CHAPTER XV.

MOVEMENTS—VOICE AND SPEECH.

Amorphous contractile substance and amœboid movements—Ciliary movements—Movements due to elasticity—Elastic tissue—Muscular movements—Physiological anatomy of the involuntary muscular tissue—Contraction of the involuntary muscular tissue—Physiological anatomy of the voluntary muscular tissue—Connective tissue—Connection of the muscles with the tendons—Chemical composition of the muscles—Physiological properties of the muscles—Muscular contractility, or excitability—Muscular contraction—Electric phenomena in muscles—Muscular effort—Passive organs of locomotion—Physiological anatomy of the bones—Physiological anatomy of cartilage—Voice and speech—Sketch of the physiological anatomy of the vocal organs—Mechanism of the production of the voice—Laryngeal mechanism of the vocal registers—Mechanism of speech—The phonograph.

THE various processes connected with the nutrition of animals involve certain movements; and almost all animals possess in addition the power of locomotion. Many of these movements have of necessity been considered in connection with the different functions; as the action of the heart and vessels in the circulation, the uses of the muscles in respiration, the ciliary movements in the air-passages, the muscular acts in deglutition, the peristaltic movements and the mechanism of defæcation and urination. There remain, however, certain general facts with regard to various kinds of movement and the mode of action of the different varieties of muscular tissue, that will demand more or less extended consideration. As regards the varied and complex acts concerned in locomotion, it is difficult to fix a limit between anatomy and physiology. A full comprehension of such movements should be preceded by a complete descriptive anatomical account of the passive and active organs of locomotion; and special treatises on anatomy give the uses and actions as well as the structure and relations of these parts.

Amorphous Contractile Substance and Amœboid Movements.—In some of the lowest forms of beings, in which hardly any thing but amorphous matter and a few granules can be recognized by the microscope, certain movements of elongation and retraction of their amorphous substance have been observed. In the higher animals, similar movements have been noticed in certain of their structures, such as the leucocytes, the contents of the ovum, epithelial cells and connective-tissue cells. These movements generally are simple changes in the form of the cell, nucleus, or whatever it may be. They depend upon an organic principle formerly called sarcode and now known as protoplasm; but it is not known that such movements are characteristic of any one definite constituent of the body, nor is it easy to determine their cause and their physiological importance. In the anatomical elements of adult animals of the higher classes, these movements usually appear slow and gradual, even when viewed with high magnifying powers; but in some of the very lowest forms of life, these movements

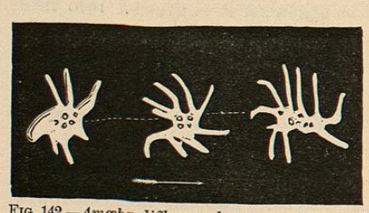

FIG. 142.—*Amœba diffluens, changing in form and moving in the direction indicated by the arrow* (Longet).

serve as a means of progression and are more rapid. Such movements are called amœboid. It does not seem possible to explain the nature and cause of the movements of homogeneous contractile substance; and it must be excessively difficult, if not impossible, to observe directly the effects of different stimuli, in the manner in which the movements of muscles are studied. They seem to be analogous to the ciliary movements, the cause of which is equally obscure.

Ciliary Movements.—The epithelium covering certain of the mucous membranes is provided with little, hair-like processes upon the borders of the cells, called cilia. These are in constant motion, from the beginning to the end of life, and they produce currents upon the surfaces of the membranes to which they are attached, the direction being generally from within outward. In man and in the warm-blooded animals generally, the ciliated or vibratile epithelium is of the variety called columnar, conoidal or prismoidal. The cilia are attached to the thick ends of the cells, and they form on the surface of the membrane a continuous sheet of vibrating processes. In general structure the ciliary processes are entirely homogeneous, and they gradually taper from their attachment to the cell to an extremity of excessive tenuity.

The presence of cilia has been demonstrated upon the following surfaces: The respiratory passages, including the nasal fossæ, the pituitary membrane, the summit of the larynx, the bronchial tubes, the superior surface of the velum palati and the Eustachian tubes; the sinuses about the head; the lachrymal sac and the internal surface of the eyelids; the genital passages of the female, from the middle of the neck of the uterus to the fimbriated extremities of the Fallopian tubes; the ventricles of the brain. In these situations, on each cell of conoidal epithelium are six to twelve prolongations, about $\frac{1}{25000}$ of an inch (1 μ) in thickness at their base, and $\frac{1}{5000}$ to $\frac{1}{4000}$ of an inch (5 to 6 μ) in length. Between the cilia and the substance of the cell, there is usually a thin, transparent disk. The appearance of the cilia is represented in Fig. 143. When seen *in situ*, they appear regularly disposed upon the surface, are of nearly equal length and are generally slightly inclined in the direction of the opening of the cavity lined by the membrane.

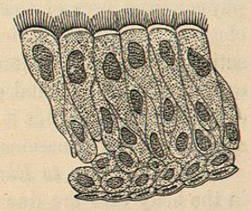

FIG. 143.—*Ciliated epithelium* (Landois).

When the ciliary movements are seen in a large number of cells *in situ*, the appearance is well illustrated by the comparison by Henle to the undulations of a field of wheat agitated by the wind. In watching this movement, it is usually seen to gradually diminish in rapidity, until what at first appeared simply as currents, produced by movements too rapid to be studied in detail, become revealed as distinct undulations, in which the action of individual cilia can be readily studied. Several kinds of movement have been described, but the most common is a bending of the cilia, simultaneously or in regular succession, in one direction, followed by an undulating return

to the perpendicular. The other movements, such as the infundibuliform, in which the point describes a circle around the base, the pendulum-movement etc., are not common and are unimportant.

The combined action of the cilia upon the surface of a mucous membrane, moving as they do in one direction, is to produce currents of considerable power. This may be illustrated under the microscope by covering the surface with a liquid holding little, solid particles in suspension; when the granules are tossed from one portion of the field to another, with considerable force. It is not difficult, indeed, to measure in this way the rapidity of the ciliary currents. In the frog it has been estimated at $\frac{1}{250}$ to $\frac{1}{175}$ of an inch (100 to 140 μ) per second, the number of vibratile movements being seventy-five to one hundred and fifty per minute. In the fresh-water polyp the movements are more rapid, being two hundred and fifty or three hundred per minute. There is no reliable estimate of the rapidity of the ciliary currents in man, but they are probably more active than in animals low in the scale.

The movements of cilia, like those observed in fully developed spermatozoids, seem to be independent of nervous influence, and they are affected only by local conditions. They will continue, under favorable circumstances, for more than twenty-four hours after death, and they can be seen in cells entirely detached from the body when they are moistened with proper fluids. When the cells are moistened with pure water, the activity of the movement is at first increased; but it soon disappears as the cells become swollen. Acids arrest the movement, but it may be excited by feebly alkaline solutions. There seems to be no possibility of explaining the movement except by a simple statement of the fact that the cilia have the property of moving in a certain way so long as they are under normal conditions. As regards the physiological uses of these movements, it is sufficient to refer to the physiology of the parts in which cilia are found, where the peculiarities of their action are considered more in detail. In the lungs and the air-passages generally and in the genital passages of the female, the currents are of considerable importance; but it is difficult to imagine the use of these movements in certain other situations, as the ventricles of the brain.

Movements due to Elasticity.—There are certain important movements in the body that are due simply to the action of elastic ligaments or membranes. These are distinct from muscular movements, and are not even to be classed with the movements produced by the resiliency of muscular tissue, in which muscular tonicity is more or less involved. Movements of this kind consist simply in the return of movable parts to a certain position after they have been displaced by muscular action, and in the reaction of tubes after forcible distention, as in the walls of the large arteries.

Elastic Tissue.—Most anatomists adopt the division of the elements of elastic tissue into three varieties. This division relates to the size of the fibres; and all varieties are found to possess essentially the same chemical composition and general properties. On account of the yellow color of this tissue, presenting, as it does, a strong contrast to the white, glistening

appearance of the inelastic fibres, it is frequently called the yellow, elastic tissue.

The first variety of elastic tissue is composed of small fibres, generally intermingled with fibres of the ordinary inelastic tissue. They possess all the chemical and physical characters of the larger fibres, but are very fine, measuring $\frac{1}{25000}$ to $\frac{1}{6000}$ or $\frac{1}{5000}$ of an inch (1 to 4 or 5 μ) in diameter. If acetic acid be added to a preparation of ordinary connective tissue, the inelastic fibres are rendered semi-transparent, but the elastic fibres are unaffected and become quite distinct. They are then seen isolated, that is, never arranged in bundles, generally with a dark, double contour, branching, brittle, and when broken, their extremities curled and presenting a sharp fracture, like a piece of India-rubber. These fibres pursue a wavy course between the bundles of inelastic fibres in the areolar tissue and in most of the ordinary fibrous membranes. They are found in greater or less abundance in the situations just mentioned; in the ligaments, but not the tendons; in the layers of non-striated muscular tissue; the true skin; the true vocal chords; the trachea, bronchial tubes, and largely in the parenchyma of the lungs; the external layer of the large arteries; and, in brief, in nearly all situations in which the ordinary connective tissue exists.

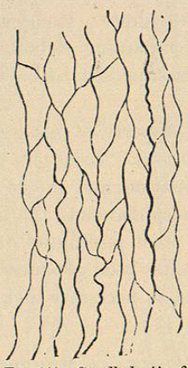

FIG. 144.—*Small elastic fibres from the peritoneum; magnified 350 diameters* (Kölliker).

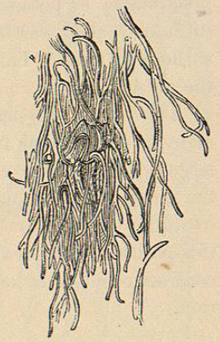

FIG. 145.—*Larger elastic fibres* (Robin).

The second variety of elastic tissue is composed of fibres, larger than the first, ribbon-shaped, with well-defined outlines, anatomosing, undulating or curved in the form of the letter S, presenting the same curled ends and sharp fracture as the smaller fibres. These measure $\frac{1}{5000}$ to $\frac{1}{3000}$ of an inch (5 to 8 μ) in diameter. Their type is found in the ligamenta subflava and the ligamentum nuchæ. They are also found in some of the ligaments of the larynx, the stylo-hyoid ligament and the suspensory ligament of the penis.

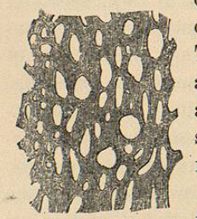

FIG. 146.—*Large elastic fibres (fenestrated membrane), from the middle coat of the carotid of the horse; magnified 350 diameters* (Kölliker).

The third variety of elastic tissue is found forming the middle coat of the large arteries, and it has already been described in connection with the vascular system. The fibres are large and flat, inosculating freely with each other by short, communicating branches. These anastomosing fibres, forming the so-called fenestrated membranes, are arranged in layers, and the structure is sometimes called the lamellar elastic tissue.

The great resistance which the elastic tissue presents to chemical action serves to distinguish it from nearly every other structure in the body. It is not affected by acetic acid or by boiling with sodium hydrate. It is not softened by prolonged boiling in water, but it is slowly dissolved, without decomposition, by sulphuric, nitric or hydrochloric acid, the solution not being precipitable by potassium hydrate. Its organic constituent is a nitrogenized substance called elastine, containing carbon, hydrogen, oxygen and nitrogen, without sulphur. This is supposed to be identical with the sarcolemma of the muscular tissue.

The purely physical property of elasticity plays an important part in many of the animal functions. Examples of this are in the action of the large arteries in the circulation, and in the resiliency of the parenchyma of the lungs. The ligamenta subflava and the ligamentum nuchæ are important in aiding to maintain the erect position of the body and head and to restore this position when flexion has been produced by muscular action. Still, the contraction of muscles also is necessary to keep the body in a vertical position.

Muscular Movements.

The muscular movements are divided into voluntary and involuntary; and generally there is a corresponding division of the muscles as regards their minute anatomy. The latter, however, is not absolute; for there are certain involuntary actions, like the contractions of the heart or the movements of deglutition, that require the rapid, vigorous contraction characteristic of the voluntary muscular tissue, and here the structure resembles that of the voluntary muscles. With a few exceptions, however, the anatomical division of the muscular tissue into voluntary and involuntary is sufficiently distinct.

Physiological Anatomy of the Involuntary Muscular Tissue.—The involuntary muscular system presents a striking contrast to the voluntary muscles, not only in its minute anatomy and mode of action, but in the arrangement of its fibres. While the voluntary muscles are almost invariably attached by their extremities to movable parts, the involuntary muscles form sheets or membranes in the walls of hollow organs, and by their contraction, they simply modify the capacity of the cavities which they surround. On account of the peculiar structure of the fibres, they have been called muscular fibre-cells, smooth muscular fibres, pale fibres, non-striated fibres, fusiform fibres and contractile cells. The distribution of these fibres to parts concerned in the organic functions, as the alimentary canal, has given them the name of organic muscular fibres, or fibres of organic life. In their natural condition, the involuntary muscular fibres are pale, finely granular, flattened, and of an elongated spindle-shape, with a very long, narrow, almost linear nucleus in the centre. The nucleus generally has no distinct nucleolus, and it is sometimes curved or shaped like the letter S. The ordinary length of these fibres is about $\frac{1}{500}$ (50 μ) and their breadth, about $\frac{1}{4000}$ of an inch (6 μ). In the gravid uterus they undergo remarkable hypertrophy, measuring here $\frac{1}{80}$ to $\frac{1}{50}$ of an inch (300 to 500 μ) in length, and $\frac{1}{2000}$ of an inch (12 μ) in breadth.

In the contractile sheets formed of involuntary muscular tissue, the fibres are arranged side by side, are closely adherent, and their extremities are, as

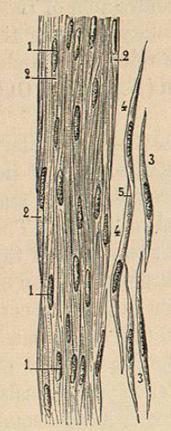

Fig. 147.—*Muscular fibres from the urinary bladder of the human subject; magnified 200 diameters* (Sappey).

1, 1, 1, nuclei; 2, 2, 2, borders of some of the fibres; 3, 3, isolated fibres; 4, 4, two fibres joined together at 5.

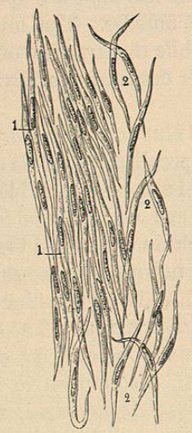

Fig. 148.—*Muscular fibres from the aorta of the calf; magnified 200 diameters* (Sappey).

1, 1, fibres joined with each other; 2, 2, 2, isolated fibres.

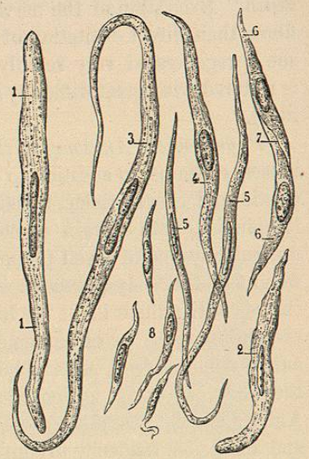

Fig. 149.—*Muscular fibres from the uterus of a woman who died at the ninth month of utero-gestation; magnified 350 diameters* (Sappey).

1, 1, 2, short, wide fibres; 3, 4, 5, 5, longer and narrower fibres; 6, 6, two fibres united at 7; 8, small fibres in process of development.

it were, dove-tailed into each other. Generally the borders of the fibres are regular and their extremities are simple; but sometimes the ends are forked and the borders present one or more little projections. The fibres seldom exist in a single layer except in the very smallest arterioles. Usually the layers are multiple, being superimposed in regular order. The action of acetic acid is to render the fibres pale so that their outlines become almost indistinguishable, and to bring the nuclei more distinctly into view.

Contraction of the Involuntary Muscular Tissue.—The mode of contraction of the involuntary muscles is peculiar. It does not take place immediately upon the reception of a stimulus, applied either directly or through the nerves, but it is gradual, enduring for a time and then followed by slow and gradual relaxation. A description of the peristaltic movements of the intestines gives an idea of the mode of contraction of these fibres, with the gradual propagation of the stimulus along the alimentary canal as the food makes its impression upon the mucous membrane. Another illustration is afforded by labor-pains. These are due to the muscular contractions of the uterus, and they last for a few seconds or one or two minutes. Their gradual access, continuation for a certain period, and gradual disappearance coincide with the history of the contractions of the involuntary muscular fibres.

The contraction of the involuntary muscular tissue is slow, and the fibres return slowly to a condition of repose. The movements are always involun-

tary. Peristaltic action is the rule, and the contraction takes place progressively and without oscillations. Contractility persists for a long time after death. Excitation of the nerves has less influence upon contraction of these fibres than direct excitation of the muscles. The involuntary muscular tissue is regenerated very rapidly, while the structure of the voluntary muscles is restored with great difficulty after destruction or division (Legros and Onimus).

Physiological Anatomy of the Voluntary Muscular Tissue.—A voluntary muscle contains, in addition to its peculiar contractile substance, fibres of inelastic and elastic tissue, adipose tissue, abundant blood-vessels, nerves and lymphatics, with certain nuclear and cellular anatomical elements. The muscular system in a well proportioned man is equal to about two-fifths of the weight of the body (Sappey). Its nutrition consumes a large proportion of the reparative material of the blood, while its disassimilation furnishes a corresponding quantity of excrementitious matter. The condition of the muscular system, indeed, is an almost unfailing evidence of the general state of the body, allowing, of course, for peculiarities in different individuals. Among the characteristic properties of the muscles, are elasticity, a constant and insensible tendency to contraction, called tonicity, the power of contracting forcibly on the reception of a proper stimulus, and a peculiar kind of sensibility. The relations of particular muscles, as taught by descriptive anatomy, involve special acts; but the most important physiological points connected with this system relate to the general properties and uses of the muscles.

The voluntary muscles are made up of a great number of microscopic fibres, known as the primitive muscular fasciculi. These are called red, striated or voluntary fibres. Their structure is complex, and they may be subdivided longitudinally into fibrillæ and transversely into disks. In very short muscles, some of the primitive fasciculi may run the entire length of the muscle; but the fasciculi usually are 1·2 to 1·6 inch (30 to 40 mm.) in length. The fasciculi, however, do not inosculate with each other, but the end of one fasciculus is united longitudinally with the end of another by a strongly adhesive substance, the line of union being oblique; so that the fibres practically run the entire length of the muscle. Each fasciculus is enclosed in its own sheath, without branching or inosculation. This sheath contains the true muscular substance only, and it is not penetrated by blood-vessels, nerves or lymphatics. In a thin, transverse section of a muscle, the divided ends of the fibres present an irregularly polygonal form with rounded corners. They seem to be cylindrical, however, when viewed in their length and isolated. Their color by transmitted light is a delicate amber, resembling the color of the blood-corpuscles.

The primitive fasciculi vary very much in size in different individuals, in the same individual under different conditions, and in different muscles. As a rule they are smaller in young persons and in females than in adult males. They are comparatively small in persons of slight muscular development. In persons of great muscular vigor, or when the general muscular system or

particular muscles have been increased in size and power by exercise, the fasciculi are relatively larger. It is probable that the physiological increase in the size of a muscle from exercise is due to an increase in the size of the pre-

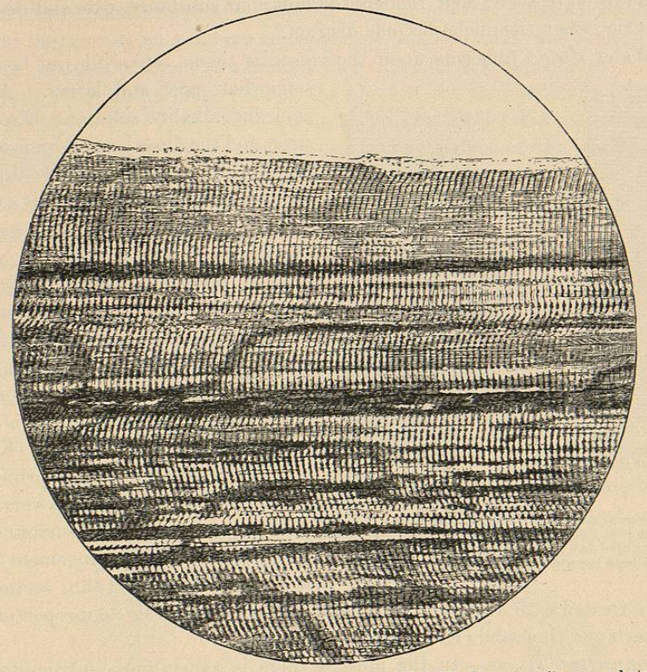

FIG. 150.—*Striated muscular fibres from the mouse; magnified* 500 *diameters* (from a photograph taken at the United States Army Medical Museum).
The injected capillaries are seen, somewhat out of focus.

existing fasciculi and not to the formation of new elements. In young persons the fasciculi are $\frac{1}{1400}$ to $\frac{1}{1200}$ of an inch (15 to 20 μ) in diameter. In the adult they measure $\frac{1}{400}$ to $\frac{1}{250}$ of an inch (55 to 100 μ).

The appearance of the primitive muscular fasciculi under the microscope is characteristic. They present regular, transverse striæ, formed of alternating dark and clear bands about $\frac{1}{25000}$ of an inch (1 μ) wide. With a high magnifying power, a very fine transverse line is observed running through the middle of each one of the clear bands. In addition they present longitudinal striæ, not so distinct, and difficult to follow to any extent in the length of the fasciculus, but tolerably well marked, particularly in muscles that are habitually exercised. The muscular substance, presenting this peculiar, striated appearance, is enclosed in a very thin but elastic and resisting tubular membrane, called the sarcolemma or myolemma. This envelope can not be seen in ordinary preparations of the muscular tissue; but it frequently happens that the contractile muscular substance is broken, leaving the sarcolemma intact, which gives a good view of the membrane and conveys an idea

of its strength and elasticity. Attached to the inner surface of the sarcolemma, are small, elongated nuclei with their long diameter in the direction of the fasciculi. These are usually not well seen in the unaltered muscle, but the addition of acetic acid renders the muscular substance pale and destroys the striæ, when the nuclei become distinct.

Water after a time acts upon the muscular tissue, rendering the fasciculi somewhat paler and larger. Acetic acid and alkaline solutions efface the striæ, and the fibres become semi-transparent. In fasciculi that are slightly decomposed, there is frequently a separation at the extremity into smaller fibres, called fibrillæ. These, when isolated, present the same striated appearance as the primitive fasciculus; viz., alternate dark and light portions. They measure about $\frac{1}{25000}$ of an inch ($1\ \mu$) in diameter, and their number, in the largest primitive fibres, is estimated at about two thousand (Kölliker). The interior of each primitive fasciculus is penetrated by a very delicate membrane closely surrounding the fibrillæ. This arrangement may be distinctly seen in a thin section of a fibre treated with a solution of common salt in water, in the proportion of five parts per thousand (Kölliker).

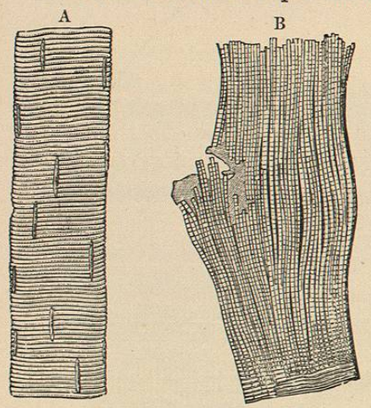

FIG. 151.—*Striated muscular fibres; magnified* 250 *diameters* (Sappey).

A, transverse striæ and nuclei of a primitive fasciculus; B, longitudinal striæ and fibrillæ of a primitive fasciculus in which the sarcolemma has been lacerated at one point by pressure.

Connective Tissue.—In the muscles there is a membrane surrounding a number of the primitive fasciculi. This is called the perimysium. The fibrous membranes that connect together the sesecondary bundles, with their contents, are enclosed in a sheath enveloping the whole muscle, sometimes called the external perimysium. The peculiarity of these membranes as distinguished from the sarcolemma is that they have a fibrous structure and are connected together throughout the muscle, while the tubes forming the sarcolemma are structureless and each one is distinct.

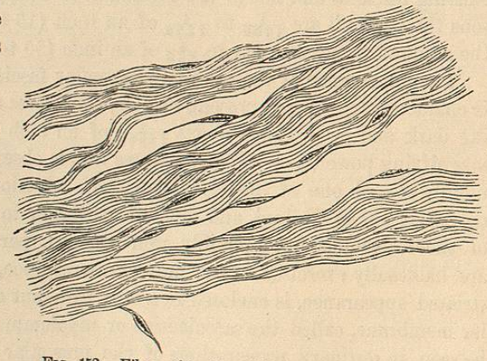

FIG. 152.—*Fibres of tendon of the human subject* (Rollett).

The name now most generally adopted for the ordinary fibrous tissue is

connective tissue. It has been called cellular, areolar or fibrous, but most of these names were given to it without a clear idea of its structure. Its principal anatomical element is a fibre of excessive tenuity, wavy and with a single contour. These fibres are collected into bundles of variable size and are held together by an adhesive amorphous substance. The wavy lines that mark the bundles of fibres give them a very characteristic appearance.

The direction and arrangement of the fibres in the various tissues present marked differences. In the loose areolar tissue beneath the skin and between the muscles, and in the loose structure surrounding some of the glands and connecting the sheaths of blood-vessels and nerves to the adjacent parts, the bundles of fibres form a large net-work and are very wavy in their course. In the strong, dense membranes, as the aponeuroses, the proper coats of many glands, the periosteum and perichondrium and the serous membranes, the waves of the fibres are shorter, and the fibres themselves interlace much more closely. In the ligaments and tendons, the fibres are more nearly straight and are arranged longitudinally.

On the addition of acetic acid the bundles of inelastic fibres swell up, become semi-transparent, and the nuclei and elastic fibres are brought into

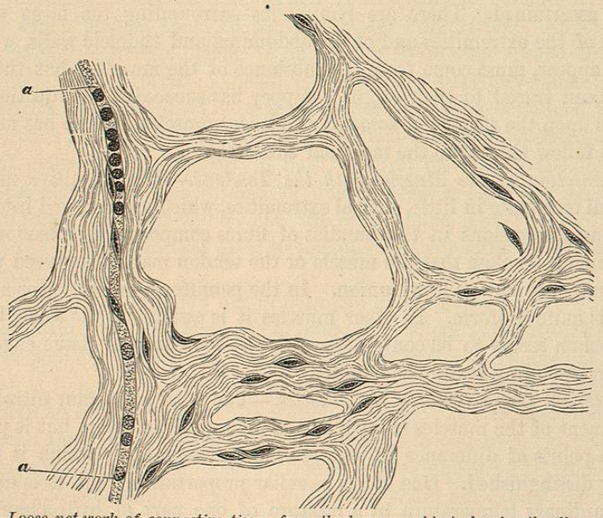

FIG. 153.—*Loose net-work of connective tissue from the human subject, showing the fibres and cells* (Rollett).

a, *a*, a capillary blood-vessel.

view. The proportion of elastic fibres differs very much in different situations, but they are all of the smallest variety, and they present a striking contrast to the inelastic fibres in their form and size. Although they are very small, they always present a double contour.

Certain cellular and nuclear elements are always found in the connective tissue. The cells are known as connective-tissue cells. They are very irregular in size and form, some of them being spindle-shaped or caudate, and