ties, the nerves beneath the mammary glands, the nerves of the nipples, and in the substance of the muscles of the hands and feet. They are found without exception on all of the great plexuses of the sympathetic system, in front of and by the sides of the abdominal aorta, and behind the peritoneum, particularly in the vicinity of the pancreas. They sometimes exist in the mesentery and have been observed near the coccygeal gland.

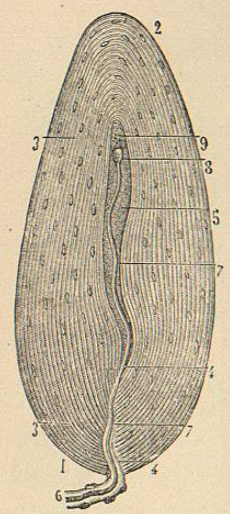

FIG. 179. — *Corpuscle of Vater* (Sappey).

1, base of the corpuscle; 2, apex; 3, 3, 3, substance of the corpuscle, in layers; 4, 4, nerve penetrating the corpuscle; 5, cavity of the corpuscle; 6, nerve; 7, nerve, which has lost its medullary substance and sheath; 8, termination of the nerve; 9, granular substance continuous with the nerve.

The corpuscles consist simply of several layers of connective tissue enclosing one, two or three central bulbs in which are found the ends of the nerve. These bulbs are finely granular and nucleated, and are regarded by most anatomists as composed of connective tissue. At the base of the corpuscle, is a pedicle formed of connective tissue surrounding a medullated nerve-fibre which penetrates the corpuscle. Within the corpuscle the medullary substance of the nerve-fibre is lost and only the axis-cylinder remains.

The situation of these corpuscles, beneath the true skin instead of in its substance, shows that they can not be properly considered as tactile corpuscles, a name which is applied to other structures found in the papillæ of the corium; and it is impossible to assign to them any special use connected with sensation, such as the appreciation of temperature, pressure or weight. All that can be said with regard to them is that they constitute one of the several modes of termination of the nerves of general sensibility.

Tactile Corpuscles.—The name tactile corpuscles implies that these bodies are connected with the sense of touch; and this view is sustained by the fact that they are found almost exclusively in parts endowed to a marked degree with tactile sensibility. They are sometimes called the corpuscles of Meissner and Wagner, after the anatomists by whom they were first described. The true, tactile corpuscles are found in greatest number on the palmar surfaces of the hands and fingers and the plantar surfaces of the feet and toes. They exist, also, in the skin on the backs of the hands and feet, the nipples, and a few on the anterior surface of the forearm. The largest papillæ of the skin are found on the hands, feet and nipples, precisely where the tactile corpuscles are most abundant. Corpuscles do not exist in all papillæ, and they are found chiefly in those called compound. In an area a little more than $\frac{1}{12}$ of an inch square (2·2 mm. square), on the third phalanx of the index-finger, Meissner counted four hundred papillæ, in one hundred and eight of which he found tactile corpuscles, or about one in four. In an equal area on the second phalanx, he found forty corpuscles; on the first phalanx, fifteen; eight on the skin of the hypothenar eminence; thirty-four on the plantar surface of the ungual phalanx of the great-toe; and seven or eight in

the skin on the middle of the sole of the foot. In the skin of the fore-arm the corpuscles are very rare. According to Kölliker, the tactile corpuscles

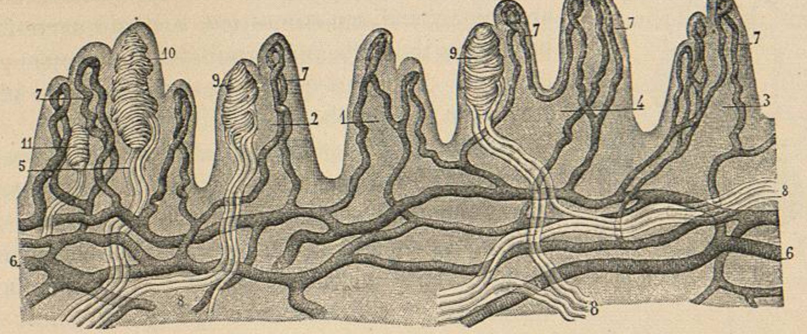

FIG. 180.—*Papillæ of the skin of the palm of the hand* (Sappey).

1, papilla with two vascular loops; 2, papilla with a tactile corpuscle; 3, papilla with three vascular loops; 4, 5, large, compound papillæ; 6, 6, vascular net-work beneath the papillæ; 7, 7, 7, 7, vascular loops in the papillæ; 8, 8, 8, 8, nerves beneath the papillæ; 9, 9, 10, 11, tactile corpuscles.

usually occupy special papillæ which are not provided with blood-vessels; so that the papillæ of the hand may be properly divided into vascular and nervous.

The form of the tactile corpuscles is oblong, with their long diameter in the direction of the papillæ, Their length is $\frac{1}{380}$ to $\frac{1}{250}$ of an inch (66 to 100 μ). In the palm of the hand they are $\frac{1}{250}$ to $\frac{1}{140}$ of an inch (100 to 165 μ) long, and $\frac{1}{550}$ to $\frac{1}{500}$ of an inch (45 to 50 μ) in thickness. They generally are situated at the summits of the secondary eminences of the compound papillæ. They consist of a central bulb of homogeneous or slightly granular connective-tissue substance, harder than the central bulb of the corpuscles of Vater, and a covering. The covering is composed of connective tissue with a few fine elastic fibres. One, two, and sometimes three or four dark-bordered nerve-fibres pass from the subcutaneous nervous plexus to the base of each corpuscle. These surround the corpuscle with two or three spiral turns, and they terminate by pale extremities on the surface of the central bulb.

End-Bulbs.—Under this name, a variety of corpuscles has been described by Krause, as existing in the conjunctiva covering the eye and in the semilunar fold, in the floor of the buccal cavity, the tongue, the glans penis and the clitoris. They bear some analogy to the tactile corpuscles, but they are much smaller and more simple in their structure. They form rounded or oblong enlargements at the ends of the nerves, which are composed of homogeneous matter with a delicate investment of connective tissue. They measure $\frac{1}{1000}$ to $\frac{1}{250}$ of an inch (25 to 100 μ) in diameter. In the parts provided with papillæ, they are situated at the summits of the secondary elevations. The arrangement of the nerve-fibres in these corpuscles is very simple. One, two, or three medullated fibres pass from the submucous plexus to the corpuscles. The investing sheath of the fibres is here continuous with the connective-tissue covering of the corpuscle, and the nerve-fibres pass into the corpuscle, break up into two or three divisions, and terminate in convoluted or knotted coils. The nerve-fibres are medullated for a certain distance, but their terminations are generally pale. The above is one form of these corpuscles. Sometimes, however, the terminal bulbs are oblong, and sometimes but a single nerve-fibre penetrates the bulb and terminates in a simple, pale filament. The principal forms of the terminal bulbs are shown in Fig. 181.

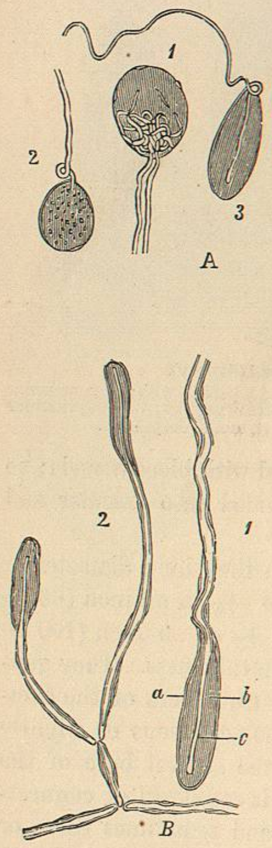

FIG. 181.—*End-bulbs, or corpuscles of Krause* (Ludden).
A, three corpuscles of Krause from the conjunctiva of man, treated with acetic acid; magnified 300 diameters: 1, spherical corpuscle, with two nerve-fibres which form a knot in its interior (portions of two pale nerve-fibres are also seen); 2, a rounded corpuscle presenting a nerve-fibre and fatty granulations in the internal bulb; 3, an elongated corpuscle with a distinct terminal fibre.
In these three corpuscles, the covering, nucleated in 1 and 2, is distinguished.
B, terminal bulbs from the conjunctiva of the calf, treated with acetic acid; magnified 300 diameters: 1, extremity of a nerve-fibre with its bulb; 2, double bifurcation of a nerve-fibre, with two terminal bulbs; *a*, covering of the terminal bulbs; *b*, internal bulb; *c*, pale nerve-fibre.

General Mode of Termination of the Sensory Nerves.—The actual termination of the sensory nerves upon the general surface and in mucous membranes is still a question of some obscurity. Although anatomists have arrived at a pretty definite knowledge of the sensory corpuscles, it must be remembered that there is an immense cutaneous and mucous surface in which no corpuscles have as yet been demonstrated; and it is in these parts, endowed with what may be called general sensibility, as distinguished from the sense of touch, that the mode of termination of the nerves remains to be studied.

According to Kölliker, in the immense majority of instances the sensory nerves terminate in some way in the hair-follicles. If this be true, it will account for the termination of the nerves in by far the greatest portion of the skin, as there are few parts in which hair-follicles do not exist; but unfortunately the exact mode of connection of the nerves with these follicles is not apparent. The following seems to be all that is positively known of the terminations of the nerves on the general surface:

Medullated nerve-fibres form a plexus in the deeper layers of the true skin, and from this plexus, fibres, some pale and nucleated and others medullated, pass to the hair-follicles, divide into branches, penetrate into their interior and are there lost. A certain number of fibres pass to the non-striated muscular fibres of the skin. A certain number pass to papillæ and terminate in tactile corpuscles, and others pass to papillæ that have no tactile corpuscles.

In the mucous membranes the mode of termination is, in general terms, by a delicate plexus just beneath the epithelium, coming from a submucous plexus analogous to the deep cutaneous plexus. In certain membranes the nerves terminate in end-bulbs, or corpuscles of Krause. In the cornea, according to the observations

of Hoyer, Lipmann and others, branching nerve-fibres pass to the nucleoli of the corneal corpuscles and to the nucleoli of the cells of the posterior layer of epithelium.

Structure of the Nerve-centres.—A peculiar pigmentary matter in the nerve-cells and in the surrounding granular substance gives to the nerve-centres a grayish color, by which they are readily distinguished from the white, or fibrous division of the nervous system. Wherever this gray matter is found, the anatomical elements of the tissue are cellular, except in the nerves formed of gray, or gelatinous fibres. Under the general division of nerve-centres, are included, anatomically at least, the gray matter of the cerebro-spinal centres, the ganglia of the roots of the spinal and certain of the cranial nerves, and the ganglia of the sympathetic system. In these parts are found cells, which constitute the essential anatomical element of the tissue, granular matter resembling the contents of the cells, pale fibres originating in prolongations of the cells, elements of connective tissue, delicate membranes enveloping some of the cells, with blood-vessels and lymphatics. The most important of these structures, in their physiological relations, are the cells and the prolongations by which they are connected with the nerves and with each other.

Nerve-cells.—The following varieties of cells exist in the nerve-centres and constitute their essential anatomical elements; viz., unipolar, bipolar and multipolar cells. These cells present great differences in their size and general appearance, and some distinct varieties are found in particular portions of the nervous system. Unipolar and bipolar cells are found in the ganglia of the cranial nerves and in the ganglia of the posterior roots of the spinal nerves. Small unipolar cells are found in the sympathetic ganglia. Multipolar cells present three or more prolongations. Small cells, with three and rarely four prolongations, are found in the posterior cornua of the gray matter of the spinal cord. From their situation they have been called sensory cells. They are found in greatest number in parts known to be endowed exclusively with sensory properties. Large, irregularly shaped multipolar cells, with a number of poles, or prolongations, are found chiefly in the anterior cornua of the gray matter of the spinal cord, and these have been called motor cells. They sometimes present as many as ten or twelve poles.

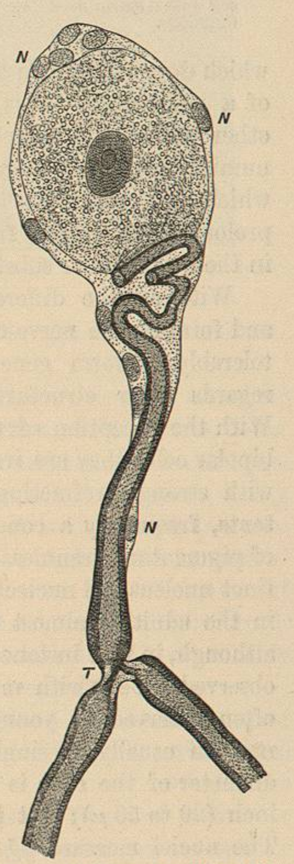

FIG. 182.—*Unipolar cell from the Gasserian ganglion* (Schwalbe).
N, N, N, nuclei of the sheath; T, fibre branching at a node of Ranvier.

Unipolar cells, such as exist in the ganglia of the nerves as distinguished from the ganglia of the cerebro-spinal axis, have but a single prolongation, which is continuous with a nerve-fibre. These cells frequently have a connective-tissue envelope, or sheath, which is prolonged as a sheath for the nerve. Unipolar cells, with a connective-tissue sheath, the pole being surrounded by a spiral fibre, have been observed in the sympathetic ganglia of the frog. These do not exist in the human subject or in the mammalia and nothing is known of the uses of the spiral fibres.

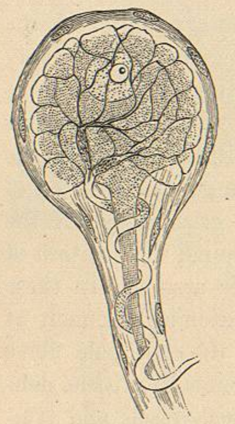

FIG. 183.—*Unipolar nerve-cell with a spiral fibre* (Landois).

FIG. 184. — *Bipolar nerve-cell* (Landois).

Bipolar cells seem to be nucleated enlargements in the course of medullated nerve-fibres. Usually the medullary substance does not extend over the cell, although this sometimes occurs.

Multipolar cells have a number of poles, but there is always one pole which does not branch and which becomes continuous with the axis-cylinder of a nerve-fibre. This is called the axis-cylinder prolongation. Of the other poles, some are continuous with poles of contiguous cells, connecting numbers of cells into groups, and others, which are sometimes called protoplasmic prolongations, branch freely and are lost in the intercellular substance.

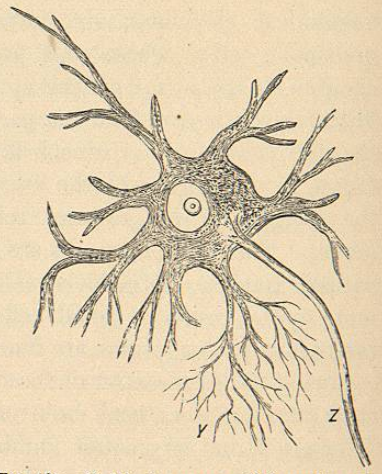

FIG. 185.—*Multipolar nerve-cell from the spinal cord* (Landois).
z, axis-cylinder prolongation; y, protoplasmic branches.

With all the differences in the size and form of the nerve-cells, they present tolerably uniform general characters as regards their structure and contents. With the exception of the unipolar and bipolar cells, they are irregular in shape, with strongly refracting, granular contents, frequently a considerable number of pigmentary granules, and always a distinct nucleus and nucleolus. The nucleus in the adult is almost invariably single, although, in rare instances, two have been observed. Cells with multiple nuclei are often observed in young animals. The nucleoli usually are single, but there may be as many as four or five. The diameter of the cells is variable. They usually measure $\frac{1}{1250}$ to $\frac{1}{500}$ of an inch (20 to 50 μ); but there are many of larger size and some are smaller. The nuclei measure $\frac{1}{2000}$ to $\frac{1}{1250}$ of an inch (12 to 20 μ). The nerve-cells are soft, have no true cell-membrane and are fibrillated, the fibrillation extending to the poles. The transverse striæ in the axis-cylinder treated with silver nitrate, noted by Fromann and confirmed by Grandry and others, have been observed by Grandry in the substance of the nerve-cells. While this fact, perhaps, shows that the substance contained in the cells and their prolongations is like the substance of the axis-cylinder, it is possible that the markings may be entirely artificial, and that they do not indicate the existence of two distinct substances.

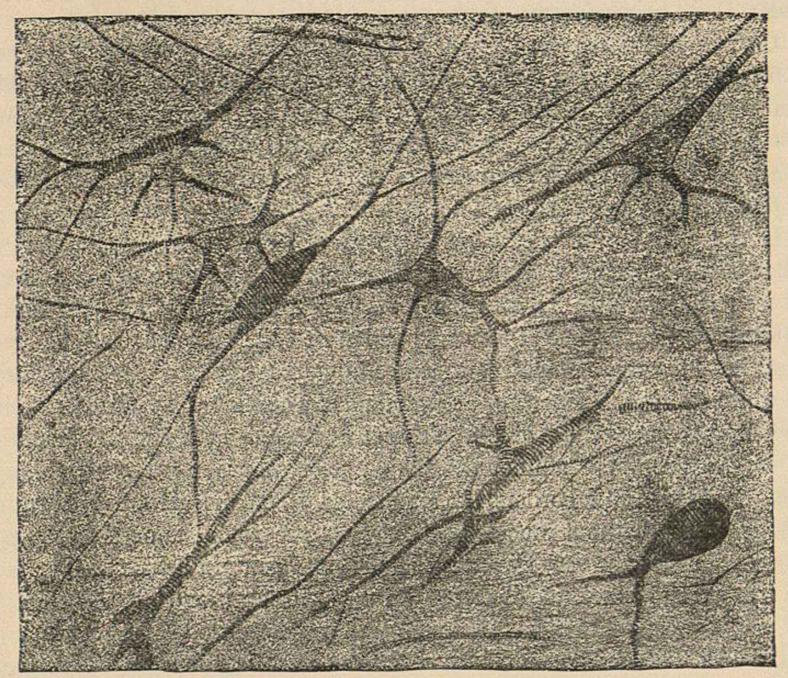

FIG. 186.—*Transverse section of the gray substance of anterior cornua of the spinal cord of the ox, treated with silver nitrate* (Grandry).

Tracing the nerve-fibres toward their origin, they are seen to lose their investing membrane as they pass into the white portion of the centres, being here composed only of medullary substance surrounding the axis-cylinders. They then penetrate the gray substance, in the form of axis-cylinders, losing the medullary substance. In the gray substance, it is impossible to make out all their relations distinctly, and it can not be stated, as a matter of positive demonstration, that all of them are connected with the poles of nerve-cells. Still, it has been shown in the gray matter of the spinal cord, that many of the fibres are actual prolongations of the cells, others probably passing upward to be connected with cells in the encephalon.

Tracing the prolongations from the cells, it is found that at least one of the poles in the gray substance gives origin to nerve-fibres, but that these fibres do not branch after they pass into the white substance. Other poles connect the nerve-cells with each other by commissural fibres of greater or less length; and it is probable that the cells are thus arranged in separate and distinct groups, possibly connected with sets of muscles.

Accessory Anatomical Elements of the Nerve-centres.—In addition to the cells of the gray matter and the axis-cylinder of the nerves, which are probably the only structures directly concerned in innervation, are the following accessory anatomical elements: 1, outer coverings surrounding some of the cells; 2, intercellular, granular matter; 3, peculiar corpuscles, called myelocytes; 4, connective-tissue elements; 5, blood-vessels and lymphatics.

Certain of the cells in the spinal ganglia and in the ganglia of the sympathetic system are surrounded with a covering, removed a certain distance from the cell itself so as to be nearly twice the diameter of the cell, which is continuous with the sheath of the dark-bordered fibres. This membrane is always nucleated and is composed of a layer of very delicate endothelium. Its physiological significance is not apparent.

In the gray matter of the nerve-centres, there is a finely granular substance between the cells, which closely resembles the granular contents of the cells themselves. In addition to this granular matter, Robin has described peculiar anatomical elements which he called myelocytes. These are found in the cerebro-spinal centres, forming a layer near the boundary of the white substance, and they are particularly abundant in the cerebellum. They exist in the form of free nuclei and nucleated cells, the free nuclei being by far the more abundant. The nuclei are rounded or ovoid, with strongly accentuated borders, are unaffected by acetic acid, finely granular and generally without nucleoli. The cells are rounded or slightly polyhedric, pale, clear or very slightly granular, and contain bodies similar to the free nuclei. The free nuclei are $\frac{1}{5000}$ to $\frac{1}{4000}$ of an inch (5 to 6 μ) in diameter, and the cells measure $\frac{1}{2500}$ to $\frac{1}{2000}$, and sometimes $\frac{1}{1500}$ of an inch (10, 12 and 15 μ). These elements also exist in the second layer of the retina.

In the cerebro-spinal centres there is a delicate stroma of connective tissue, chiefly in the form of stellate, branching cells, which serves in a measure, to support the nervous elements. This tissue, which is peculiar to the white substance of the encephalon and spinal cord, is called neuroglia.

The blood-vessels of the nerve-centres form a capillary net-work with large meshes. The gray substance is richer in capillaries than the white.

A peculiarity of the vascular arrangement in the cerebro-spinal centres has already been described in connection with the anatomy of the lymphatic system. The blood-vessels here are surrounded by what have been called perivascular canals, first described by Robin and afterward shown by His and Robin to be radicles of the lymphatic system.

Composition of the Nervous Substance.—The chemistry of the nervous substance, as far as it is understood, throws little light on its physiology. Certain albuminoids have been extracted which do not possess more than a purely chemical interest. The substance called cerebrine is composed of carbon, hydrogen, oxygen and nitrogen, without either sulphur or phosphorus. Protagon is a nitrogenized substance containing phosphorus (Liebreich, 1865). By some chemists protagon is thought to be a mixture of cerebrine and lecethine. Lecethine is regarded as a nitrogenous fat. Other substances which have been extracted—xanthine, hypoxanthine, inosite, creatine and various volatile fatty acids—have no special physiological interest connected with the nervous system and are found in many other situations. Cholesterine, which always exists in considerable quantity in the nervous tissue, has been considered in connection with the physiology of excretion. The ordinary fats are in combination with other fats or with peculiar acid substances. The reaction of nerve-tissue is either neutral or faintly alkaline under normal conditions, soon becoming acid after death.

Degeneration and Regeneration of Nerves.—The degenerations observed in nerves separated from the centres to which they are normally attached, first studied by Waller, in 1850, are now used in following out certain nervous connections too intricate to be revealed by ordinary dissection. This is known as the Wallerian method. If an ordinary mixed nerve be divided in its course, both the motor and sensory fibres of the peripheral portion undergo fatty degeneration and lose their excitability. As regards the spinal nerves, degeneration occurs in the motor fibres only, when the anterior spinal root has been divided, and the nerve has degenerated fibres (motor) mixed with the sensory fibres, which latter retain their anatomical and physiological characters. The motor fibres of the spinal nerves are degenerated when separated from their connections with the anterior cornua of gray matter of the cord. If the posterior roots of the spinal nerves be divided beyond the ganglia, the peripheral sensory fibres degenerate; but if the ganglia be exsected, the central as well as the peripheral portions degenerate. These experiments show the existence of centres which preside over the nutrition of the nerves. The centres for the motor filaments of the spinal nerves are in the anterior cornua of gray matter of the cord. The centres for the sensory fibres are the ganglia of the posterior roots. The centres for the sensory cranial nerves are the ganglia on their roots; and the centres for the motor cranial nerves are probably the gray nuclei of origin of these nerves. The Wallerian method has been found useful in studying the paths of conduction in the encephalon and spinal cord, as will be seen in connection with the physiology of these parts.

The excitability of the motor nerves disappears in about four days after their section. Of course, in experiments upon this point, it is necessary to excise a portion of the nerve to prevent reunion of the divided extremities; but when this is done, after about the fourth day, stimulation of the nerve will produce no contraction in the muscles, although the latter retain their contractility. This loss of excitability is gradual, and it continues, whether the nerve be exposed and stimulated from time to time or be left to itself, progressing from the centres to the periphery. In the researches of Longet upon this subject, it was found that the lower portion of the peduncles of the brain lost their excitability first, then the anterior columns of the cord, then the motor roots of the nerves, and last of all, the branches of the nerves near their terminations in the muscles.

The sensibility of the sensory nerves disappears from the periphery to the centres, as is shown in dying animals and in experiments with anæsthetics. The sensibility is lost, first in the terminal branches of the nerves, next in the trunks and in the posterior roots of the spinal nerves, and so on to the centres.