blood-cells. The structure of the cells, however, is not portrayed with equal truthfulness, the granular aspect of the granular corpuscles being exaggerated, while the nuclei of the finely granular cells are much too prominent. The changes in form already mentioned are essentially those of budding or gemmation. At the same time that they are transpiring the original nucleus, if there be but one, may suffer division either by fission or gemmation. Usually each large bud draws into it a nucleus, if the budding is to result in cell-multiplication.

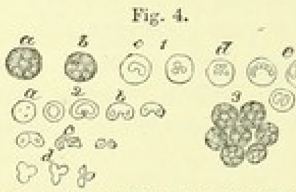
The lymph-corpuscle, instead of putting out buds, may present a constriction in the cell-body, which may progress until both the nucleus and cell are cut into two. Thus, two new cells may be the result of division by scission.

The portion of the cell cut off from the original mass in the two ways above indicated may vary much in size. Unless the new mass contain a nucleus it cannot be regarded as a complete cell. Whether such a nucleated mass be capable of development into a perfectly formed corpuscle endowed with powers of reproduction and of ulterior usefulness is a question which remains open. In every specimen of lymph there are such masses to be found, varying greatly in size, but never presenting large dimensions.

The movements above considered, because of their resemblance to those of the uni-cellular animals called amœbæ, were termed by Max Schultze *amœboid movements*, and the jelly-like substance of which the cells are composed, on account of its general resemblance to the material of certain vegetable cells, received the name of *protoplasm*.

Degrees of vitality.—The various colorless elements of the lymph appear to be endowed with different degrees of vitality and of activity. In every collection of fresh lymph properly prepared for microscopic examination, there are some colorless corpuscles which, as long as the examination is continued, remain unchanged, and, of those which show signs of life, some present much more sluggish movements than others. Of the immobile cells, those which show a sharply defined nucleus, or two or more of the same kind, or which contain great numbers of fatty molecules, may be considered moribund or perfectly inert, and perhaps already advanced in the process of disintegration. Ranvier regards these as identical with varieties of pus-corpuscles (see Fig. 4). Those which still preserve their opales-

Fig. 4.



PUS-CORPUSCLES.—1, *a*, *b*, in water; *c*, *d*, *e*, after the action of acetic acid. 2, division of nuclei—*a*, *b*, division progressing; *c*, *d*, more or less complete. (*Virchow.*)

cent finely granular appearance, and their nucleus partly or not at all visible, may, for periods, remain in a dormant state, and be capable of being awakened therefrom by the action of a sufficient stimulant.

Chemical and physical influences.—Of the agents which variously affect the lymph-corpuscles, some of the chief are heat, moisture, oxygen, acids, and electricity. Whilst a certain degree of heat is essential, not only for the manifestations of amœboid

movements, but also, even for the existence of life in the corpuscles, yet, on the other hand, the temperature cannot pass above a certain elevation without endangering the life of the cell. The two extremes of heat within which the amœboid cells are active, seem to be for the warm-blooded animals about 70° and 106° F. The temperature of the lymph can be brought much lower than 70° F. without necessarily destroying vitality. Indeed, these cells have been seen to show every phenomenon of life after freezing and thawing. Protracted lowering of the temperature below the extreme, however, is certain to induce the death of the cellule. The nearer the heat approaches the highest extreme the more rapid become the amœboid movements until the limit is reached, when they suddenly cease in the destruction of the life of the element, the crisis being manifested by the retraction of the amœboid prolongations, the resumption of the spherical form of the corpuscle, and the distinct appearance of the nucleus, and of the granules contained in the body of the cell. The highest extreme of temperature cannot be surpassed without resulting in death.

Not only is warmth necessary for the life and activity of the lymph-corpuscles of warm-blooded animals, but, according to Ranvier, oxygen seems also to be essential. When the cells are deprived of it, they become sluggish, asphyxiated, and finally die. Amœboid movements of the cells are excited by it, and sluggish corpuscles in which the vital activities lie dormant or in suspense are resuscitated and put into vigorous motion. As will be seen below, the lymph-plasma, especially in the larger trunks, contains only a minimum of oxygen, a circumstance in harmony with the known comparative inactivity of the lymph-corpuscles in the passage-ways of the lymphatic system. When floating in a medium nearly devoid of oxygen their activities being, as a rule, dormant, their form is generally spherical, and their movements are mostly only passive. When it is remembered that it is by means of their amœboid movements that they apply themselves to surfaces, creep along, and pass through them, and that it is upon these movements their stickiness or so-called *viscosity* depends, it will be readily understood how important for the economy is the fact that in the great lymphatic system, where the fluids move so slowly, and where, consequently, sticky elements could readily crowd together and obstruct the channels, one of the essential stimulators of the amœboid movements, oxygen, should be almost entirely wanting.

A sufficient fluidity of the elements themselves and of their surrounding medium is also necessary for the lively movements of the lymph-corpuscles. An increased specific gravity of the plasma retards, while, *vice versa*, within certain limits, a lowered specific gravity accelerates the amœboid movements. By the addition of water, in sufficient quantity, to the medium in which the lymph-corpuscles float, the cellular protoplasm is swollen and made more transparent, the nucleus becomes distinct, finally the granules which may be contained within the cell assume the Brownian movement and the cell dies. These various phenomena of the death of the cell become more marked and follow each other in more rapid succession if an acid be added to the water.

Viability.—The viability of lymph-corpuscles is great. Under favorable conditions of heat and oxygen and other surroundings, they readily live a long time without the organism. When properly preserved they have given evidence of life hours, days, and even weeks after extraction from the animal.

Lymph-corpuscles exposed in the moist chamber to the action of vapor of iodine become fixed and killed the instant the vapor reaches them. Most of the cells assume a yellow tint, while the nucleus and granules become distinct. According to Ranvier, a few cells are stained mahogany-brown, the color characteristic of glycogenic matter. This author states that, in these cells the glycogenic matter is diffused throughout the whole of the element. It may be extruded from the cell in the form of drops, and if the action of the iodine be sufficiently prolonged these drops may fuse together and form a halo or atmosphere around the cell of a brown-mahogany color. The presence in the lymph-corpuscles of this matter explains why chemical analyses have revealed the presence of sugar in the lymph.

Absorption.—By means of their amœboid movements, lymph-corpuscles possess the faculty of drawing into themselves minute particles with which they come in contact. They have been seen also to expel such particles from within their interior. Thus they may absorb minute particles at one location, carry them for awhile in their meanderings, and subsequently discharge their cargo at a distant point, to be absorbed perhaps again by another living cell. This circumstance has an important bearing upon the positiveness of deductions, respecting the nature of inflammation, which have been drawn concerning the identity, in the tissues outside of the bloodvessels, of lymphoid and other cells containing in their interior minute foreign particles which at some point have been injected into the blood-stream.

Lymph-corpuscles may become loaded with absorbed innocuous minute foreign particles without having their activity seriously impaired. Many lymph-corpuscles are found which inclose in their interior various substances naturally met with in the course of their circulation, as for example fat drops, granules of blood-pigment, fragments of red blood-globules, and sometimes even small red blood-disks. Those cells which contain small red blood-disks have given rise to much dispute among physiologists, some believing that the blood-disks are formed within the cell, others claiming that the red disks reach their singular location in the same manner that other extraneous particles become absorbed. From their supposed power of elaboration of certain products, which may be discharged either as waste material or as matter to be used by other elements of the economy, Ranvier has suggested that the lymph-corpuscle is a *uni-cellular wandering gland.*

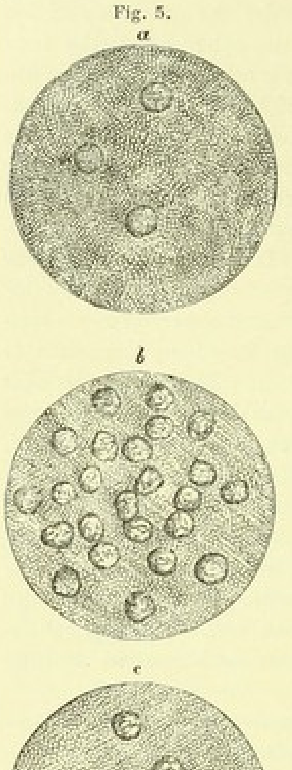
c. Red corpuscles.—Another element constantly found in the lymph is the red blood-corpuscle. It is usually met with only in small numbers when the lymph has been very carefully extracted. Its source may be traced to diapedesis from the blood-capillaries, which doubtless is to some extent a never-ceasing means ot supply. But it is also possible that many may be the outcome of a new formation somewhere within the lymphatic system.

Plasma.—The plasma of the lymph, as has already been stated, is, when fresh and normal, a colorless transparent substance of fluid consistence. According to Chevreul, a thousand parts of the lymph of a dog yielded, of water, 926.4; of albumen, 61; of fibrin, 4.2; of salts, 8.4. In estimating the gases in the lymph, Hammarsten found in 3.527 ounces of fluid 1.664 cubic inches of gas, of which .054 *c. i.* were nitrogen, .016 *c. i.* oxygen, and 1.594 *c. i.* carbonic acid. In consequence of the fibrin-elements which it contains, the plasma of the lymph soon coagulates into a gelatinous mass when collected. If set aside for a while, this mass separates, like the blood-plasma, into two portions, the serum and the clot, which latter, in its elements, does not differ microscopically from that of the blood.

CHYLE.

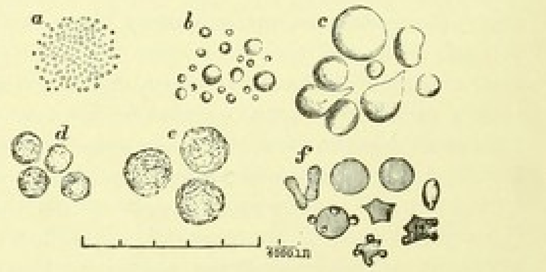
The fluid collected by the lacteals, transported through the mesenteric lymphatic vessels and emptied into the thoracic duct with the lymphatic fluids from other locations, is lymph which contains elements already described. In the intervals of digestion, it contains many more *minute granules* (*a*, Fig. 6) in a given volume of fluid than the lymph usually carries, but during digestion the number of minute particles is so enormous that, when viewed by the naked eye, the chyle presents an opalescent appearance, which is entirely due to their increased numbers. The most minute of them usually exhibit the Brownian movement. These granules do not consist solely of fat, as some have contended, but they possess a protoplasmic body which forms an envelope or frame for the load of fat which each of them holds. Under a high power of the microscope, after treatment with the proper reagents, each minute particle is seen to consist of a small fat-drop imbedded within a mass of protoplasm, which envelops it as a thin shell. Acetic acid added to the fluid dissolves these delicate protoplasmic envelopes and sets free the fat-globules, many of which then run together to form larger fat-drops (*b*, *c*, Fig. 6). When a collection of chyle is placed in a flask, and

Fig. 5.



MOLECULAR BASE AND CORPUSCLES OF CHYLE.—At *a*, from a lacteal on the intestine; *b*, from a mesenteric gland; *c*, from the receptaculum chyli. From Man. (*Carpenter.*)

Fig. 6.



CONTENTS OF CHYLE.—At *a*, primary molecules of chyle; *b*, secondary molecules of chyle; *c*, fatty globules; *d*, chyle-corpuscles; *e*, pale cells; *f*, red corpuscles. (*Carpenter.*)

after the addition of ether is set aside for a day or two, there is found at the bottom of the vessel a deposit which consists of lymph-corpuscles and minute granules. The latter have retained their original globular or angular shape, have become more translucent, and have been entirely deprived of their fat.

BLOOD.

Like the lymph, the blood, when naturally flowing, consists of a colorless transparent fluid plasma, in which freely float numerous and varied minute animal forms. The proportion of the volume of these form-elements to that of the plasma is about as follows: In 1000 parts of blood there are—

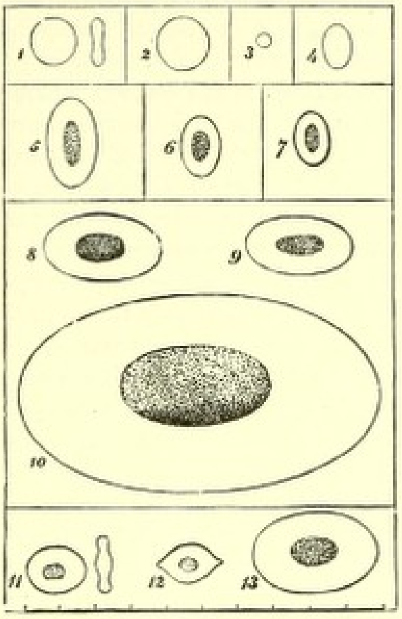
Water	790.
Globules	127.
Proteid substances	73.
Fatty matter and salts	10.

Besides the fluids and solids above enumerated, the blood is always more or less charged with gases, of which carbonic acid, oxygen, and nitrogen are the chief. The capacity of the blood for the absorption of oxygen is peculiarly great, being more than eight times that of water. Whilst the oxygen of the blood is almost, if not quite, exclusively held in the red corpuscles, the carbonic acid is united with the plasma.

Number and size of red corpuscles. — By far the most numerous and most important form-element of the blood of vertebrate animals is the red blood-corpuscle, or red blood-disk. We learn from the enumeration of Malassez, that in cartilaginous fishes the number of these elements ranges from 140,000 to 230,000 per .03937 cubic inch (a cubic millimetre); in the osseous fishes the number varies between 700,000 and 2,000,000 per cubic millimetre. The same investigator places the number of these corpuscles per *c. m.* in birds at 1,600,000 to 4,000,000, while the extreme numbers per *c. m.* in the mammiferæ are recorded at 3,500,000 and 18,000,000. We have the authority of the same writer for the statement that the mean volume of the corpuscles is almost always in inverse ratio to their numbers. This proposition is not absolute, however, for a small number of the colored corpuscles may not be entirely compensated by an increase in the volume of the corpuscle.

By consulting Fig. 7 and the table subjoined, the enormous difference in size, as well as in shape, of the colored corpuscles of the blood of different vertebrate animals can be readily appreciated. It will be noticed that the long axis of the red corpuscle of the proteus is recorded in the table as $\frac{1}{400}$ of an inch, a magnitude sufficiently large to be appreciated by the naked eye under favorable circumstances. Yet the colored blood-disk of the *Amphiuma* (Congo eel) is quite one-third larger still.

Fig. 7.



All the corpuscles here shown are drawn to the uniform scale, at the bottom of the wood-cut, of 1-4000th of an English inch, and the measurements are expressed in vulgar fractions of that inch. T. D. signifies transverse diameter; L. D. long diameter; S. D. short diameter. (*Gulliver.*)

MAMMALIA.	T. D.	L. D.	S. D.
1. Red Corpuscle of Man, seen on the flat surface and also on the edge; thickness 1-12400	1-3200		
2. " of Elephant	1-2745		
3. " of Musk Deer	1-12325		
4. " of Dromedary, thickness 1-15337	. . . .	1-3254	1-5921
AVES.			
5. " of Ostrich	. . . .	1-1649	1-3000
" Nucleus of Ostrich . . .	. . . .	1-3200	1-9166
6. " of Pigeon	. . . .	1-2314	1-3429
7. " of Humming Bird . . .	. . . .	1-2666	1-4000
REPTILIA.			
8. " of Crocodile	. . . .	1-1231	1-2286
9. " of Python	. . . .	1-1440	1-2400
10. " of Proteus	. . . .	1-400	1-727
PISCES.			
11. " of Perch	. . . .	1-2461	3-3000
12. " of Pike	. . . .	1-2000	1-3555
13. " of Shark	. . . .	2-1143	1-1684

According to the statements of various observers, the mean number of the colored corpuscles in the blood of man may be regarded as varying in health between four and five millions per cubic millimetre. The counts of the corpuscles made upon the blood of the same individual appear to vary considerably, according to the location whence the blood is obtained. It seems, however, to be pretty well established that in any portion of the economy where there is a condensation of the plasma of the blood by loss of fluid,

either from evaporation, or from excretion, or the like, there is usually to be found in the blood of the part an increased number of corpuscular elements. On the contrary, under opposite conditions, the number of red globules has usually been found to be below the mean. In the left heart, and in the large arteries of the limbs, the number of globules is identical, but in the arterioles it is increased. The venous blood of the skin, where evaporation is rapidly going on, and the venous blood of the kidneys, where excretion is taking place, is much more rich in red blood-disks per *c. m.* than is the blood of the corresponding arteries. In the interim of *digestion*, the mesenteric venous blood is richer in red cells than is the arterial blood, yet less rich in this respect than the blood of the cutaneous veins. During digestion, however, there are fewer red corpuscles per *c. m.* in the mesenteric veins than in the supplying arteries. There is, of course, in the latter case an accession of fluid in the veins by absorption of the intestinal juices. The emptying of the lymph into the blood-stream at the mouth of the thoracic duct, also causes a lowering of the number per *c. m.* of the red corpuscles in the blood-current on the proximal side of that point. The splenic vein is much richer in red disks than is the artery. The subhepatic veins have fewer red cells per *c. m.* than have either the portal veins or the ascending cava. There is in the liver a probable destruction of red globules.

Besides these, so to speak, local variations in the number of colored corpuscles in a given volume of the blood, there is, perhaps, a physiological mean variation for each individual, as well as a difference in individuals dependent upon the conditions of sex. According to some investigators, there would also appear to be slight fluctuations in the mean volume of the colored cells without a marked disturbance of health, as well as differences in the intensity of the coloring matter of the corpuscle. The same authors claim that certain abnormal states of the economy show these fluctuations in a more or less marked degree. Thus Hayem declares that in *chronic anæmia* the mean dimensions of the red globules are always lessened. 100 globules of anæmic blood may correspond in volume to less than 80 healthy globules. At the same time, the intensity of the coloring matter of the corpuscles may be lessened one-quarter or one-half.

The fresh fluid blood of vertebrates, as is well known, presents to the naked eye, when seen by reflected light, and in considerable quantity, a homogeneous opaque aspect and an intense red color. It is opaque to the naked eye for the same reason that an emulsion of oil is opaque. When spread out in an extremely thin layer, however, and examined under a very high magnifying power by transmitted light, the fluid or plasma of the blood is seen to be perfectly transparent, colorless, and structureless. The form-elements which float in it in enormous numbers are of three general classes: colored cells, colorless cells, and minute free granules. The colored cells or corpuscles, instead of being red, are, when examined by transmitted light, of a slight orange-green tint if seen single, and only approach a reddish tinge when cell is imposed upon cell several layers deep.

Form of colored corpuscles.—The general form of the colored corpuscle has been found to vary greatly in different orders of animals. In nearly all mammals the outline has been found circular, whilst in nearly all of the lower vertebrates it has been seen to be more or less elliptical. There are a few fishes (the lamprey eel and allied forms), however, in which round colored corpuscles have been met with; while, on the other hand, two species of mammalian animals (the camel and the llama) possess red cells of oval outline. A more rigid dividing line between the mammalian and the lower vertebrate animals with respect to their colored blood-corpuscles is afforded in the presence or absence of a nucleus. In the lower vertebrates, whether the red cell be round or elliptical, there is a central nucleus present. In the adult healthy mammalian corpuscle, the nucleus is generally admitted to be absent. Nevertheless, in opposition to this latter statement, Bœtcher and a few others have sought to prove the existence of the remains of a nucleus in the red corpuscle of mammalians also (man, among others).

Varieties of colored corpuscles.—In the healthy blood of adult man, the red corpuscles present two general varieties of form and dimension—the *red blood-disk* or *corpuscle* proper and the *microphyte*. Much the more numerous of these is the *red blood-disk*.

The red blood-disk or corpuscle.—As the word indicates, instead of being a spherical body, the red blood-cell is flattened into the form of a thin disk. Its outline is naturally circular, and in fresh arterial blood the central area of the disk presents a concavity on each side. In other words, besides being circular, the disk is normally *bi-concave*. The edge of the disk instead of being sharp or acute is rounded. In consequence of its peculiar shape, this form of the colored corpuscle, when seen in surface by transmitted light and properly focussed, should be most intense in color in the peripheral ring corresponding to the thicker portion. The color appears still more

intense when the disk is seen in profile. The colored corpuscle consists of three principal parts: the stroma, the fluid contents, and the coloring matter. According to some late investigators, the body of the colored blood-corpuscle is composed of a fine felt-work of minute fibrillæ (*b*, Fig. 1) of an albuminoid material, holding in its meshes a soft semifluid substance. The latter holds more or less closely united with it the coloring matter of the corpuscle, a substance which has been named *hemoglobin*. The weight of authority seems to incline to the opinion that the corpuscle is membraneless. The red disk is naturally elastic, capable of assuming any form which a moderate pressure may require, and of returning again to its original shape when the pressure is removed. Many experienced and accurate observers declare that they have seen it manifest limited contractile power. But most writers assert that it is incapable of any other than passive movements, regarding it as a more or less inert body, the altered remains of a once complete cell.

Fig. 8.

HUMAN BLOOD-GLOBULES.—*a*, seen from the surface; *b*, from the side; *c*, united in rouleaux; *d*, rendered spherical by water; *e*, decolorized by the same; *f*, blood-globules shrunk by evaporation. (*Gray.*)

The red disks of human blood, when the latter is freshly drawn and spread out upon a glass slide for microscopic examination, frequently show a marked tendency to apply themselves one against the other by their broad surfaces to form rows similar to rouleaux of coins—a phenomenon the cause of which is unknown.

Alterations of the red corpuscles.—The colored corpuscle of man may experience various alterations of form and composition, which are purely physical or chemical, in contradistinction to amœboid or vital movements.

Water causes them to swell, to lose their bi-convex discoid shape and become more or less spherical, and to discharge their coloring matter into the surrounding plasma—which latter is now uniformly stained, while the corpuscle is apparently structureless, colorless, and sharply outlined. Many solutions of salts of less density than that of the blood have much the same action upon the red corpuscles.

On the contrary, when the density of the blood-plasma or of the artificial serum in which the colored corpuscles are examined is increased either by slow evaporation or by other means, the surface of the corpuscles, which is notably smooth, becomes wrinkled; subsequently, little prickles or spines appear all over the surface of the elements; finally, the corpuscles become more or less globular in form and diminished in diameter, retaining the while their prickly appearance. They are then known as crenated corpuscles. A few of this kind of cells are met with in nearly every specimen of blood. The addition of water causes them to swell and their spines to disappear, but they retain the spherical form. Carbonic acid causes the bi-concave disks to swell. When acting upon the crenate corpuscles, it causes the spines to disappear and the corpuscles to partly resume their former concave appearance. The action of this gas is generally not sufficient to effect a return of the concave surface upon both sides, but the corpuscle is made to assume a saucer shape.

A strong electric current first causes the red disks to become crenate and spherical; afterwards the corpuscles swell and lose their color.

Bile causes the red globules at first to become pale; after that they suddenly disappear, leaving no trace.

Urea causes the red disks to become globular, but does not effect a decoloration. Upon the surface of the corpuscle there are formed little drops of matter apparently entirely similar to the body of the cell, which are united with each other and with the body of the corpuscle by fine filaments.

The addition of tannic acid in sufficient amount to a portion of blood causes the hemoglobin to separate more or less completely from the body of the corpuscle and to form globular projections upon the surface, of the characteristic color.

Rapid desiccation of a thin film of blood, spread out on a glass slide, very perfectly preserves the form and dimensions of colored corpuscles.

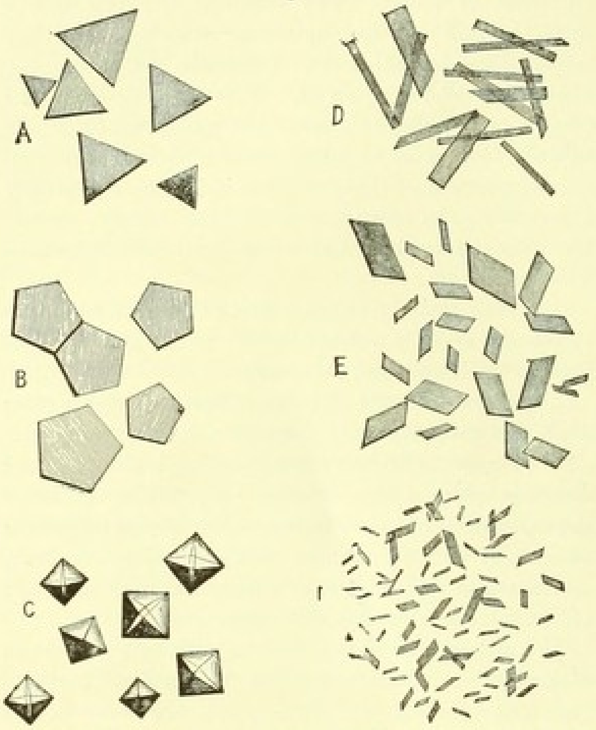
When blood is raised to a temperature near 134° F., the globules begin to lose their discoid form, and to assume a spherical shape. At the same time little buds make their appearance upon the surface of the corpuscle, united to it and to each other by fine filaments. When the temperature reaches 158° F. the globules become decolored and broken up into small transparent spheres of very unequal size.

Cold causes a dissolution of the hemoglobin, and an effect similar to that of water.

Blood-crystals.— When extravasated into the tissues, colored corpuscles disintegrate by breaking into minute portions, the coloring matter of which finally is transformed into brown pigment-granules, known as *hematin*. Besides these granules of pigment, such extravasations may contain crystalline needles of a reddish-brown color—*hematoidin*-crystals. But the characteristic crystals of the blood are those of *hema-*

globin, usually deposited from a considerable quantity of blood. The form of the hemaglobin-crystals varies in different animals, and is often quite peculiar to certain species. These characteristic forms often

Fig. 9.

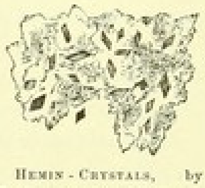


BLOOD-CRYSTALS.—A, trihedral crystals from blood of Guinea-pig. B, pentagonal crystals from blood of Squirrel. C, octahedral crystals from blood of Rat and Mouse. D, hematin-crystals from Human blood. E, hematoidin-crystals from an old apoplectic clot. F, hemin-crystals from blood treated with acetic acid. (*Gray.*)

yield valuable suggestions as to the kind of animal from whence they came.

Crystalline forms, artificially derived from hemoglobin, and valuable in medico-legal examinations of supposed blood-stains, are those obtained from dry blood by the action of glacial acetic acid. They consist of nut-brown, rhombic, crystalline plates, called *hemin*-crystals, or hydrochlorate of hematin.

Fig. 10.



HEMIN-CRYSTALS, by Teichmann, in hydrochlorate of hematin.

The red blood-disk of man varies somewhat in dimensions. Its mean diameter, as is seen by reference to the table on a previous page, is about $\frac{1}{3200}$ of an inch. This size may vary somewhat among different individuals, and in the same person at different times.

The microphyte.—In every specimen of human blood there are among the red bi-concave disks, already described, a small number of colored globular corpuscles of much less diameter, and of a darker tint. Their size may be not greater than $\frac{1}{5000}$ or $\frac{1}{6000}$ of an inch. They appear to possess the same intimate structure, and to give the same chemical reactions as do the red bi-concave disks. They have been called *microcytes*. By some histologists they are regarded as young, not yet fully developed, red blood-corpuscles (*hematoblasts* of Hayem), since they seem to be more numerous at times when the blood is undergoing repair. By others they are thought to be the old bi-concave disks undergoing retrograde changes. They are especially abundant in progressive pernicious anæmia.

The white or colorless corpuscles. — Of the *colorless corpuscles* of human blood, cells similar to those of the three general classes of colorless cells described as present in the lymph are found, and it is not necessary here to review their characteristics. Their number, however, is usually far below that of the colored elements. It varies much even in health, and in the same individual, from one time to another. In comparing the white corpuscles with the red, Welcker has the average as 1 white to 335 red, Moleschott 1 white to 357 red, Klein has placed the highest number in health at 1 white to 650 red. We have the authority of Moleschott for the statement that boys have 1 colorless to 226 colored corpuscles, old men 1 to 381, girls 1 to 389, young women menstruating 1 to 247, the same women when not menstruating 1 to 405, pregnant women 1 to 281. According to Hirt the proportion of white corpuscles to the red is low immediately after eating, while two or three hours later, the proportion is again near the normal. The same author states that the proportion in the blood of the splenic vein is 1–60; in the splenic artery 1–2260; in the hepatic veins 1–170; in the portal vein 1–740. It would seem from these figures that there may be at times a physiological leucocytosis, although this has been denied by some later investigators. Groucher declares that the proportion of the white to the red corpuscles varies little in the course of the day. In disease the relative number of the white corpuscles has even surpassed the proportion of 1 white to 3 red cells.

Red granular corpuscles. — Besides the ordinary white corpuscles, Semmer has observed in the blood of mammals certain numbers of more or less granular, nucleated, colorless cells, of somewhat larger size than those above considered, which contain red granules of considerable size, and has named them *red granular corpuscles*. According to this author, as well as A. Schmidt, they are probably intermediary

forms between the white cell and the red corpuscle of the blood.

Ovoid colorless cells.—Von Recklinghausen has met with a few colorless, ovoid, granular, nucleated cells in the blood of frogs. In these animals they seem to be more numerous in certain seasons of the year, being much more frequent in the spring and summer.

Many accurate observers have seen similar colorless elements in the blood of man. They have been met with chiefly in the blood of patients suffering with certain febrile disorders. In the blood of relapsing fever subjects they are not infrequent; they have also sometimes been encountered in typhoid fever. In the two latter cases these cells are often loaded with fine fatty granules. The writer has met with such cells, in some abundance, in inflammations affecting the bloodvessels, and believes with Semmer that they may be regarded as normal to the blood of certain, if not all, mammals. During the same study of inflammation of bloodvessels we had the opportunity once or twice to observe under the microscope endothelial cells, lining the vessels, become detached and carried off in the blood-current. These observations leave us no doubt that at least some of the ovoid, colorless cells, above mentioned, are to be assigned to a similar origin, namely, a limited desquamation of the endothelia lining the vessel walls.

Free granules.—The plasma of the blood also carries in suspension numbers of minute particles apparently identical with the *free granules* described as present in the lymph; their number as well as their nature varies in much the same manner. Of course, in the blood some of these minute particles arise from a destruction by disintegration and fragmentation of the superannuated red blood-disks.

Regeneration.—In the blood, as in the other tissues of the organism, the various stages of generation, development, vigorous activity, decay, and disintegration are constantly presented by the different elements. After hemorrhage, whether natural or accidental, it would seem that the investigator has offered to him very ample opportunity of studying the methods of regeneration by which immense losses of the red blood-globules are rapidly repaired. To replace the ordinary periodic destruction of red blood-disks which women suffer at the time of their catamenia, about one hundred and seventy-five million of red corpuscles, it has been calculated, must be produced every minute during the intermenstrual period. Yet, the question of the renewed supply of colored elements of the blood, notwithstanding the many exhaustive investigations of hematologists, has not up to the present moment been satisfactorily answered. It seems to be generally admitted, however, that in some way the red disks are elaborated from the colorless cells, either of the blood or of the lymph, but the diversity of opinion as to the precise method of formation during adult life, is great among some leading modern histologists.

Movements of the corpuscles.—Heat and the other reagents which were mentioned when considering the elements of the lymph, have identical effects upon the colorless cells of the blood. Wherever the circulation of the blood is sluggish, and heat and oxygen are present in sufficient quantities, large numbers of the white corpuscles put forth active movements. These movements are much more energetic in the small venules than in any other portion of the circulatory system. It is here and in the capillary vessels that the viscosity or stickiness of the colored elements especially shows itself, and it is mainly here also that the amœboid corpuscles stick to the walls of the vessels and ultimately pass through them. The fact that they do traverse the walls of these vessels is not now questioned; but writers are not yet agreed as to the manner in which the act is accomplished, some believing that it is effected by the active creeping of the corpuscles through minute pores, which ordinarily are filled with a soft permeable substance, others claiming that the extravasation of the corpuscle is passive, entirely effected by the outward pressure of the blood against the walls of the vessel; still other opinions have been advanced. It is admitted, however, that the more active the amœboid movements from any cause, the more rapid and extensive is the emigration. It has long been known that the red elements also escape through the vessel walls. The diapedesis of these elements, however, is generally believed to be in the main passive; perhaps it takes place through passage-ways already opened by the previous emigration of a white amœboid cell. In these emigrations of the elements of the blood through the walls of the vessels, the cells are often fragmented, and the fragments are according to circumstances carried off by the lymph current without the vessel or by the blood current within it.

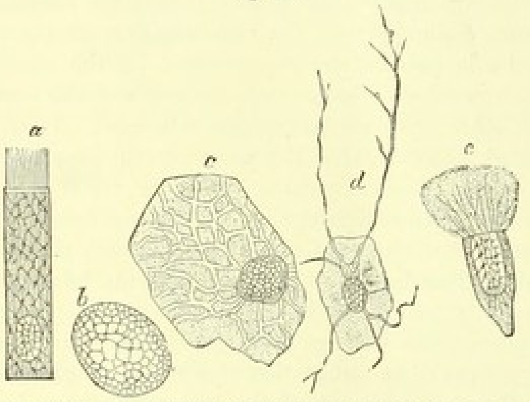
Like the lymphatic fluid, the *plasma* of the blood contains a certain proportion of fibrin which sooner or later deposits itself when the blood is left to stand. The nature and structure of the fibrin of the blood are very similar to those of the fibrin of the lymph. It is supposed to be the result of the action of a so-called fibrinogenous upon a fibrinoplastic substance contained in the plasma.

Derivation of blood and lymph.—All the foregoing elements in the lymph and in the blood are to be regarded as derivatives immediately or indirectly of the connective-tissues of the organism—descendants from the middle or connective-tissue layer of the blastoderm, or mesoblast.

ENDOTHELIUM.

We now pass to the consideration, in the endothelia, of another variety of the connective-tissue elements which are widely distributed. They are flat cells, which usually in a single layer are found lining the surface of serous cavities, the inner surface of blood- and lymph-vessels, and the synovial membranes. They consist of a more or less flat cell-plate, of an albuminous somewhat elastic substance, and one or more nuclei possessing a double-contoured membrane, a more or less oval outline, and an excentric location in the body of the cell. The cell-plate consists of an elastic network of fibrils (the intra-cellular reticulum) inclosing in its meshes a semifluid homogeneous colorless substance. The nucleus also consists of a similar but denser network (the intra-nuclear), holding in its spaces a similar semifluid substance (see *c*, Fig. 11).

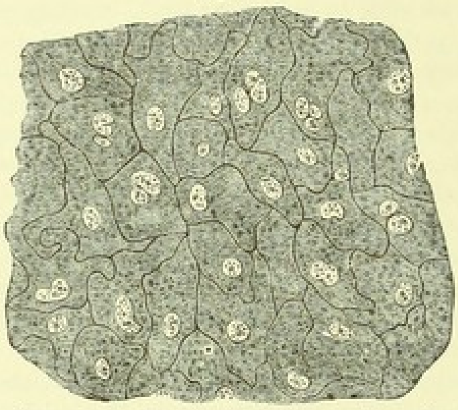
Fig. 11.



CELLS SHOWING THE RETICULUM IN THE PROTOPLASM AND NUCLEUS.—*a*. Columnar epithelial cell provided with cilia, the latter being prolongations of the intra-cellular network. *b*. Nucleus of a glandular epithelial cell from the stomach of a Newt, showing the intra-nuclear network. *c*. Endothelial cell of the mesentery of a Newt, containing in a hyaline ground-substance a plexus of fine fibre-bundles—intra-cellular network—in connection with the intra-nuclear network. *d*. Connective-tissue corpuscle from mesentery of Newt, showing very clearly the intra-cellular network of fibrils and the hyaline ground-substance; the former extends into the branched processes, and is also connected with the more delicate intra-nuclear reticulum. *e*. Goblet-cell from the stomach of a Newt, showing the intra-cellular network in connection with fibrils of the intra-nuclear network; the upper part of the cell is greatly swollen by mucus. (*Klein*.)

The cell appears to be without a membrane. The nucleus is much flattened when the cell-plate is thin, and causes a prominence corresponding with its location. Normally the cell-plate is so thin and transparent that its outlines are indistinguishable, the nucleus alone being visible. Neighboring cells are placed nearly in contact by their edges, being separated only by a very small amount of structureless transparent viscid substance which holds them together. This material has been called *cement-substance* (*intercellular cement*). When these cells are seen in profile they appear to be more or less linear or spindle-form, the thickness of the spindle corresponding to the nucleus of the cell. After staining with a weak solution of nitrate of silver, the intercellular cement is so darkened that the outline of the cell is made very distinct. It is thus found that endothelial cells have more or less irregular polygonal outlines (consult Fig. 12), and that the

Fig. 12.



NORMAL ENDOTHELIUM OF VISCERAL PERICARDIUM OF A TOAD, silver-treated and highly magnified. (*Chapman*.)

extent of the cell-plate is extremely variable. In the arteries and larger lymph-vessels the cells are more or less lozenge shape, with the border lines only slightly wavy. In the veins and lymph-capillaries, the cells are much broader as a rule, and their periphery is represented by extremely irregular indented lines (consult figs. 1, 3, Plate XII.). Upon the surface of the serous cavities the outlines of the elastic cell-plates present still another picture, as will be seen by reference to fig. 1, Plate I. Besides variations in the outlines of endothelial cells, there are other differences which are shown mainly upon serous surfaces In the adult animal the greater part of these surfaces is covered by a single layer of extremely thin, nearly hyaline, and somewhat broad cell-plates. There are, however, limited areas more or less numerous scattered here and there upon which the cells offer a very different aspect. They are much narrower, their edges are much less irregular, they are much thicker when seen in profile (approaching a cubical form), are quite granular, and possess two or more nuclei. In fact, they appear to be in a decidedly active state, while, on

the other hand, the vital proclivities of the first mentioned very thin hyaline cell-plates seem to be entirely dormant. These granular cells are said by Klein and some others to be germinating, and have been called by them *germinating endothelia* (see *e*, fig. 1, Plate I.). They are generally arranged around the mouth of a vertical canal connecting a lymph-channel of the sub jacent connective-tissue with the serous cavity. The activity of this germinating endothelium may be such that the granular cells proliferate and form new-cells, some of which may be set free in the serous cavity. These new cells are similar in every respect to the other lymph-corpuscles which float in the lymph-plasma, and cannot, after separation from their place of generation, be distinguished from them. The endothelia covering some portions of the abdominal cavities and the fenestrated septa of the mediastinum are thus a very fruitful source of supply of the colorless corpuscles of the lymph.

The endothelia are, as already stated, somewhat elastic. When the membrane which they cover is stretched, they become thinner, and spread out in order to cover a wider extent of surface, and their border becomes straighter. On the contrary, when the membrane retracts, their broad diameter lessens, their borders become more sinuous, and the cell be comes thicker. Thus during full inspiration the endothelia covering the pleural surface of the lungs are much thinner and broader than at the end of expiration. At the latter instant the pulmonary endothelia are quite cubical in shape.

As has already been indicated, the endothelia not only of the serous cavities, and of the lymph-vessels, but also of the bloodvessels as well, may be regarded as some of the sources of the colorless elements to the lymph and blood.

CONNECTIVE-TISSUE CELLS.

Still another group of the elements derived from the mesoblast is formed by the cells of the connective-tissue. They may be considered under two general heads—the wandering cells and the fixed cells.

Wandering cells.—The *wandering cells* of the connective-tissue are not different from the colorless cells already described when considering the lymph. They are in reality lymph-corpuscles, existing in the radicles of the lymphatic system, and do not call for any particular description here. One form may be considered for a moment, however, before dismissing them. There are found in the interstices of the loose connective-tissues which are especially vascular, small numbers of large granular corpuscles slightly pigmented (plasmatic corpuscles of Waldeyer). They are more frequent along the walls of vessels, and do not usually exhibit marked amœboid movements.

Connective-tissue corpuscles.—The *fixed cells* of the connective-tissue vary much in shape according to the arrangement of the fibrous tissue in which they are imbedded.

The cellular elements of the great connective-tissue system are met with only within or upon the sides of the spaces which permeate that system, whether they be in the form of fine channels or in the nature of lymph-cavities, and whether those spaces be large or small. The large spaces, as, for example, the peritoneal cavity, the pleural cavity, the arachnoid cavity, the heart and bloodvessels, the larger lymph-vessels, are lined throughout by a complete covering of endothelial cells; the minute spaces which exist between the bundles of connective-tissue fibrils have as a rule only a more or less incomplete lining. But whether the space be of one kind or of the other, it is lined by cells of an essentially identical nature; only their forms and the arrangement of some of their structures, vary according to the circumstances which surround them. Although the fixed cells of the connective-tissue are here considered under a special section different from that in which the endothelia were discussed, it is not because these two species of cells differ in anything more than form.

The so-called fixed cell of the connective tissue tends to assume a form which is a more or less perfect mould of the space in which it is found. It presents two general forms, the one plate-like, the other stellate. The plate-like forms more nearly resemble the cell-plates of the endothelia than do the stellate forms, and will therefore be considered first (see *c*, fig. 3, Pl. IX.).

Flat tendon-cells.—In white fibrous tissue such as tendon, etc., the spaces formed by the apposition of several bundles are linear, and are limited laterally by the convex surfaces of the fibrous bundles. The surface of the space thus formed is usually partially lined only. On one side is a longitudinal row of flat elastic cell-plates, applied more or less tightly to the surface of the fibrous bundles forming that side. The opposite side of this minute lymph-space is void of cellular lining. The cells constituting this row are placed edge to edge, and at the line of junction the border of the cell is quite straight, and generally transverse to the direction of the bundle. These cells thus have two long straight parallel sides. The lateral borders of the cell are more or less notched,

and sometimes processes of considerable length, and more or less branched, spring from them. A single cell will generally spread across two or more bundles. When this is the case, the indentation of the space caused by the convex surface of two bundles coming together, is filled out by the substance of the cell-plate. In consequence of this circumstance, when the cell-plate is detached from its position and examined at once, a ridge extends from one parallel side of the cell to the other (see *e*, *B*, fig. 2, Plate III.). This ridge appears like a band running in the body of the cell when the latter is viewed in surface. Sometimes it may be developed into a secondary cell-plate of some width, springing from the first, thus complicating the form of the cell. These cells are known as the *flat tendon-cells* of Ranvier. They may very justly be regarded as a special form of endothelium. The cell-plate is elastic, and contains an ovoid nucleus near one straight side. It consists of an intercellular network which corresponds with the extent of the elastic plate, and at the notched sides extends beyond the plate into the processes; and the nucleus contains an inter-nuclear reticulum. Seen edgewise, these flat tendon-cells appear spindle-form, and when seen in optical or real transverse section they present a more or less branched or stellate aspect.

Stellate cells.—In loose connective tissue, or areolar tissue, where the bundles of fibrils intercross in every conceivable direction, the most irregularly formed minute lymph-spaces are found. These spaces are more or less stellate, and they often contain one or more fixed stellate cells. These are the *connective-tissue corpuscles*, par excellence. They lie in the small lymph-cavity, loosely attached to one of the sides of the space. The simplest form of this cell in adult tissue is that of a thin cell-plate of more or less irregular outline, and containing an ovoid nucleus. The nucleus has an enveloping membrane of double contour, and contains an intra-nuclear, very dense network, the nucleus seeming to be implanted nearer to

EXPLANATION OF PLATE I.

Fig. 1. Peritoneal surface of the centrum tendineum of a Rabbit, silver-stained and highly magnified. (After Klein.)

b, Smaller endothelial plates, situated over the straight lymphatic vessels which lie between (*a*) the tendon-bundles; *c*, true stomata, some widely open, some collapsed,—they form a means of communication between the serous cavity of the peritoneum and those straight lymphatics last mentioned, and are lined with endothelial cells of a germinating character; the dotted line starting from *c* represents the outline of a lymph-sinus below the surface, and in communication with the before-mentioned straight lymph-vessels.

Fig. 2. Highly magnified view of the spine-covered epithelial cells of the rete mucosum, or deep layer of the cutaneous epithelium. The section is parallel with the surface, and includes some underlying connective-tissue. (After Ranvier.)

a, Bloodvessels with surrounding lymph-spaces; *f*, connective-tissue bundles cut transversely; *b*, union of the epithelium with the tissue of the cutis; *e*, polyhedral epithelial cells of the rete mucosum, containing oval nuclei and minute brilliant nucleoli. These cells are united together by means of their spines, *c*; an intercellular cement fills the interspaces formed by the spines.

Fig. 3. Various forms of epithelium, fresh and much magnified. (After Ranvier.)

a, Thin, broad, epithelial scale from the inside of the cheek, showing a very small nucleus, and finely-granular contents,—the imprint of adjoining cells is observable in the innermost line; *b*, smaller epithelia, from the deeper epithelial layers of the bladder, and *c*, a larger epithelial cell from a more superficial layer; *d*, an isolated spinous epithelial cell from the rete mucosum of the skin; *n*, the nucleus of a ciliated columnar epithelial cell, whose vibratile cilia are shown at *g*; *k*, the elastic striated plate from which project the cilia of a smaller ciliated columnar epithelium; *p*, *q*, the deep extremities of columnar cells.

Fig. 4. Three isolated columnar epithelia from the intestine.

h, The striated elastic plate which limits their free extremity; *n*, the oval, double-contoured nucleus of the cell.

Fig. 5. *A*. Profile view of epithelia of the bronchus of a Rabbit, showing, between the regular ciliated columnar epithelium, *d*, the existence of *branched cells*, *e*, of a different nature, whose processes form a more or less complete network with each other, as well as a communication with the branched connective-tissue corpuscles, *a*.

B. A surface view of the same epithelia, the letters having a similar indication.

C. Shows a longitudinal section of a minute bronchus. *d*, Columnar epithelia, of which, *c* are the cilia; *v* is the muscular coat, the smooth muscle-fibres being cut transversely; *a* is a lymph-vessel of the adventitious coat of the bronchus. (After Klein.)

PLATE I

Fig 1

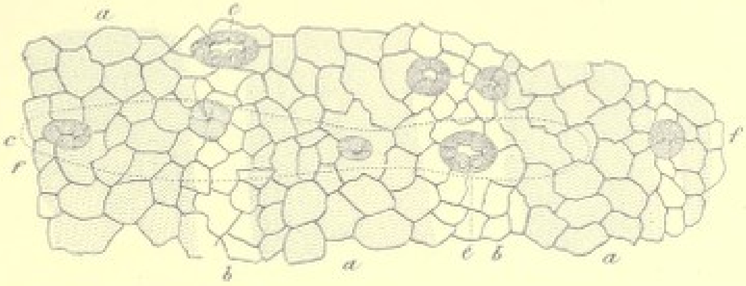


Fig. 2

Fig. 3

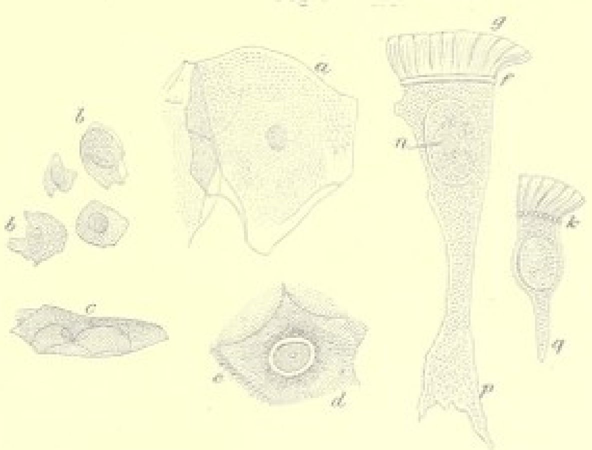


Fig. 4

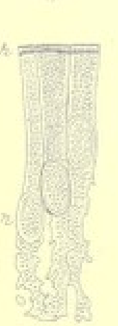
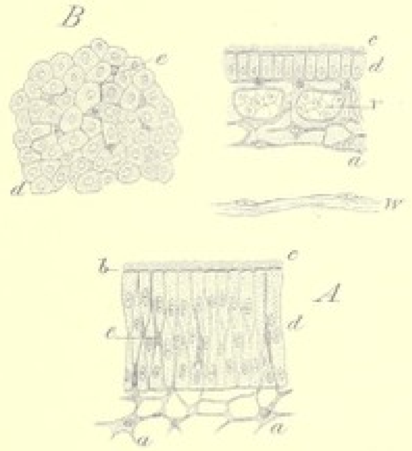


Fig. 5



one surface of the cell than to the other. This intranuclear network is in connection with an intra-cellular network, which is in part imbedded in the elastic cell-plate, but it at some points extends beyond the edge of this plate to form more or less branched processes (see *d*, Fig. 11), which attach themselves to the adjacent fibrous bundles, or to the processes of other branches or of other cells. Instead of presenting this simple form, secondary cell-plates may spring from the primary body and send off processes, when the connective-tissue corpuscle becomes a very complex affair. Yet it essentially consists of a thin elastic plate similar to that of the flat tendon-cell already described, and can be classed in the same category.

These fixed cells of the connective-tissues are believed by some accomplished histologists to be capable of limited vital movements during health. It is undeniable that under the influence of irritation they can, and often do, return to an active state, when they may put forth all the powers of the amœboid lymph-corpuscle.

EPITHELIUM.

With this subject we come to the study of a class of elements possessing an ancestry and functions totally different from those of the minute forms previously considered.

The cutaneous epithelia are the representatives of the epiblast, or the upper layer of the blastoderm. On the other hand, the epithelial cells of the intestinal canal spring from the lower layer, or the hypoblast of the blastoderm of the embryo.

THE EPITHELIUM OF THE SKIN.

Spinous cells.—The cellular elements covering the skin afford several varieties of investing epithelium. In the rete mucosum the epithelial cell is soft, apparently granular, membraneless, and polyhedral from mutual pressure. It is constituted by a cell-body, and generally only one spherical vesicular nucleus. The cell-body consists of a network of fibrils holding in its meshes a semifluid, hyaline substance. The nucleus also is formed of a network, and an interfibrillar substance, and is limited by a double-contoured membrane. There are also in the nucleus often one or more small granules (nucleoli), the remains of a hyaline, albuminoid material, from which the nucleus was originally developed. The periphery of these soft membraneless cells of the rete mucosum is furnished with small prickles or spines (see *c*, fig. 2, Plate I.), which are frequently wanting on the periphery of neighboring cells. These *spinous cells* have been called by various names, such as the dentate-cell, the prickle-cell, and the riff-cell. Adjacent cells are effectually held together by the union of their spines, and by a viscid cement substance (intercellular cement) similar to that above mentioned for the endothelium.

During irritation this cement substance increases in amount but lessens in viscidity. The lines of separation between the cells then become quite distinct. Fig. 2, Plate I., presents a very truthful picture of the relations which these cells bear to each other.

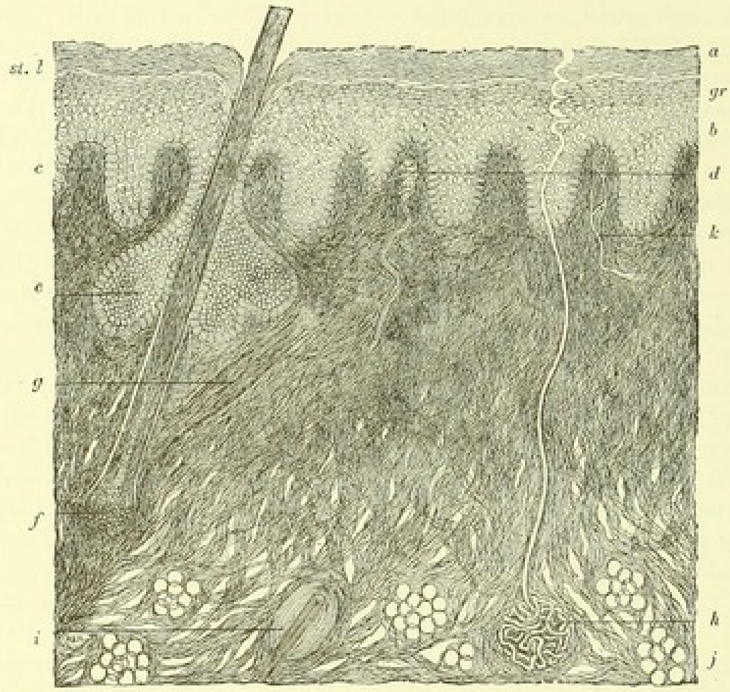
The deepest of the rete-cells, namely those in contact with the fibrous tissue of the cutis, are more or less *columnar*, or rather conical in form. The large ends abut against the polyhedral rete-cells previously mentioned, while the small ends fit accurately into indentations of the papillary layer of the derm. In the dark-skinned races, these columnar cells are more or less pigmented.

Stratum granulosum, and stratum lucidum.—The outermost layer of the rete-cells is covered with a thin lamina of flattened, intensely granular cells, forming a layer about two cells deep, the *granular layer* of Langerhans (see Fig. 13). Immediately external to the thin granular layer is a second, which has received the name of the *stratum lucidum* of Schrön. This layer is of slight thickness, the cells are transparent and hyaline, and occasionally exhibit nuclei.

Corneous layer.—Placed upon the stratum lucidum are the most superficial cells of the cutaneous epithelium. They are all converted into dense, *corneous plates*, with no trace of their reticular or nuclear structure remaining. They form a layer of variable thickness in different locations—the *stratum corneum*, or corneous layer.

The outermost cells of the rete mucosum, or rete Malpighii, have lost their regularly polyhedral form, and have become somewhat flattened, so that in a vertical section of the skin they are seen in profile, and appear more or less spindle-shaped. The cells of the granular layer are still more flat. Those of the stratum lucidum have been flattened into mere scales, which, seen in profile, look like interrupted lines. In the cutaneous epithelium we have, therefore, five varieties of epithelial cells, named from below upwards as follows: the columnar, granular, spinous, lucida, and corneus. Among the soft, membraneless, polyhedral cells of the rete mucosum are, according to some late investigators, a few spindle-form, or stellate nucleated cells, whose branching processes run in the intercellular cement-substance, and

Fig. 13.



VERTICAL SECTION OF THE HUMAN SKIN.—*a*. Corneous layer of epithelium. *st. l.* Stratum lucidum. *gr.* Stratum granulosum. *b.* Rete mucosum and papillary layer of cylindrical cells. *c.* Papillæ of skin. *d.* Tactile corpuscle. *e.* Sebaceous gland. *f.* Hair-bulb. *g.* Erector pili muscle. *h.* Convolution of sweat-gland. *i.* Pacinian corpuscle. *j.* Panniculus adiposus (fat-layer). *k.* Vascular loop. Low power. Partly diagrammatic. (*Duhring.*)

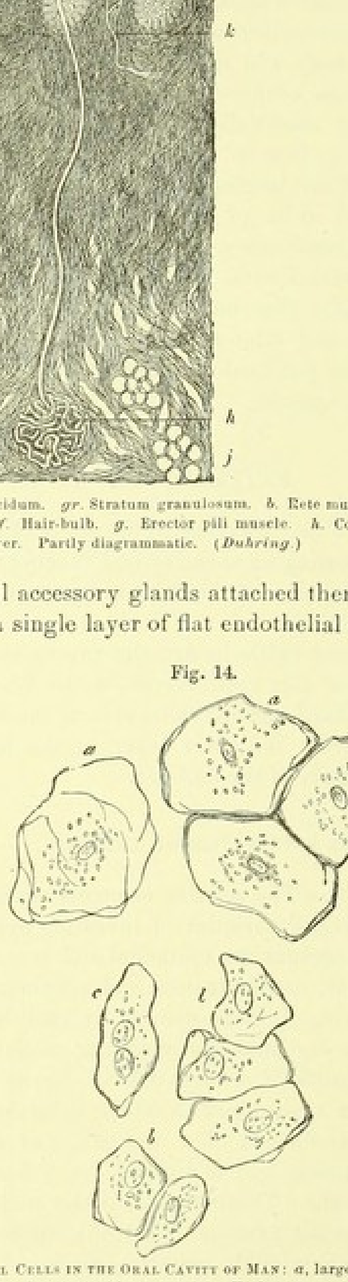
often unite with the processes from neighboring cells of a similar nature (see *e*, fig. 5, Plate I.). They are thought by some to possess the characteristics of connective-tissue corpuscles; others believe them to be only amœboid lymph-corpuscles; while still others believe them to be peripheral nerve-corpuscles in communication, by their deep processes, with fine filaments of the superficial cutaneous nerves.

The covering of the skin, being composed of numerous layers of cells superimposed upon each other, mainly of a flattened scaly form, is termed a *stratified squamous* epithelium.

THE EPITHELIUM OF MUCOUS MEMBRANES.

Squamous epithelium.—In the mouth of man, the epithelial covering of the mucous membrane is nearly identical with that which covers and protects the skin. The stratum granulosum and the stratum lucidum, however, are absent. Moreover, because of the constant moist condition of the epithelial layers upon this mucous membrane, the corneous layer of cells is comparatively thin, and is composed of thin scales in which small nuclei may be seen. The deep layer of columnar cells is but little pigmented. Some later histologists note, throughout mucous membranes and the small accessory glands attached thereto, the existence of a single layer of flat endothelial cells, between the epithelium and the connective-tissue upon which it rests.

Fig. 14.



EPITHELIAL CELLS IN THE ORAL CAVITY OF MAN: *a*, large; *b*, middle-sized; *c*, the same with two nuclei. High power. (*Gray.*)

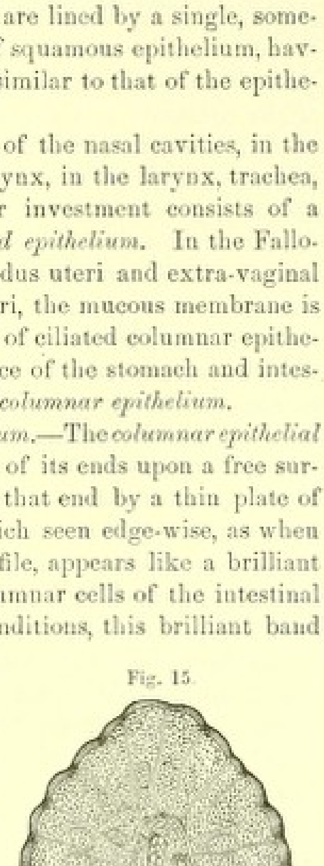
The cellular covering of the mucous membrane of the oral cavity is, therefore, to be regarded as a *stratified pavement of squamous epithelium.* This is the character and arrangement of the epithelium of the lower part of the pharynx, of the œsophagus, the edges of the epiglottis and of the true vocal cords, of the anus, of the intra-vaginal portion of the cervix uteri, of the vagina and vulva, of the glans penis and prepuce, and of the anterior third of the nasal cavity.

The pulmonary alveoli are lined by a single, sometimes interrupted layer of squamous epithelium, having a histogenetic origin similar to that of the epithelium of the bronchi.

In the olfactory region of the nasal cavities, in the upper portion of the pharynx, in the larynx, trachea, and bronchi, the cellular investment consists of a *stratified columnar ciliated epithelium.* In the Fallopian tubes and in the fundus uteri and extra-vaginal portion of the cervix uteri, the mucous membrane is covered by a single layer of ciliated columnar epithelium. The internal surface of the stomach and intestines is lined by a *simple columnar epithelium.*

Simple columnar epithelium.—The *columnar epithelial cell*, when it presents one of its ends upon a free surface, usually is limited at that end by a thin plate of considerable stiffness, which seen edge-wise, as when the cell is viewed in profile, appears like a brilliant band. In the simple columnar cells of the intestinal canal, under favorable conditions, this brilliant band seems to be vertically striated (see Fig. 15). By violence the thin limiting plate is often partially or completely detached from the end of the cell. Frequently the cell possesses a very delicate limiting membrane, which, however, is probably only a condensed film of the body of the cell. The columnar cell is somewhat soft and pliable, and may, therefore, readily assume shapes imposed upon it by pressure. It is rarely absolutely columnar; it is frequently more nearly conical. Often its deep end divides into two or more short thick branches (see *p*, fig. 3, Plate I.). It is provided with a nucleus which is oval or more or less rod-shaped possesses a thin membrane of double contour, and generally one or more distinct nucleoli. The nucleus is usually located near the deep extremity of the cell. The body of the cell is composed of a network of fibrils, whose meshes have a decided linear shape, mainly parallel with a long axis of the cell. The nucleus also contains a network which, like the nuclei of other cells, is denser than that of the cell-body. The finely granular appearance of the cells is due to the existence of this reticulum. The semifluid material contained in the meshes of the reticulum may vary in amount, and cause the interfibrillar spaces to increase more or less in extent, thus increasing or lessening thereby the granular aspect of the whole or a part of the cell.

Fig. 15.



Section of a Villus of a Rabbit, furnishing examples of non-ciliated columnar epithelium. High power. (*Stricker.*)

Ciliated columnar epithelium.—The *ciliated columnar epithelium* is essentially similar in structure to the simple columnar cell. It differs from the latter only by the presence of a number of fine cilia or hairs vertically attached to the thin plate at the free extremity of the cell (see *g*, fig. 3, Plate I.). These cilia pass through the thin limiting plate and are directly attached to the fibres of the intra-cellular reticulum (see *a*, Fig. 11). During the life and the activity of the cell the cilia are in more or less vigorous vibratile motion, and those agents which excite or retard movements in the amœboid corpuscles have the same action upon the movements of the cilia.

In stratified ciliated columnar epithelial coverings, the ciliated columnar cells constitute the superficial layer. They are usually present in a single row. Between and below the deep extremities of these ciliated cells are a greater or lesser number of spindle-form and more or less irregular polyhedral epithelial cells. These are usually membraneless, and contain one or more spherical nuclei, the minute structure of the cell being reticular. Scattered here and there among the columnar and other cells are a few soft granular membraneless bodies, sometimes fusiform, sometimes branched, apparently similar to the analogous cells mentioned under the cutaneous epithelium (see *c*, fig. 5, Plate I.).

Goblet-cells.—Some of the columnar cells, whether ciliated or not, may become distended and distorted with a collection of mucus near the free end. Such cells are known as *goblet-cells* (see *e*, Fig. 11). The nucleus is generally pressed aside and crowded into the deep end of the cell. If the accumulation of the mucus continue, the thin limiting plate is broken or detached, an occurrence which results in the discharge of mucous drops upon the free surface of the

epithelium, and the probable ultimate destruction and desquamation of the cell. During the progress of gastric digestion, these goblet-shaped columnar cells are to be found in great numbers upon the mucous coat of the stomach.

The epithelial cells of the mucous membranes, like those of the skin, are slightly separated, yet closely and firmly held together by an intercellular cement. According to the investigations of some authors (Klein among others), foreign particles placed upon the surfaces of mucous membranes are absorbed mainly, if not exclusively, by means of the intercellular cement-substance, which, at the surface of the fibrous tissue, is in direct communication with the superficial lymph-spaces of the connective-tissue. Even in the intestines the minute particles of the chyle, according to Klein, are not taken up by the columnar cells, and thence passed into the radicles of the lacteals, but they enter the intercellular cement, which reaches the free surface, and pass along this until they reach the lacteal capillaries.

GLANDULAR EPITHELIUM.

Under this caption we consider cells of widely-varying function and location. As a rule, they have an embryonal derivation similar to that of the investing epithelium, upon which the ducts of their glands empty. In fact, they commonly begin to develop at an early period of intra-uterine life by epithelial buds, which project from the deepest layers of this investing epithelium into the subepithelial connective-tissue.

Glands of mucous membranes.—The epithelial glands, which open upon the surface of mucous membranes, seem to be constructed upon two general plans, if we are to judge from the nature of their lining epithelium. The various forms of these glands seem to be only modifications of two models.

1. *Simple tubular mucous glands.*—The simplest kind of epithelial gland is, perhaps, the crypt or follicle of Lieberkühn. It usually presents the form of a small tube, closed at the deep extremity by a cæcal end, and opening at the other upon the surface of the intestinal canal. The cells, lining the tube in a single layer, are apparently identical in structure and form to the columnar epithelium of the surface. They are short, cubical, or columnar cells, which possess a spherical or oval nucleus, with a thin, double-contoured limiting membrane. The gland-tube is usually single, but sometimes may be branched in its deep extremity. The deeper portion of the gland is frequently slightly larger in diameter than is the upper portion or neck of the gland. In the wider portion the cells are longer. The columnar cells consist of a network, which is denser in the nucleus than in the cell-body. The fibres of the reticulum have a general direction parallel with the long axis of the columnar cell, namely, perpendicular to the wall of the tube. They are separated from the latter by a thin, flat, sometimes branched, endothelial cell, and separated from their neighbor-cells by a small amount of cement-substance, into which sometimes branches of the endothelial cells above mentioned may project. The free end of the columnar cell may contain a drop of mucus, when it constitutes what has already been described as the goblet-cell. The chief, if not, indeed, the only function of these cells is the secretion of mucus, and the gland itself may be regarded as the simplest form of a mucous gland. The cells in the quiescent state are smaller, and apparently more granular than when the cell is actively forming and excreting mucus. At no time, however, during health, is the cell coarsely or densely granular. It is to be remarked also that the longitudinal striation of the cell—an appearance in itself due to the prevalent longitudinal direction of the meshes of the intra-cellular and intra-nuclear reticula—is somewhat more marked in the neck, and at the orifice of the gland, than in its fundus. Besides the foregoing characteristics, these purely mucous tubular glands possess a distinct lumen throughout their length.

2. *Compound tubular mucous glands.*—In the mucous glands of the mouth we have an example of a compound tubular gland, whose chief function is the excretion of mucus. Here we have not only a modification of the form of the simple tubular gland, but there is also a complication of the lining of the tubes. Some of the largest of these glands may be taken as a type for description. Each gland consists of a large duct, funnel-shaped at its mouth. The duct passes more or less obliquely through the mucosa. Reaching the submucous tissue it divides into a number of smaller tubular branches, each of which soon slightly enlarges to form an infundibulum. Very soon the infundibulum again narrows, and passes into the secreting portion of the tube, which, after turning irregularly in numerous convolutions, ends in a cæcal extremity. In man, the funnel-shaped mouth of the duct has a lining of stratified pavement epithelium. At a slight depth, however, the epithelial lining of the duct is seen to consist of a single layer of long, narrow columnar cells, with intra-cellular and intra-nuclear

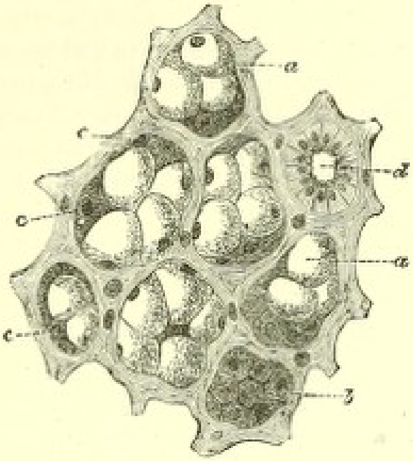
networks, producing a distinct longitudinal striation, and a slightly granular appearance of the cell. The lumen of the duct has considerable width. In the narrow tubes, into which the duct branches, the epithelium is still in a single layer only, but the cells are now much shorter and wider. They may be cubical, or even more flattened. The cells still contain networks, but these are neither dense nor arranged so as to produce an apparent striation.

In the infundibulum the lining epithelium still preserves this more or less flattened form. The lumen of the infundibulum is consequently comparatively wide. As the deep portion of the infundibulum is reached it again slightly narrows to pass into the convoluted tubes. At the same time the character of the lining epithelium again changes. Their cells now become columnar and very slightly granular. They contain a round or oval double-contoured nucleus, which is located near the outer end of the cell, both cell-body and nucleus consisting of a network of fibrils forming comparatively large meshes when the gland is fully developed. When the latter is active, these cells contain drops of mucin in their inner portion, and present every characteristic of goblet-cells. When exhausted, they shorten very considerably and become very granular, and consequently somewhat opaque. The lumen of the convoluted tube is characteristically large. The epithelia of these glands rest upon a layer of endothelial or connective-tissue cells which are more or less branched, some of the branches penetrating as septa between the intercellular cement which holds the cells together.

Sometimes in the convoluted portion of the glands two, three, or more embryonal cells are found at rare intervals along the course of the tube massed together in thin clumps, and they are always located between the previously described columnar epithelium and the layer of endothelial cells which form the basement-membrane of the tubes.

The sublingual gland of man and the submaxillary gland of the dog are mucous glands still larger than those last considered, but they are constructed upon the same general plan with, however, an epithelial lining a little more complicated. In the convoluted portion of the tubes, protoplasmic collections between the mucus-cells and the basement-membrane of stellate endothelia, somewhat similar to the embryonal cells mentioned as occasionally present in the last-described mucous glands of the mouth, are in these glands very numerous. These protoplasmic masses are more or less crescentic, and have received the name of the *crescents of Gianuzzi*, after the anatomist who first accurately described them. They are densely granular uni- or poly-nucleated masses without a defined membrane, but with projections which fit into the spaces between the epithelial cells with which

Fig. 16.



SUBMAXILLARY GLAND OF DOG.—*a*. Mucus-cells. *b*. Protoplasm cells. *c*. Crescents of Gianuzzi. *d*. Transverse section of excretory duct with its peculiar columnar cells. High power. (*Stricker*.)

they are in contact. In other respects the contents of these compound tubular glands are apparently identical with those of the smaller mucous glands of the mouth.

3. *Compound tubular salivary glands.*—The parotid gland of man is built upon the same plan as is the sublingual so far as the arrangement of the tubes is concerned, but its function is quite different, and so also are the characters of the lining epithelia of the convoluted secreting tubes. The epithelial cells of this portion of the tubes are more or less cubical, and are densely granular and proportionately opaque. They contain a round nucleus located near the basement-membrane, and limited by a thin envelope of double contour. The nucleus and cell-body consist of a dense network of fibrils with irregular and small meshes, containing, in the quiescent state, a minimum of fluid substance. During activity, this fluid increases very considerably, and distends the meshes, thus causing the cell to become considerably larger and more transparent. Crescents of Gianuzzi are found in these tubes also, but in fewer numbers than in the purely mucous glands. Another distinction between these purely salivary glands and the purely mucous glands is in the diameter and the size of the lumen of the convoluted tube. In the mucous gland the lumen is distinctly recognizable, of considerable size, and is generally patulous, while, on the contrary, in the purely salivary glands it is often doubtful if the

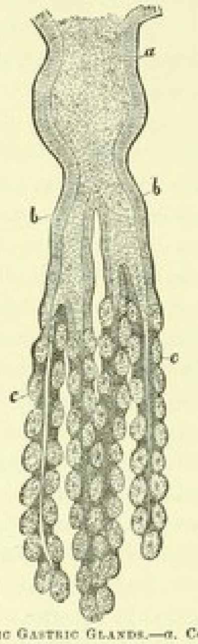
convoluted tube has a real lumen. It is at all times so small and generally so plugged with a substance much like the intercellular cement, that some authors have denied the existence of a true lumen in this portion of the tube, and have claimed that the small intercellular spaces act the part of a duct for the secretions.

In the submaxillary gland of man we have presented a large compound tubular gland still more complicated than either the large purely salivary, as the parotid, or the large purely mucous, like the sublingual, for in this gland the functions and the structure of the two latter seem to be united in one. It is a compound tubular gland of mixed function—the secretion of a salivary fluid and the excretion of mucus, and it combines more or less intimately and perfectly the anatomy of each. Some of the lobules of the gland are composed of convoluted tubules, which possess an entirely salivary character, while others present a purely mucous structure and function. Further, even in the same lobule, some of the convoluted tubes may possess the one character, while others represent the other variety.

4. *Gastric glands.*—In the stomach are two varieties of compound tubular glands, which possess an epithelial lining presenting peculiarities somewhat different from the preceding.

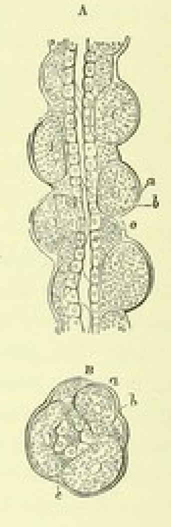
In looking at the mucous surface of the stomach with a good magnifying hand-lens, immense numbers of minute holes can be seen. They are generally collected together in groups of three to five or more. These small holes are orifices of the ducts of glands occupying the thickness of the mucosa. They have been called *peptic glands.* They are constructed upon the model of the compound tubular gland. They consist of a common duct with a wide lumen. The surface of the mucous membrane of the stomach is covered by a single layer of columnar epithelia. During digestion many of these cells elaborate and discharge mucus, and in doing so assume the form of goblet-cells. Columnar cells, identical in appearance with those of the mucous surface, line in a single layer the walls of these ducts. Near the middle of the thickness of the rete mucosa the ducts suddenly narrow and divide into two or more smaller branches, which immediately become constricted, to form the neck or intermediary portion of the secreting tube. The neck of the secreting tube is lined by a continuation of the epithelium in the duct, but the cells are much shorter. Immediately outside of the latter, and between them and the basement-membrane, are scattered here and there single cells of a very granular aspect containing a round or oval nucleus, both cell and nucleus being more or less flattened. They consist of an intra-cellular and an intra-nuclear network, and have been called by some authors *peptic cells* (Figs. 17, 18). They do

Fig. 17.



Peptic Gastric Glands.—*a.* Common duct. *b, b.* Its chief branches. *c.* Terminal cæca with spheroidal gland or peptic cells. (*Carpenter.*)

Fig. 18.

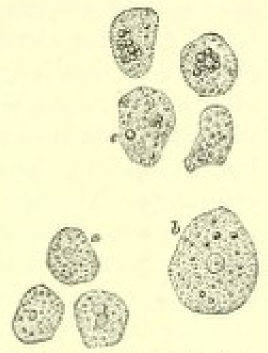


Portion of one of the Cæcæ of a Peptic Gastric Gland more highly Magnified; seen longitudinally at A; transversely at B. *a.* Basement-membrane. *b.* Large glandular or peptic cell. *c.* Small epithelial cells surrounding the lumen. (*Carpenter.*)

not constitute a continuous layer. They are more closely aggregated in the neck and upper portion of the secreting tube than towards the fundus, although they are also present in the deepest end of the tube. The secreting tubes into which the large duct divides are somewhat wavy in their course. They are often quite curved at their cæcal extremities. After the constriction of the neck they gradually increase in diameter until the deep end of the tube is reached. As the tube widens the lining epithelium lengthens, still, however, leaving a distinct lumen for the passage of the mucous secretion. The cells of the fundus contain a spherical nucleus in the outer end of the cell, and an intra-cellular and intra-nuclear network whose meshes do not, however, present a linear arrangement such as is seen in the cells which line the neck of the secreting tubes and the common duct. Between the epithelia upon the surface of the gastric mucous membrane is a scant reticulum of branched connective-tissue or endothelial cells. Similar cells and their processes also penetrate the intercellular cement of the whole epithelial lining of the peptic glands.

Liver- and kidney-cells.—The gland cells of the liver possess one, sometimes two spherical vesicular nuclei with an investing membrane of double contour and an intra-cellular and intra-nuclear network. The network appears to be arranged somewhat as a honeycomb. In the spaces of this honeycomb are drops of fat, with biliary granules, and occasionally pigment. The cells are polyhedral from mutual pressure, their outlines generally presenting five or six sides. They are soft, membraneless, and apparently granular.

Fig. 19.



ISOLATED HEPATIC CELLS.—*a*, *b*, Normal, but *b* more highly magnified, showing the nucleus and distinct oil-particles; *c*, cells in various stages of fatty degeneration. (*Carpenter.*)

The cells lining the tubules of the kidneys present diverse aspects according to the relative portion of the tubules in which they are located. Those in the convoluted portions of the tubes are more or less granular and opaque. Here they are membraneless, and each contains a round or slightly oval nucleus a little towards the deep part of the cell. The cells are more or less cubical in form with a tendency to a columnar shape. They are longitudinally striated—an appearance due to the presence of large numbers of minute rod-like fibres with a general direction perpendicular to the axis of the tube. These minute rods or fibres are in truth united into a network, the meshes of which are extremely long and narrow. The nucleus also contains a network.

Glands of the skin.—1. *Sweat-glands.* The sudoriparous glands of the cutaneous surface are simple tubes which at their deep portions are very much convoluted. In the straight portion of each tube, as it passes through the derma, there is an epithelial lining consisting of a single layer of more or less cubical or short columnar cells. These cells contain a nucleus, and are more or less longitudinally striated—an appearance due to the presence of an intra-cellular and intra-nuclear network, the prevalent direction of whose fibrillæ is longitudinal. In the convoluted portion the epithelial cells are much less striated, because the meshes of the reticulum of which they are in part composed are much more irregularly arranged.

2. *Sebaceous glands.*—The sebaceous glands consist of two or more lobules attached to an excretory duct. The lobules are as a rule regular, ampullar dilatations, lined with two or more layers of epithelial cells. The peripheral layer of cells rests upon the basement-membrane, and consists of cubical epithelia having spherical or flattened nuclei containing one or more nucleoli. These cells are more or less granular—an appearance due in part to the presence of a fine reticulum in the cell-body and nucleus, and also in part to the presence in the meshes of this reticulum of small fatty particles. The second layer of elements is composed in the main of cells similar to those of the outermost layer, which have undergone a metamorphosis into fat-vesicles. The molecules of fat, which are at first scattered through the meshes of the reticulum, accumulate so rapidly that they distend its meshes inordinately, and finally cause the atrophy and destruction of the nucleus and the breaking-down of the fibres of the reticulum. The small fatty particles then run together and form a large fat-drop, which ultimately bursts its protoplasmic envelope and becomes free in the lumen of the gland.

Hair and hair-follicles.—Epithelium enters into the construction of the shaft and the sheath of hair—structures met with very extensively on the surface of the body. The hair-follicle begins its development in the skin as early as the third or fourth month of the existence of the fœtus. The first stages of development are exactly similar to those of the sweat-gland. Both these organs arise by an ingrowth of the cutaneous epithelium, in the shape of buds, which rapidly extend in length, burrowing their way into the depth of the connective-tissue; for some time after development has begun, it is impossible to say whether a certain epithelial bud, growing into the connective-tissue, will ultimately form a sweat-gland or a hair-follicle. After the epithelial bud has thus entered some distance, the mass presents the first characteristic indication of the formation of a hair, by a more or less definite appearance of two layers: viz., an axial and a peripheral layer, or the true hair and its investing sheath. By further evolution these two portions, into which the mass of cells filling the depression in the derma has separated, subsequently develop, the axial portion into the shaft, the peripheral portion into the sheath of the hair. After this stage of growth has been reached, the space thus channelled out of the connective-tissue, and filled with the sheath and shaft of the hair, receives definitely the name of *hair-follicle.* The adult hair follicle normally contains epithelial elements very similar to those of the common epidermis, but presenting some characteristics of form and arrangement which are peculiar to the hairs. Since the hair-follicle, sheath, and shaft are formed by

an infolding of cutaneous surface, the arrangement of the various elements is essentially the same as upon the surface of the skin. The *sheath of the hair* is composed of an inner and an outer portion. The outer portion is a continuation of the rete mucosum of the skin, and consists of epithelial cells identical in structure and arrangement with those of the normal rete mucosum (*b*, fig. 1, Plate II.). Interspersed among these epithelia is a small number of branched protoplasmic cells, in every way similar to those upon the surface of the derma. Internal to the cells corresponding to the rete mucosum of the skin is the inner sheath (*c*, fig. 2, Plate II.). It is composed of two strata of transparent cells, the innermost stratum containing elements with a visible nucleus. Both cell and nucleus are somewhat ovoid in shape, while the cells of the outermost stratum are destitute of nuclei. The latter are, perhaps, a continuation of the cells of the stratum granulosum of the surface, although they contain no granules. Within the innermost sheath, is the axial *shaft* or hair proper, itself covered with a very thin cuticle (*e*, fig. 2, Plate II.). The cuticle consists of a single imbricated layer of thin epithelial scales without visible nuclei (*c*, fig. 1, Plate II.). The hair-shaft comprises two portions when seen transversely, viz., a cortical cylinder and a medullary axis. With its investing cuticle, the shaft, except in and near the hair-bulb at the root of the hair, consists entirely of extremely thin corneous epithelial scales without a vestige of nuclei. They are so densely packed together, that it is impossible, even after mechanical dissociation, to distinguish the outlines of the cells. After the action of sulphuric or nitric acid upon them, the intercellular cement-substance is dissolved, when the thin scales can be readily separated by means of needles, and their characters demonstrated (fig. 4, Plate II.). The corneous cells of the shaft represent, therefore, the stratum corneum ot the epidermis. Some of the minute interstices between the corneous scales may contain particles of fatty matter or pigment-granules. The greater or lesser abundance of the latter determine the light or dark color of the hair. Some of these minute capillary spaces may contain air. When many of them are filled with air, and at the same time the pigment particles, previously mentioned, are present only in small numbers or are entirely absent, the hair presents a glistening silvery aspect. The medullary or axial portion of the shaft consists of an irregular aggregation of shrunken epithelia of an original form more or less polygonal. These shrunken angular cells sometimes contain pigment-granules, sometimes minute vacuoles filled with air, and the same gaseous substance generally fills the interstices between the shrunken cells. The medullary axis of the hair-shaft, no matter what the color of the cortical cylinder may be, shines through the latter, presenting a lighter and more glistening appearance.

The foregoing characters of the hair are commonly observed in those portions above the bulb or root of adult hair. As the bottom of the follicle is reached, the distinctions between the inner and outer sheath become lost in the general embryonal character of the epithelium. The hair-shaft is now also changed both in shape and in the character of the constituent elements. It expands into a bulb-shaped extremity a little above the bottom of the follicle. The cuticle covering this *bulb* is composed of slightly granular epithelia containing distinct nuclei. At the bottom of the follicle these cells are more or less spherical, but they flatten and their size and the distinctness of their nuclei lessen gradually from below upwards, as can be seen by reference to the figure already indicated, until, above the bulb, the nucleus is lost entirely, and the cell is converted into the thin transparent cuticular plates or scales already mentioned.

The two portions of the hair-shaft also present in the root an aspect entirely different from that of the outermost end. For a slight distance above the bulb the cells of the cortical cylinder are less corneous and they contain a trace of a nucleus. As the bulb is approached, the epithelia of this cylinder gradually increase in thickness, while their nuclei also become larger and more defined. In the bulb itself, the epithelial cells present the characteristics of the most superficial cells of the rete mucosum.

A vascular connective-tissue papilla springs from the bottom of the hair-follicle and penetrates the centre of the hair-bulb. On the sides, it is ensheathed by the cellular accumulation which is continuous above with the corneous cortical cylinder of the hair-shaft. Above this papilla is a mass of epithelial cells, similar to those of the cortical part of the bulb, which is continuous with the shrunken irregular corneous cells of the medulla or axis of the shaft. These medullary cells of the bulb pass by slow gradations from below upwards into the irregular corneous cells already described as existing in the axis of the hair, but they still present distinct nuclei at a level much higher than that of the bulb. The papilla seems to be the main source of the vitality and growth of the hair.

Destruction and regeneration of epithelium.—The various investing epithelia, of the cutaneous surfaces

and of the mucous surfaces as well, seem to undergo a constant destruction and regeneration. Desquamation is constant upon the external surfaces, and it seems also to be a common although less rapidly occurring phenomenon upon the mucous surfaces. This constant loss of cells must be fully compensated by an active new formation of elements. It is generally conceded that the new supply of cells must come from the layer corresponding to the rete mucosum in the stratified epithelial coverings. Whether these new cells are produced by a proliferation of the soft finely granular polyhedral epithelial cells of the rete mucosum, or whether they arise from the wandering cells which are always present in greater or lesser numbers in the epithelial coverings, or whether they are in part derived in both ways, investigators have not entirely determined. Many uphold one of the extreme opinions, while some defend the middle ground.

It is quite certain that under the influence of irritation not only do the rete cells proliferate, but even those which have begun to approach the corneous condition return to the embryonal state, or exhibit other evidences of an awakened formative power. Under such a stimulus, some of the cells may contain an endogenous progeny. Such a condition is frequently met with in and around tumors, and upon epithelial surfaces secreting pus.

The regeneration upon granulating surfaces of epithelium, or its new formation over abrasions, seems in some way to be more or less closely related to the action of previously existing epithelial cells. The newly formed epithelium is almost always connected directly with the old epithelium at the edges of the wound. If a large abraded surface be sprinkled freely with epithelial scales, isolated islands of newly formed epithelia, which exhibit no direct connection with the epithelium at the edges, may after some time make their appearance.

Skin-grafting.—One means of healing extensive granulating surfaces is, by the employment of skin-grafts. This method is in some respects essentially identical with that of dusting the surface with epithelial scales. In both instances, the presence of epithelium seems to affect the granulation-cells in a peculiar manner, and cause the latter to develop into epithelia. There seems to be an *infection* of the granular cells by the epithelia, or, so to speak, an "action of presence" of the epithelial scales, which is shown in the tendency of the embryonal cells acted upon to form epithelium rather than connective-tissue.

THE CONNECTIVE-TISSUE SYSTEM.

Having reviewed some of the numerous cellular elements which in part constitute the human organism, we now enter upon the consideration of the histological relation which they bear to other constituents. We have already studied the lymph and the blood—tissues which from their derivation may be classed as congeners of connective-tissue.

The connective-tissue, in one form or another, besides special offices which it may perform in the human economy, acts as the framework upon which and within which the various elements and organs are supported. Upon it rests the investing epithelium. In it are imbedded the glands, the muscles, the vessels, and the nerves.

The great connective-tissue system comprises the following groups of tissue, which will be examined in the order in which they are here enumerated: Mucous-Tissue; Varieties of Connective-Tissue, properly so called—Cartilage, Bone, Dentine, and Cementum; Muscle, Nerve, and the Connective-Tissue exhibited in the Bloodvessels and Lymphatics.

MUCOUS- OR GELATINOUS-TISSUE.

In the human adult this form of tissue is of extremely limited distribution. It is found in the vitreous humor of the eye, and perhaps in the enamel-organ of the teeth. In the embryo it is very extensive. It presents two general varieties, which are distinguished by the character of the cellular elements, and the intercellular substance which surrounds them.

The simplest form of mucous- or gelatinous-tissue is that represented by the vitreous humor of the eye. It consists of a transparent, colorless, gelatinous semifluid substance, which contains a more or less considerable quantity of mucin, or of a substance which has a very similar reaction. It is precipitated by weak acids in the form of minute granules, which then give to this semifluid ground-substance under the microscope a finely granular aspect and a slight opacity when viewed by the naked eye. Imbedded in this gelatinous semifluid ground-substance, cellular elements are present in more or less considerable numbers, according to the age of the subject and the quiescent state of the tissue. In the adult they are scattered at rare intervals. These cells are lymphoid elements of more or less spherical or oval outline.

They are capable of limited movements, which, however, are perhaps not usually sufficient for locomotion, although some of them are doubtless wandering cells. They have no limiting membrane; possess one, sometimes two or more nuclei, and consist of an intra-cellular and an intra-nuclear network, which give to the element a more or less granular aspect. The ground-substance seems to be void of bloodvessels in the adult.

Another variety of mucous-tissue, a type of which is met with in the Whartonian jelly of the umbilical cord, has a more complicated structure, and is a grade higher in the scale of development. In a gelatinous mucin-containing ground-substance similar to that of the simplest variety, is to be found a network, or rather felt-work of soft, delicate, slightly refracting fibres. These are collected into bundles or bands, sometimes of considerable width. Upon and near these bundles, cells more or less stellate, and in other respects similar to the flat-branched cells of loose connective-tissue which have already been particularly described, are to be seen, these branches forming by their communications a more or less complete network of stellate cells. Some of the bundles contain, in their interior, bloodvessels with distinct and somewhat thick walls. The inter-fibrillar areas are also sometimes permeated by capillary bloodvessels with large loose meshes, and with strong, distinct walls. These capillary vessels are ensheathed by a network of branched cells. The interfibrillar spaces also contain, in small numbers, the lymphoid cells common to the simplest variety. Sometimes networks, composed of fusiform or of branched connective-tissue cells (fig. 5, Plate II.), are seen occupying the inter-fibrillar spaces. In some pathological formations of mucous-tissue there is, in addition to the foregoing structure, a sparse network of fine single elastic fibres.

WHITE FIBROUS-TISSUE.

Fibrous bundles.—White fibrous connective-tissue is most extensive in its distribution. It consists of extremely fine fibrils collected together into bundles varying widely in thickness and form. These bundles of fibrils may be cylindrical or band-like, the sides of the cylinders or bands being usually parallel. The bundles may be branched, but the individual fibres never are so. The course of the bundles may be straight, or more or less wavy, according to whether they are tense or loose. The minute fibrils which constitute the bundles are united and held together by a transparent viscid cement, which may be dissolved by weak acids, lime-water, baryta water, 10 per cent. solution of salt, and by other means known to the histologist. In some locations, the bundles are

EXPLANATION OF PLATE II.

Fig. 1. A profile view of a Human hair-follicle, containing a hair under a high power. (After Frey.)

a, The fibrous sheath; *b*, the external root sheath; *c*, the cuticle of the hair-shaft; *p*, the papilla of the hair; *h*, *e*, the medullary axis of the hair-shaft; *h*, the cortical cylinder of the hair-shaft; *g*, the transition of the corneous epithelial scales of the cortical cylinder of the hair-shaft above, with the soft, nucleated, and membraneless epithelium of the bulbar portion of the hair; *e*, point of transition of the soft nucleated epithelium of the bulbar portion of the medulla of the hair-shaft into the shrunkened, deformed, and dry corneous granules which fill the medulla of the upper portion of the shaft.

Fig. 2. Transverse section of half of a Human hair, with its root sheaths, still higher power. (After Frey.)

h, Hair-shaft; *e*, hair-cuticle; *c*, two layers of the internal root-sheath; *b*, external root-sheath, showing an outer layer of columnar cells; *f*, basement membrane; *a*, the external fibrous sheath.

Fig. 3. *a*, *b*, *c*, Stellate mucous-tissue cells, whose processes form a more or less complex network. (Moderate enlargement.)

Fig. 4. Represents isolated cells of various parts of the hair. Highly magnified. (After Frey.)

e, Nucleated epithelial cells of the bulbar portion of the hair; *b*, *h*, cells from the cuticle of the hair; *h'*, corneous epithelial cells of the cortical portion of the shaft, treated with sulphuric acid, the same resolved into separate plates at *h.''*

Fig. 5. Mucous tissue (gelatinous tissue) from the umbilical cord of a Lamb, very highly magnified. (After Ranvier.)

c, Branched cells; *n*, embryonal cells, or lymph corpuscles; *F*, connective fibres; *B*, intercellular amorphous fluid-substance, containing mucin.

PLATE II

Fig. 1

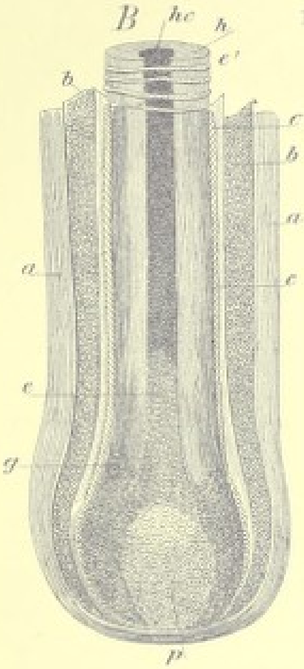


Fig. 2

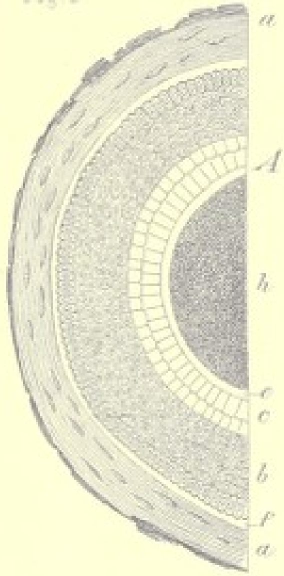
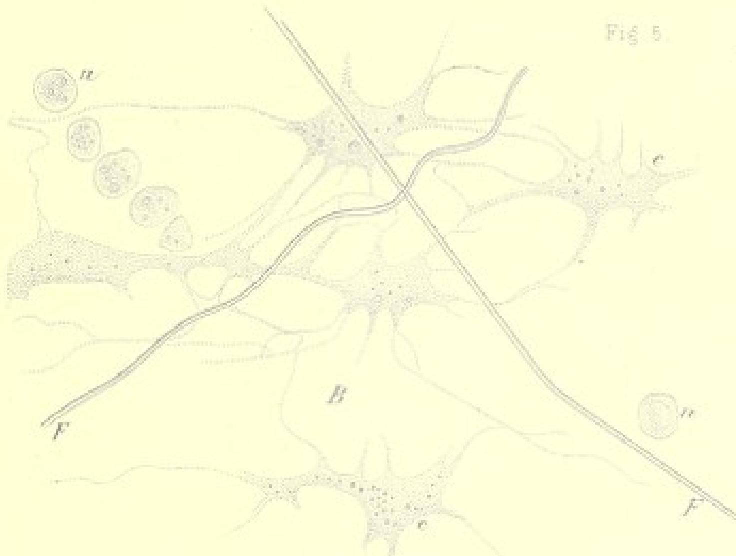


Fig. 3

Fig. 4.

Fig. 5.



more or less completely enveloped in a thin elastic sheath. Such ensheathed bundles are to be found in the subcutaneous connective-tissue, in the subarachnoid of the brain, in aponeuroses, in tendons, and in some other locations.

Structure and arrangement of fibrous bundles.—The bundles of fibrils present a distinct longitudinal fibrillation when seen under a sufficient magnifying power. When they are loose and wavy, they also appear to have an indistinct, transverse striation. This is an optical illusion caused by short and very frequent waves in the course of the fibrils. This wavy appearance of the fibrils, and consequent apparent transverse striation, may be seen sometimes even when the sides of the bundle seem to be perfectly straight.

Water and weak acids cause the interfibrillar cement to swell, and give the bundle a hyaline or homogeneous aspect. These agents have no such effect upon the elastic sheath which envelops some of the bundles. Ensheathed bundles appear swollen in some places, and constricted in others, thus presenting a beaded outline.

The bundles of fibrous tissue may be variously arranged with respect to each other. The simplest arrangement is that of a collection into secondary bundles or bands, which run parallel with each other and are spread out, side by side, to form lamellar membranes, as in aponeuroses, or are collected together to form rounded cords, as in tendons. They may, on the other hand, cross each other in various directions, forming a loose felt-work with wide meshes, as in the loose connective-tissues; for example, the subcutaneous- or mucous-tissue, the inter-muscular connective-tissue, the loose interstitial connective-tissue of glands, etc. Or they may be closely packed together to form a very dense felt-work, such as the cutis, the dura mater, etc.

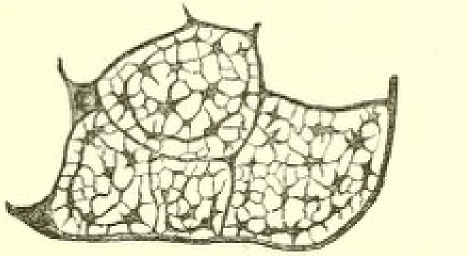
On the other hand, the bundles may form a loose network spread out in the form of a membrane with more or less wide meshes, like the mesentery, the ligamentum dentatum of the spinal cord, etc.

Interfibrous spaces, and their cellular contents.—The spaces left between the fibrous bundles are consequently of forms varying according to the direction of the bundles. They are filled with lymph, and constitute the radicals of the great lymphatic system.

In tendons, the spaces left between the bundles are more or less linear when viewed longitudinally, and when seen in transverse section appear more or less stellate.

When speaking of endothelia and connective-tissue corpuscles, we described the flat elastic cells which form a partial lining of the lymph-space formed between adjacent parallel bundles of tendons, and stated their relation to the bundles of fibrils upon which they were more or less closely applied. It was then stated that these cells (the flat tendon-plates of Ranvier) spread across two or more bundles. Fig. 2, Plate III., shows very beautifully this peculiar arrangement of the tendon-cells. The drawing represents a number of (primary) bundles united together into a (secondary) larger bundle forming a small tendinous cord in the tail of a young rat. In larger tendons we have a number of such secondary bundles collected together to form the tendon. Tendons of this kind have their external surface covered by a complete layer of large flat endothelial plates such as line serous cavities, which rest upon an extremely thin elastic apparently structureless membrane. Such a tendon, after proper treatment by nitrate of silver, when placed under the microscope and seen longitudinally, shows this superficial covering of endothelial cells. By lowering the focus the flat tendon-cells of Ranvier next come into view. The latter if seen in surface present the appearances already described *à propos* of the cells of the connective-tissue. If their position upon the secondary bundles is such that they are seen in profile, they then appear as lines or spindles with slightly projecting bellies corresponding to the location of the nucleus. When a tendon composed of secondary bundles is cut transversely, and properly stained, it presents a number of more or less markedly stellate bodies (Fig. 20) connected the

Fig. 20.



TRANSVERSE SECTION OF TENDON: showing so-called branched corpuscles, inclosing spaces which, left blank, are naturally filled with tendinous fasciculi. High power. (*Carpenter.*)

one with the other by anastomosing branches (*C*, fig. 2, Plate III.). These bodies were formerly regarded as stellate connective corpuscles. They are, in normal tendon, generally nothing more than the cross cuts of the more or less flat tendon plates of Ranvier. These stellate forms may consist of two or more of such plates in apposition. Sometimes even one or more lymphoid

cells may be mingled with them. They may thus be formed of aggregations of cells, in which case several nuclei may be visible within them. The anastomosing branches appear to be sections of the primary or secondary cell-plates and their lateral ramifications. The clear spaces constituting the meshes formed by the previously mentioned anastomoses correspond to transverse sections of bundles of fibrils which have not taken the staining.

Besides the fixed cells above described, leucocytes or wandering cells are found in small numbers in the lymph spaces of the connective-tissue.

Elastic fibres.—When tendons are thoroughly boiled the white fibrous tissue which constitutes them is dissolved, and the other elements previously mentioned disappear. The more complete this effect of boiling, the more visible becomes a network formed of single highly refracting elastic fibres. These elastic fibres are very small in diameter, are more or less perfectly cylindrical, are branched at intervals, and are apparently homogeneous.

Their branches unite to form a network, whose meshes are long and narrow, the long diameter of the meshes being parallel with the axis of the tendon bundles which they accompany. These elastic fibres are in contact with the sheath which envelops the primary bundles more or less completely. They are so difficult to be seen that unless they are specially prepared they are generally invisible.

In *aponeuroses*, where the fibrous bundles are arranged so as to form thin lamellæ of considerable width, the fibres of a given lamella run parallel with each other, and are crossed at an angle by those of the lamella next above or below. In many such lamellar fibrous-tissues, the fibres in adjoining lamellæ cross at right angles. The tendon-cells are then found to be much more irregularly formed than in the simplest variety of tendon. In the adult these cells are not so frequently arranged in rows as in the simple tendons, and the secondary plates which spring from the body of the cell may then have a direction corresponding to that of the different fibrous bundles with which they are in contact.

Loose connective-tissue.—In the loose connective-tissue, for example the subcutaneous cellular-tissue so called, the bundles of fibrils run in every conceivable direction, sometimes branching and forming frequent anastomoses. The spaces left between the fibrous bundles are generally large, and they freely intercommunicate. Fluid or air injected into them readily passes from one to another. After having been distended by air and dried, they present the appearance to the naked eye of large cells or vesicles, hence the name of *cellular-tissue.* Some of the bundles of fibres are ensheathed as already mentioned, many of them are not. The fixed cells of the connective-tissue are not very numerous in adult tissue of this kind. They are loosely applied to the surface of one or more bundles, frequently at their points of crossing (see fig. 3, Pl. IX). The wandering lymphoid cells are much more numerous in this form of connective-tissue than in the tendons or aponeuroses.

Yellow elastic fibres are also to be met with. Here they are frequently much larger than in tendon, but they bear much the same relations to the fibrous bundles in the one case as in the other. The larger elastic fibres have been found by some investigators to be enveloped by a thin, dense membrane, which in most locations is extremely difficult to demonstrate. In the loose subarachnoid connective-tissues of the brain, and in some other locations, this investing sheath is quite distinct.

This variety of fibrous tissue may exist in the form of a thin, fenestrated membrane. Some portions of the omentum furnish an example of such, the fenestræ in this case representing the dilated lymph-spaces existing between the bundles of fibrous tissue. It is thought by some authors (Axel Key and Retzius) that many of the loose connective-tissues are composed of scant felt-works of fibrous bundles spread out in many superimposed lamellæ, which are more or less separated from each other by a single layer of flat endothelial cells resting upon one side of an extremely thin, structureless elastic membrane.

Dense connective-tissue.—The dense felts of white fibrous tissue, as, for example, those of the true skin, of the dura mater, etc., are essentially identical in structure to the loose felts of the subcutaneous connective-tissue, of the submucous-tissue, and of the interstitial connective-tissue of muscles, and of glands. The fibrous bundles being now much more closely packed together, the lymph-spaces are consequently smaller. The cellular elements are also present in much smaller numbers.

Bloodvessels.—The bloodvessels supplying this form of connective-tissue have much the same character as in the fibrous variety of mucous or gelatinous-tissue already described.

There are two other varieties of white fibrous connective-tissue, namely, the *neuroglia* and the *reticular*, or *lymphoid* tissue, which will be briefly considered when we study respectively the nervous system and the lymphatic system.

YELLOW ELASTIC-TISSUE.

Another form of connective-tissue presents itself in the yellow elastic-tissue. The fibres or bands composing it differ in chemical constitution from those of white fibrous tissue. They are not influenced by the action of water, weak acid, or strong alkalies. Unlike the white fibrous tissue, the individual elastic fibres frequently branch, and by the anastomoses of those branches form a genuine network with meshes, varying in size and shape according to the location and the variety of elastic-tissue.

Fine elastic fibres.—As already indicated, every form of white fibrous tissue contains a variable amount of elastic tissue in one form or another.

Perhaps the simplest and most widely distributed variety of yellow elastic-tissue is that which is present among the bundles of white fibrous tissue in the form of a loose sparse network of fine cylindrical apparently homogeneous and highly refracting fibres. These fine elastic fibres lie in close proximity to the (primary) white fibrous bundles, never within them. After nearly every method of preparation they seem homogeneous, presenting no trace of fibrillation or other structure. But when freshly submitted to the action of osmic acid, and examined under a moderately high magnifying power, they appear transversely striated. If a power of eight or nine hundred diameters with a good lens is employed, the transverse striæ are resolved into highly refracting lenticular or somewhat spherical forms, imbedded in a less dense, hyaline, transparent substance.

The fibres of elastic-tissue are straight or curved according to the tense or loose condition of the tissue in which they are found. When broken they curl up at the extremity. This form of elastic fibres is met with also in the matrix of yellow elastic cartilage.

Coarse elastic fibres.—Besides the network formed of such delicate elastic fibres just described, many white fibrous tissues contain an elastic plexus, composed of much coarser fibres. These coarser, elastic fibres are cylindrical or band-like. Schwalbe proved them to be covered by a delicate elastic sheath, which is ordinarily invisible. After the action of osmic acid upon perfectly fresh specimens, the coarse fibres are also seen to possess the peculiarity of structure already described for the finer fibres. This variety of yellow elastic fibres is also met with in the skin and other felt-works of white fibrous tissues. In the superficial portion of the trachea and bronchi they are closely packed together to form, with but a sparse amount of interstitial white fibrous tissue, a dense longitudinal layer. The most marked development of this form of yellow elastic-tissue is found in the ligamentum nuchæ and the ligamenta subflava, which may be regarded as, *par excellence*, types of yellow elastic tissue. Even in these two locations there is always a certain quantity of white fibrous bundles

Fig. 21.

YELLOW ELASTIC-TISSUE.—High power. (*Gray.*)

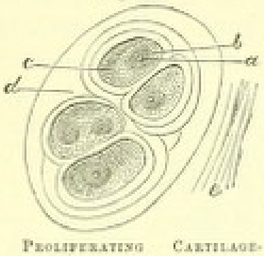
scattered through the meshes formed by the large yellow fibres, and there are also a small number of the formative connective-tissue cells present. The latter bear their customary relations to the lymph-spaces and the fibres. In this tissue the elastic fibres pursue mainly a longitudinal course, and are closely applied to each other. But if thin sections are made, and pulled out laterally by needles, it is easily seen that they really constitute a network. This form of yellow elastic-tissue is also found well developed in the walls of large arteries and veins.

The elastic networks heretofore considered are more or less sponge-like in their arrangement. There are elastic fibres which are band-like and in some locations form only lateral anastomoses. In this case we have an elastic fenestrated membrane, such as is present in the inner and middle coats of arteries and veins (see fig. 3, Plate III.).

Furthermore, instead of a fenestrated membrane, we may have a continuous layer of yellow elastic-

while the descendants have received the name of *daughter cells*. If the process of division be slow each new cell may form around it a new capsule (see Fig. 24). In this case the mother capsule contains a series of daughter capsules. If, however, the process of multiplication is rapid the newly born cells will not have time to secure the formation of a capsule before they give birth to new cells. Hence, the orginal mother capsule must now contain two or a greater number of cells of a more or less embryonal nature. The healthy cartilage-cell lives, then, within an envelope or shell which it builds for itself as a habitation.

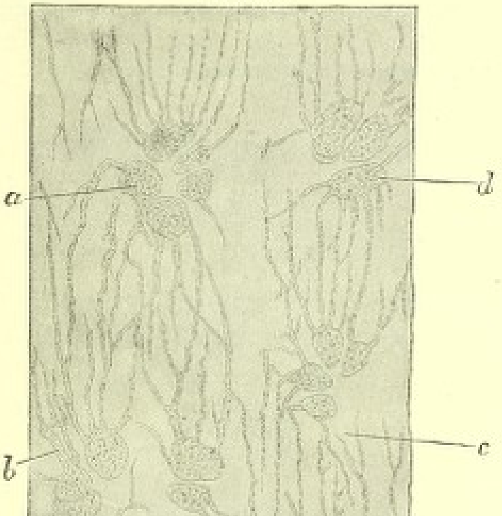
Fig. 24.



PROLIFERATING CARTILAGE-CELLS.—*c*. Protoplasm of the cell; *a*, nucleolus; *b*, nucleus; *d*, primary and secondary cartilage capsules; *e*, ground substance. In one of the cartilage-cells are seen two nuclei.

The inner surface of this envelope, *the cartilage capsule*, forms the boundary of a lymph-space, more or less spherical, which is normally quite filled by the body of the cartilage-cell (see figs. 4, 5, Plate III.). Preparations of cartilage usually show the cartilage-cell to be more or less angular, and occupying only a small

Fig. 25.



CARTILAGE OF A CUTTLE-FISH.—*a*, *d*. Body of cell. *b*. Anastomosing branches of the cells. *c*. Fundamental substance. ×400. (*Ranvier*.)

proportion of the space within the capsule. This is a distortion, due to the death and shrinking of the cell.

In the depth of cartilage the capsules usually have a tendency to assume the spheroid form, while towards the surface they become more or less flattened or lenticular in outline. In the superficial layer, at the articular surfaces, the cells are quite flat, and sometimes branched. In the articular cartilages, near the periphery, where the fibrous tissue of the synovial membrane is attached, the cartilage-cells are often branched, and at the line of attachment the processes of the branched cells sometimes communicate with those of the connective-tissue corpuscles of the fibrous tissue. Branched cells, like those seen in Fig. 25, are not uncommon in hyaline cartilage of some lower animals.

Matrix.—The intercellular substance, the ground-substance, or, as it is technically called, the *matrix* of hyaline cartilage, is usually hard, somewhat elastic, homogeneous, and transparent. In adult cartilage, after staining, the matrix faintly shows, by slight differences in shade, very indistinct and shadowy marking for some distance around the capsule (fig. 5, Plate III.). The cartilage-cell seems to have been a centre around which on all sides the matrix has been deposited in successive layers from without inwards, the existing capsule being last deposited. Under some circumstances the shadowy areas around the capsule seem to be composed of a number of concentric shells. The whole ground-substance appears to consist of an aggregation of these shadowy areas surrounding the cells.

Fibrillation of matrix.—Sometimes in adult hyaline cartilage the matrix is seen to be very finely fibrillated. This condition is met with most frequently in the costal cartilages of the aged, and in the calcifying layer of ossification of cartilage (see fig. 1, Plate IV.).

Embryonal cartilage.—The cells of hyaline cartilages may be closely aggregated, or they may be sparsely distributed through the matrix. When the intercellular substance is so small in amount that it is scarcely appreciable, the cartilage is known as parenchymatous or *embryonal cartilage*.

In the deep portion of articular cartilages, in the neighborhood of lines of ossification, the cartilage corpuscles assume an arrangement in parallel rows more or less vertical to the articular surface.

Perichondrium.—Each variety of cartilage is enveloped in a fibrous membrane, the *perichondrium*, which covers it everywhere except upon the articular surfaces and in the lines of ossification.

Calcification of cartilage.—Cartilage may be infiltrated with *calcareous particles*. When this is the case lime granules, minute and more or less angular, are first deposited in the ground-substance, immediately around the cartilage capsules. From these points the

infiltration may gradually spread until the whole matrix may be incrusted, and the cells transformed into calcified elements. By transmitted light the particles of lime are dark and opaque, large collections of them consequently appear more or less black. By reflected light they are brilliant and shining. This deposit of lime does not appear to permanently change the constitution of the cells or matrix. Weak acids readily dissolve it, leaving both apparently in their original condition.

YELLOW ELASTIC OR RETICULAR CARTILAGE.

This variety of cartilage is met with in man, in the Eustachian tube, in the epiglottis, and a few other places. It differs from hyaline cartilage only by the presence in the matrix of fine, yellow elastic fibres in greater or lesser numbers. These fibres are generally collected together so as to form a trabecular network in the matrix. In the meshes thus formed the cells are found enveloped in capsules, which are surrounded by a variable amount of hyaline groundsubstance (see fig. 3, Plate IV.).

Near the perichondrium the elastic fibres gradually disappear.

WHITE FIBROUS CARTILAGE.

This form of cartilage appears to occupy, histologically, an intermediate place between white fibrous connective-tissue and hyaline cartilage.

Its distribution in man is somewhat more extensive than the yellow elastic cartilages. It is chiefly found in the intervertebral disks and in the bursæ of tendons.

The intercellular substance or the matrix consists of white fibrous tissue arranged in parallel bundles. Frequently the fibres are arranged in lamellæ, and sometimes, as in the intervertebral disks and the symphysis pubis, the bundles constituting the lamellæ have a concentric arrangement. The cells of this form of cartilage have the same relation to the bundles as the flat cells of Ranvier do to the parallel bundles of tendons or aponeuroses. The cells themselves are not quite so flat or so much branched as the endothelial cell-plates of tendons. They are enveloped by the characteristic capsule of the cartilage-cell (fig. 2, Plate IV.). In some places the capsules are surrounded by a very small amount of hyaline substance. In the transition of tendon into fibro-cartilage the tendon-cells gradually thicken and become invested with a capsule, the only visible change noticeable. In the transition of fibro-cartilage into hyaline cartilage, as is observed at the edges of the intervertebral cartilages for example, the fibrous intercellular substance slowly disappears and merges in the hyaline matrix, while the cartilage-cells gradually swell and approach the spherical form.

Lymphatics of cartilage.—Cartilage, like all the other connective-tissues, is permeated by *lymph spaces.* The cartilage-capsules are perforated by almost numberless minute canals. The openings of these minute capillary tubes or pores communicate at one end with the interior of the capsule, which is a lymph-space containing the cartilage-cell, and at the other end open into large canaliculi which ramify in the cartilage matrix, and which, in their turn, communicate with the lymphatics of the perichondrium.

BONE OR OSSEOUS TISSUE.

Bone is the greatest in weight of all the solid tissues of the organism, and is the most extensive of the groups of the great connective system.

It presents for study a ground-substance, inclosing cellular elements and vessels, both lymph and capil-

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EXPLANATION OF PLATE IV.

Fig. 1. Section of calcified and fibrillated hyaline cartilage, from the costal cartilage of an old Man. High power.

a, Intercellular matrix infiltrated with minute calcareous granules, they are found more densely aggregated at *c*, around the cartilage capsules; *b*, fine fibrillæ, imbedded in the intercellular hyaline matrix.

Fig. 2. Fibro-cartilage from the intervertebral disk of Man. High power.

a, Fibrous matrix or intercellular substance; *c*, *b*, cells contained within a cartilage capsule, and exhibiting various stages of multiplication.

Fig. 3. Reticular or elastic cartilage, from the epiglottis of Man, showing the so-called cartilage cells in various phases of division within their enveloping capsules. High power.

b, Elastic fibres imbedded in the intercellular matrix.

PLATE IV.

Fig. 1.

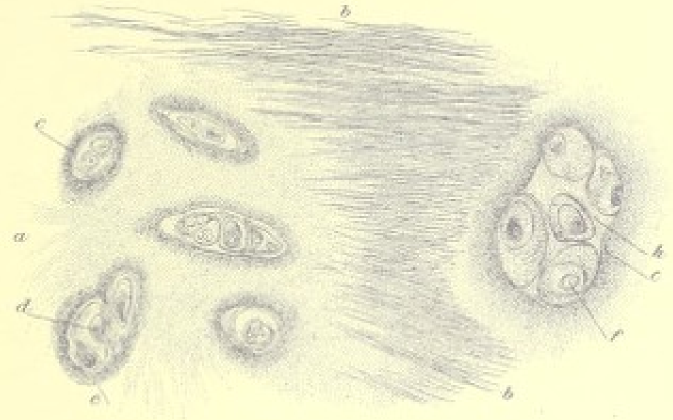


Fig. 2.

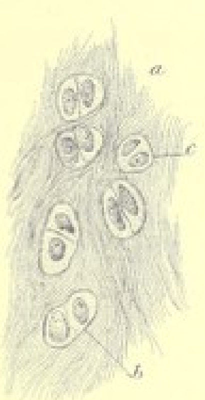
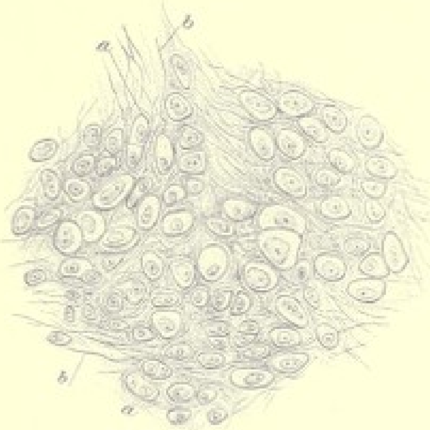


Fig. 3.



lary. The ground-substance is dense and compact, as at the boundary of the medullary canal of long bones, and at the periphery of both long and flat bones; or, on the other hand, it is porous or spongy, as in the diploë of flat bones, in the interior of epiphyses, and between the outer and inner compact layers of the diaphyses of long bones.

Compact bone.—The ground-substance of compact bone is hard and brittle, owing to its infiltration with salts of lime, which in the fluids of the body are ordinarily insoluble. They are, however, readily dissolved by the employment of acids. After decalcification through this means, bone may readily be cut into thin sections and stained. Thin plates of the hard, brittle bone, may also be obtained by grinding. A transverse section of the compact substance of the shaft of a long bone prepared by the latter method, and mounted dry, presents an appearance, when examined under a high power of the microscope, which is very fairly represented by fig. 1, Plate V.

Haversian canals.—The ground-substance is permeated by a number of small canals, the *Haversian canals*, which have a general direction mainly parallel with the axis of the shaft. They intercommunicate by means of short transverse or oblique branches, thus forming a network of elongated, and more or less rectangular meshes. The Haversian canals convey a capillary bloodvessel and one or more lymph-vessels, besides a variable amount of delicate, loose connective-tissue of a reticular variety, inclosing cellular elements,—a tissue essentially identical with the bony marrow which fills the Haversian spaces of spongy bone.

Arrangement of bony lamellæ.—Between the Haversian canals of compact bone the *ground-substance* is arranged in the following manner: Immediately around the canal the bony fibrous tissue shows from four to fifteen or twenty *concentric lamellæ*, the number varying according to the age of the formation. The greater the age the more numerous are the concentric lamellæ. The Haversian canals, with their surrounding concentric lamellæ, are known as the *Haversian systems.* Between, and separating the Haversian systems, the ground-substance is constituted by what have been termed the *interstitial lamellæ.* They comprise bands of osseous substance of variable width, running in various directions. Among these interstitial lamellæ of variable direction are some bands of lamellæ which pursue a course in general parallel to the periosteal surface of the bone. These are known as the *parietal lamellæ.* Running among the interstitial and the parietal lamellæ are sometimes found a small number of scattered elastic fibres which are very difficult to demonstrate. Interlacing with the parietal and interstitial lamellæ are found a few small bundles whose basis is white fibrous tissue, and whose direction is more or less perpendicular to that of the lamellæ which they penetrate (see fig. 3, Plate V.). They are called *perforating fibres*, or *fibres of Sharpey*, and are supposed to be the remains of bundles of white fibrous tissue originally forming a part of the inner layer of the periosteum, for at the periphery of the bone similar fibres are continuous with fibrous bundles belonging to the inner layer of that covering.

In flat bones or in thin bony plates, the compact substance presents essentially the same features. The arrangement of the Haversian systems, however, is by no means so regular as in the diaphyses of long bones.

Bone corpuscles.—Between the bony lamellæ of these different systems are numbers of *lymph-spaces*, in which lay connective-tissue corpuscles, just as in other forms of lamellar fibrous tissue. These lymph-spaces and their cellular contents constitute the so-called *bone-corpuscles.* Each lymph-space is in communication with its neighbors by means of minute *canaliculi*, the branches of the so-called bone-corpuscle. These canaliculi penetrate the bone lamellæ, and pass through them, usually nearly perpendicular to the direction of the latter. When a thin preparation of compact bone is made by grinding, and the thin plate is mounted dry, these lymph-spaces and their canalicular branches are filled with air, and by transmitted light consequently appear dark upon a light ground. In Haversian systems cut transversely, the body of the bone-corpuscle is seen in profile, and consequently presents an ovoid or fusiform outline, the long axis being parallel with the course of the lamellæ. The canalicular branches, more or less straight, and running perpendicular to the length of the concentric lamellæ, give to the Haversian systems a beautiful striated aspect, the fine striæ radiating from the Haversian canal as a centre. In the interstitial and parietal lamellæ the canaliculi produce a visible transverse striation. The canaliculi, besides forming an intercommunication between the lymph-spaces of the ground-substance, also bring them into connection with the lymph-vessels of the Haversian canals.

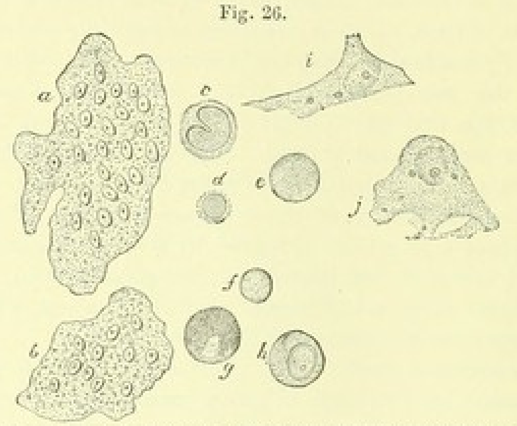
When a so-called bone-corpuscle with its canalicular branches is isolated from the surrounding bony substance in which it is imbedded, and is properly treated, it is found to consist of an elastic shell forming a branched lymph-space. Within this branched lymph-space floats a flat connective-tissue cell similar

to the flat branched cells of loose connective-tissue. This is really the *bone-cell*. Its structure is identical with that of the connective-tissue corpuscle. It gives off delicate branches which enter and pass some distance along the minute canaliculi.

Spongy bone.—The *spongy portion of bone* offers a gross formation quite different from that which we have just studied in the compact tissue. In the latter, the Haversian canals occupy a small area in proportion to that of the intervening ground-substance, and contain a minimum of marrow-tissues. In the spongy substance, on the contrary, the bony matter is small in amount compared to the area of the spaces which correspond to the Haversian canals of the compact tissue, but which here are called *Haversian spaces*. Moreover, the Haversian spaces are filled by a cellular mass, known as the *bony marrow*, in which numerous bloodvessels with extremely thin and delicate walls ramify. The large Haversian spaces are not surrounded by concentric lamellæ, but are separated from each other by more or less delicate trabeculæ of bone which represent the interstitial and parietal bands of the compact substance, and which have a minute structure identical with them. These bony trabeculæ form a loose spongy osseous network in the meshes of which rests bone marrow.

Marrow of bone.—The marrow of bone is an extremely vascular, cellular tissue which presents two chief varieties, the yellow and the red. The *yellow marrow* of bone is especially found in the central cavities of the long bones. It consists mainly of fat-vesicles such as are met with in adipose tissue, and it is the fat-cells which give the tissue its yellowish color. Among these adipose vesicles are a variable number of other elements. A few flat, more or less branched connective-tissue cells together with a sparse amount of delicate connective-tissue fibres sometimes form thin septa between the vesicles. There are also in the latter location a small number of cellular elements, which,

Fig. 26.



Cells from the Marrow of Bone during their period of Development.—*a*, *b*. Multinuclear "giant cells" (Frey). *c*, *f*, *g*. Lymph-cells from the marrow of the tibia of the Guinea-Pig, examined in the serum of the blood; *c*, *d*, *h*, after the action of alcohol and water 33 per cent. *i*, *j*. So-called osteoblasts from the femur of a new-born Dog, after the action of alcohol 33 per cent. High power. (*Ranvier.*)

EXPLANATION OF PLATE V.

Fig. 1. Transverse section of compact substance of shaft of a long bone of Man. High power.

a, The circumferential or peripheral lamellæ, whose course is, in the main, parallel to the surface of the bone; *b*, the concentric lamellæ constituting the Haversian systems, in the centre of which are the Haversian canals, *f*, *g*; another system of lamellæ is represented at *c*, *d*, the interstitial or intermediate lamellæ; *h*, bone corpuscles, with their radiating canaliculi.

Fig. 2. Longitudinal section of similar bony tissue. Same power.

a, Haversian canals; *c*, their walls; *d*, bone corpuscles, separated by the bone lamellæ, whose direction is usually parallel with that of the Haversian vessels.

Fig. 3. Some of the bony lamellæ from an intermediary or interstitial system, forcibly stripped off after decalcification of the bone, showing the bone corpuscles, and the fibres of Sharpey, *c*.

Fig. 4. Vertical section of the deep layer of ossifying portion of a metatarsal bone, showing some of the phases of development of bone from cartilage. High power. (After Müller.)

a, Cartilage cells, arranged in rows, some with shrunken cell bodies; *b*, ground substance of the cartilage; *c*, medullary canal in process of formation, and containing vessels and medulla cells; *d*, the remains of the ground substance of the cartilage, covered by a thin layer of newly-formed bone, *g*; *e*, osteoblasts covering the recently formed bone; *f*, a bone cell in process of forming a bone corpuscle, still connected with the osteoblastic layer of cells; *k*, recently developed bone corpuscle, containing a young bone cell; *m*, a medullary space, from which the contents have been displaced.

PLATE V

Fig. 1

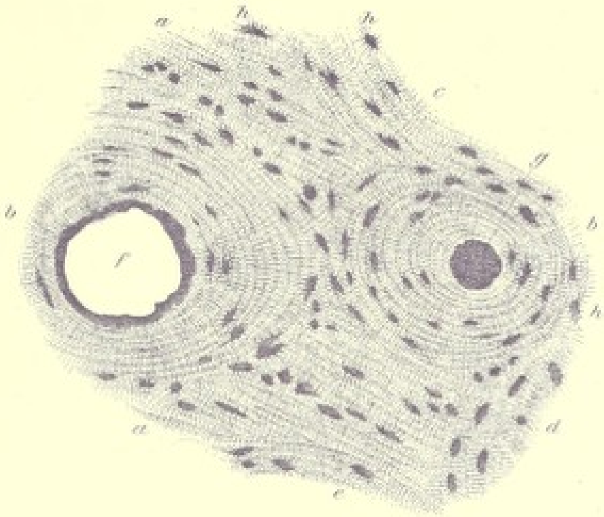


Fig. 3

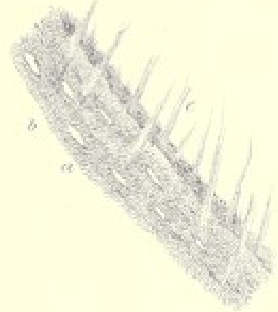


Fig. 2

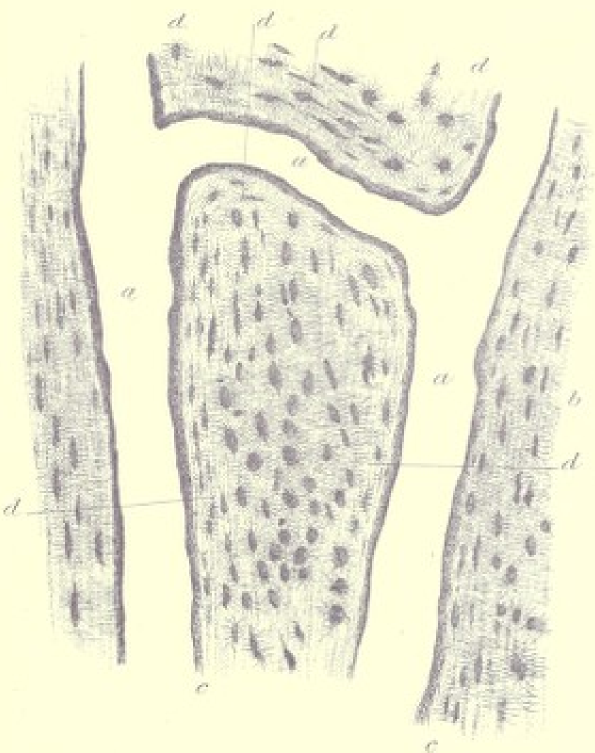
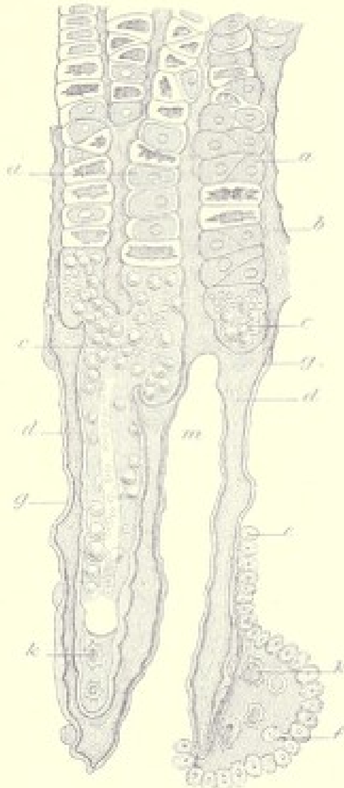


Fig. 4



by their size and structure, cannot when isolated be distinguished from colorless lymph-corpuscles. The smallest of the latter have been called *medulla cells* (*d*, *f*, Fig. 26). *Multinuclear giant cells* (myéloplaxes, *a*, *b*, Fig. 26) are also present in small numbers. The latter elements consist of a large, soft, membraneless, irregularly-formed, sometimes branched and flattened cell-body, of a fine granular appearance, and contain a fibrillar network like that of other cells. They inclose a large number of nuclei. The vessels are similar to those of the other varieties of marrow.

Red marrow of bone is met with in the Haversian spaces of spongy bone. To the naked eye it differs from the yellow marrow mainly by the entire absence of fat vesicles, or by their presence only in very small numbers, and by the extreme vascularity of the tissue. This form of marrow consists of reticulated fibres similar to those of lymph-glands or lymphoid tissues to be described later. In the meshes of this reticulated tissue, cells of the following forms are closely crowded: 1st, perhaps an extremely few fat-cells; 2d, large numbers of medulla-cells; 3d, considerable numbers of multinuclear giant cells; 4th, polynucleated cells, which have a diameter slightly larger than that of the red blood-corpuscles, and which possess a smooth, apparently homogeneous body presenting a yellowish-green tinge, — these cells, according to Neumann and Bizzozero, subsequently become converted into red blood-corpuscles, by losing their nucleus and becoming bi-concave; 5th, along the osseous trabeculæ are a single row of cells, which are larger than the ordinary colorless elements of the marrow, and are more or less prismatic or flattened by mutual pressure. They have been called by Gegenbauer *osteoblasts*, since they seem to take an active part in the formation of the bony substance.

All of the foregoing cellular elements possess, in a more or less active degree, the power of movement.

Besides the cellular forms already described there are always present in the bony marrow some colored cells, which are not distinguishable from red blood-corpuscles.

Red bone-marrow is very richly supplied with bloodvessels, which have extremely thin and delicate walls.

Periosteum.—The external surface of bone is covered by a fibrous membrane—the *periosteum*. It consists of two layers, an outer and an inner. The outer layer is composed of one or more lamellæ of dense white fibrous tissue, the direction of whose bundles is parallel to the surface of the bone. Among these white fibrous bundles is a limited quantity of fine yellow elastic fibres, and in the lymph-spaces formed by the apposition of the bundles are cellular elements similar to those of dense, white fibrous tissue. In this external, or *fibrous* layer of the periosteum, blood and lymph-vessels ramify and form networks.

The *inner* or *osteogenetic layer* of the periosteum consists of an extremely loose fibrous tissue, the meshes of which are filled by cells very similar to the osteoblasts described as existing upon the trabeculæ of spongy bone. Among these are numbers of elements which present characters similar to those of lymph-corpuscles. The osteogenetic layer of the periosteum is richly supplied by bloodvessels, which run among the cells occupying the meshes.

Beneath the periosteum the surface of growing bone is covered by a bony network, the meshes of which are crowded by cells which are contiguous with those which fill the inter-fibrillar spaces of the osteogenetic layer. Here and there the most superficial portion of this bony network sends a pointed and somewhat curved spicule of bone into the depth of the osteogenetic layer of the periosteum. The points of these somewhat conical spicules are usually continuous with fibrous bundles of the osteogenetic layer. The surface of the trabeculæ forming this osseous network, as well as of the bony spicules which project into the osteogenetic layer of the periosteum, are covered by the so-called *osteoblasts* of Gegenbauer, through the agency of which not only the bony trabeculæ and spicules springing therefrom increase in size, but also the fibrous bundles at the end of the spicules are converted into bone. In this manner the bone grows beneath the periosteum.

OSSIFICATION.

Bones increase in length by a process which is known as *ossification*. In young growing bone, the epiphyses are united to the diaphyses by the intervention of a plate of cartilage—the *intermediary cartilage*. The successive conversion into spongy bone of the layers of this cartilage which are in immediate apposition with the diaphysis, furnishes an excellent opportunity to examine the process of ossification of cartilage.

Line of ossification.—A longitudinal section passing through the diaphysis and intermediary cartilage of a long bone shows to the naked eye a straight line of union between the spongy bone and the cartilage. This line is called the *line of ossification*. The cartilage above it seems to be divided more or less dis-

tinctly into three layers—the lowest layer or the one forming the line of ossification is more or less opaque, the middle layer is unusually transparent, the upper layer is quite normal in appearance. If a thin piece of the spongy bone and cartilage is shaved off, and after being properly prepared for examination, is placed under the microscope, the following appearances may be noted (see fig. 4, Plate V.). In the upper layer or zone of cartilage, the capsules and intercellular ground-substance are normal. In the middle layer, the cells have begun to enlarge and to multiply. Some of them show signs of disintegration, and the spaces which contain the cells have also considerably increased in dimensions. The increase is mainly in a direction perpendicular to the line of ossification, and on account of this tendency the cells are applied against each other so as to form linear rows. The intercellular substance is consequently encroached upon and somewhat softened.

In the lower zone, the cartilage matrix which remains between the now greatly elongated capsules, in consequence of the further enlargement of the latter, is reduced to narrow trabeculæ which are infiltrated with calcareous deposits. The enlarged elongated capsules frequently fuse together. They are now in part filled by an embryonal marrow. The cartilage-cells which occupy their upper ends approach a wedge-shape, and are piled upon one another in such a manner that the bases alternate with the spaces as seen at *a*, fig. 4, Plate V.

In a yet lower zone, the linear spaces between the narrow trabeculæ of cartilage matrix are completely filled with a mass of cells similar in every respect to that of the bony marrow in the Haversian spaces, and they are now permeated by loops of capillary blood-vessels, which are in communication with the vessels of the marrow of the spongy bone below. The thin trabeculæ of cartilaginous matrix, separating these spaces, are still infiltrated with calcareous salts. They are now more or less completely encrusted with a thin layer of osseous substance of variable thickness (see *g*, fig. 4, Plate V.).

This thin osseous incrustation is itself covered by a layer of osteoblasts of a prismatic, ovoid, or sometimes slightly-branched outline. Here and there in the thickest points of this incrusting layer of osseous substance an oval-shaped, incompletely-branched bone-corpuscle is visible. By carefully searching along these incrustations pouch-shaped notches are occasionally met with opening upon the surface. These are filled by osteoblastic cells which may be connected with other cells in the osteoblastic layer by broad or narrow branches (see *f*, fig. 4, Plate V.). It is thus seen that the bone-cells are osteoblasts which have become included and completely imbedded in the osseous substance which they have formed around them.

In a still lower zone, we recognize the same general features presented by that last described. But the lamellæ of bone incrusting the cartilaginous trabeculæ are much thicker, and the cartilage matrix has entirely disappeared in many places.

Below this zone, there is no trace of cartilage matrix, and we have only the ordinary structure of spongy bone. The spongy substance thus gradually encroaches upon the intermediary cartilages until they finally disappear. The line of ossification presents essentially the same features whether the cartilages be intermediary plates between diaphyses and epiphyses, or cartilages which cover articular surfaces.

It is then noticeable, that in the growth of spongy bone at the expense of hyaline cartilage, the latter does not really become bone, is not really ossified, but is gradually *substituted and replaced* by bony substance which is the direct product of some of the cells belonging to the marrow contained in the Haversian spaces of the spongy bone. This latter tissue is more or less directly an outgrowth from the osteogenetic layer of the periosteum.

It may be stated in general terms that there is no ossification which does not come either directly or indirectly from the periosteum or from similar membranes which represent it. The perichondrium which envelops cartilage as the periosteum does the bone, may be regarded as such a representative, for the structure of the one is similar to that of the other, and their functions are parallel.

DEVELOPMENT OF BONE.

The original development of bone almost always is accomplished through the intermediation of cartilage. The bones of the face, however, and some of those of the cranium, are built directly upon fibrous membranes as a foundation. But whether or not cartilage be employed in the process of development, the formation of bone always starts from the periosteum.

In the embryonal cartilage which nearly always precedes the formation of bone, we have areas wherein certain changes take place preliminary to the development of bone. These areas have been called *points of ossification*. When these points of ossification appear in cartilage we have a development of what has been termed *endochondral bone*.

ENDOCHONDRAL BONE.

In an embryonal cartilage which is preparing to be replaced by bone, the following succession of alterations may be observed.

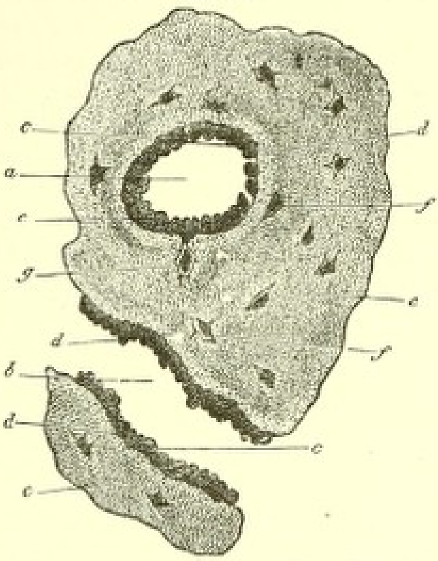
Formation of embryonal spongy bone.—At a certain point in the inner or chondrogenetic (osteogenetic) layer of the perichondrium, a loop or two of capillary bloodvessels project into the cartilage-substance. In advance of these loops the cartilage-cells are enlarging and multiplying within their capsules, which also are enlarged. These cells finally absorb the cartilage-matrix between them and the mass of cellular elements which surrounds the projecting capillary loops; they then communicate with the cells of the osteogenetic layer. By a continuation of this process of absorption of the cartilage in front of the advancing capillary loops, and by the addition of the contents of the capsules to the mass of cells surrounding the vessels, the embryonal cartilage becomes channelled by vascularized cellular trabeculæ or granulations springing from the inner layer of the perichondrium.

The next step everywhere in the close vicinity of the vascular granulations, is the enlargement of the cartilage-capsules, and the multiplication of their cell-contents. This enlargement continues, and results in the intercommunication of many adjacent capsules and the connection of their contents with the vascular granulations. By the enlargement of the spaces containing the cartilage-cells, the intervening ground-substance is eaten away until nothing is left of it but an irregular network of anastomozing trabeculæ, the surfaces of which are notched at the place where the capsules have communicated with the general cellular mass. At the same time the cartilage-matrix in this riddled area is infiltrated with a deposit of the insoluble salts of lime. We have now an area more or less irregular of calcified, spongy cartilage, the meshes of this spongy formation being filled with a vascularized marrow, similar in constitution to that already described when discussing the encroachment of spongy bone upon the intermediary cartilage.

The next step is the incrustation of the calcified cartilage-trabeculæ with a thin envelope of osseous tissue. This first takes place near the central portion of the spongy area, and the bone is formed through the agency of osteoblasts which cover the trabecula. This process advances until the whole cartilage is converted into spongy bone. (Fig. 27).

Formation of bony marrow.—Sooner or later, in the central portions of this embryonal spongy bone, the osseous trabeculæ soften and disappear (*osteoporosis*). In this manner a central marrow cavity results. The spongy bone continues to be slowly absorbed, and converted into marrow until finally the whole of the embryonal spongy bone may be thus absorbed.

Fig. 27.



TRANSVERSE SECTION FROM THE FEMUR OF A HUMAN EMBRYO ABOUT ELEVEN WEEKS OLD.—*a.* A medullary sinus cut transversely. *b.* Another, cut longitudinally. *c.* Osteoblasts. *d.* Newly formed osseous substance of a lighter color. *e.* That of greater age. *f.* Lacunæ, or blood-corpuscles, with their cells. *g.* A cell still united to an osteoblast. (*After Gegenbaur.*)

At the same time that the embryonal spongy bone is being absorbed at the centre, there is a continual new formation of spongy bone by the osteogenetic layer of the perichondrium (which latter may now be regarded as a periosteum), practically identical with that already described for the periosteal growth of bone.

In the older portions of *periosteal* spongy bone, Haversian systems and canals begin to form through the successive development of concentric lamellæ within the Haversian spaces, by means of the osteoblasts which cover their surfaces. Layer within layer is thus formed in concentric deposits until the Haversian space is converted into a Haversian system with its narrow central canal. The original osseous trabeculæ, which formed the meshes of the periosteal spongy bone, persist as interstitial bands between the Haversian systems.

Absorption of bone (Osteoporosis).—Around the central marrow-cavity, which has been formed as indicated above, a process of absorption is at work. The compact tissue is disappearing, and being reconverted into spongy tissue through the absorption of the Haversian systems and their substitution by bone-marrow. The

process of absorption does not stop at the accomplishment of this result. The interstitial osseous trabeculæ of the spongy bone next succumb, and the softened area is added to the central cavity.

Thus it is that while the bones are growing at the periphery they are being eroded at the centre.

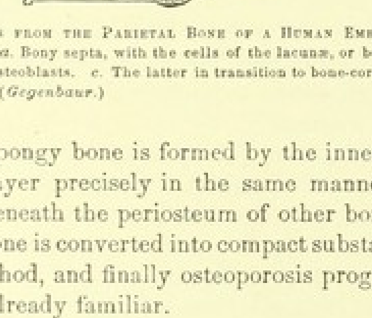
According to Kölliker, Rindfleisch, Klein, and others, solution of bone is effected by the agency of the multinuclear giant-cells. These cells have consequently received the name of *osteoclasts*. They are believed to elaborate an acid by whose action the bony substance with which they are in contact is first softened and then dissolved.

In the development of bone, the various stages in the process of ossification may succeed each other with varying rapidity in different bones, and in different parts of the same bone. In long bones, for example, the middle portion of the diaphyses often entirely consists of periosteal bone, while at the extremities the embryonal spongy bone has scarcely begun to disappear.

INTERMEMBRANOUS BONE.

The intermembranous formation of bone is analogous to the development of bone from the periosteum. For instance, the bones of the cranium have their origin in a fibrous membrane which soon presents a division into two layers similar both in structure and function to the outer and inner layers of the periosteum. Spongy bone is formed by the inner or osteogenetic layer precisely in the same manner as it is formed beneath the periosteum of other bones. This spongy bone is converted into compact substance by the same method, and finally osteoporosis progresses in a manner already familiar.

Fig. 28.



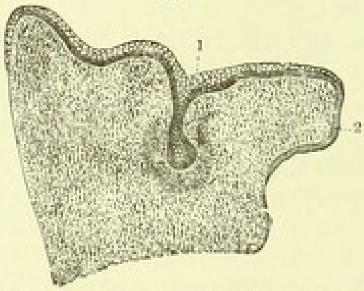
OSTEOBLASTS FROM THE PARIETAL BONE OF A HUMAN EMBRYO THIRTEEN WEEKS OLD.—*a*. Bony septa, with the cells of the lacunæ, or bone-corpuscles. *b*. Layers of osteoblasts. *c*. The latter in transition to bone-corpuscles. Very high power. (*Gegenbaur*.)

TEETH.

Although the first rudiments of the teeth are offshoots from the epithelium covering the surface of the gums, and although the enamel which covers the exposed surface of the fully-developed tooth is of epithelial derivation, yet the greater portions of the teeth, namely, the dentine, the cement, and the pulp, are of connective-tissue origin, and may properly be classed with the connective-tissues. Because of the entrance of bone into their structure, as well as for other reasons, an examination of their histology would seem to have an appropriate place after the study of bone.

Development of the teeth.—The first rudiment of the tooth is met with early in embryonic life, at a period when the connective-tissue of the gum has scarcely advanced in development beyond the state of fibrous mucous-tissue. It is observed in the form of a club-shaped duplicature of the stratified epithelium of the gum. (See Fig. 29.) This epithelial infolding is constituted externally by a single layer of columnar epithelia, identical with those which form the deepest layer of the covering of the gum, and internally by a collection of polyhedral epithelial-cells. These cells, like those of various other epithelial coverings, are held together by an intercellular cement-substance.

Fig. 29.

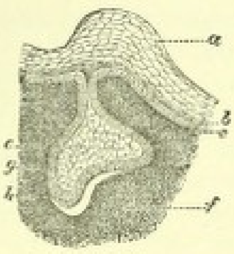


VERTICAL SECTION OF THE UPPER JAW OF A FŒTAL SHEEP, about 2¾ inches long, showing the enamel-germ, with the semilunar rudiments of the dentine-germ and dental sac in transverse section. 1. Dental groove; 2. Palatal process. Magnified 50 diameters.

This club-shaped mass of epithelial cells is the *primary enamel-organ*. Later this club-shaped mass penetrates deeper into the connective-tissue and increases greatly in thickness, at the same time changing its outline. The club-shaped extremity has now spread out and become indented by a slight elevation of the connective-tissue which has begun to advance into it. (See *f*, Fig. 30.) This elevation is the first appearance of what will subsequently constitute the dentine and the pulp of the tooth. The milk, or first teeth, are now

in full process of development. A preparation for the growth of the permanent teeth is, even at this stage, often to be met with in the shape of an offshoot from

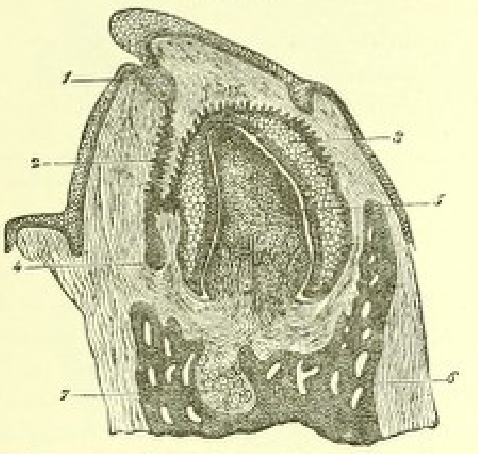
Fig. 30.



SAME, AT A LATER PERIOD OF DEVELOPMENT.—*a*. Epithelium. *b*. Younger layer of epithelium. *c*. Inferior layer of the epithelium. *e*. Enamel-organ. *f*. Dentine-germ or papilla. *g*, *h*. Inner and outer layers of the sacculus that is about to form. (*Carpenter.*)

the epithelial mass already spoken of as the primary enamel-organ. 4, Fig. 31, represents such an epithelial

Fig. 31.



VERTICAL SECTION OF THE LOWER JAW OF A HUMAN FŒTUS, measuring about four inches in length, magnified 25 diam. 1. Dental-groove. 2. Remains of the enamel-germ. 3. Enamel-organ of a deciduous tooth, presenting epithelium on both its outer and inner surface, *i. e.*, where it lines the sacculus and where it covers the papilla. 4. Enamel-germ of the permanent tooth. 5. Dentine-germ. 6. Section of inferior maxilla. 7. Meckel's cartilage. The dental sacculus will be observed to present a number of fine papillæ opposite the dental papillæ. (*Carpenter.*)

offshoot after the changes in the growth of the milk-tooth have so far progressed that the connection with the enamel-organ of the latter has been severed.

Fig. 31 represents a much later stage in the formation of the tooth. The connective-tissue papilla has grown into the enamel-organ until the latter has been completely invaginated. The enamel-organ now covers the apex and sides of the tooth-papilla like a cap, and it has been cut off from its former connection with the epithelial covering of the gum. This cap-shaped epithelial mass is termed the *secondary enamel-organ*. Through the invagination of the epithelial mass constituting the enamel-organ, it results that the cap covering the papilla, when seen in section longitudinal to the long axis of the tooth, seems to be formed by three principal layers. The uppermost is composed of a single row of cubical epithelium; the lowest layer consists of a single row of long cylindrical cells; the middle layer is formed of more or less compressed and branched epithelial cells, with a large amount of intercellular cement between them. They contain small oval or spherical nuclei, and, according to some authors, afford with the intercellular substance an example of mucous-tissue. Klein denies to this layer any other than an epithelial constitution.

It is the lowest layer of long columnar or prismatic epithelial cells which ultimately furnishes the enamel of the tooth. The two upper layers gradually diminish in thickness, and finally form a thin epithelial covering, which is found upon the surface of the enamel when the tooth first makes its appearance above the gum (*membrane of Nasmyth*).

At first the lower layer of enamel-cells is separated from the papilla by a thin elastic membrane, the remains of the basement-membrane upon which the epithelium of mucous surfaces is implanted. Later this disappears, when the enamel rests directly upon the dentine, which, as we shall see below, is formed by the papilla. It is still a mooted question whether the enamel of the tooth is secreted by the lower layer of columnar cells, or whether it is the product of a direct transformation of the cells themselves.

The *dentine* of the tooth is formed by the mediation of a double row of branched fusiform and columnar cells, which cover the pulp or papilla.

The *dental cement*, or bony incrustation of the dentine in the root and neck of the tooth, is developed from the fibrous tissue of the dental processes or alveoli. This tissue here has the structure and functions of the periosteum of bone.

STRUCTURE OF THE TEETH.

The fully-developed tooth consists of a crown, neck, and one or more roots, which like the long bones have a central marrow cavity. In this central cavity run the nerves and walls of the vessels.

Dentine.—Nearly the whole solid portion of the tooth is formed of a hard, compact, brittle substance called *dentine*. In the crown, the dentine is covered by a coating of *enamel*, the hardest substance met with in the human frame. In the neck and roots the dentine is incrusted by a shell of true bone of varying thickness. This incrustation of bone, technically

termed *cement*, is thickest at the deep end of the root. It gradually thins off toward the neck, until at this location it is lost in the enamel.

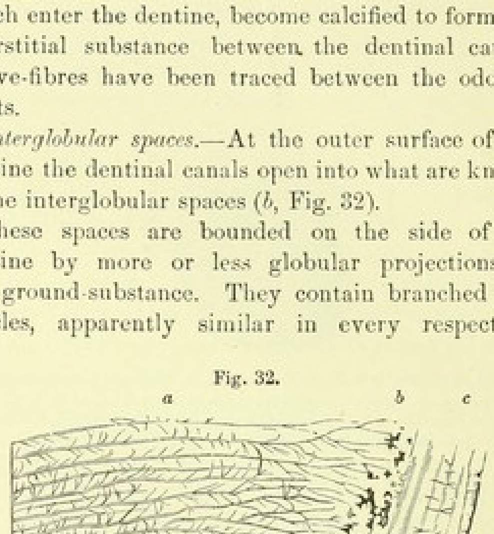
Dentinal pulp.—The *dentinal pulp* consists of an intricate reticulum of delicate branched connective-tissue corpuscles, with proportionally large and distinct round or oval double-contoured nucleus, and a small amount of cell-body, except that which constitutes the branched processes. Among these processes is a small number of lymphoid corpuscles and delicate connective-tissue fibres. The capillary bloodvessels have an investing cellular sheath just as in the fibrous form of mucous-tissue. Upon the external surface of the pulp is placed a double layer of branched columnar and fusiform cells, already alluded to. The cells nearest the pulp are more or less fusiform or stellate, with processes running into the pulp, and a few short lateral branches also, which connect one cell of the row with another. The outer ends of the cells of this row taper off into a fine long extremity, which passes between the cells of the outer row, and perhaps beyond them into the dentinal canals.

Odontoblasts, and dentinal fibres.—The outer row of columnar cells (so-called *odontoblasts*) is in contact with the dentine. These cells are more or less club-shaped, with the thick end of the club toward the pulp. The nucleus, which is usually somewhat oval in shape, is in this portion of the cell. The outer end of the club-shaped cell tapers off into a fine, long, somewhat tough, and apparently elastic process (*dentinal fibre of Tomes*). This long process of the odontoblast passes outward through the dentine, and in doing so frequently branches. The general course of the main fibres is straight or slightly wavy, and is perpendicular to the external surface of the dentine. By means of the lateral branches anastomoses are frequently formed with the processes of neighboring odontoblasts. According to most recent investigators, the dentinal fibre is surrounded by a thin structureless membrane, the *dentinal sheath of Neumann*. The interstitial substance between these dentinal sheaths, which latter constitute the dentinal canals, is a dense reticular substance made extremely hard and brittle by infiltration with the carbonates and phosphates of lime. When a thin plate of dentine is mounted dry the dentinal canals are filled with air, and when examined by transmitted light appear dark, like the canaliculi of bone-corpuscles similarly prepared. According to Klein, the dentinal fibres which lie in the dentinal canals are the processes of the inner row of the double layer of cells covering the pulp, and have no distinct connection with the outer row of odontoblasts. The same author thinks that those processes of the latter which enter the dentine, become calcified to form the interstitial substance between the dentinal canals. Nerve-fibres have been traced between the odontoblasts.

Interglobular spaces.—At the outer surface of the dentine the dentinal canals open into what are known as the interglobular spaces (*b*, Fig. 32).

These spaces are bounded on the side of the dentine by more or less globular projections of the ground-substance. They contain branched corpuscles, apparently similar in every respect to

Fig. 32.



SECTION THROUGH THE ROOT OF A MOLAR TOOTH.—*a.* Dentine traversed by its tubuli. *b.* Nodular layer. *c.* Cementum. (*Carpenter.*)

branched bone-cells. Their branches are continuous with the dentinal fibres, and with branches of cells in neighboring interglobular spaces. Where the dentine is covered with cement, these spaces communicate with adjacent bone-corpuscles, by means of the fine canaliculi of the latter. Beneath the enamel the interglobular spaces send a few short and irregular blind tubes among the deep ends of the enamel-prisms.

Cement (cementum).—The *cement*, or bony crust around the root of the tooth, presents the laminated ground-substance and the branching corpuscles of bone. Sharpey's fibres are present in small numbers. In the thickest portions, even Haversian systems with their small central canals are sometimes met with. Except in these rare instances of Haversian systems, the lamellæ are mainly found parallel to the surface of the root. The bone-corpuscles are sometimes unusually large; they possess numerous branched canaliculi, having the ordinary relations and structure of bone-corpuscles elsewhere, and they inclose typical bone-cells.

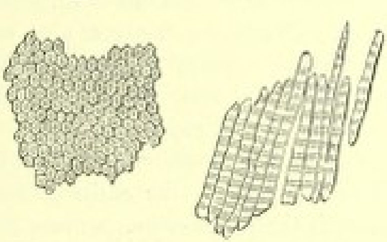
Enamel.—The *enamel* of the fully formed and healthy tooth is densely calcified. Seen under a high power, in a thin section vertical to the surface, the enamel appears to be formed of closely-

packed striæ, whose direction in general radiates from the pulp-cavity as a centre. In certain spots these radiating striæ are crossed by less distinct lines running mainly parallel to the surface of the enamel (transverse striæ). Besides these fine striations, there are often two, three, or more narrow, faint, darkish stripes (*parallel stripes of Retzius*) of considerable length; they exhibit a slightly undulating course, and, as a rule, run parallel to the enamel-surface.

The significance of these stripes is not fully understood. They may, perhaps, represent the division between successive deposits of enamel. The places at which transverse striæ are seen crossing the radiating striæ, contain enamel-fibres running in opposite directions. A minute description of the radiating striæ will suffice for both. They consist of long prisms or cylinders of calcified enamel-cells. When seen in transverse section these enamel-prisms appear more or less regularly hexagonal in outline (A, Fig. 33). In longitudinal section after maceration in hydrochloric acid, the enamel-prisms present the appearance represented in B, Fig. 33. At regular intervals the transparent hyaline-substance of the prism is seen to be crossed by extremely minute lines. A further maceration in the acid results in the breaking up of

Fig. 33.

A



Diagrammatic Representation of the Structure of Enamel.—A. Transverse section of enamel, showing the hexagonal form of its prisms. B. Separated prisms seen lengthwise. (*Carpenter.*)

the prism into as many somewhat cubical sections as there are areas occupied by these minute cross-lines. These prisms are separated from each other by a small amount of cement-substance. When the enamel begins to form, the enamel-cells lengthen towards the dentine. The lengthened portion soon becomes calcified, the calcareous deposit first appearing at the sides of the prism, or in the intercellular cement. After the calcification of the newly-formed end of the columnar enamel-cell has measurably progressed, the dentinal end of the cell again lengthens, and this new portion of the cell is in its turn calcified. This process repeats itself, until the original columnar enamel-cell is much lengthened, and the whole is gradually converted into successive sections of the enamel-prism. It is this successive periodic transformation of the enamel-cell into calcified prisms which gives to the latter the peculiar appearance shown in B, Fig. 33.

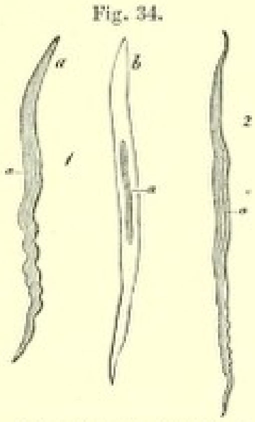
MUSCLE.

Muscular tissue comprises two general varieties, unstriped or smooth, and striated. The elements of this tissue are derived from the mesoblast, and are well supplied with capillary vessels and nerves.

SMOOTH OR UNSTRIPED MUSCLE.

This variety of muscular tissue is composed of spindle or fusiform cells, whose transverse diameter is usually small in proportion to the length of the long axis of the cell. These cells are soft, and are often more or less prismatic from mutual pressure. They may occur more or less isolated, but are usually collected into bundles. The cells constituting the bundles are closely packed together, the spindle extremity of one cell fitting between the bellies of two or more. These closely-packed muscle-cells are slightly separated from each other by a small amount of intercellular cement, apparently similar to that which unites the cells of epithelial surfaces. In this albuminous intercellular cement are often found a small number of flat, connective-tissue cells, more or less branched, and sometimes a very few scattered, delicate connective fibres. This intercellular material corresponds to the *endomysium* of striped muscles.

Fig. 34.

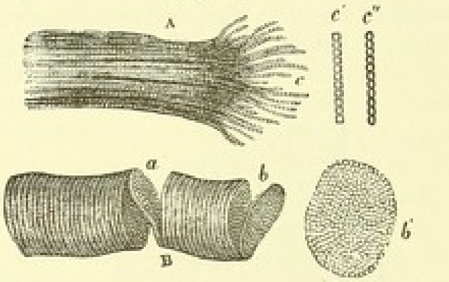


Smooth or Unstriped Muscular-Fibre-Cells from Arteries [Human].—1. From the popliteal artery. A, without, B, with acetic acid. 2. From a branch of the anterior tibial; *a*, rod-shaped nuclei of the fibres. Magnified 350 diameters. (*Gray.*)

Arrangement and distribution of smooth muscle-fibres.—The muscular bundles thus composed are separated by a variable quantity of ordinary loose connective-tissue—an analogue of the *perimysium* surrounding bundles of striped muscles. The bundles of smooth muscles may anastomose with each other so as to form a regular muscular network. Such a muscular network may be spread out with a fenestrated layer. Frequently the bundles are placed side

b′, Fig. 36, gives a vertical view of a transverse disk after the latter has been differentiated into its ulti-

Fig. 36.

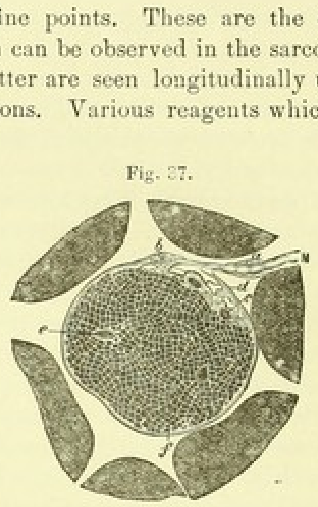


FRAGMENTS OF STRIPED ELEMENTARY FIBRES, showing a cleavage in opposite directions. High power.—A. Longitudinal cleavage. The longitudinal and transverse lines are both seen. Some longitudinal lines are darker and wider than the rest, and are not continuous from end to end. This results from partial separation of the fibrillæ. *c*. Fibrillæ separated from one another by violence at the broken end of the fibre, and marked by transverse lines. *c′*, *c″*. Two appearances commonly presented by the separated single fibrillæ more highly magnified. At *c′* the borders and transverse lines are all perfectly rectilinear, and the included spaces perfectly rectangular. At *c″* the borders are scalloped and the spaces bead-like. When most distinct and definite, the fibrilla presents the former of those appearances. B. Transverse cleavage. The longitudinal lines are scarcely visible. *a*. Incomplete fracture following the opposite surfaces of a disk, which latter stretches across the interval, and retains the two fragments in connection. The edge and surfaces of this disk are seen to be minutely granular, the granules corresponding in size to the thickness of the disk, and to the distance between the faint longitudinal lines. *b*. Another disk nearly detached. *b′*. Detached disk (more highly magnified), showing the sarcous elements. (*Gray.*)

mate sarcous elements, by the action of some reagent which has softened or dissolved the interstitial substance between them.

Fields of Cohnheim.—If a perfectly fresh and living muscle is frozen, and cut into thin transverse sections, and immediately examined under a high magnifying power, the following appearances are noted: At first the surface of the section is uniformly gray. Very soon the field begins to be mottled. The surface is now everywhere marked by fine brilliant lines which cross each other in such a manner as to form an irregular bright network inclosing darkish-gray areas. The dark-gray areas are the ends of the ultimate sarcous elements or the dark rods seen as above stated when the longitudinal fibrillation becomes apparent. The light lines correspond to sections of the bright substance between the dark rods. The width of the bright lines mottling the gray field gradually increases a little during the observation, while at the same time the dark areas limited by the meshes correspondingly lessen in extent. The dark areas are the so-called *fields of Cohnheim.* The central object in Fig. 37 very well represents the appearance above described, although it was intended merely to show the manner of termination of a nerve. The dark areas or fields of Cohnheim are dotted with extremely fine points. These are the ends of fine fibrils which can be observed in the sarcous elements when the latter are seen longitudinally under favorable conditions. Various reagents which effect the

Fig. 37.



TRANSVERSE SECTION OF ONE OF THE MUSCLES OF THE THIGH OF THE LACERTA AGILIS (A COMMON EUROPEAN LIZARD), made whilst frozen, and magnified 400 diameters.—N. Nerve of a muscle-fibre which is surrounded by portions of six others. *a*. Nucleus of the nerve-sheath. *b*. Nucleus of the sarcolemma. *c*. Section of nucleus of terminal plate of nerve. *d*. Transverse section of terminal plate, surrounded by granular material. *e*. Transverse section of muscle-nuclei. *f*. Fine fat-drops. The angular dark particles are sections of groups of sarcous elements. (*Carpenter.*)

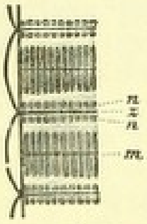
death of the constituents of the muscle-fibre cause the sarcous elements to shrink from each other and leave proportionately large spaces between them, which are filled with an interstitial cement-substance—the light network seen in transverse sections, and the light lines observed between the rod-shaped sarcous elements when the fibre is viewed lengthwise.

Sarcolemma, intermediate disks, etc.—The muscle-fibre is more or less closely enveloped in a thin, tough, elastic, apparently hyaline sheath—the *sarcolemma.* This elastic tube is partitioned across at short, regular intervals by thin plates which are offshoots from the inner wall of the sarcolemma. Such plates consist of substance somewhat similar to that of the sarcolemma, but are not so tough and resistant. They cross the tube through the middle of the light or interstitial disk, and are known as the membranes or *intermediate disks of Krause* (*z*, Fig. 38).

The intermediate disks of Krause, therefore, divide the tube formed by the sarcolemma into cylindrical sections, placed end to end. Each of these cylindrical sections contains a dark contractile disk, with a half of an interstitial disk above and below, separating it from the intermediate disks of Krause. In each half of the light interstitial disk is frequently found a thin transverse layer of somewhat dark substance which separates into granules when the dark contractile disk shows a division into sarcous elements. This thin layer of dark substance has been

called the *secondary* or *collateral disk* (*n*, Fig. 38). It requires strong and well-defining lenses for the demonstration of these details of the structure of muscle-

Fig. 38.



STRUCTURE OF STRIATED MUSCULAR FIBRE, AFTER ENGELMANN, FROM TELEPHORUS MELANURUS (A COMMON EUROPEAN BEETLE). CUTANEOUS MUSCLE FROM THE ABDOMEN.—*m*. Median disk. *n*. Secondary disk. *z*. Intermediate disk. Magnified 1000 diameters. The sarcolemma is seen on the left side.

fibres. Engelmann and Hensenn have each recorded the presence, in the middle of the transverse or contractile disk, of a transverse, lighter band which they have called the *median disk* (diagrammatically shown at *m*, Fig. 38). The above-described dark elements of the striped muscle have been found to be doubly refracting; they consequently polarize light, while the light substance which separates them has not a similar effect upon the luminous rays.

The shortening and transverse thickening of the dark rods or sarcous elements of the contractile disk, which takes place during contraction of the fibre, causes the interstitial substance to apparently increase in amount. Since the thickened rods are then more closely pressed together, the fluid portion of the interstitial substance must necessarily be squeezed out above and below, and increase the volume of the half of the light or interstitial disk above and below the contractile disk. Frequently a part of this expressed interstitial substance finds its way between the sarcolemma and the edge of the contractile disk, and separates the two, thus producing a convexity or bulging of the sarcolemma at these points. This condition is shown somewhat diagrammatically on the left in Fig. 38. Sometimes the attachment of the intermediate disk of Krause to the sarcolemma breaks, either from a destructive process at work in the fibre itself, or from the action of reagents which soften the intermediate disk and cause the substance of the light interstitial disk to swell greatly. The sarcolemma may then be separated from the surface of the muscle-fibre for a considerable part or the whole of its length. Occasionally the muscle-fibre may suffer a transverse fracture within the sarcolemma. A retraction of each fragment then takes place, resulting in their separation. Such a condition is shown in 1, fig. 1, Plate VI. The ensheathing sarcolemma remaining unbroken becomes wrinkled, and perhaps twisted, as is seen at *n*, 1, in the figure last mentioned. These fractures invariably pass through the light or interstitial disk.

The interstitial substance between the sarcous elements often contains, especially in the lower animals, minute molecules, sometimes of pigment, sometimes of fat—the *interstitial granules* of Kölliker.

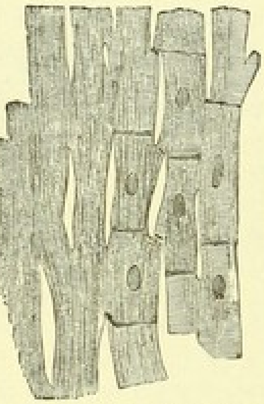
Muscle-corpuscles.—Besides the constituents above enumerated, striped muscle-fibres contain, at more or less scattered intervals, cellular elements which appear to be closely analogous to connective-tissue corpuscles. In nearly all the muscles of most of the higher animals, these elements rest upon the surface of the muscle-fibre, and form a part of it. They are not connected with the sarcolemma. In some of the Amphibia, these cells are scattered through the substance of the fibre (see *c*, Fig. 37). In birds they are found in both locations. In the muscle of the heart of man they exist near the centre of the fibre. When in the depth of the fibre, they are imbedded in the interstitial substance, and they consist of a flattened oval nucleus, containing one or more nucleoli, the long axis running parallel with the length of the fibre. In the adult, fully-matured, normal muscle-fibre, the nucleus is surrounded by a very small amount of protoplasm, which is more extensive at the ends of the oval nucleus, where it is frequently lengthened out into a tapering extremity. The broad surface of the cell then presents a somewhat fusiform outline. When seen in profile the outline appears more linear. The protoplasm usually contains a certain number of dark, or, sometimes, shining granules, mostly aggregated at the poles of the cell.

These cells are known as *muscle-corpuscles*. Their office has been variously interpreted. Some have thought them to be the terminal organs of the nerves, which supply the fibre. Others have regarded them as simple connective-tissue corpuscles. The weight of opinion, however, seems to support the view that they are the builders of the muscle-fibres. The relation which they bear to the growth of muscle will be considered when we speak of its development.

Cardiac muscle-fibres.—In the heart of man the muscle-fibres possess certain peculiarities. In the first place they seem to be destitute of an investing sarcolemma. In the second place they are very short, and are branched in the manner shown in Fig. 39. Each fibre possesses one or more nuclei, which are imbedded in the depth of the fibre. The end of a branch of one fibre abuts against the end of that

of another. In this way an anastomosis of the branched muscle-fibres is formed. When heart-

Fig. 39.



Anastomosing Muscle-Fibres of the Heart, seen in a longitudinal section. On the right the limits of the separate cells with their nuclei are exhibited somewhat diagrammatically. (*Gray.*)

muscle is cut transverse to the direction of the muscle-fibres, instead of the cross-section of the fibre presenting a circular outline, as in ordinary striped muscle, it is often elongated. This is the case when the cut has passed through the body of the fibre near the point where it branches. Because of the extreme shortness of the branched muscle-fibres almost every one of them in the cross-section is seen to contain near its centre a muscle-corpuscle.

Termination of muscle fibres.—As has already been mentioned, each individual muscle-fibre terminates in a tapering conical extremity. Whether these extremities end in tendon, or in the depth or body of the muscle, in the endomysium between the muscle-fibres of the primary bundles, they are attached to connective-tissue fibres (*t*, 2, fig. 1, Plate VI.). It seems to be still unsettled exactly how this connection is established.

Unless the tissue is especially prepared for examination, the longitudinal fibrillæ appear to be directly continuous at their extremity with the connective-fibres, and the one seems to pass insensibly into the other. Perhaps such a simple connection may really exist in many instances; but it is probable that, in most cases, where muscle is inserted into tendon, there is a different mode of communication. The sarcolemma probably continues without interruption around the conical end of the muscle-fibre, and at this point is attached by its external surface to the bundles of fibrous tissue which form the tendon. Whether the

EXPLANATION OF PLATE VI.

Fig. 1. The appearances of striated muscle-fibres after varied treatment. Moderate power. (Frey.)

1. A muscle-fibre (*m*) ruptured at *n*, showing the sheath or sarcolemma partly emptied and twisted.

2. The end of a muscle-fibre from the biceps of Man, *m*; a fibrous bundle, *t*, of the interstitial connective-tissue is attached to its pointed extremity.

3. A Human muscle-fibre after prolonged treatment with hydrochloric acid. It can now be readily split up into transverse disks. *n*, nucleus of muscle-corpuscles.

4. A muscle-fibre from the leg of a Frog after protracted treatment with dilute hydrochloric acid. From the cut end, *t*, very fine fibres, upon which minute granules are distributed, are seen projecting.

Fig. 2. Transverse section of Human biceps. High power. (After Frey.)

m, Muscle-fibres, cut across; *v*, a section of a bloodvessel; *c*, a fat vesicle in the interstitial connective-tissue.

Fig. 3. Fragment of sartorius muscle of a Frog. High power. (After Ranvier.)

n, Nuclei of muscle-corpuscles, seen partly in face.

Fig. 4. Muscle-bundle of the dorsal fin of the *Hippocampus* (a fish commonly known as the sea-horse), showing method of attachment of the fibrous bundle of the tendon. High power. (After Ranvier.)

m, Muscle-fibres; at *t* they are attached to the tendon-fibres through the intermediation of a double-contoured membrane, which is continuous with the elastic sheath (*n*) of the bundle.

Fig. 5. Highly-magnified capillary bloodvessel, after injection with a weak solution of nitrate of silver, and subsequent staining with picrocarminate of ammonia. The dark lines mark out the boundaries of the endothelial cells forming the wall of the vessel; the nuclei are also distinctly seen. (Ranvier.)

Fig. 6. Shows a capillary bloodvessel, surrounded by and attached to the fibres of the reticular tissue. (Ranvier.)

c, The capillary; *r*, the reticular fibres; *n*, nuclei of flat endothelial cells upon the reticular fibres.

PLATE VI

Fig. 1

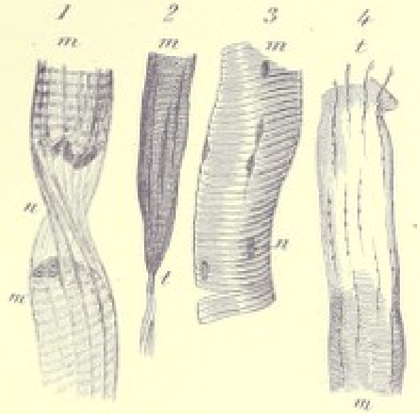


Fig. 4

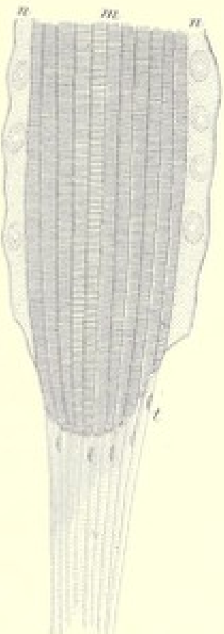


Fig. 2

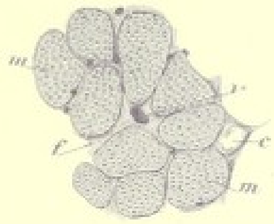


Fig. 5

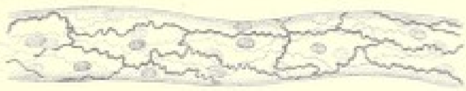


Fig. 3

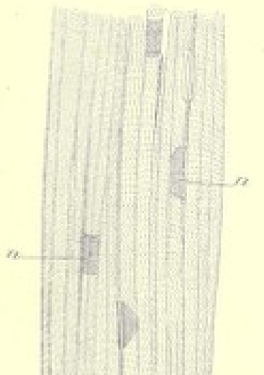
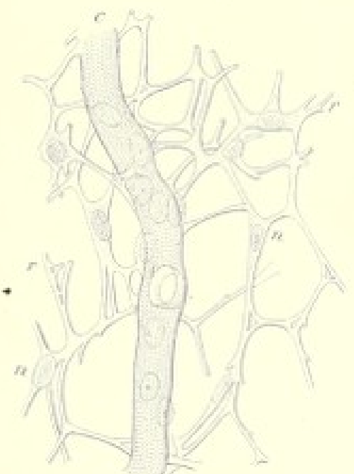


Fig. 6



fibres of the tendon are inserted into the sarcolemma at this point, or are simply glued upon its exterior surface by the intervention of a tough, sticky material, has not yet been determined. Fig. 4, Plate VI., represents such a mode of insertion of a muscle-fibre into tendon. The preparation from which the drawing was made is from the large dorsal fin of the *Hippocampus*, or sea-horse. But the artist has failed to show distinctly the most important feature of the preparation. At *t*, where the muscle fibre ends in the tendon, the line between the two should have a double contour, and be continuous with the double-contoured line representing the sarcolemma ensheathing the muscle-fibre.

DEVELOPMENT OF MUSCLE.

Muscular tissue is developed from the cells of the middle or connective-tissue layer of the blastoderm. The fibres of striped muscles originate in the following manner: A fusiform cell in the connective- or gelatinous tissue of the embryo suffers a division of its nucleus. The two new nuclei divide again, and this process continues until the original uni-nucleated spindle-cell has become more or less completely filled with a number of nuclei arranged in a linear series from one end of the cell to the other. Proceeding equally with this increase of nuclei, the cell thickens somewhat, and greatly elongates. Here and there the cell-body soon begins to show cross-markings—the earliest appearance of the transverse disks. This transformation of the cellular protoplasm into the contractile elements of the full-grown muscle continues to spread throughout the fusiform cell-body, until nearly the whole of the latter becomes transversely striated. The protoplasm immediately surrounding the nucleus is the last to experience this metamorphosis.

Even in the full-grown and adult fibre a small portion of the original protoplasm remains around the nucleus, and constitutes, with the latter, the muscle-corpuscle above described. It is not yet known whether the sarcolemma is the product of an excretion by the protoplasm of the muscle-cell, or whether it is a formation from the surrounding connective-tissue.

Reproduction of muscle fibres.—In various muscles of the human organism are many striped fibres containing a very large number of muscle-corpuscles, surrounded by a proportionately large quantity of protoplasm, and presenting other evidences of growth. It is probable that in health there is a continual destruction and reproduction of muscle-fibres. It is certainly so in many diseases.

BLOODVESSELS.

The blood of man flows throughout the body in a system of channels, which, according to their size, construction, and the character of the blood passing through them, are denominated arteries, veins, capillaries, sinuses.

Each of these species of bloodvessels has a characteristic structure which generally differentiates it from all the others. But while there is a general plan of construction common to the members of each species, there are slight differences which constitute varieties. Some of these variations will be incidentally noted.

Capillaries.—The simplest form of bloodvessel met with in man is the blood-capillary—an extremely minute tube. The most primitive form of the capillary is that of a simple cylindrical channel hollowed out in the connective-tissue, with no other definite wall than that of a delicate, elastic, limiting membrane, consisting of a single complete layer of flat, thin, elastic, endothelial plates, such as have already been described as covering serous surfaces. Each of these endothelial plates contains one, sometimes two, flattened ovoid nuclei. Under favorable conditions intra-nuclear and intra-cellular networks can be demonstrated in these cells. Staining by nitrate of silver and exposure to light blackens the intercellular cement between their edges, which are normally in apposition with edges of the adjacent endothelia, and if the preparation is subsequently stained with carmine the nuclei show a brilliant red. The capillary, of which fig. 5, Plate VI., is a very faithful drawing, has been treated in this manner. The outlines of the cells are shown deep black upon the top of the capillary cylinder, and by dotted lines on the bottom portion. The cells are seen to be more or less lozenge shaped, with the long axis of the cell running with the length of the capillary. The edges of cells are observed to be sinuous. The sinuosity of the edges of the cells is much lessened when the capillaries are distended. Under the influence of irritation or inflammation the endothelia swell up. Their edges then become separated at points, thus forming openings in the capillary wall. The smallest of these are called *stigmata*, the largest *stomata*. Probably it is through these openings that the elements of the blood escape during inflammation. According to some authors, they are in direct communication with the lymph-spaces of the surrounding connective-tissue.

A little more complex form of the blood-capillary consists of an addition to the vessel of an incomplete sheath of fusiform or stellate connective-tissue cells, whose branches form a network. These cells float in a thin lymph-space, which in part surrounds the vessel, and the two together constitute a delicate outer or *adventitious coat* (*tunica adventitia*). In some locations the capillaries are completely invested by a cylindrical lymph-channel, in which case the walls of the channel are lined with endothelium, and the exterior surfaces of the capillaries are also covered by similar cells. This is usually the character of the capillaries of the brain and spinal cord.

When capillaries run through reticular tissue their walls are connected with the branches of the reticulum (fig. 6, Plate VI.).

The capillaries vary greatly in size in different locations. In the cerebro-spinal nervous system and in the lungs they are smallest, in the marrow of bone they are largest.

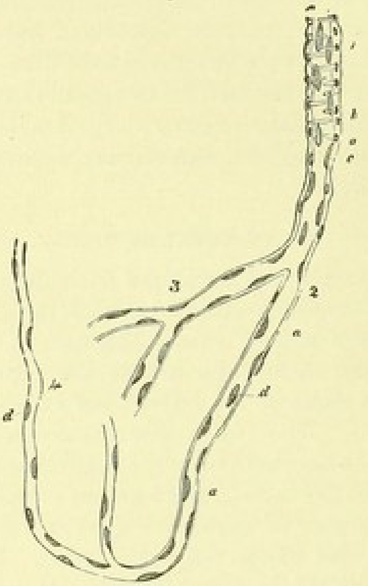
Moreover, in some locations, they are quite irregular in calibre. In the inner layer of the dura mater, and in the interstitial connective-tissue of many muscles, they sometimes present varicosities or even diverticula of odd forms.

Many authors have claimed for the capillaries a moderate contractile power, through the agency of which their calibre may be more or less modified.

Arteries.—The simplest structure of the artery is found in the smallest vessels of this class. Such vessels are known as *arterioles.* The capillaries pass so gradually into the arterioles that it is often difficult to say exactly where the one begins and the other ends. The wall of each arteriole has a much greater thickness than that of the capillary in which it ends, and is more complex in its structure. Next to the blood-stream lies the same endothelial layer as is found in the capillaries. It has also an adventitious coat externally, which is a further development of the delicate tunica adventitia surrounding many capillaries. Between these two inner and outer coats of the arteriole is a third or middle muscular coat. The distinctive feature of the arteriole is the existence of this muscular tissue in the middle coat of the vessel. The muscle-fibres are short, smooth, and spindle-form, and run around the inner coat in a transverse direction.

In that part of the arteriole nearest the capillary, these transversely arranged smooth muscle-fibres do not form a continuous layer. The cells are usually a little too short to completely encircle the vessel. At intervals, two or three are grouped together on one side of the arteriole, while the opposite side remains uncovered. By means of an alternation of these groups of cells around opposite sides of the vessel, the arteriole is practically supplied with the means of narrowing and widening its lumen. A little nearer the heart the layer of muscle-fibres

Fig. 40.



Cerebral Arterioles (Human).—1. Smallest artery. 2. Transition vessel. 3. Coarser capillaries. 4. Finer capillaries. *a.* Structureless membrane still with some nuclei, representative of the adventitious coat. *b.* Nuclei of the muscle-fibre-cells. *c.* Nuclei within the small artery, perhaps appertaining to the endothelium. *d.* Nuclei in the transition vessels. Highly magnified. (*Gray.*)

forms a continuous uninterrupted membrane. The wall of the smallest artery may then be regarded as composed of three coats or tunics—the *external coat* or tunica adventitia, the *middle* (*muscular*) *coat* or tunica media, and the *inner coat* or tunica intima. The tunica adventitia of the larger arterioles still represents the tunica adventitia or lymph-sheath of the capillaries above described. There is a network of branched corpuscles which lie in lymph-spaces formed by a loose reticulum and felt-work of white fibrous tissue. Between the tunica adventitia and the tunica media in the larger vessels of this class there are frequently found a few fine elastic fibres collected into a network. Between the tunica media and the tunica intima in these vessels is also a small number of elastic fibres, the elastic layer of the tunica intima. Between such a delicate elastic layer and the endothelia lining the tunica intima exist, even in arteries of this size, a small number of branched connective-tissue cells connected together into a membranous network.

In *arteries of a larger calibre*, the various elements

entering into the construction of the different arterial tunics are more fully developed, while a few other characteristics are added. The tunica adventitia has gained in thickness by a more complete development of a connective felt-work, whose fibres now have a prevalent longitudinal course. Scattered among these bundles of white fibrous tissue appear a few fine elastic fibres. In the loose meshes formed by the inter-crossing of the fibrous bundles are more or less numerous connective-tissue corpuscles and lymphoid cells. These loose meshes thus formed are lymph-spaces, which very freely intercommunicate.

The elastic fibres become more abundant and larger as the tunica media is approached. At the line of union between the outer and middle coats, the elastic fibres form a dense network, and spread out more or less into a fenestrated membrane which constitutes the line of division between these two tunics. This dense collection of elastic fibres has been termed the *external elastic* membrane.

The tunica media is now constituted by a much more numerous collection of smooth muscle-fibres; but, instead of forming as before a continuous muscular membrane composed of a single layer of cells, the latter are arranged in several more or less continuous layers, the cells of each layer, however, still running transversely around the axis of the vessel. The several muscular layers of which the tunica media is now composed are separated from each other by plates of elastic tissue in the form of fenestrated membranes. These elastic plates run mainly longitudinally and at the same time parallel to the curved surface of the vessel. They are connected with those internal and external to them by means of networks of fine elastic fibres (fig. 3, Plate III.) which run among the cells of the muscle-layers. Between the muscular membranes which the last-named cells constitute, is also to be found now for the first time a very small amount of fibrous connective-tissue with elements which usually accompany it.

At the external boundary of the tunica intima, and forming a sharp, distinct line of division between it and the media tunica, is another dense accumulation of elastic tissue—called the *internal elastic membrane*. It consists, in small arteries, of two or more fenestrated elastic layers so closely packed against each other as to present in section an appearance of a simple structureless elastic membrane. Internal to this elastic layer of the tunica intima is a slight accumulation of delicate white fibrous tissue. The direction of these fibres is mainly longitudinal. They intercross, however, at acute angles, and form between them lymph-spaces elongated with the axis of the vessel. These spaces contain fusiform and branched connective-tissue corpuscles, as well as an occasional lymphoid cell. This connective layer is covered internally by the endothelia lining the lumen of the vessel. The outline of these cell plates is that of a sharp-pointed lozenge, and their edges are somewhat sinuous. When the artery is cut transversely, the internal elastic layer of the tunica intima is shown beautifully festooned—an appearance which gives the inner surface of the arterial wall an extremely wavy outline. Seen in face, the inner surface of the artery appears covered with longitudinal folds or ridges.

In the large arterial trunks, the tunica media and intima become much thicker. In the tunica media, the number of muscular layers is much increased, as well as are the thickness and size of the elastic plates between them. The elastic fibres which form a network among the muscle-cells are also much stouter than before. Instead of nearly all the muscle-fibres running transversely, as in the smaller vessels, there are to be found in some arteries longitudinal and oblique bundles, especially in the inner portion of the tunica media. These are occasionally met with in the tunica adventitia, but rarely in the longitudinal fibrous layer of the tunica intima.

The elastic layer of the tunica intima is much thicker, and is also laminated. Between the laminæ is to be found a small amount of connective-tissue. The layer of longitudinal fibrous bundles beneath the endothelial lining of the lumen of the vessel is now quite distinct.

As a rule, the larger the artery the thicker becomes the muscular tunic and the more numerous the muscle-fibres. In the aorta, however, we have a partial exception to this rule (fig. 1, Plate VII.). Of this great vessel the following characteristics may be enumerated. The tunica adventitia is here comparatively thin. The tunica media is thick, but the layers of muscular tissue are thin, and the muscle-fibres which constitute them are scattering. In the inner portion of the tunica media the elastic plates which separate the muscular layers are also thickened and laminated. The fibres of the elastic network which unite the plates and which anastomose among the muscle-fibres are thick, tough, elastic cylinders, whose main direction is longitudinal to the axis of the vessel. In the outer portion of the tunica media the elastic plates are less laminated and are not so thick as in smaller arteries; neither are the elastic fibres so large. An appreciable amount of connective-tissue is scattered through the middle coat. The tunica intima is

thicker, but does not otherwise differ from that of other large arteries.

The muscle-fibres of the arteries are in the main simple, smooth, fusiform cells with rod-shaped nuclei. In the larger trunks the ends may be more or less bifurcated or even branched. In the aorta, flattened, stellate muscle-cells are often met with.

The walls of the arteries are relatively thick, and, owing to the large amount of elastic tissue composing them, the lumen is usually patulous. The thickness of the arterial wall varies considerably, according to whether the vessel is distended or not. In the large vessels the outer and middle coats are supplied with bloodvessels—the *vasa vasorum*. In a few instances, capillary vessels even enter the tunica intima.

Veins.—The veins differ considerably from the arteries. In the first place, the lumen of the vein is usually considerably larger than in the artery of the same grade, yet the wall of the vein is much the thinner. There are differences also in the minute structure. The smallest vessels which collect the blood from the capillaries are known as *venules*. Their walls are extremely thin, yet they can be readily differentiated, as with the arteries, into three coats—the external or *tunica adventitia*, the middle or *tunica media*, and the internal or *tunica intima*. The tunica adventitia consists of a simple network of fusiform or stellate cells floating in a narrow lymph-channel. The tunica media is composed of simple connective-tissue scarcely differentiated. It contains as yet no muscle-elements. The tunica intima is very thin, and is separated into thin layers which closely correspond to those of the tunica intima of arterioles. The outer layer consists of a delicate fibrous membrane with the fibres running longitudinally. The middle layer is represented by a few stellate cells with their branches anastomosing. Resting upon these stellate cells is the inner layer composed of thin endothelial cell-plates similar to those of the arteries in all except outline. They are much broader and shorter than are the same cells of the arteries, and have rather more sinuous outlines. *Stigmata* and *stomata* are formed here as in the capillaries, and there may be consequently out-wandering of the blood-cells.

In veins of a little larger calibre, the tunica adventitia increases in thickness and strength by an accession of fibrous bundles, which have a prevalent longitudinal direction, but which branch and interlace in such manner as to form a loose meshwork in which lie branched connective-tissue corpuscles, and a few lymphoid elements. At the junction of the tunica adventitia with the tunica media the connective-tissue bundles are aggregated so as to form a more or less distinct fibrous membrane, corresponding in position to the external elastic membrane of the arteries. In most veins of this size the tunica media contains, in addition to the elements of loose connective-tissue, a few scattered, smooth muscle-fibres ar-

EXPLANATION OF PLATE VII.

Fig. 1. Longitudinal section of thoracic aorta of Man. High power. (After Ranvier.)

The central part of the middle coat is not drawn.

1. Internal layer of the internal coat, or tunica intima.

2. External layer of the internal coat.

3. Elastic lamina dividing the internal and middle tunics of the artery.

4, 5. Smooth muscular fibres of the middle coat, cut transversely; among them are elastic fibres and elastic plates.

6. External coat.

Fig. 2. Showing development of capillary bloodvessels in the normal omentum of a Rabbit. High power. (After Klein.)

a, Capillary bloodvessels; *b*, connection of the capillaries with branched cells of the extravascular tissue. It is by metamorphosis of these branched cells that new vessels are formed.

Fig. 3. Shows an artificial injection of the blood and lymph-vessels of the parietal peritoneum. Medium enlargement.

l, Network of lymph-trunks; *v*, venules and arterioles; *c*, capillary bloodvessels.

Fig. 4. *A*. Shows, under a moderate power, an injection of the capillary network in the walls of the alveoli of an inflated lung. The vessels were filled from the pulmonary artery.

B. An injection of the pulmonary blood-capillaries (*b*) in the lung of a human fœtus—the air-vesicles (*a*) never having been inflated.

Fig. 5. Shows a silver injection of the bloodvessels of the lung of a Frog. High power.

v, Larger vessel; *v′*, small arteriole which distributes its blood to capillaries (*c*) in the walls of the air-vesicles; *a*, inter-capillary areas.

Fig. 1.

Fig. 2.

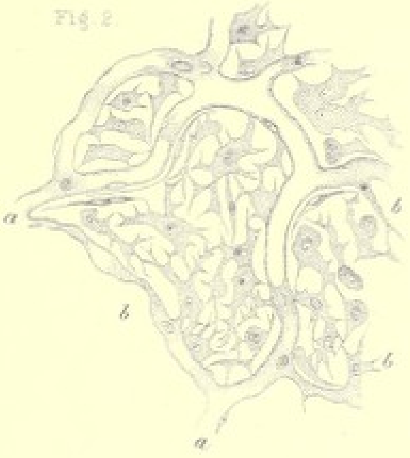


Fig. 3.

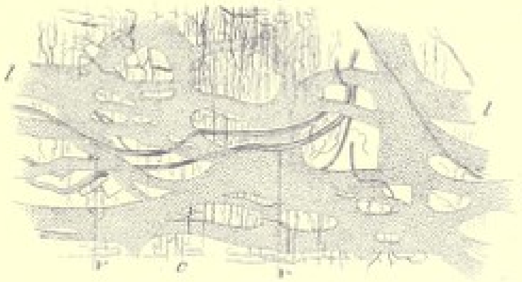


Fig. 4.

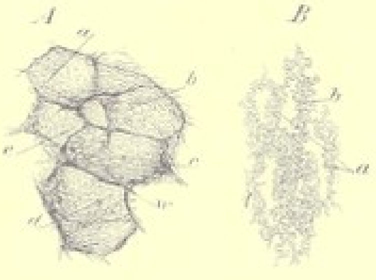
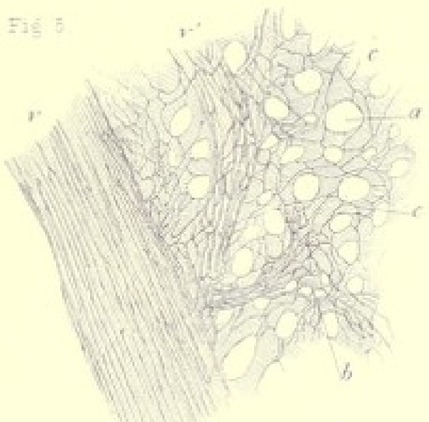


Fig. 5.



ranged transversely. The tunica intima is extremely thin, and presents the same structure as in the venules.

In the *larger venous trunks* the structure of the vessel is essentially the same as that of the vessels last described. The tunica adventitia is strengthened by the presence of a greater quantity of connective-tissue fibres. The tunica media in most cases contains a number of muscle-layers with the cells, for the most part running transversely; elastic tissue is, however, entirely absent. The layers of muscle-cells are separated by lamellæ of fibrous tissue whose individual bundles pursue a general longitudinal course. The outer layer of the tunica intima consists of a dense fibrous membrane, sometimes laminated. The sub-endothelial layer contains longitudinal fibrous bundles, in the interspaces of which are stellate and lymphoid cells. The endothelial lining is not different from that of the smaller veins.

In many veins, the tunica media possesses no muscle-fibres. The veins of bone, of muscle, of the retina, of the membranes of the brain and spinal cord, the cardiac ends of venous trunks emptying into the superior vena cava have no muscles. Some veins possess only a longitudinal muscular coat, as the veins of the pregnant uterus. Others possess an outer longitudinal and inner circular layer of muscle-fibres.

In some veins, the distribution of the muscle-fibres is not limited to the middle coat. They are not infrequently found in the tunica adventitia, and are occasionally present even in the tunica intima.

The foregoing division of the walls of veins into three distinct coats as in the arteries is not accepted by all investigators. Ranvier thinks that the walls of these vessels should be regarded as consisting of only two tunics, an inner and an outer. According to him, it is in the innermost portion of the latter that muscle-fibres are usually located, but they may at times be found throughout the greater part of its thickness.

Nearly all the veins are furnished with *valves* for the purpose of preventing a backward flow of the blood. At the location of the valves, there is a slight ampullar enlargement of the calibre of the vein, a provision which prevents a serious encroachment upon the diameter of the blood-channel when the valves are open and their leaflets flattened against the walls of the vessel. The following peculiarities in the structure of the valves may be adverted to here: Each surface is covered with a single layer of endothelial plates. Upon the inner surface the endothelia are entirely similar to those lining the vein, *i. e.*, more or less lozenge-shaped, with the long axis parallel to the axis of the vein. Upon the outer surface, however, the long axis of the endothelial plates is, in the main, transverse to the axis of the bloodvessel. Immediately beneath the endothelium is a subendothelial layer of connective-tissue fibres interspersed with a few elastic fibres. This layer is thicker and much more abundant in elastic fibres upon the inner than upon the outer surface of the valve. Between and upon these fibres connective-tissue cells, both fixed and wandering, are present in variable number. The subendothelial layers of the two surfaces of the valve are separated from each other by a thin, tough, fibrous membrane composed of interlacing white fibrous bundles whose general direction is parallel to the edge of the valve. Some elastic fibres are also scattered among the white fibrous bundles, and according to the statements of some authors a few muscle-fibres may be found near the base of the valve. When muscle-fibres are present, the direction of their long axis is usually transverse to the axis of the vessel. The endothelium and the subendothelial layer, lining the ampullar enlargement of the vein at the location of the valves, are similar to those which cover the outer surface of leaflets of the valve.

Sinuses.—Custom among anatomists has fixed upon the term sinus a double and somewhat indefinite significance. Many vessels of the human economy which have received this name possess no circumstance which distinguishes them from veins, other than the simple fact that they constitute various channels in fibrous membranes, *e. g.*, some of the cerebral sinuses. Most, if not indeed all, of the sinuses of the blood-vascular system may be justly regarded as varieties of veins, for their blood is that of the venous system, and so also in many respects is their histology.

The cavernous sinus, and the cavernous tissue of the corpus cavernosum of the penis, present two distinct types of genuine sinuses.

In the former we have a vein whose calibre is broken up into reticulæ of various sizes and shapes by fibrous trabeculæ springing from the walls of the sinus, and extending across the lumen of the vessel. The fibrous bundles are continuous with the middle tunic of the vessel, and contain such elements as are present in that coat. The trabeculæ are covered by endothelial-cells and a subendothelial tissue similar to those of the walls of the sinus. They sometimes inclose small bloodvessels.

The corpus cavernosum of the penis presents a somewhat different construction. As its name implies, it is a cavernous tissue. It consists essentially

of a reticulum of interlacing bands, or trabeculæ of smooth muscle-fibres, associated with a variable amount of elastic fibres and bundles of white fibrous tissue. The spaces formed by the interlacement of these trabeculæ are of variable size and outline, and they freely intercommunicate. The surfaces of the trabeculæ are covered with a layer of endothelial cells and a subendothelial tissue very similar to those of large veins. The trabeculæ contain arterioles which distribute their blood to a plexus of capillary vessels which also are contained within the trabeculæ. Most of these capillaries empty into the cavernæ formed by the interlacing trabeculæ. The blood of these sinuses or cavernæ is collected by venous trunks, and the communicating cavernæ may consequently be regarded as a complicated venous sinus.

Development of bloodvessels.—The earliest form of the complete bloodvessel is the capillary. By the successive addition of the elements which constitute their distinctive features, arteries and veins are formed from vessels which were originally in the condition of capillaries. These minute blood-channels frequently give origin to new capillaries in the following manner:—

In young, growing connective-tissue the walls of the simplest form of capillary, above described, here and there give off solid protoplasmic projections, which may be more or less branched, and which are frequently irregular in outline (fig. 2, Plate VII.). The nuclei contained in these solid protoplasmic cylinders divide and increase in number. The portion in connection with the previously-formed capillary becomes hollowed out and filled with blood from the open lumen of the vessel. In the portion more remote from the capillary, vacuoles appear at intervals in the protoplasmic cylinder. These soon open into one another, and constitute a channel in the protoplasmic branch. By an extension of this process of vacuolation a hollow tube is produced, the lumen of which freely communicates with the lumen of the original capillary. As this process of vacuolation proceeds, the nuclei are pushed to the side of the protoplasmic cylinder, where they remain to form the nuclei of the future endothelium. The calibre of the new capillary ultimately becomes regular in outline, and what remains of the original protoplasm of the tube divides into endothelial plates and their intercellular cement.

Instead of the formation of a new capillary loop by vacuolation of a protoplasmic projection from the wall of a capillary, a connective-tissue corpuscle, which by one of its branches is connected with the wall of a capillary, may swell up, experience division of its nucleus, enlargement of its branches, and through the same process of vacuolation be converted into a young capillary.

This process of vacuolation may even affect con-

EXPLANATION OF PLATE VIII.

Fig. 1. An injection of the bloodvessels of a racemose gland, as seen in a very thin section. Medium enlargement.

Fig. 2. Scheme of the relations and distribution of the bloodvessels of the kidney. Low power. (After Ludwig.)

A. External portion of the cortex; *c* being the limiting capsule. *B.* The cortex. *C.* Boundary layer. *D.* The medulla. *E.* The apex of the papilla.

a, Portion of a small artery coursing along the boundary between the cortex and medulla,—it gives off an external twig (inter-lobular branch), which at varying intervals distributes an afferent arteriole to a Malpighian glomerulus, *m*; v, corresponding vein which receives an analogous external (inter-lobular) branch,—the latter collects blood directly from the efferent vessels of the glomeruli, *m*, and from (*r*) the capillary network (*rete mirabile*) surrounding the tortuous uriniferous tubes of the renal cortex, and it drains the renal medulla directly through bundles of *venulæ rectæ*, which empty into the inter-lobular vein as represented at v, on the left of the figure. Corresponding to the venulæ rectæ are the *arteriolæ rectæ*, not represented in the diagram, which arise at the base of the inter-lobular arterial twigs.

Fig. 3. Arrangement of bloodvessels in an intestinal villus. High power.

a, Arteriole; *v*, collecting venule; *c*, capillary plexus.

Fig. 4. Arrangement of bloodvessels in a filiform papilla of the tongue. High power.

a, Arterioles; *v*, collecting venules; *l*, capillary loops.

Fig. 5. Arrangement of minute bloodvessels in the muscular tissue of the tongue. Medium enlargement.

a, Arteriole; *m*, capillary plexus, the long axis of whose meshes corresponds with the length of the muscular fibre; *t*, capillaries running with muscle-bundles, which are vertical to the surface of the section.

PLATE VIII.

Fig. 1.

Fig. 2.

Fig. 3.

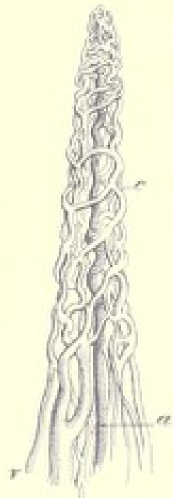


Fig. 4.

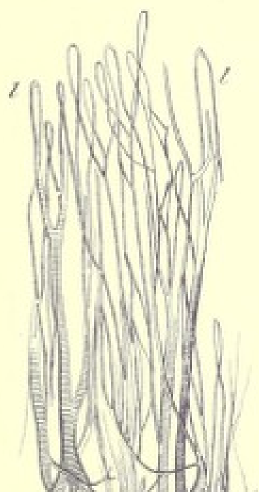
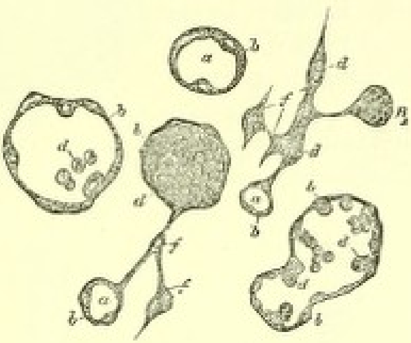


Fig. 5.

nective-tissue corpuscles at some distance from a capillary and not in direct communication with it, and thereby influence the formation of hollow protoplasmic tubes, which finally form a connection with the capillaries.

Those connective-tissue corpuscles which take part in the formation of new vessels, Ranvier regards as cells of special function, namely, the formation of vessels. He has called them *vasoformative cells*.

Fig. 41.



VARIOUS FORMS OF MOTHER-CELLS (SO-CALLED VASOFORMATIVE CELLS) UNDERGOING DEVELOPMENT INTO BLOODVESSELS, FROM THE MIDDLE LAYER OF THE CHICK'S BLASTODERM (KLEIN).—*a*. Large mother-cells vacuolated, forming the rudiments of vessels. *b*. Their walls, formed of protoplasm, with nuclei embedded and in some cases more or less detached and projecting. *d*. Blood-corpuscles. *f*. Small mother-cells—vacuolation commencing. *B*. Mother-cell in which only obscure granular matter is found.

In the development of new capillary bloodvessels from connective-tissue corpuscles, the elements of the blood are sometimes formed in small numbers, by a process similar to that of the original formation of blood and bloodvessels in the embryo. They may more or less completely fill the channels of the vasoformative cells, even before a communication is effected with the lumen of a previously-formed capillary.

The method of formation of the earliest bloodvessels in the embryo is essentially identical with that by which a so-called vaso-formative cell of the young or adult animal is transformed into a capillary. The bloodvessels are thus derived from the middle layer of the blastoderm.

Arrangement of the bloodvessels.—By branching the arteries diminish in calibre until the arteriole is reached. These, after running a short distance, almost always pass into a capillary network, which in its turn yields its blood to a collecting venule. In a few instances, however, the arterioles discharge their blood into the veins without the intermediation of capillary vessels. This is the case, for example, in the matrix of the nails, and in the ends of the fingers and toes. In the cavernous tissue of the genital organs a similar direct communication between the arteries and veins exists. Like the arteries, the veins also vary their diameter as branches are received. This is not so, however, with the capillaries, whose calibre is neither increased nor lessened by ramifying. The branch is usually of the same size as the capillary from which it receives its blood and the one into which it empties.

The distribution of the terminal bloodvessels varies according to the arrangement of the elements of the tissues in which they ramify. (Refer to descriptive text accompanying Plate VIII.)

NERVOUS TISSUE.

The nervous system comprises nerve-centres, peripheral terminations, conducting fibres uniting them, commissural fibres running from centre to centre, and a connective-tissue framework.

The whole nervous apparatus has generally been considered under two divisions, the cerebro-spinal system and the sympathetic system.

In the cerebro-spinal system we have nerve-centres constituted by nerve ganglia, or *gray substance*, and conducting fibres, or *white substance*. From these centres nerves pass to various parts of the economy.

CEREBRO-SPINAL NERVES.

Nerve-sheath.—Cerebro-spinal nerves, after leaving their centres, are surrounded by a sheath of white fibrous connective-tissue, in which there is a certain amount of yellow elastic tissue.

At the exterior this fibrous tissue is somewhat denser than ordinary loose connective-tissue, and presents characters very similar to those of the cutis. Within this denser envelope the fibrous bundles and other elements are arranged in a manner analogous to the loose connective-tissues elsewhere.

The arteries and veins of the nerve-trunk ramify in this loose tissue, and the lymph also courses through it. As in other loose connective-tissue, adipose vesicles may be found between the fibres. This fibrous tissue is technically known as the *epineurium*—a continuation of the dura mata. A cerebro-spinal nerve contains, within the epineurium, one or more bundles of individual nerve-fibres. Immediately around the bundle of the nerve-fibres the connective-tissue of the epineurium becomes condensed into a laminated enveloping membrane—the *perineurium*—a continuation of the arachnoid. Between the lam-

inæ of the perineurium exist shallow lymph-spaces, containing connective-tissue elements, and partially lined by endothelium. The perineurium may inclose a single bundle (*funiculus*) of individual nerve-fibres, or it may ensheathe a number of such bundles, and constitute what has been termed a *nerve-fasciculus*.

Neuroglia.—In the simple funiculus the nerve-fibres are more or less closely packed side by side, imbedded in a soft, semifluid, somewhat granular substance, in which are scattered a few very fine connective-tissue bundles, a number of minute individual fibrillæ, and some flat and branched connective-tissue corpuscles. In this tissue (the *endoneurium*—a continuation of the neuroglia), run the capillary vessels, with much elongated meshes. As the endoneurium approaches the perineurium, it often becomes condensed into a more resistant layer, which is slightly separated from the inner lamina of the perineurium by a thin encircling lymph space (a continuation of the subarachnoid space). At very numerous points this lymph-space is crossed by uniting trabeculæ of connective-tissue, and is everywhere lined by a layer of endothelia. When the perineurium ensheathes a number of funiculi, the latter are separated from each other by more or less complete partitions of the endoneurium, consisting of fibrous septa from the inner surface of the perineurium.

The fine connective fibrillæ of the endoneurium between the nerve-fibres are often closely interlaced around the nerve-cylinders as if to constitute for the latter a special protection. The endoneurium, besides carrying the capillary bloodvessels, is permeated by a network of capillary lymph-spaces.

Nerve-fibres, medullated and non-medullated.—The nerve-fibre, nerve-cylinder, or nerve-tube will be now described. When an ordinary cerebro-spinal nerve is cut across transversely, after proper hardening, the section offers, under a moderate power of the microscope, an appearance well represented in fig. 1, Plate IX. Within the perineuria (*c*), which present circular sections, are cross-cuts of simple bundles or funiculi of nerve-tubes. In the granular ground-substance (the endoneurium) are a few delicate fibrous bundles. Scattered more or less unevenly through the endoneurium are seen small, round, light spots, and in or near the centre (*d*) of each is a dark dot. The latter corresponds to the central or conducting fibres (the *axis cylinder*) of the nerve-tube, and the light ring around it is an ensheathing insulating cylinder of fatty material (*the medullary sheath*). These light, circular, dotted spots are sections of *medullated nerve-fibres*. Each considerable bundle of nerves contains, besides the medullated tubes, a number of *non-medullated nerve-fibres*.

The fully-developed medullated nerve-fibre, when fresh and properly prepared, presents the following characteristic structures: the axis-cylinder, the medullary sheath, and the sheath of Schwann, or neurilemma (Figs. 42–46).

a. The *axis-cylinder* is a finely-fibrillated cord running nearly in the axis of the nerve-tube. It consists of a small bundle of extremely fine unbranched fibrils, held very closely together by an albuminous semifluid cement-substance, which often contains very minute granules arranged in rows between the fibrils. (*b*, Fig. 43.)

Fig. 43.

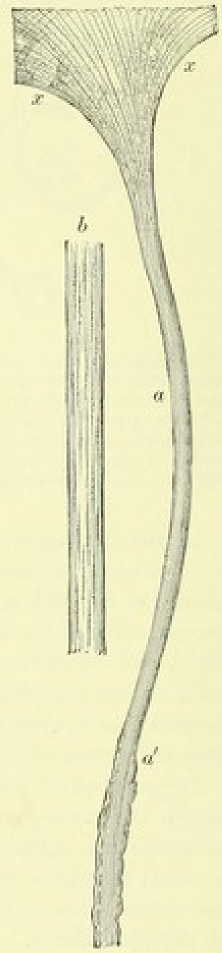
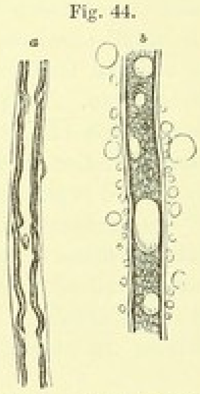


Fig. 42.

Diagram of Structure of Medullated Nerve-Fibre.—1. Neurilemma or sheath of Schwann. 2. Medullary sheath. 3. Axis-cylinder. (*Carpenter.*)

Fig. 44.



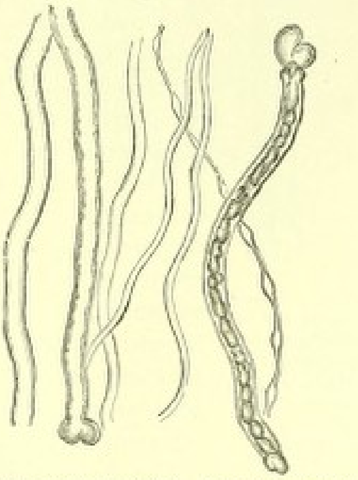
Nerve-Tubes.—*a.* Nerve-tube of the common European Eel in water. The delicate line on its exterior indicates the neurilemma. The dark double-edged inner line is the white substance of Schwann, slightly wrinkled and divided into bevelled segments. *b.* The same in ether. Several oil or neurine globules have coalesced in the interior, and others accumulated around the exterior of the tube. The white substance has in part disappeared. Magnified 300 diameters. (*Gray.*)

Axis-cylinders of Nerves.—*a.* Axis-cylinder, showing its fibrillar structure; at the upper part, *x*, *x*, it is seen to arise from a ganglion-cell, only partially represented, and to become inclosed by a medullary sheath at *a'*. *b.* Naked axis-cylinder, from the dorsal region of the spinal cord of the Ox. The medullary sheath has been removed. High power. (*Stricker.*)

b. The *medullary sheath* enveloping the axis-cylinder is not, as formerly supposed, a continuous uninterrupted

insulating tube. It is composed of a great number of short *tubular sections*, placed end to end, or imbricated. The ends of these sections are bevelled as represented very poorly in *a*, Fig. 44. Each of these bevelled-edged tubal sections consists of a fatty, semifluid substance, held within the meshes of a fine reticulum (Klein). This fatty substance has long been known as *neurine*. Water, pressure, and various reagents cause the semi-fluid fat of these sections, which normally is homogeneous, to break up into granules and drops. The medullary cylinder then becomes coarsely granular, and if the neurilemma be broken the fat extrudes in drops of considerable size, as shown in *b*, Fig. 44.

Fig. 45.

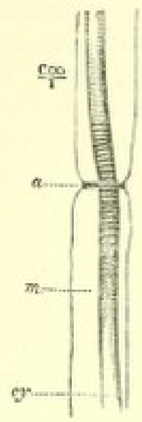


HUMAN NERVE-TUBES, highly magnified. Four of them are fine, one being varicose, and two of middling thickness and of simple contour; whilst three are thick, two of which are double-contoured, and one incloses grumous contents. (*Gray.*)

c. The *neurilemma*, or sheath of Schwann, is a delicate, elastic, homogeneous membrane, which envelops the medullary cylinder as a continuous tube. It is the analogue of the sarcolemma. Between the neurilemma and the medullary sheath is a thin lymph-space. The axis-cylinder and the surrounding medullary sheath are also slightly separated by a thin lymph-space. This latter lymph-space is probably in communication with the outer lymph-space beneath the neurilemma, by means of the spaces between the bevelled ends of the tubal sections of the medullary cylinder.

Nodes of Ranvier.—The neurilemma is not a tube with straight sides, and even calibre from one end to the other, but presents at more or less regular intervals sharp *annular constrictions* (*a*, Fig. 46), which divide the nerve-tube into segments. At the place of these annular constrictions, first described by Ranvier, a septum from the neurilemma passes across the nerve-fibre interrupting all of its parts except the axis-cylinder and the lymph-space immediately surrounding the latter. When a perfectly fresh and uninjured medullated nerve-fibre is treated by nitrate of silver, and exposed to light, the annular constriction becomes very distinct. If the nerve is submitted long enough to the action of the silver salt, the latter will penetrate to the periaxial lymph-space around the axis-cylinder, and extend along it for a little distance. When this is the case the surface of the axis-cylinder is covered by transverse markings (*lines of Frommann*), which are due to coagulations in the lymph-space. In consequence of this dark staining of the annular constrictions, and of the axis-cylinders for some distance above and below them, a *dark cross* becomes conspicuous. These constrictions are known as the *nodes of Ranvier*, and the portions of the nerve-cylinder between the constrictions are known as *inter-annular segments*. Each interannular segment comprises a number of bevelled-edged imbricated tubular sections of the medullary sheath, and also contains a flattened nucleated corpuscle. The nucleus of this cell consists of a fine reticulum and an enveloping membrane of double contour. It is a flattened-oval in shape, and is surrounded by a small amount of protoplasm which also contains a fine reticulum. The corpuscle is flattened upon and partially sunk into the surface of the medullary sheath, sometimes extending across one or more bevelled sections of the cylinder. It has no connection with the neurilemma. It is the analogue of the muscle-corpuscle, and has been named the *nerve-corpuscle*.

Fig. 46.



NERVE-FIBRE FROM THE SCIATIC NERVE OF THE RABBIT AFTER THE ACTION OF NITRATE OF SILVER.—*a.* Ring formed by thickened membrane of Schwann. *m.* White substance of Schwann rendered transparent by glycerin. *Cy.* Cylinder-axis, which just above and below the level of the annular constriction presents the lines of Frommann. (*Frommann.*)

Size of nerve-fibres.—The size of a medullated nerve-fibre varies according to the diameter of the axis-cylinder, and the thickness of the insulating sheath or medullary cylinder. The thickness of the medullary sheath to some extent varies with the distance to which the nervous impulse is to be conducted. The greater the course the nerve-fibre has to traverse, the greater the thickness of the insulating cylinder, is a rule which has numerous exceptions.

In the nerve-centres the medullary sheath is comparatively thin, except in certain tracts of the spinal cord, where fibres which run a great distance are located.

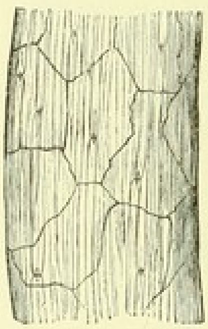
As the medullary nerve-fibre approaches its peripheral termination, its medullary cylinder gradually becomes thinner and thinner until it entirely disappears, leaving only some flat nerve-corpuscles between the neurilemma and the axis-cylinder. There are many nerve-fibres of this structure to be seen in nearly every section of a nerve-bundle. They are generally scattered around unevenly among the fibres which are still medullated. In a given nerve-bundle the medullary fibres may be nearly uniform in size, or they may have very different diameters.

Division of nerve-fibres.—In their course the nerve-bundles generally branch in order to widen the extent of their distribution. In some instances branches derived from two or more bundles are bound together to form a nerve-bundle. In this manner a plexus of nerve-bundles may be formed within a common epineurium. Occasionally, also, complete nerves may branch and form nerve-plexuses.

While the branching of whole nerves and of their constituent bundles is of universal occurrence, it has been doubted if the individual medullated fibres ever divide. Some well-reputed authors have in recent years both described and figured an occasional bifurcation of medullated nerve-fibres, especially when near their peripheral termination. This bifurcation takes place invariably at one of the nodes of Ranvier. The axis-cylinder divides, and each branch is enveloped in a neurilemma and medullary sheath which are continuations of those which surround the fibre above the point of division.

Microscopic nerve-bundle.—In branching, a nerve becomes smaller and smaller and its constitution less and less complex until a microscopic size is reached. This microscopic nerve may consist of a single small bundle of medullated and other fibres ensheathed in a perineurium, which, instead of being formed by dense lamellated connective-tissue, is represented by a delicate film of connective-tissue. The external surface of the endoneurium, as in the larger nerves, is still covered by an investment of endothelia. The appearance of such a microscopic nerve, after it has been withdrawn from its perineural sheath and submitted to the action of nitrate of silver and light, is very well represented in Fig. 47.

Fig. 47.



NERVE-FUNICULUS OF THE TAIL OF A MOUSE, AFTER IMPREGNATION WITH NITRATE OF SILVER.—Large flat endothelial cells are seen covering its surface. For explanation of the small crosses see preceding figure. (*Ranvier.*)

A microscopic funiculus of this character continues to divide and subdivide until the smallest microscopic medullated nerve is reached, inclosed in a perineurium composed of a single layer of endothelial cells.

These smallest medullated nerves are not infrequently slightly moniliform—an irregularity of outline due to the accumulation at intervals of lymph or periaxial cement-substance in the lymph-space between the cylinder-axis and the medullary sheath (Fig. 45).

The nerve-fibre finally loses its medullary sheath. From this point it passes through the tissue with a simple covering of neurilemma and occasional nerve-corpuscles. From time

EXPLANATION OF PLATE IX.

Fig. 1. Transverse section of a small branch of a cerebro-spinal nerve. Medium enlargement.

a, Common sheath; *b*, lymph-space within it; *c*, *perineurium* carrying bloodvessels, *v*, and lymph-vessels; *d*, axis cylinders of medullated nerve fibres. These fibres are collected together into bundles, inclosed within a sheath, which consists of a condensation of the connective-tissue of the *perineurium*. The individual nerve fibres constituting such a bundle are separated from each other by a delicate tissue known as the *endoneurium*.

Fig. 2. Minute subdivisions of the nerves in the superficial layer of the cornea, termed the *subepithelial plexus*, as seen in the cornea of a Rabbit after treatment with chloride of gold. High power.

Fig. 3. Connective-tissue elements of the perineurium of a cerebro-spinal nerve. Very high power. (After Ranvier.)

f, Connective-tissue bundles; *c*, flat connective-tissue or endothelial-cells.

Fig. 4. A minute bundle of medullated nerve-fibres in the tongue of a Cat, showing axis-cylinders, *c*, and nuclei of the neurilemma, *n*. High power.

Fig. 5. Vertical section of anterior epithelium, *a*, *b*, and superficial layers, *e*, *c*, of the fibrous tissue of a cornea stained with gold, showing the penetration of the nerve-filaments between the corneal epithelium, and the formation there of an inter-epithelial network of minute nerve-fibres. (After Cohnheim.)

PLATE IX.

Fig. 1.

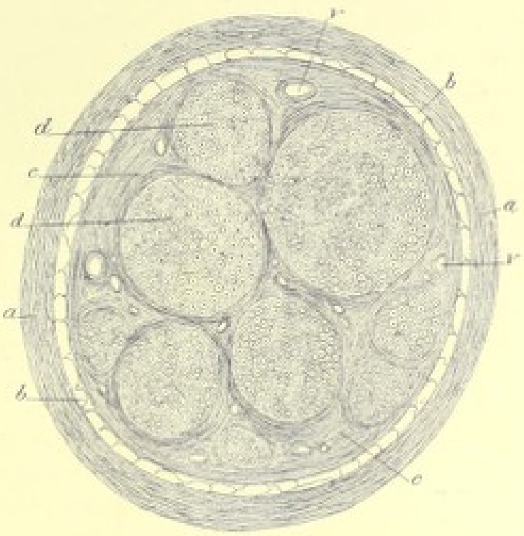


Fig. 2.

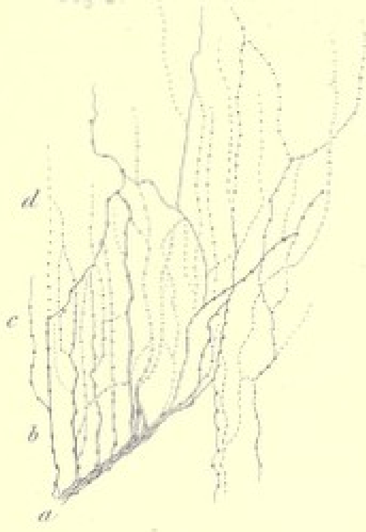


Fig. 4.

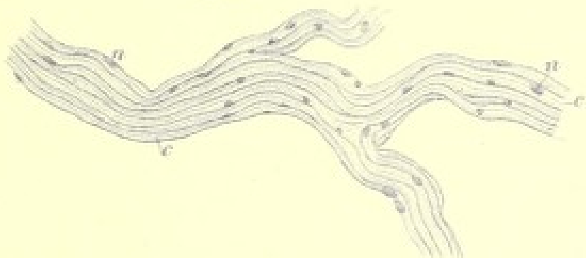
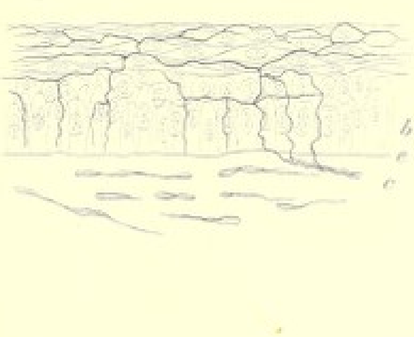


Fig. 3.

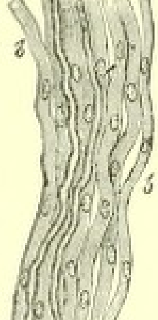
Fig. 5.



to time the axis-cylinder splits up into branches, which, by further division, become so small as to be composed of an extremely small number of fibrils loosely bunched together. In these minute divisions of the axis-cylinder the neurilemma ultimately disappears, and the only remains of the original envelopes of the medullary nerve-fibre are a few flattened connective-tissue cells which at scattered points wrap more or less completely around the small bundles of nerve-fibrils. By this time the nerve-fibrils have become beaded (fig. 2, Plate IX.). After the axis-cylinder has lost its medullary sheath and has branched in the manner above indicated, the nerve-fibrils are frequently collected again into delicate fibrillar bundles to form networks. Notwithstanding these numerous ramifications and anastomoses of collections of minute nerve-fibrils, it is believed that an individual fibril itself never divides.

Fibres of Remak.—Attention has thus far been called to three different forms of nerve-fibre. It is now proposed to consider a fourth variety—the gray or gelatinous fibre or the *fibre of Remak*. This does not sensibly differ from a variety of medullary fibre already described, namely, the one which has lost its medullary sheath, and is composed simply of neurilemma, nerve-corpuscle, and axis-cylinder.

Fig. 48.



a

A Small Nerve-Branch from the Sympathetic of a Mammal. — d. Two dark-bordered nerve-tubes among a number of Remak's fibres, b. (*Frey.*)

In the cerebro-spinal nerves the medullated fibres greatly preponderate over the non-medullated or gelatinoid fibres. In the sympathetic nerves this order is usually, although not always, reversed, and the medullated nerves are frequently finer than in the cerebro-spinal nerves. In nerves of a mixed character the sympathetic fibres may run in a bundle by themselves or they may be indiscriminately mixed with the other fibres. Of the medullated nerves, the sensory fibres, as a rule, retain their medullated sheath longer than do the motor fibres.

PERIPHERAL TERMINATIONS OF NERVES.

This subject may be considered under two general heads: *a*, the peripheral termination of sensory nerves; and, *b*, those of motor nerves.

a. Peripheral terminations of sensory nerves.—As has been already indicated, the smallest microscopic medullated nerve consists of a perineurium surrounding a bundle of nerve-fibres. Some fibres lose the medullated sheath earlier than others. When the nerve is very near its termination, usually the medullary cylinder and the neurilemma disappear from all the fibres within the investing perineurium. The fibrils of the different axis-cylinders, being now more free than before, interlace in such a manner that the nerve-bundle appears much like a longitudinal network of fibrils collected into a cord. In the skin and mucous membranes, near the surface, and in many other locations, these non-medullated branches ramify and unite into a plexus; each limb of the plexus, even when it comprises not more than two nerve-fibrils, is still invested by a delicate membrane which is the representative of the perineurium. Along the course of these ramifications, and especially at the nodal points of the plexus, are a few nuclei.

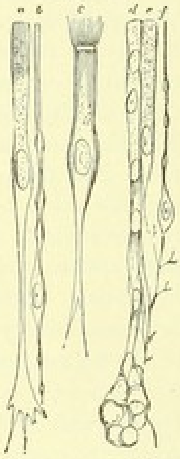
Subepithelial plexuses and networks.—In the skin and mucous membranes a plexus exists beneath the epithelial covering. Hence it has been called the *subepithelial plexus* or ground-plexus. From this subepithelial plexus, single, fine, beaded fibrils, or small collections of such fibrils, come off and unite with each other into a network of meshes of various sizes and outlines. This network of nerve-fibrils is located immediately beneath the epithelium, and has consequently been called the *subepithelial network* (fig. 2, Plate IX.).

Intercellular networks.—Some of the branches of the subepithelial network enter the layer of epithelium, passing in the intercellular cement between the epithelial cells. These branches ramify among the epithelia to form an *intercellular network* of single-beaded fibrils (fig. 5, Plate IX.). In some locations the subepithelial networks are peculiarly arranged with respect to the direction of the fibrils and the consequent outline of the meshes. Beneath the epithelium of the cornea, for example, the branches which come from the ground-plexus give origin to ramifications, which with the stem whence they arise present an appearance that has been compared to the cat-o-nine-tails (fig. 2, Plate IX.).

There is a great diversity of opinion as to whether the nerve-fibrils from the subepithelial plexus simply end in the cement-substance, between the epithelial cells, in a network such as above indicated, or whether they terminate by free extremities, some of which communicating with the stellate cells among the epithelium, others extending to the surface.

It seems to be certain that some of the nerves of special sense terminate among epithelial cells. In the Schneiderian membrane the olfactory nerves form a subepithelial plexus, fibres from which terminate in certain rod-shaped elements (*b*, Fig. 49), the superficial ends of which reach the surface between the columnar epithelial cells of that membrane. The terminations of the optic nerve are conical and rod-like organs, which are imbedded between epithelial cells. The auditory nerves probably have an analogous ending. The gustatory nerve has a peculiar terminal organ (the taste-bulb) implanted among the lingual epithelium (Fig. 50).

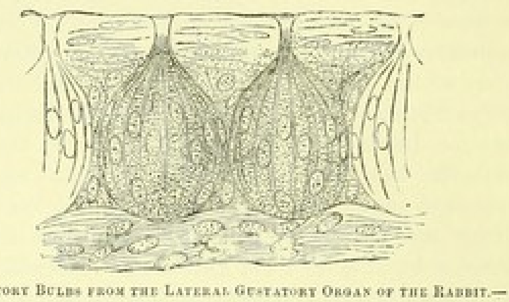
Fig. 49.



Cells of the Olfactory Mucous Membrane.—*a*, *b*, *c*. After Schultze. *d*, *e*, *f*. After Lockhart Clarke.

In some kinds of connective-tissue, also, sensory nerves seem to end in complicated nervous networks. In the cornea, for example, besides a superficial subepithelial nerve-plexus, above mentioned, there is also a deep plexus which supplies the posterior lamellæ. Fig. 1, Plate X., accurately represents (according to Klein) the manner of distribution of the minute beaded fibrillæ to a deep stratum of the cornea of a rabbit. *a*. Is a part of the ground-plexus (or nerve of the first order)—a bundle of interlacing, free nerve-fibrillæ, inclosed by an extremely delicate sheath, representing the perineurium. *b*. Are branches from the ground-plexus (or nerves of the second order) still possessing an investing sheath, but comprising only a small number of fibrils—they also anastomose to form a network. *c*. Are single, minute, beaded fibrils (nerves of the third order), which arise from the network formed by *b*, and pursue a rectilinear course among the fibrous bundles of the connective-tissue—they unite with fibres of a similar appearance to form a network of rectangular meshes. *d*. Are nerves of the fourth order, still finer beaded isolated fibrils, which arise from the nerves of the third order, and form a network with very small, irregular meshes. The fibrils of this last minute network frequently appear to be in contact with some part of the surface of the corneal corpuscles, the analogues of connective-tissue corpuscles. Opinion is evenly divided as to whether this last network is to be regarded as the peripheral termination of these nerve-fibrils, or whether still more

Fig. 50.



Gustatory Bulbs from the Lateral Gustatory Organ of the Rabbit.—High power. (*Stricker*.)

EXPLANATION OF PLATE X.

Fig. 1. Represents the distribution of the nerves in the depth of the cornea. Very high power. (After Klein.)

a, Nerve of the first order; *b*, nerve of the second order; *c*, beaded nerve of the third order, forming a rectangular network; *d*, beaded nerve of the fourth order, which forms a network, perhaps upon the surface of the branched corneal corpuscles, which latter, with their branches (*e*) and their nuclei, are represented in the figure.

Fig. 2. End bulb, *b*, and medullary nerve, *c*, *d*, of the conjunctiva of a Calf; *a*, axis-cylinder termination of the nerve within the bulb. High power. (After Krause.)

Fig. 3. Pacinian corpuscle. High power.

a, Axis-cylinder of medullary nerve-fibre; *c*, termination of the sheath of Schwann in the fibrous lamellæ, *d*, of the Pacinian body; *a*, *c*, the axis-cylinder; *b*, its division and termination near the end opposite the entrance of the nerve-fibre.

Fig. 4. Distribution of nerves in the wall of a small arteriole. High power. (Arnold.)

a, Larger nerve-twigs which branch into minute subdivisions, some of which, according to Arnold, terminate in the nucleoli or within the nuclei, *c*, of the smooth muscle-fibres of the tunica media.

Fig. 5. Shows the relations of the minute nerves to the walls of a capillary bloodvessel. High power. (After Klein.)

PLATE X

Fig. 1.

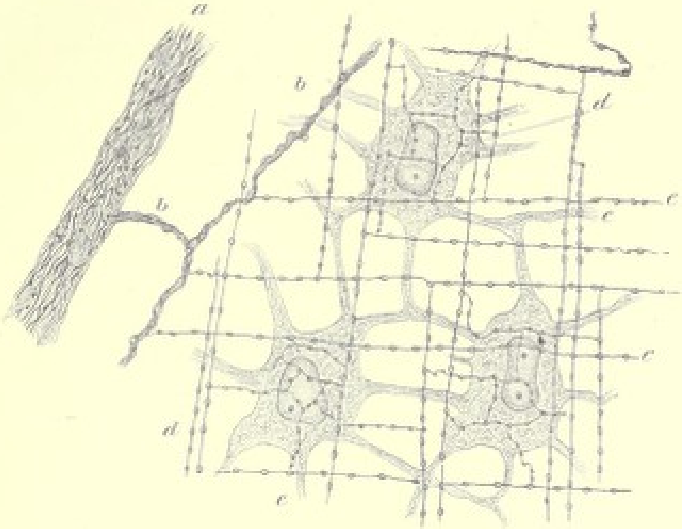


Fig. 2.

Fig. 3.

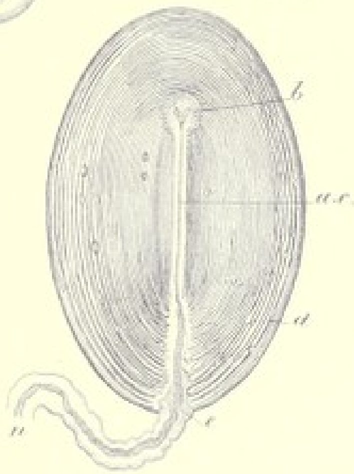


Fig. 4.

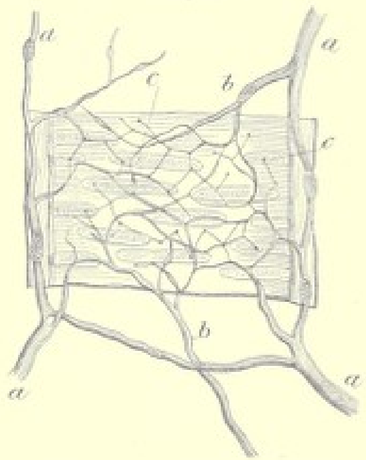
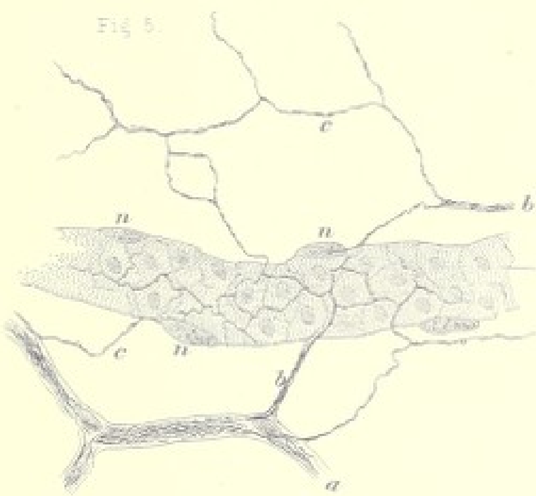


Fig. 5.



minute fibrils come off from it, and enter the substance of the corneal corpuscles to terminate therein.

Besides the foregoing modes of peripheral distribution of sensory nerves, there are yet to be mentioned certain special structures in which nerves of this character frequently end. The most important of these are the Pacinian corpuscles, tactile corpuscles, and the end-bulbs of Krause.

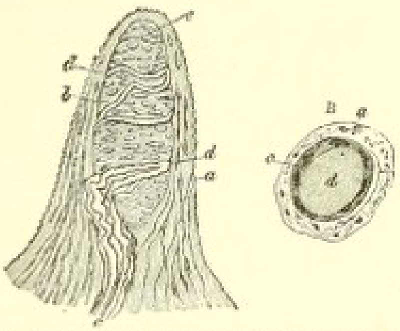
End-bulbs of Krause.—These organs are met with in small numbers at the peripheral ends of some of the medullated nerves terminating in the deeper layers of the conjunctiva, especially near the cornea. They appear to have a simple plan of structure.

b, fig. 2, Plate X., represents, under a low power, the simplest form of such an end-bulb from the conjunctiva of the calf. In this case its outline is somewhat cylindrical, with rounded ends, and it is fixed upon the end of a medullated nerve-fibre, *c*. The nerve-fibre is seen to pass nearly straight along the axis of the elongated bulb, and to terminate in a slightly tapering extremity, near the end opposite the point of entrance. In man the end-bulbs of Krause are often more or less spherical, and the nerve-fibre, after entering the organ, instead of pursuing a direct course, is frequently more or less convoluted, and even sometimes branched. The nerve-fibre upon which it is placed possesses a distinct perineurium, enveloping a neurilemma, within which is an axis-cylinder insulated by a medullary sheath : all these parts exhibit their usual characteristics. When the nerve reaches the end-bulb the perineurium spreads out and envelops it, forming in some instances a slightly laminated sheath. Ordinarily, but not always, the nerve-fibre loses its medullary sheath upon entering the bulb. The axis-cylinder enters the body of the bulb and passes to the opposite end, either in a straight or somewhat wavy course, or after first forming several tortuous curves or convolutions. It may end in a tapering extremity, extend into a knot, or divide into two or more branches, each ending in a terminal enlargement. Among the convolutions nuclei are generally found in some numbers, embedded in a slightly granular substance. Occasionally the medullated sheath continues for some distance along the convolution.

Bulbous nerve-terminations somewhat similar to those above described are found in considerable numbers upon the genital organs.

Tactile corpuscles.—The *tactile corpuscles* are nerve-terminations of much wider distribution than the end-bulbs of Krause, and are somewhat more complex in structure. They are found mainly in the apex of papillæ of the skin, and because of their location in greatest numbers at the ends of the fingers, and upon other surfaces endowed with the most delicate sense of touch, they have been called tactile bodies or corpuscles. In their simplest form they consist of an enlargement shaped somewhat like a pine cone upon the end of a medullated nerve-fibre. (Fig. 51.) The

Fig. 51.



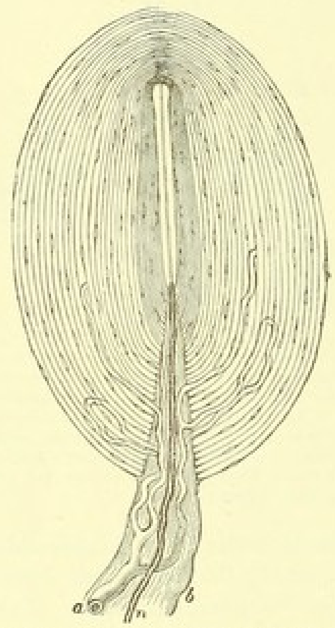
TACTILE CORPUSCLE.—A. Side view of a papilla of the hand. *a*. Cortical layer. *b*. Tactile corpuscle, with transverse nuclei. *c*. Small nerve of papilla, with neurilemma. *d*. Its two nervous fibres running with spiral coils around the tactile corpuscle. *e*. Apparent termination of one of these fibres. B. A tactile papilla seen from above, so as to show its transverse section. *a*. Cortical layer. *b*. Nerve-fibres. *c*. Outer layer of the tactile body, with nuclei. *d*. Clear interior substance. From the Human subject, and treated with acetic acid. Highly magnified. (*Gray.*)

perineural sheath of the fibre thickens and spreads out to form a tolerably thin laminated fibrous covering or capsule for the touch-corpuscle. The main contents of this capsule are large, clear, vesicular, nucleated cells frequently flattened from above downward, and piled one upon the other somewhat like the disks of a Voltaic pile. The medullated nerve-fibre penetrates the touch-corpuscle at its deep end, sometimes losing its medullary sheath, sometimes retaining it for some distance within the body of the corpuscle. Upon entering the body of the tactile corpuscle the nerve-fibre coils around the surface of the previously mentioned cells in a sort of ascending spiral, which, sinking into the indentation between the cells, is ultimately lost to view. Fine fibrils, probably continuous with the axis-cylinder of the coils between the cells, wind around the surface between the coils, and cause an appearance of fine transverse fibrillation. Exactly how the nerve fibrillæ terminate in this complex body is not known.

Pacinian corpuscles.—The *Pacinian corpuscles*, in which some medullated sensory fibres end, are comparatively large ovoid bodies, which in favorable locations are distinctly visible to the naked eye. They are most frequently found in the subcutaneous and submucous loose cellular tissue, and in the loose connective-tissue between bundles of muscle-fibres.

They are also not infrequently present in serous coverings. The mesentery of the cat is the most favorable position in which to study them. They consist of a thick, dense capsule formed by a large number of thin concentric membranous laminæ of white fibrous tissue (Fig. 52, and fig. 3, Plate X.). These laminæ are

Fig. 52.



Pacinian Corpuscle with its system of capsules and central cavity.—*a.* Arterial twig, ending in capillaries, which form loops in some of the intercapsular spaces; one penetrates to the central capsule. *b.* The fibrous tissue of the stalk prolonged from the neurilemma. *n.* Nerve-tube advancing to the central capsules, there losing its white substance, and stretching along the axis to the opposite end, where it is attached by a tubercular enlargement. (*Gray.*)

slightly separated by very thin strata of semifluid substance, in which is imbedded an extremely thin—probably elastic—film consisting of a single layer of flat endothelial cells. In sections of the Pacinian corpuscle, such as the figure represents, the nuclei of these endothelial cells appear as rows of fusiform bodies between the concentric lamellæ. The capsule incloses a narrow axial space of an elongated, somewhat cylindrical form, usually having a slight enlargement, sometimes even a bifurcation of the upper end. This capsule fits over the extremity of the nerve-fibre in the following manner. The perineural sheath of the medullated nerve-fibre thickens and becomes continuous with the outer lamellæ of the fibrous capsule of the corpuscle. The sheath of Schwann and the medullary sheath are generally lost, as the nerve-fibre penetrates the thickness of the capsular covering. By the time that the axis-cylinder has reached the axial space of the capsule it has usually lost all of its coverings. It passes up the central portion of the space until the enlargement at the end is reached. Here the axis-cylinder terminates generally in a single button-shaped or cauliflower knob. Sometimes just before reaching this point the axis-cylinder bifurcates or trifurcates, each division ending in a similar enlargement.

Instead of the axis-cylinder pursuing a nearly rectilinear course in the axial space of the capsule it may be more or less convoluted. Sometimes the medullary sheath continues into the lower part of the axial space. This central space, besides containing the terminal ends of the nerve-fibrils, is filled with a semifluid albuminoid substance. Its walls are covered with a layer of endothelial plates. It is doubtful whether the individual fibrillæ of the axis-cylinder terminate in the upper portion of the axial space by free extremities with a minute bulb, or whether they end in an extremely fine terminal network.

Besides a nerve-fibre, each Pacinian corpuscle is supplied with a minute afferent and efferent bloodvessel and an intermediate capillary plexus. The bloodvessels usually enter and emerge with the nerve-fibre, but sometimes they pass into the capsule at the opposite extremity. The capillaries are distributed between the lamellæ of the fibrous capsule, and never reach the central axial space. Occasionally, instead of one Pacinian body being connected with a nerve-fibre, as is usual, the fibre may divide at a node of Ranvier, and each branch end in a Pacinian corpuscle. The group of corpuscles is then often connected together by longer or shorter bands of fibrous tissue.

Hair-bulbs.—The *hair-bulbs* receive the terminations of medullary nerve-fibres, and are sometimes exquisitely sensitive.

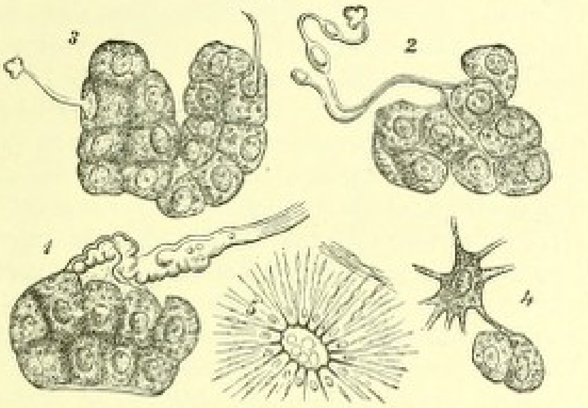
Nerve-endings in gland-cells.— Pflüger, among others, has carefully studied the relations of nerves to some of the secreting glands, and has found nerve-fibres in direct connection with the nuclei of cells in the acini, and even in the ducts of glands. Fig. 53 shows four modes of direct termination of nerve-fibres in gland-cells.

b. Termination of motor nerves.—The *motor nerves* have their peripheral endings among muscle-fibres.

Nerve-endings in smooth muscle.—In *smooth muscles* their character, distribution, and termination are not the same as in striped muscle. Non-medullated nerve bundles run and branch in the loose connective-tissue between the bundles of muscular fibres. They are enveloped in a cellular sheath, which is a representation of the perineurium, and they are composed of

interlacing fibrils which have no medullary sheath, or sheath of Schwann, but are covered at intervals by flat cells, which are probably the remains of the nerve-corpuscles belonging to the medullary sheath.

Fig. 53.



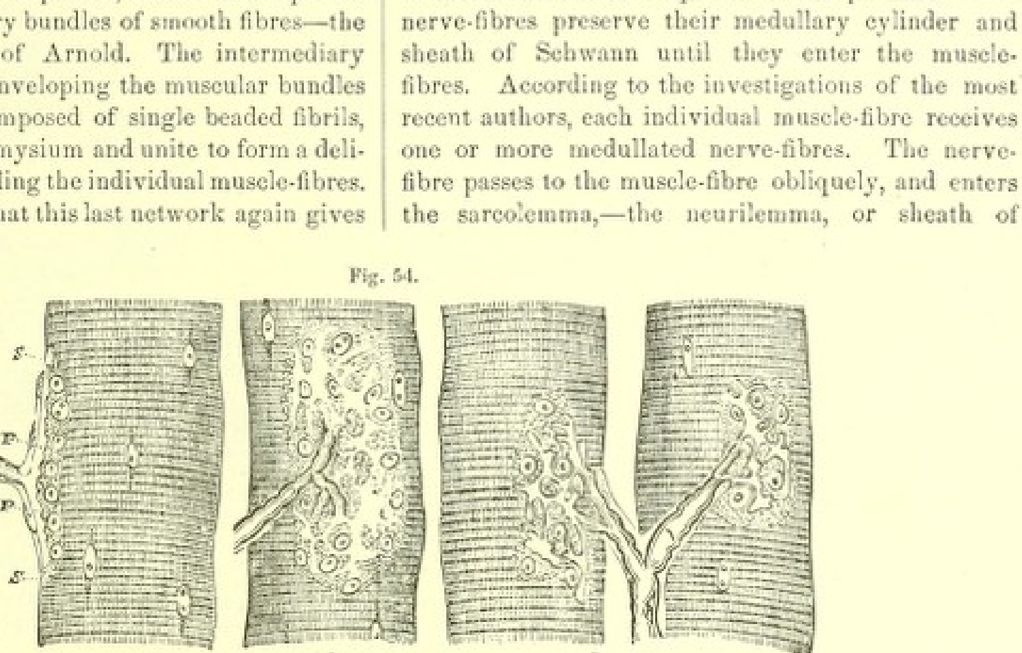
Modes of Termination of the Nerves in the Salivary Glands.—1 and 2. Branching of the nerves between the salivary cells. 3. Termination of the nerve in the nucleus. 4. Union of a ganglion-cell with a salivary cell. 5. Varicose nerve-fibres entering the cylindrical cells of the excretory ducts. (*Pflüger.*)

Such branches communicate with their neighbors to form a plexus—the ground-plexus of Arnold. From this ground-plexus come off smaller branches composed of small groups of individual fibrils. These smaller branches are still covered by a cellular-sheath. They also unite into a plexus, which envelops the perimysium of primary bundles of smooth fibres—the intermediary plexus of Arnold. The intermediary plexus immediately enveloping the muscular bundles gives off branches composed of single beaded fibrils, which enter the endomysium and unite to form a delicate network surrounding the individual muscle-fibres. Some authors claim that this last network again gives off extremely minute fibrils, which penetrate the muscle-cell and end in the nucleus; others declare the network to be the peripheral termination of these nerve-fibres. Occasionally a few pear-shaped enlargements are met with upon the fine fibrils of this last network.

Fig. 4, Plate X., represents, according to Arnold, the nerve-supply of the smooth muscle-fibres in the walls of a small artery. Non-medullated bundles of fibrils, similar to those of the ground-plexus described above for smooth muscles, unite to form a ground-plexus in the tunica adventitia. (It should be mentioned here, in passing, that in the nodes of these ground-plexuses of nerves in smooth muscle there are often located one or more cells, which many regard as ganglion nerve-cells.) This ground plexus gives origin to minute but still compound branches, which themselves again unite into a more delicate plexus—the intermediary plexus. This last plexus gives off single fibrils which enter the tunica media, pass between the individual muscle-cells, and unite there to form a fine network. The same difference of opinion exists as in the former case concerning the direct connection of the nerve-fibrils with the nuclei of the muscle-cells. In many places capillary bloodvessels are surrounded by networks of nerve-fibrils, as shown in fig. 5, Plate X.

Nerve-endings in striped muscle.—The termination of motor nerves in *striped muscle* is peculiar. The nerve-fibres preserve their medullary cylinder and sheath of Schwann until they enter the muscle-fibres. According to the investigations of the most recent authors, each individual muscle-fibre receives one or more medullated nerve-fibres. The nerve-fibre passes to the muscle-fibre obliquely, and enters the sarcolemma,—the neurilemma, or sheath of

Fig. 54.



Muscular Fibres of Lacerta, with the Terminations of Nerves in End-Plates of Kuhne.—*a.* Seen in profile. P. The nerve end-plates. S. The base of the plate, consisting of a protoplasmic mass with nuclei. *b.* The same seen in face, when a perfectly fresh fibre is examined, the nerve-ends probably being still excitable. *c.* The same as seen two hours after death from poisoning by curare. Highly magnified. (*Kühne.*)

Schwann, ending in and being continuous with the elastic envelope of the muscle-fibre (Figs. 37 and 54). The nerve-fibre, composed of a medullary sheath and axis-cylinder, penetrates the sarcolemma and passes into and is lost in a large flat body, located upon the substance of the muscle-fibre, called the *end-plate of Kühne*. Before disappearing in the substance of this end-plate the still medullated fibre may branch and the branches ramify upon the end-plate, each yet retaining its medullated sheath. Where the medullary sheath ends, the axis-cylinder spreads out into the surface of the end-plate, and is soon lost to view. The end-plate is usually more or less granular, and sometimes contains a considerable number of oval nuclei. The granular appearance is generally due to the presence of a minute reticulum, which may, perhaps, be continuous with the fibrils of the axis-cylinder. The nerve-fibrils are not known to pass into the contractile substance of the muscle-fibre. Some authors believe they have seen the branches of the nerve-fibre extend upon the surface of the sarcous substance beyond the end-plate.

Beale denies entirely this mode of ending of the nerves in striped muscles, and substitutes for the end plate of Krause within the sarcolemma a simple network of medullated nerve fibres with a number of nuclei in the meshes, claiming that the network rests upon the outside of the sarcolemma.

NERVE-CENTRES.

The nerve-centres are constituted by *gray* or vesicular nerve-substance, and *white fibrous substance*. The latter consists of nerve-fibres in most respects similar to those which have already been described when considering the nerves, but they have no definite neurilemma. The nerve-fibres will, therefore, not occupy particular attention in this place.

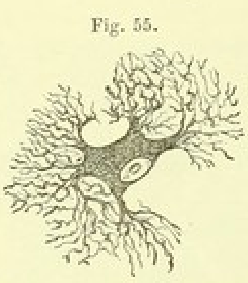
The former, the gray matter, contains special cells of peculiar form and structure which have been called nerve- or *ganglion cells*.

Neuroglia. — In the cerebro-spinal nerve-centres both nerve-fibres and nerve-cells are found imbedded in a soft finely-granular variety of connective-tissue which has received from Virchow the special name of *neuroglia*. In the gray substance of the cerebro-spinal centres it is possible, as we shall see below, that the neuroglia may possess peculiarities of function which are probably not common to the neuroglia of the white substance. The neuroglia of the latter consists of a semifluid, homogeneous substance containing a network of extremely minute fibrils which are probably of an elastic nature. At occasional intervals, among this minute elastic network, are to be seen branched connective-tissue corpuscles whose fine ramifications are in communication with the fine network already described. These branched connective-tissue corpuscles are known as *neuroglia-cells*. Between the medullated nerve-fibres of the white substance the minute fibrils of the neuroglia-network have mainly a longitudinal direction.

In the gray substance, the meshes formed by the neuroglia-fibres are extremely minute and are quite irregular and sponge-like. In addition to the neuroglia-network above mentioned, there is superadded a minute network of fine fibrils which are derived from the branching processes of the ganglion nerve-cells present in large numbers in the gray matter—a network difficult, if not impossible, to distinguish from that composed of simple neuroglia-fibres. This has been termed the *nervous reticulum of Gerlach*. Some investigators add to the neuroglia of the gray substance of the spinal marrow still another nervous reticulum, which derives its minute fibres from a repeated division, in the posterior portions of the cord, of nerve-fibres from the sensory roots. In this complex neuroglia of the gray substance the vessels, the ganglion-cells with their branches, and a limited number of medullated fibres, are imbedded.

Ganglion-cells.—The *ganglion-cell* is contained within a small lymph-space in the neuroglia. It is of an irregular outline more or less closely corresponding to the shape of the cell. The size of the latter is comparatively large, but different ganglion-cells vary widely in their dimensions. Some are relatively of enormous volume. The largest are usually found in the anterior horns of the spinal cord, and in the motor centres of the cerebrum. They also vary greatly in form. Some are oval without processes (*apolar*); some fusiform with one or more processes at either end (*bipolar*); but the majority of them have many branches which may come off at any portion of their surface (*multipolar*). The body of the ganglion-cell contains an intra-cellular network of fine fibrils. Nearly all the processes of these cells repeatedly branch dichotomously until the resulting fibres become

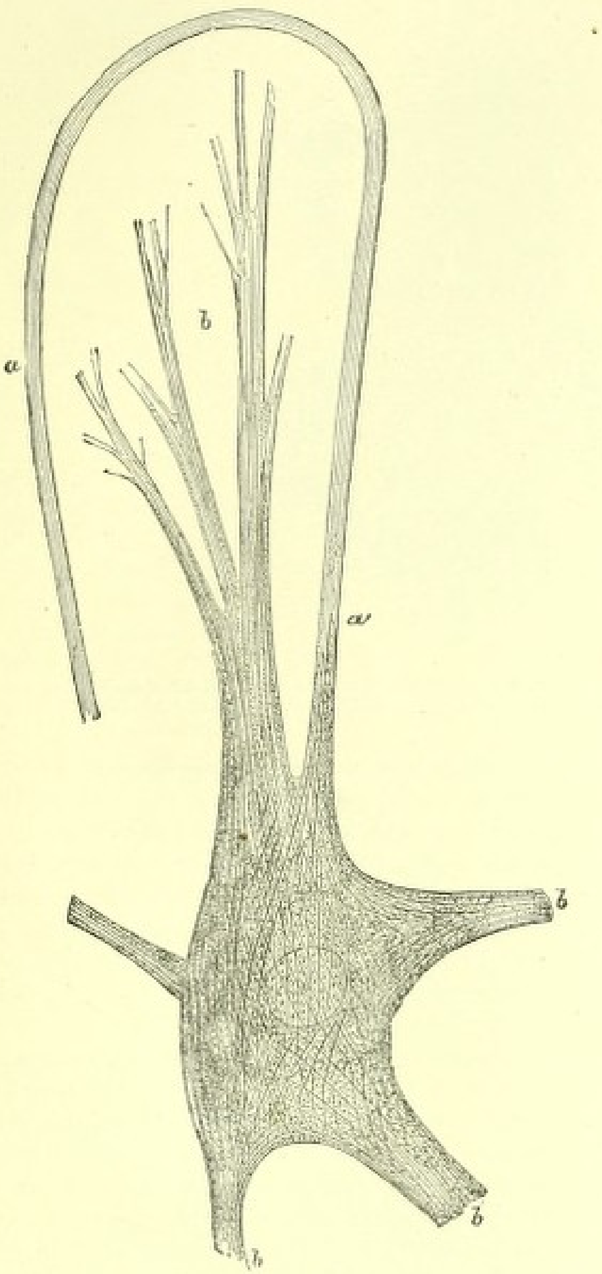
Fig. 55.



Stellate Nerve-cell, from the nucleus cervicis cornu (posterior vesicular column) of a Fœtus of six months, showing the minute reticulum formed by the dichotomous branching of the processes (nervous reticulum of Gerlach). Magnified 420 diameters. (*Carpenter.*)

extremely fine, when they form a minute network in the neuroglia—the nervous network of Gerlach above mentioned. Each one of these branching processes contains a continuation of the intra-cellular

Fig. 56.



A Medium-sized Ganglion-cell, from the anterior horn of the gray matter of the spinal cord of a Calf, isolated after a short maceration in serum containing a little iodine in solution. Magnified 600 diameters. Some of the processes (as at *b*) are abruptly broken off; *a* is the axis-cylinder process of Deiters. (*Stricker.*)

network, the meshes of which are narrow and greatly elongated in the direction of the length of the process. The fibres of the reticula of the processes spread out in the cell-body, and cause the latter to appear to be crossed in various directions throughout its substance by fine fibrillæ (Fig. 56, and refer also to fig. 2, Plate XI.).

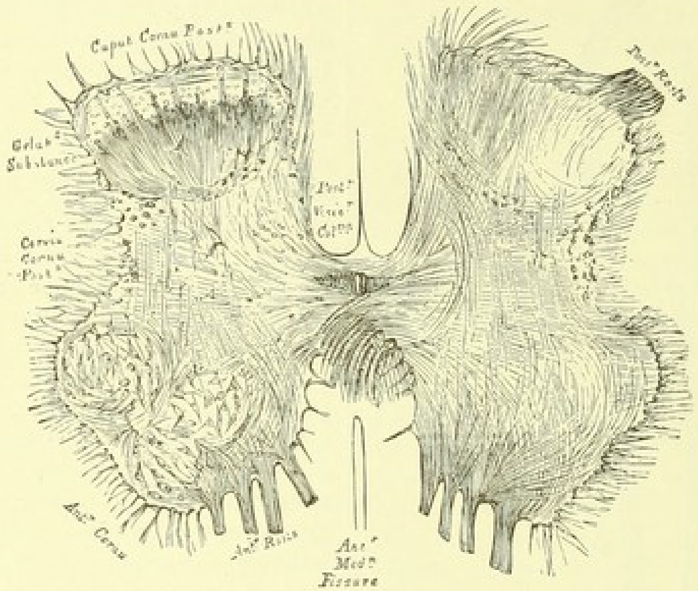
In the motor areas of the cerebro-spinal system are found large multipolar ganglion nerve-cells, of which one of the processes differs from the previously described branching processes in several respects. In the first place, the process is smaller at its connection with the body of the cell than are the others (*a*, Fig. 56). Secondly, as the distance from the cell increases, so also the process enlarges, until finally it becomes surrounded by a medullary sheath (*a*, Fig. 43). This process has been called the *axis-cylinder process of Deiters.* It has a distinct longitudinal fibrillation. Those branched ganglion nerve-corpuscles which possess an axis-cylinder process of Deiters on the one hand communicate with the motor nerve-fibres through their axis-cylinder process, whilst on the other hand they are united intimately with the nervous reticulum of Gerlach by means of their finely branching processes. Each ganglion-cell contains near its central portion a large spherical nucleus limited by a double-contoured membrane, and inclosing sometimes one or more distinct brilliant nucleoli. The nucleus, like the cell-body, is composed of an intra-nuclear network in connection with the intercellular reticulum. In the meshes of these reticula is inclosed a soft semifluid substance sometimes holding in suspension brownish-yellow pigment-granules. As has been already indicated, these ganglion-cells are suspended in lymph-spaces—the *pericellular lymph-spaces* which sometimes even in health may contain a small number of lymph-cells.

The ganglion-cells of the gray matter of the cerebro-spinal centres vary greatly in size, shape, and distribution.

Gray matter of the spinal cord.—In the spinal cord they are smallest in the posterior portion of the posterior gray horns, and are largest in the lateral portion of the anterior horns. Instead of being scattered evenly or irregularly throughout the gray matter of the cord, they are mostly collected into certain well-known groups which extend up and down the cord and form columns of cells. In Fig. 57, three such groups are represented in the anterior horn—the so-called internal, anterior, and lateral groups. It is thought by some authorities that these are the only ganglion-cells of the spinal cord which possess axis-cylinder processes, and a direct connection with medullated nerve-fibres. In front of and in the anterior

portion of the gelatinous substance in the posterior horn is another column. At the root of the posterior horns in the dorsal region there is still another column of ganglion-cells located near the posterior white columns (Clarke's column). Around the central canal or its remains is another aggregation of ganglion-cells. The finely-branched ganglion nerve-cells of the posterior horns possess no axis-cylinder processes, and are in communication with the nervous network of Gerlach only by means of their minute branches.

Fig. 57.



TRANSVERSE SECTION OF THE GRAY SUBSTANCE OF THE SPINAL CORD THROUGH THE MIDDLE OF THE LUMBAR ENLARGEMENT.—On the left side of the figure groups of large cells are seen; on the right side, the course of the fibres is shown without the cells. Magnified 13 diameters. (After *J. L. Clarke.*)

In the cervical region of the cord a few ganglion-cells are found in the white columns adjoining the lateral group of multipolar cells in the anterior horns.

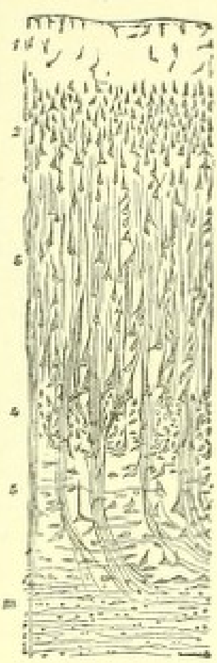
Ependyma of the cord.—Around the central canal of the cord the neuroglia of the gray substance becomes a little more dense than elsewhere, and the fibres of the reticulum have an arrangement peculiar to this location. They follow three main directions. Some are longitudinal, parallel with the axis of the canal; others are concentric, and a few radiate perpendicular to the surface of the canal. The radial fibres are continuous with fine processes of ciliated columnar epithelial cells which line the surface of the central canal in a single layer. In the human adult the central canal is rudimentary below the cervical region of the cord, and is not patulous. This condensation of the neuroglia at the surface of the central canal constitutes the *ependyma* of the cord. The canals and various ventricles of the brain are lined by a similar tissue which is there also known as the ependyma, and is invested by a single layer of ciliated columnar cells whose deep ends divide into processes which communicate with the neuroglia-fibres. The particular arrangement of the nerve-fibres and the nerve-cells of the cord will be described in the subsequent chapters of this work.

Cortical or gray matter of the brain.—In the cortex of the brain the gray substance presents general microscopic appearances which are peculiar to it. It seems to be arranged in several illy-defined layers, one passing almost insensibly, and by small gradations into those adjoining. Fig. 3, Plate XI., very well represents a view of the cortex of the human cerebrum as it appears when ordinarily prepared for examination, but Fig. 58 gives a more intelligible diagrammatic sketch of the minute anatomy of the gray matter covering a cerebral convolution. According to Meynert, "speaking generally, the cortex presents five laminæ (see Fig. 58). The first or superficial lamina (1) is principally composed of an evenly punctated non-nervous matrix, with a few small stellate cells, and near its surface numerous fine varicose nerve-fibres decussating in all directions. The second (2) is a layer of close-set, small pyramidal corpuscles. The third (3) is a layer of large pyramidal corpuscles. The fourth (4) is a layer of small, close-set, irregular-shaped cor-

puscles; and the fifth (5) is a layer of fusiform corpuscles.

"The different parts of the same hemisphere are connected, first, by the numerous intercommunicating processes of the cells, and second, by a system of arcuate-fibres (*m*, Fig. 58) of different lengths lying immediately inside the cortex."

Fig. 58.



TRANSPARENT SECTION OF A FURROW OF THE THIRD CENTRAL CONVOLUTION OF MAN. Moderately magnified. 1. Layer of scattered small cortical corpuscles. 2. Layer of close-set, small, pyramidal, cortical corpuscles. 3. Layer of large pyramidal corpuscles. 4. Layer of small, close-set, irregularly shaped, cortical corpuscles (granule-like formations). 5. Layer of fusiform cortical corpuscles. *m*. Medullary layer. (*Meynert.*)

Lockhart Clarke differs somewhat from Meynert in his description of the general cortex of the cerebrum. He recognizes *seven* layers, and describes them as follows:—

"Most of the convolutions, when properly examined, may be seen to consist of at least *seven* distinct and concentric layers of nervous substance, which are alternately paler and darker from the circumference to the centre. The laminated structure is most strongly marked at the extremity of the posterior lobe. In this situation all the nerve-cells are small, but differ considerably in shape, and are much more abundant in some layers than in others. In the *superficial* layer, which is pale, they are round, oval, fusiform, and angular, but not numerous. The *second* and darker layer is densely crowded with cells of a similar kind, in company with others that are pyriform and pyramidal, and lie with their tapering ends either towards the surface or parallel with it, in connection with fibres which run in corresponding directions. The broader ends of the pyramidal cells give off two, three, four, or more processes, which run partly through the white axis of the convolution, and in part horizontally along the plane of the layer, to be continuous, like those at the opposite ends of the cells, with nerve-fibres running in different directions. The *third* layer is of a much paler color. It is crossed, however, at right angles by narrow and elongated groups of small cells and nuclei of the same general appearance as those of the preceding layer. These groups are separated from each other by bundles of fibres, radiating towards the surface from the central white axis of the convolution, and together with them form a beautiful fanlike structure. The *fourth* layer also contains elongated groups of small cells and nuclei, radiating at right angles to its plane; but the groups are broader, more regular, and, together with the bundles of fibres between them, present a more distinctly fanlike structure. The *fifth* layer is again paler and somewhat white. It contains, however, cells and nuclei which have a general resemblance to those of the preceding layers, but they exhibit only a faintly radiating arrangement. The *sixth* and most internal layer is reddish gray. It not only abounds in cells like those already described, but contains others that are rather larger. It is only here and there the cells are collected into elongated groups, which give the appearance of radiations. On its under side it gradually blends with the central white axis of the convolution, into which its cells are scattered for some distance.

"The *seventh* layer is the central white stem or axis of the convolution. On every side it gives off bundles of fibres, which diverge in all directions, and in a fanlike manner towards the surface, through the several gray layers. As they pass between the elongated and radiating groups of cells in the inner gray layers, some of them become continuous with the processes of the cells in the same section or plane, but others bend round and run horizontally, both in a transverse and longitudinal direction (in reference to the course of the entire convolution), and with various degrees of obliquity. While the bundles themselves are by this means reduced in size, their component fibres become finer in proportion as they traverse the layers towards the surface, in consequence, apparently, of branches which they give off to be connected with cells in their course. Those which reach the outer gray layer are reduced to the finest dimensions, and form a close network with which the nuclei and cells are in connection.

"Besides these fibres which diverge from the central white axis of the convolution, another set, springing from the same source, converge or rather curve inwards from opposite sides, to form arches along some of the gray layers. These arciform fibres run in different planes—transversely, obliquely, and longitudinally—and appear to be partly continuous with those of the diverging set which bend round, as already stated, to follow a similar course. All these fibres establish an infinite number of communications in every direction, between different parts of each convolution, between different convolutions, and between these and the central white substance."

The cerebro-spinal nerve-centres are enveloped by

membranous structures, which will be especially considered hereafter. They carry the blood and lymph to and from the nervous tissue. In the white and gray substance of the cerebro-spinal centres, the bloodvessels of all sizes run in lymph-channels. The blood-capillaries of the brain are some of the smallest in the whole organism. The capillary vessels are much more numerous in the gray than in the white substance.

SPINAL NERVE-GANGLIA.

As is well known, the sensory roots of the spinal nerves pass through a collection of ganglion nerve-cells before uniting with the anterior roots to form a nerve of double function. In leaving the spinal marrow, and passing out of the spinal canal, the nerves perforate the frail envelope of the cord without receiving any part of it as a covering. In penetrating the arachnoidal and the dural investment of the cord, however, the roots of the spinal nerves receive fibres from each of these membranes, and are consequently surrounded by an inner or arachnoidal and an outer or dural sheath, which form respectively a subarachnoid and a subdural lymph-space around the nerve-root, each entirely separated from the other; but communicating freely with the corresponding space of the spinal cord. As the nerve-roots pass on and unite to form the spinal nerve, the dural sheath becomes continuous with, and is represented by, the epineurium, while the arachnoid is represented by the perineurium.

The spinal ganglia are enveloped in fibrous tissue arranged in a manner quite analogous to that of the nerves. Groups of ganglion-cells are surrounded by a laminated connective-tissue identical in structure and continuous with the perineurium of the nerve-bundles. The ganglion is composed of a larger or smaller number of such groups separated and held together by a loose, tough connective-tissue in which small arteries and veins ramify. This represents the epineurium of the nerves, and is continuous with it. The ganglion-cells constituting a group are separated from each other by a variable amount of delicate, loose connective-tissue very similar to the endoneurium separating the individual fibres of the nerve-bundles which penetrate between the ganglion-cells of a group. In this endoneurium capillary bloodvessels course, and single nerve-fibres or groups of medullated and non-medullated fibres run between the ganglion-cells.

Ganglion-cells.—The *ganglion nerve-cells* are comparatively large, and of divers sizes and forms. The prevalent form is that of an oval or somewhat pear-shaped body, with one, rarely two or more processes. This large nerve-cell contains one large spherical, generally excentric, nucleus, containing one or more refractile nucleoli. The nucleus is enveloped in a

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EXPLANATION OF PLATE XI.

Fig. 1. Represents half of a transverse section of the spinal cord of Man in the lumbar region. Very slight enlargement.

f, The anterior median fissure; *f'*, the posterior median fissure; *d*, the remains of the central canal lined with columnar epithelium, and located in the gray commissure. In front of the latter is seen the decussation of the white fibres of the commissure; *c*, the anterior horn of the gray matter; *a*, bands of nerve-fibres issuing from the anterior horn to form the anterior root of a spinal nerve; *b*, posterior root issuing in a single band from the gray matter of the posterior horn; *m*, the lateral tract; *t*, the posterior radical tract; *g*, the column of Goll; the fibres of the two latter together form the posterior column.

Fig. 2. Transverse section of a portion of the external anterior border of the gray matter of an anterior horn of the spinal cord of Man. Highly magnified.

c, Cross-sections of medullated nerve-fibres of the adjoining white substance; *a*, nuclei of the neuroglia of the gray matter; *n*, *n*, nerve-fibres running in the gray matter; a multipolar ganglion-cell, finely striated, is seen imbedded in the gray substance; within the ganglion-cell a large vesicular nucleus containing a nucleolus is distinctly visible.

Fig. 3. Vertical section of the cortex of a cerebral convolution of Man. Medium enlargement.

a, Cortical layer in which the prevalent direction of the connective-tissue or neuroglia-fibres is parallel to the surface; *b*, layer of small club-shaped nerve-cells; *g*, layer of larger club-shaped nerve-cells; *c*, capillary bloodvessels.

Fig. 4. A surface view of a fibrous lamella of the cornea after treatment with silver nitrate. High power.

l, *s*, Lymph-spaces; *n*, a corneal nerve-bundle ensheathed in a covering of endothelial cell-plates.

PLATE XI.

Fig 1

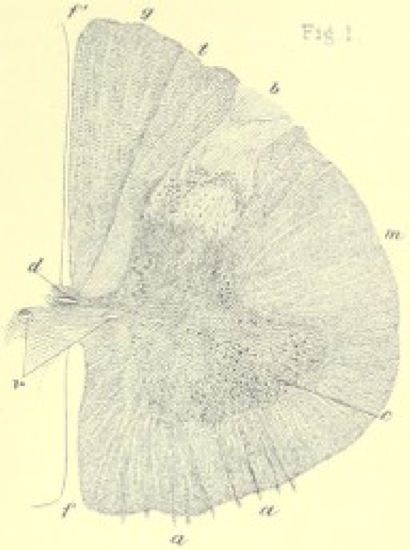


Fig 2

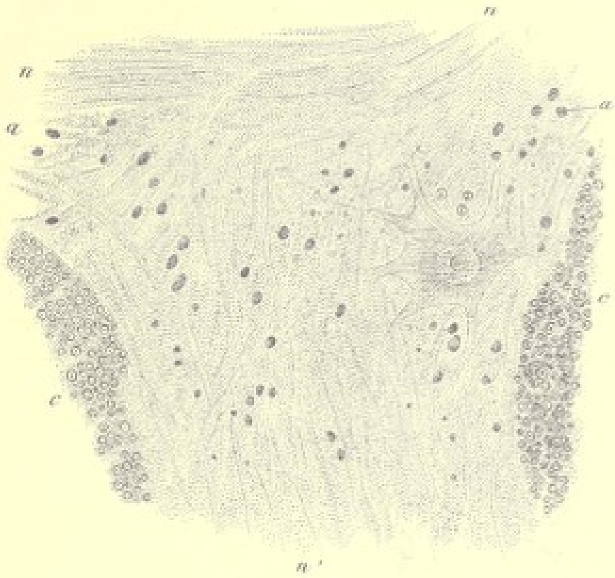
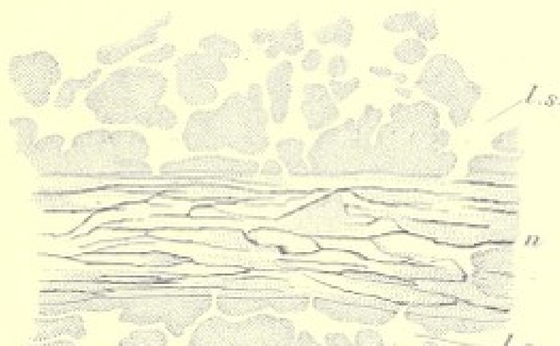


Fig 3

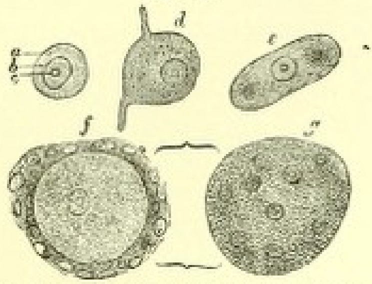
Fig 4



T. Sinclair & Son, Lith.

double-contoured membrane, and contains an intra-nuclear network, in communication with an intra-cellular network in the body of the cell. This intra-cellular network continues into the process. The latter may be regarded as an *axis-cylinder process.* The ganglion-cell is enveloped by a thin homogeneous membrane or capsule, which is continuous with the neurilemma or sheath of Schwann of the nerve-fibre with which it is connected. The enveloping membrane of the ganglion-cell is lined by granular, flattened, somewhat polyhedral cells. They are analo-

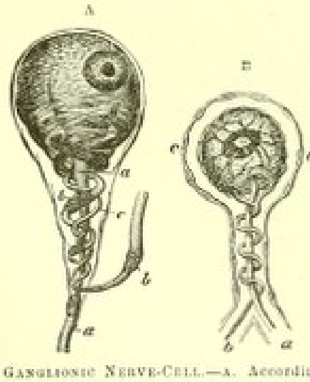
Fig. 59.



NERVE-CELLS FROM THE GASSERIAN GANGLION OF THE HUMAN SUBJECT.—*a*. A globular one with defined border. *b*. Its nucleus. *c*. Its nucleolus. *d*. Caudate cell. *e*. Elongated cell with two groups of pigment-particles. *f*. Cell surrounded by its sheath or capsule of nucleated bodies. *g*. The same, the sheath only being in focus. Magnified 300 diameters. (*Gray*.)

gous with the nerve-corpuscles of the medullary sheath of a nerve. The ganglion-cell usually fills the space formed by the enveloping membrane. It frequently contains a small number of yellowish or dark-brown pigment-granules in some portions of the cell-body. Instead of the ganglion-cell being unipolar, it may be bipolar or even multipolar.

Fig. 60.



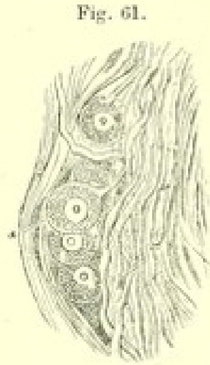
STRUCTURE OF GANGLIONIC NERVE-CELL.—A. According to Dr. Beale: *a*, straight process; *c*, spinal fibre. B. According to Arnold. Highly magnified.

A, Fig. 60, represents, according to Beale, a peculiar form of bipolar glanglion-cell not infrequently found in the spinal ganglia of frogs, and occasionally met with among mammals. It differs from the last-described unipolar cells by having, in addition to a straight axis-cylinder process similar to that of the common unipolar cell, a smaller branch which winds more or less spirally around the larger straight process until it has passed a little distance from the body of the cell, when it leaves the straight process and turns to pursue an opposite direction. The spiral turns are entirely within the common membranous envelope of the cell. The straight process proceeds on its course without acquiring a medullary sheath, while the spiral-fibre soon becomes ensheathed in a medullary cylinder. Within the ganglia the nerve-fibres arising from the ganglion-cells are generally gray, gelatinous fibres without a medullary sheath; the latter, nevertheless, they may or may not subsequently acquire. The bundles of nerve-fibres which pass into a group of ganglion-cells spread out and wind around among the cells to emerge again after losing some fibres and gaining others, ultimately to end in their final distributions.

SYMPATHETIC NERVE-GANGLIA.

The larger ganglia of the sympathetic nervous system do not essentially differ from the spinal ganglia, either in their general plan of construction or in

Fig. 61.



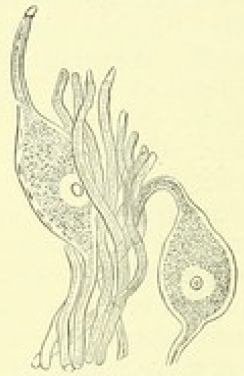
MICROSCOPIC GANGLION FROM HEART OF THE FROG. (*Stricker*.)

the character of their ganglion-cells. They need not be more particularly mentioned here.

Along the course of the sympathetic nerves are found single ganglionic cells and isolated small groups of cells, constituting simple *microscopic ganglia*. These microscopic ganglia and isolated ganglion-cells are of quite frequent occurrence in the nervous plexuses supplying involuntary muscles, as, for instance, the unstriped muscles of the intestine, the walls of blood-vessels, and the heart. The ganglion-cells are usually located at or near the nodal points of the nervous network, the larger groups being found in the ground-plexus, or compound bundles of non-medullated free

axis-cylinders contained within a delicate perineural sheath. The cells are within the perineurium and among the nerve-fibrils with some of which they are continuous. The smallest groups and isolated cells

Fig. 62.



BIPOLAR GANGLIONIC CELLS AND NERVE-FIBRES FROM THE GANGLION OF FIFTH PAIR IN THE LAMPREY. (*Frey.*)

are also sometimes situated in the ground-plexus, but they are frequently located at the nodal points of the smaller compound bundles of free axis-cylinders. These ganglion-cells are found to present the same general characters as those of the large sympathetic ganglia, and need not be more particularly dwelt upon. They are very frequently loaded with dark pigment-granules.

THE LYMPHATIC SYSTEM.

The lymphatic is the most extensive system of the organism, and one of the most important. It is mainly by the way of the lymph that the nutritive supply from the blood ultimately reaches the morphological elements of the tissues, for only a very small proportion of the latter are brought into direct contact with the blood-capillaries. There is a constant exudation of the fluids of the blood through the delicate walls of its vessels into the neighboring lymph-spaces, and there is an incessant flow from the latter towards the collecting trunks of the lymphatic system. It is entirely by the overflow from the blood that the tissues of the body are irrigated. In comparison to the velocity of the blood, the lymph-current is extremely sluggish. It is impelled principally by a *vis à tergo*—the slow oozing from the blood-vessels caused by the centrifugal pressure upon their walls through the impetuous rush of the blood-torrent. It is aided by the pressure of surrounding parts in movement, and to some extent also by the action of muscle-fibres which sometimes appertain to the lymphatic system. This broad though sluggish stream has been very aptly denominated a supplement of the blood-circulation.

The lymph flows in channels which are variously related to each other, and to the different components of the organism. Their structure and their relations to each other will be first considered.

The lymph-passages comprise large and small trunks, into which capillaries empty, and which, in their turn, receive lymph from the adjacent interstices of the tissues, the latter being either small lymph-spaces, as the lymph canalicular system of von Recklinghausen, or large lymph-cavities like the peritoneal, the pleural, the pericardial, the arachnoid, etc. Along the course of the lymph-current are interposed numerous aggregations of a peculiar *reticular tissue*. The most complex arrangement of this peculiar tissue into special organs is found in the so-called compound lymphatic glands, such as those of the axilla, the groin, the mesentery.

Large lymph-vessels.—The *largest lymphatic trunks* consist of a wall of some thickness and complexity of structure. This wall is very similar to that of veins. It is composed of three coats—an external, middle, and internal, which are respectively known as the tunica adventitia, the tunica media, the tunica intima. The internal coat is very thin and delicate, consisting of an inner layer of endothelial plates similar to those of veins; of an external layer of longitudinal connective fibres and a few elastic fibres; and of a middle layer of a few stellate, flattened corpuscles. The tunica media contains a few circular, smooth muscular fibres. The tunica adventitia is composed of a feeble network, mainly longitudinal, of fibrous bundles interspersed with a few elastic fibres, also united into a network. Vasa vasorum and nervæ vasorum run in the tunica adventitia, and ramify in the tunica media.

Small lymph-vessels.—The *smaller trunks* have extremely delicate walls; the latter are reduced to a simple endothelial lining of the lymph-channel. By their wall simply they are often not distinguishable from the lymph-capillaries. When empty, in consequence of the flabbiness of their walls, they are completely collapsed, and their cross-section appears as a mere slit in the tissues. When distended, these smaller lymphatic trunks are more or less cylindrical in form.

Valves.—Lymphatic trunks are distinguished by the presence of valves at frequent intervals. The valves often constitute the only distinction between

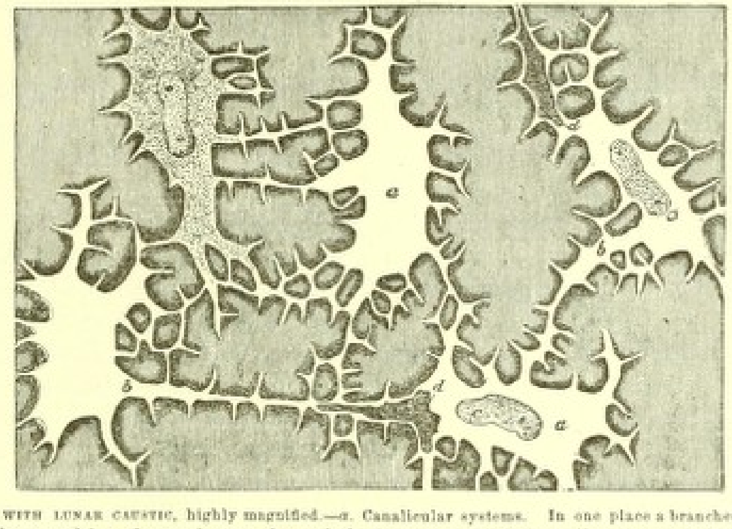
small trunks and capillaries. They consist of folds of the tunica intima projecting into the lumen of the vessel, usually in the shape of two hemispherical sacs, which rest lightly against the wall of the vessel, except when the lymph attempts to flow backwards. Then they project into the lumen until the opposite sacks meet and form a kind of lymph-sac. At the location of these valves there is a slight bulging outward of the lymphatic walls. Such ampullar enlargements along the lymphatic trunks are very prominent when the vessels have been artificially injected. In the small lymph-trunks the lining endothelia usually have somewhat the outline of a long lozenge, with slightly sinuous edges. The smaller lymph-trunks sometimes anastomose with each other, and form a plexus.

Lymph-capillaries.—The small lymphatic trunks communicate with plexuses of *lymph-capillaries.* Lymph-capillaries are channels through the tissues, with walls possessing a simple endothelial lining of broad, sinuous-edged cells, and with outlines extremely varied. Their lumen, even when full, may be oval, slit-like, ampullar, or jagged. Unlike the capillary bloodvessels, which they enormously exceed in size (fig. 3, Plate VII.), they are frequently larger than the trunks into which they empty. Their general direction and their form are very considerably influenced by the arrangement of the tissues among which they lie.

Until the investigations of von Recklinghausen, Klein, Axel Key, Retzius, and others, in recent years threw a flood of light upon the subject, lymph-capillaries were considered to be the ultimate ramifications of the lymphatic system.

Lymph-canalicular system.—Von Recklinghausen demonstrated a connection between the small irregular plasmatic spaces, existing in the albuminoid, semifluid cement, in which the connective-tissue fibres are imbedded, and the lymphatic capillaries. These irregular spaces, with their canalicular branches and the connective-tissue cells which they frequently contain, von Recklinghausen described as a *lymph-canalicular system* (Fig. 63), and recognized as the ultimate radicles of the lymphatic vessels. By their branching canaliculi these lymph-spaces intercommunicate with one another, and those nearest the lymph-capillary open into the latter. These minute lymph-spaces among the tissues normally may contain, as we have already seen, one or more flattened connective-tissue corpuscles usually applied to one side of the space. They have no other endothelial lining. In those spaces directly communicating with a lymph-capillary, the connective-tissue corpuscle, by one of its processes, is often continuous with an endothelial plate lining the capillary. The point of communication of a lymph-canaliculus with the lumen of a lymph-capillary corresponds to an opening between the edges of the endothelium—a *stoma.* The lymph-spaces are of extremely variable size and form. Sometimes stellate, sometimes slit-shaped, sometimes more or less cylindrical, they are moulded by the direction of the fibrous bundles, membranes, or other tissues in which they are imbedded. There are in different portions of the body all gradations in size and form

Fig. 63.



Cornea of the Frog treated with lunar caustic, highly magnified.—*a.* Canalicular systems. In one place a branched flattened corneal corpuscle with its nucleus is seen; in two other places nuclei, *c*, of corneal corpuscles; and, *d*, migrating or wandering cells, are seen in the lacunæ of the canalicular system. *b.* Branched channels, which connect the lacunæ of the canalicular system. (*Carpenter.*)

between minute, more or less stellate lymph-spaces and genuine large lymph-cavities, whose surfaces are covered with a complete endothelial lining. Slit-like spaces are frequently found, particularly in laminated fibrous membranes, lined only on one side with a complete endothelial layer.

Relations of the lymph-canalicular system with lymph-capillaries and serous cavities.—The serous cavities have already been described. They are, on the one hand, in communication with the lymph-spaces or lymph-canalicular system adjoining them, and, on the other hand, through the mediation of lymph-capillaries, are directly continuous with lymphatic trunks. Von Recklinghausen first demonstrated the communication between the cavity of the peritoneum and lymphatic trunks of the diaphragm, but we owe our most positive knowledge of the anatomy of the lymphatic system of the abdominal and thoracic cavities to the valuable and painstaking labor of Klein.

According to Klein, the peritoneal surface of the centrum tendineum of the diaphragm is covered by an endothelial lining, whose cells have not all the same character and arrangement. The great majority of the endothelia are ordinary, thin, elastic cell-plates, with slightly sinuous outlines, and flat, oval nuclei. At intervals over this surface are clumps of smaller, polyhedral granular cells (*germinating endothelia*), with sometimes two and even a greater number of nuclei. These small collections of germinating endothelia surround a small hole in the serous surface. The holes are known as *true stomata*, in contradistinction to certain small groups of similar germinating endothelia (*pseudo-stomata*) in which no hole is apparent (fig. 1, Plate I.). The centrum tendineum consists of two general layers of fibrous bundles. In the lower, or peritoneal layer, the bundles have a direction radiating from the centre of the aponeurosis. In the upper, or pleural layer, the fibrous bundles are concentric. Between the fibrous bundles of each of these aponeurotic layers is a system of lymph-capillaries. Their main direction is, of course, the same as that of the fibrous bundles between which they run. The capillaries of the same layer occasionally anastomose with their neighbors by lateral branches, and the two systems also intercommunicate by vertical canals running from one layer to the other. Now, the above-mentioned *stomata vera* are located upon the peritoneal surface, over the spaces between the radiating fibrous bundles of the lower layer. They open into superficial, small, vertical canals, which lead into the nearest lymphatic capillaries. Upon the pleural surface of the diaphragm, over the interspaces between the concentric fibrous bundles of the upper aponeurotic layer, are also numbers of *stomata vera*. These latter open by short vertical lymph-channels into a superficial plexus of lymphatic trunks between the basement-membrane of the diaphragmatic pleura and the centrum tendineum. This superficial plexus of lymphatic trunks is provided with numerous valves. It is in communication below with the lymphatic capillaries of the upper layer of the tendon of the diaphragm, and, as a consequence, with the cavity of the peritoneum. The lymph which reaches the subpleural plexus of lymphatic trunks is conducted by two different ways into the general circulation. Over the anterior two-thirds of the upper surface of the diaphragm, the lymph is drained off by two main trunks, one for each side, which pass forward to the anterior wall of the chest, and ascend behind the sternum as far as the manubrium, where each enters a lymphatic gland. The lymph of the posterior third of the above plexus is conveyed by means of two main short trunks directly into the thoracic duct. The movements of respiration cause this diaphragmatic system of lymphatics to act somewhat as a pump in draining the peritoneal cavity.

Lymphatic system of muscles.—In the aponeurotic sheath of muscles it has been found that the inner and outer layers each possess a system of lymph-capillaries which bear much the same relation to each other as do those of the diaphragm. The outer plexus of lymphatic capillaries is drained by lymph-trunks with numerous valves. The lymph-capillaries and lymph-spaces of the endomysium are in communication, on the one hand, with the lymph-cylinders surrounding the ultimate or primary muscle-fibre, and, on the other hand, with the lymph-passages of the perimysium.

Communications of the cerebro-spinal cavities.—The large serous cavities of the cerebro-spinal axis have various ramifications and connections. The space between the encephalon and the inner surface of the dura mater is a double serous cavity. The one part of this cavity is separated from the other by a delicate partition—the arachnoid. The space between the dura mater and the arachnoid has been termed the *subdural cavity;* while that between the arachnoid and the intima pia has been named the *sub-arachnoid cavity* of the cranium. It is claimed that the one has no communication with the other. Some authors recognize also a third general lymph-space existing between the pia mater and the cerebral substance.

Between the coverings of the spinal cord there are also corresponding lymph-cavities, which are separated from each other by the arachnoid, namely, the subdural and the subarachnoid cavities of the cord. They freely communicate with the corresponding cavities of the brain. The external surface of the dura is covered with endothelium, as are also the surfaces of the large lymph-spaces of the cerebrospinal nervous system.

The subarachnoid cavity of the brain communicates with the ventricles of the cerebrum. The bloodvessels from the arachnoid pass through the pia into the brain, taking a lamina of the arachnoid with them as a sheath (the perivascular sheath), the lymph-spaces of which are in communication with the subarachnoid space. The perivascular sheath of the smallest vessels is a simple layer of endothelium, partially lining a perivascular lymph-channel, whose wall is simply the surrounding neuroglia. The lymph leaks out through this porous wall and percolates among the minute meshes of the neuroglia-fibres to reach the *pericellular lymph-spaces* surrounding the ganglion-cells of the gray substance and the *perifibrillar lymph-spaces* existing between the neuroglia and the bare medullated nerve-fibres of the white substance. In this manner the ganglion-cells and the nerve-fibres of the cerebrum are brought into communication with the subarachnoid lymph-cavity of the cerebrum.

An essentially similar arrangement of the lymph-circulation exists in the spinal cord.

Lymphatics of the spinal nerves.—While considering the minute anatomy of the spinal ganglia, occasion was taken to refer to the continuation of the subdural and subarachnoid cavities of the cord into the spinal nerves: the subarachnoid being continuous with the perineural lymph-space of the nerve; the subdural communicating with the epineural lymph-spaces. The endoneurium between the individual nerve-fibres contains lymph which on one side communicates with spaces around the nerve-fibres—on the other with the subperineural space. The cranial nerves have a lymph-circulation similar to that of the spinal nerves. In the spinal ganglia the epineural and the perineural lymph-spaces communicate with corresponding spaces of the cord and of the nerve to which they are attached.

Lymphatics of bloodvessels.—The bloodvessels of large size generally possess two systems of lymphatics—one for the tunica intima and one for the two outer tunics. Fig. 2, Plate XII., represents the lymph-canalicular system of the middle or connective-tissue layer of the tunica intima of a large arterial trunk. The tunica adventitia is pre-eminently a trabeculated peri-vascular lymph-space which is in free communication with lymph-spaces scattered through the tunica media. Besides the lymph-spaces in the tunica adventitia, the vessel may be partially or completely ensheathed by a perivascular lymph-space (fig. 1, Plate XII.), or be surrounded by a dense plexus of lymph-vessels.

These perivascular lymphatics frequently communicate with the lymph-canalicular system of the tissue through which they pass. Fig. 1, Plate XII., shows a capillary bloodvessel having such a relation to the lymph-spaces of the surrounding tissue. A, fig. 3, Plate XII., is a faithful reproduction of a small branch of a pulmonary artery, *a*, and an accompanying lymphatic capillary, *b*, which communicates with the lymph-canalicular spaces, *c*, in the inter-alveolar septa. B, same figure, gives a surface view of the inter-alveolar lymph-spaces.

Lymphatics of bones.—In bones the lymph-canalicular system is represented by the bone-corpuscles. By their canaliculi, these lymph-spaces freely open into the lymphatic capillaries of the Haversian canals. The Haversian lymph-vessels accompany or more or less completely ensheathe, as perivascular lymphatics, the bloodvessels of these canals, and in their turn communicate with the lymph-vessels of the periosteum.

Lymphatics of cartilages.—Cartilage also possesses a canalicular lymphatic system which directly empties into the lymphatics of the perichondrium. The expansions of the lymph-canalicular system of cartilage are the cartilage-capsules.

Lymphatics of epithelial structures.—Not only is the lymph-canalicular system of von Recklinghausen in direct open communication with lymph-canals and cavities as above stated, but, according to Thoma, Arnold, and others, the intercellular cement between the epithelia of the skin, mucous membranes, and glands, and between the endothelia lining the lumen of bloodvessels, is often continuous with the contents of neighboring lymph-spaces, and should in such cases be regarded as a projection of the lymph-canalicular system. In this intercellular cement, circulation is generally very slow, but nevertheless quite manifest. It is through these channels that minute solid particles enter the submucous lymphatics of the air-passages and the interalveolar lymph-spaces of the air-vesicles of the lungs. The probability that the minute molecules of the chyle reach the capillary lacteals of the villi in a similar manner, and that for-

eign particles injected into the blood pass out between the cells of the excreting glands, has already been alluded to.

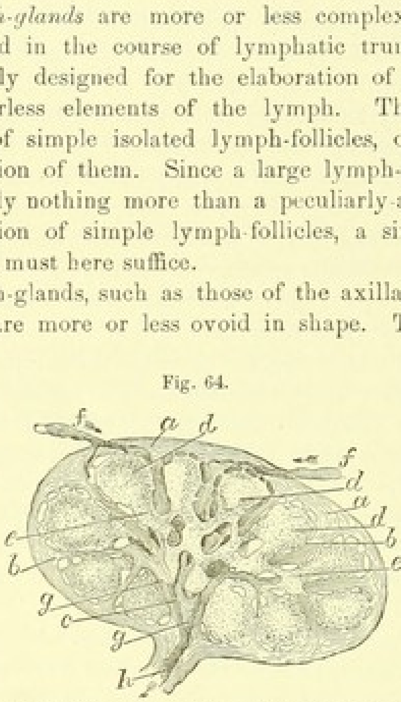
LYMPHATIC GLANDS.

Lymph-glands and allied reticular or lymphoid tissues, important parts of the great lymphatic system, yet remain to be considered.

Lymph-glands are more or less complex organs implanted in the course of lymphatic trunks, and apparently designed for the elaboration of some of the colorless elements of the lymph. They may consist of simple isolated lymph-follicles, or of an aggregation of them. Since a large lymph-gland is practically nothing more than a peculiarly-arranged aggregation of simple lymph-follicles, a single description must here suffice.

Lymph-glands, such as those of the axilla or mesentery, are more or less ovoid in shape. They are

Fig. 64.



SECTION OF SMALL LYMPHATIC GLAND, HALF DIAGRAMMATICALLY GIVEN, WITH THE COURSE OF THE LYMPH.—*a*. The envelope. *b*. Septa between the follicles or alveoli of the cortical part. *c*. System of septa of the medullary portion, down to the hilus. *d*. The follicles. *e*. Lymph-cords of the medullary mass. *f*. Afferent lymph-vessels, the different lymphatic streams from which surround the follicles, and flow through the interstices of the medullary portion. *g*. Confluence of these to pass through the efferent vessel (*h*) at the hilus. (*Frey*.)

enveloped by a capsule (Fig. 64), which generally consists of two layers: an outer layer of loose connective-tissue, and an inner lamellated layer of dense fibrous tissue. Among the fibrous bundles of these two layers are, in some animals, a variable number of smooth muscle-fibres. Upon one side of the gland two or more large lymphatic trunks, which convey the lymph to the gland (*afferent vessels*), enter the outer layer of the capsule and ramify therein to form a dense plexus. The afferent trunks are supplied with circular muscular fibres in their middle tunic, and with numerous valves. At the opposite side or hilus of the gland a number of small vessels unite to form a large trunk which receives the lymph from the gland and conveys it off (*the efferent vessel*). Upon examination of longitudinal section of the gland made from the convex surface towards the hilus, the section appears unevenly colored and somewhat mottled. The central third is of a deeper red, and seems more homogeneous, while the outer border is lighter colored and is mottled. The inner is the *medullary*, the outer is the *cortical* portion of the gland. The minute anatomy of the organ is somewhat different in these two regions. From the inner surface of the dense lamellated inner layer of the capsule, membranous partitions or septa (*b*, Fig. 64) project inwards in such a manner as to form in the cortical layer a series of honeycomb-like compartments, which, in consequence of the fact that the dividing septa converge towards the centre of the gland, are more or less conical with the bases outward. When these septa reach the medullary area, they break up into a large number of thinner or thicker bands or *trabeculæ*, which branch and anastomose with one another so as to form a loose, sponge-like network. The meshes of this medullary inter-trabecular network communicate with each other and with the conical compartment of the cortical layer. The membranous septa between these compartments are often incomplete.

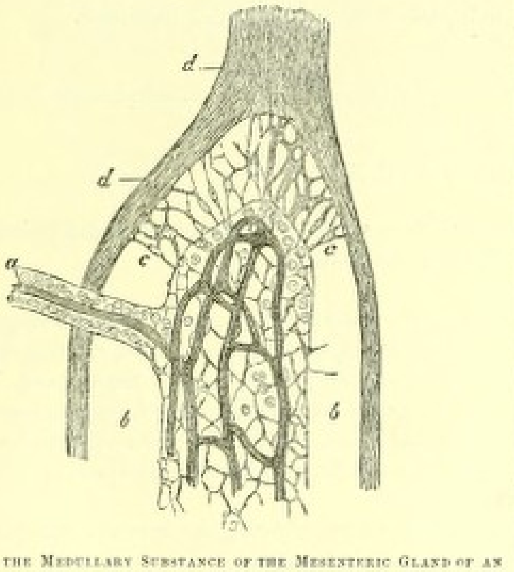
The conical compartments of the cortical, or *follicular layer*, as it has been called, are more or less completely filled by a pear-shaped cellular mass, the so-called *follicle* (*d*, Fig. 64). At the border of the medullary portion of the gland this cellular mass tapers down to a narrow stem, which passes into the intertrabecular spaces, and becomes a *medullary cylinder*, or cord (*e*, Fig. 64). In the medullary portion of the gland the medullary cylinders branch and anastomose in a complex manner to form an irregular network of cellular cylinders.

The cortical follicles and the medullary cylinders consist of a reticular or adenoid tissue permeated by a rich network of blood-capillaries. They do not entirely fill the spaces in which they lie, but are separated from the septa of the cortex, and the trabeculæ of the medullary portion by a lymph-sinus of considerable size. The lymph-sinuses surrounding the cortical follicles are continuous with those which surround the medullary cylinders. The afferent lymph-vessels ramifying in the capsule, as above described, penetrate the inner laminated layer of the capsule and open freely into the cortical lymph-sinuses. The efferent lymphatic trunks (*g*, *h*, Fig. 64) of the hilus directly communicate with the lymph-sinuses enveloping the medullary cylinders. The free course of the lymph is, therefore, from the afferent vessels of the capsule into the cortical peri-

follicular sinuses, thence through the medullary sinuses into the collecting trunks which empty into the efferent vessels emerging from the hilus.

The flow of the lymph through these sinuses is greatly impeded by innumerable fine fibres united into a network which crosses the space from the follicles to the septa in the cortical region, and from the medullary cylinders to the trabeculæ in the medullary portion (*c*, Fig. 65). The fibres of this

Fig. 65.



Portion of the Medullary Substance of the Mesenteric Gland of an Ox.—The artery injected with chromate of lead. Highly magnified. *a*. Medullary cylinder with capillary network, fine reticulum of connective-tissue, and a few lymph-corpuscles. *b*, *b*. Superficial lymph-path or medullary sinus traversed everywhere by a reticulum of nucleated cells. This reticulum has been represented only at *c*, with numerous anastomosing prolongations. The lymph-corpuscles have for the most part been removed with a camel's-hair brush. *d*, *d*. Trabeculæ, composed almost exclusively of unstriped muscular tissue. A small medullary cord or bridge, containing a bloodvessel and numerous lymph-corpuscles, is shown at the left of the figure as springing from the medullary cylinder. (*Stricker.*)

reticulum are hyaline, and present every variation in shape from the flattened band to the cylinder. At their nodal points they slightly enlarge, and very frequently a flattened oval nucleus is seen at these enlargements. The reticulum consequently appears to be formed by a network of large stellate cells resembling branched connective-tissue corpuscles. But in the adult tissue this is an illusion. The nuclei belong to flat endothelial plates which closely invest the fibres of the reticulum. Every part of the surface of the lymph-sinuses above described is lined with a complete layer of endothelial plates. They cover the reticular partitions as well as the septa and trabeculæ on the one side, and the surface of the follicles and cylinders on the other.

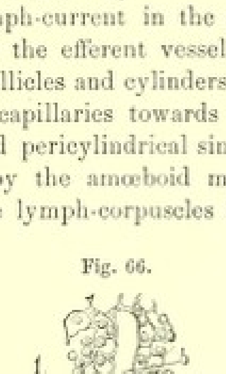
Each of the coarse meshes of this reticulum in the lymph-sinus contains two or more lymph-corpuscles which quite fill it.

The cortical follicles and the medullary cylinders have the same constitution. They consist of a reticulum of a construction very similar to that of the lymph-sinuses. But the fibres which form it are very much more delicate, and the meshes are much smaller. At some of the nodal points of this reticulum a flattened ovoid nucleus may be seen. As in the former case, these flattened nuclei belong to endothelial plates resting upon the fibres. In the follicles and cylinders, however, the surfaces of the reticulum are not completely covered with endothelial cells. The small meshes of this reticulum are closely packed with one, two, or more lymph-corpuscles which are usually of the smallest size, consisting of a large round nucleus surrounded by a minimum amount of cell-protoplasm. They are supposed to be young developing lymph-cells.

The fine reticulum of the follicles and cylinders is permeated by a rich network of capillary bloodvessels (Fig. 65). The walls of these capillaries are enveloped by and connected with the fibres of the reticulum (fig. 6, Plate VI.).

Besides a lymph-current in the sinuses from the afferent towards the efferent vessels, there is also a current in the follicles and cylinders setting outwards from the blood-capillaries towards the surrounding perifollicular and pericylindrical sinuses. The latter current, aided by the amœboid movements of the cells, washes the lymph-corpuscles from the follicles

Fig. 66.



1. Reticular Tissue, from a lymphoid follicle of the vermiform appendix of the rabbit, with the system of meshes, and remains of the lymph-cells *a*. Most of the latter have been removed artificially. *b*. Lymph-vessel. 2. Longitudinal section of a Lieberkühn's gland, showing the surrounding reticular tissue. In the meshes of this are seen the lymph-cells *a*. *b*. Lumen of a vessel. *c*. Lumen of the gland. (*Frey.*)

and cylinders out into the surrounding sinuses, and the current in the latter finally carries the cells into

the efferent vessels. The meshes of the reticulum of the sinuses, and especially those of the follicles and cylinders, are so packed with lymph-corpuscles that, in sections ordinarily prepared, nothing can be seen but the crowd of cells. In order that the reticula may become visible, it is necessary to gently pencil the sections with a camel's-hair brush or to persistently shake them in a fluid medium. When this procedure is successful, a thin section of the medullary portions presents a picture very well reproduced in Fig. 66.

The arterioles and venules which communicate with the capillaries of this tissue run in the septa and trabeculæ.

Reticular tissue (adenoid tissue of His) is a lymphoid tissue which has its perfect type in the structure of the follicles and medullary cylinders of lymph-glands. It is, therefore, unnecessary to describe it more particularly in this place. It is present in a diffuse form in the mucous membrane of the intestine and of other localities. It is met with in serous cavities in the form of patches and cords of variable extent, and it is found in numerous other localities.

EXPLANATION OF PLATE XII.

Fig. 1. A silver preparation of a pencilled omentum of a Rabbit, showing relations of blood- and lymph-vessels. High power. (After Klein.)

v, A venule filled with blood-corpuscles; the venule gives off capillary branches; *l*, lymphatic capillary, invaginating the bloodvessels, and lined with endothelium, the outlines of which are mapped out by the serrated dark lines; *s'*, branches of the lymph-vessels in some places communicating with the neighboring lymph-spaces.

Fig. 2. Internal tunic of the Human aorta, treated with silver. High power. (After Langhans.)

a, Superficial lymph-spaces; *b*, deeper lymph-spaces; both freely intercommunicate, and are separated from one another by the ground-substance, *g*.

Fig. 3. *A*. From a section of a Guinea-pig's lung, which had been injected with silver nitrate, showing the relations of blood and lymph-vessels. High power.

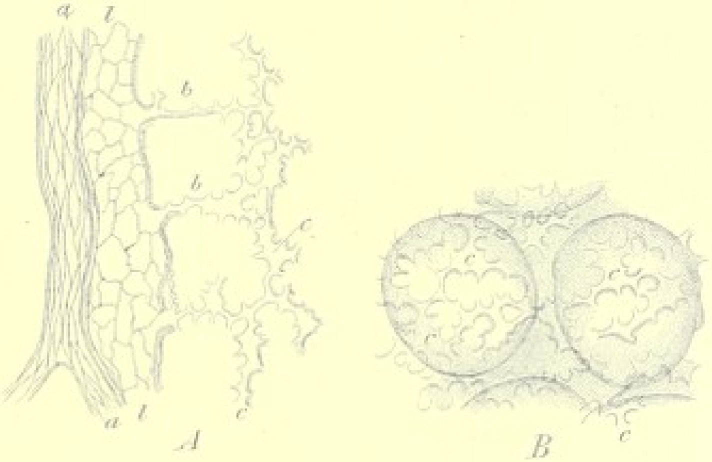
a, Branch of pulmonary artery; *l*, lymph-vessel lined with endothelial plates, and in connection with the lymph-canalicular system or inter-alveolar lymph-spaces, *c*, of the walls of the alveoli.

B. Same lung, showing the inter-alveolar lymph-spaces, in surface. (After Klein.)

Fig. 1

Fig. 2

Fig. 3



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Third. The physician needs some account of the uses of the organs. This subject overlaps physiological anatomy. That much only will be succinctly given as may be said properly to illustrate the subject from an anatomical point of view, and at the same time be free from controversy.

Fourth. The physician must have a true conception of the nature and general behavior of morbid processes, and of the manner in which such processes are modified by locality. His comprehension of the changes due to diseased action in a given place must be fairly proportional to his knowledge of the normal anatomy of that place. This subject, which will receive the name of *localization of diseased action*, will be illustrated for the most part by concise statements of recorded cases, in which the essential feature of each case will be emphasized, and the bearing it has on the subject treated of clearly shown. In presenting anatomical features in explanation of given lesions, or of signs or symptoms, care has been taken to give the sources of the statements made.

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