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Research Article

The Study of Neurons and Satellite Cells Under an Electron Microscope. Methodological Approaches

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Abstract

The main contribution of electron microscopy was the solution of problems concerning Nissl's substance, the Golgi apparatus, neurofibrils, myelin sheath and synapses. However, many problems remain unresolved due to the special nature of the neuron and the complexity of the structure of its processes. The use of an electron microscope led to the emergence of ideas about the structure and functions of the endoplasmic reticulum, protein, myelin sheath, Schwann cells, nodes of Ranvier, synapses, and the contents of presynaptic endings. This article presents the elements of the peripheral nervous system, new information about them and functions that can be further used in the study of the mechanisms of the occurrence of diseases and methods of treatment.

Kew Words: electron microscopy; peripheral nervous system; Golgi apparatus; myelin sheath; neuron

Introduction

When reviewing the extensive literature on electron microscopy of the peripheral nervous system, one can conclude that the main contribution of this method was the resolution of those problems that could not be solved with the help of light microscopy. This is true for many neural structures. Questions concerning the Nissl substance, the Golgi apparatus, neurofibrils, the myelin sheath, and synapses were largely resolved only after the electron microscope was applied to their study. However, many problems remain unresolved. It should be said that these problems arose in connection with the special nature of the neuron and the extreme length and complexity of the structure of its processes. At present, the electron microscope cannot give satisfactory answers to questions of this kind until the proper morphological "standards" have been established [2,8].

The application of the electron microscope to the study of the peripheral nervous system not only made it possible to resolve a number of questions that had arisen earlier, but also led to the emergence of many new ideas about the structure and functions. Here are just a few examples: the endoplasmic reticulum and protein synthesis, the myelin sheath as a derivative of the plasma membrane of Schwann cells and the interpretation of the structure of membranes in general, the structure of the nodes of Ranvier and its significance for jumping impulse conduction, the structural features of the synapse and the chemical identification of the contents of presynaptic endings. Electron microscopic observations related to these other issues have provided the basis for many new approaches to the study of the peripheral nervous system. And when the various nerve elements are sufficiently characterized in morphological terms, it is possible to launch an offensive from new positions and to more complex areas of the peripheral nervous system - ganglia of the autonomic nervous system, intramural plexuses in the intestine and receptor apparatus [8,25].

Methods

Most of the methods for preparing preparations for electron microscopy are generally suitable for studying the peripheral nervous system. Various mixtures with tetravalent osmium oxide are widely used as a fixative. When studying myelin and other cellular membrane structures, potassium permanganate gives a particularly good effect. As a standard method, fixation was used by immersing samples in a fixative, taking into account artifacts associated with the methods of isolating the studied nerve elements and depending on the speed of penetration of the fixative. Webster and Collins, using the central nervous system perfusion fixation method, perfused the whole animal with mixtures of O3O4 or glutaraldehyde followed by perfusion with O3O4. This usually results in excellent fixation,

somewhat better with O3O4 perfusion. For casting, a number of epoxy resins widely used for this purpose are used.

It cannot be argued that the best possible methods for preserving structure have already been developed. However, if the criteria for neural tissue are correct, it is clear that fixation by perfusion and embedding in epoxy resins provides uniform, high-quality fixation.

Descriptive part

A. Neurons

1. Cytoplasm

In the electron microscopic picture of the cytoplasm of a neuron, special attention is drawn to its density. While most vertebrate cells are largely similar to each other in terms of the structural components of their cytoplasm, the neuron stands out among them for the abundance of organelles it contains. Such a pronounced quantitative difference of the neuron in terms of the content of organelles, apparently, indicates a high activity of cells of this type. There are, of course, exceptions, which will be given below. Since various organelles have been discussed in other chapters, in our presentation we will limit ourselves to only those aspects of the structure of the cytoplasm that are characteristic only of the neuron [2,8,25].

2. Nissl substance. Of the long-standing problems of neurophysiology, it was precisely the question of the nature of Nissl's substance that was resolved with the greatest success with the help of an electron microscope. Comparing electron micrographs with adjacent thick sections stained with thionine, it was possible to describe the Nissl substance in terms that have a certain meaning [11]. Elucidation of its actual nature made it possible to confirm the data that the relative magnitude and mass distribution of this substance vary depending on the type of peripheral neuron. In spinal ganglion cells, Nissl bodies are larger and more evenly distributed than in ganglion cells of the autonomic nervous system. In other neurons, the Nissl substance is contained in small amounts, it is diffusely distributed and does not form compact bodies [11].

Apart from these rather superficial differences, it can be argued that Nissl bodies are accumulations of the granular endoplasmic reticulum. The granular reticulum consists of two components - flattened cisterns and ribonucleoprotein granules (ribosomes). Ribosomes are located either on the outer surface of the membranes that form cisterns, or between these membranes in the form of groups (rosettes) of 4-5 granules. The number of free ribosomes varies from cell to cell; it is believed that there are more of them in more active cells [8,11].

The developing cell of the spinal ganglion contains many free ribosomes and a granular reticulum cisterna. The postganglionic neuron is characterized by many ribosomal rosettes. The granular reticulum is not organized into discrete Nissl bodies, but diffusely distributed in the cytoplasm. A more mature spinal ganglion neuron contains discrete Nissl bodies. In the neuron, one can see the nucleus with a light granularity and a clearly defined nucleolus [8,11].

3. Golgi apparatus and other membrane systems. This organelle consists of three main elements, the number and size of which vary depending on the cell and its functional state. The agranular Golgi membranes form densely chained flattened cisterns, groups of small rounded vesicles and a small number of large vacuoles. The latter probably represent the widened ends of the cisterns [21]. Numerous chains of small vesicles and expanded cisterns are visible in the vast Golgi complex. It has been argued that the classical Golgi apparatus is in fact an artifact, since it is formed by a heavy metal precipitate. Let's admit that this sediment sketches a real structure consisting of the elements mentioned above [18].

Apparently, in all parts of the cell occupied by the organized Golgi, there is also a system of flattened tanks, tubules and small vesicles, which is called the agranular reticulum, since its membranes are not covered with ribosomes [18,21]. It is shown that this system, together with the Golgi zones and the granular reticulum, is related to the synthetic functions of the cell [8,18]. Although the role of this system in the synthetic activity of the neuron has not been specifically studied. Such groups are often found in close proximity to elements of the Golgi apparatus [21]. The function of this structure has not been established [18,21].

Structures have been recently described. It is assumed that here it performs similar functions. Another structure was found in various neurons - a group of concentric structures associated with the endoplasmic reticulum system in neurons of various types [21]. This is the flattening of the cisterns lying under the very plasma membrane of the body of the neuron; and were called subsurface cisterns. In the peripheral neurons studied so far, the most obvious examples of these structures can be found in the cells of the spiral and vestibular nuclei. The subsurface cisterns are over 1 micron in length with a lumen width of less than 0 A. They are usually separated from the plasma membrane of the neuron by only 50-80 A [8,18,21]. These cisterns are connected to the granular endoplasmic reticulum, although they are usually devoid of ribosomes. Their function is not exactly known, but it has been suggested that they play some role in the membrane phenomena that take place in the neuron [8,21].

4. Mitochondria. In neurons, mitochondria are usually smaller and the cristae are less regular than in other cells. However, in their general properties, they are quite identical to the mitochondria of any other cells [8].

5. Other organelles and inclusions. Neurons contain in varying amounts other cytoplasmic organelles and inclusions, which have already been described when considering other types of cells. These include multivesicular bodies, dense granular inclusions, large heterogeneous bodies resembling lysosomes, glycogen, lipofuscin pigment, basal bodies, and cilia [8].

6. Neurofilaments. In the perikaryon of a neuron, long thin filaments about 100 A thick are described. They cross the cytoplasm in all directions, forming a dense network [6]. It was concluded that neurofibrils detected with a light microscope after silvering by the Gross-Bilynovsky method are the result of the combination of neurofilaments into dense bundles and their encrustation with heavy metal [29].

B. Satellite cells

Both the body and the processes of peripheral neurons are surrounded by a layer of numerous satellite cells, or Schwann cells. Although the two names are synonymous, since indeed these cells are probably the same in origin and function, for practical reasons it seems reasonable to us to differentiate their use. We will call satellites those cells that form a shell around the body of the neuron and its dendrites, and Schwann cells - those that surround the axon [4,23].

The processes of the satellite cell, covering the body of the neuron, become very thin, so that in most areas the processes of several cells overlap each

other. As a result of this extreme thinning of the processes, no cytoplasmic components are visible in such places, except for a few vesicles or small mitochondria. Only when studying the wide perinuclear regions of the satellite cell, it is possible to consider the structure of its cytoplasm. Large accumulations of elements of the granular endoplasmic reticulum, Golgi membrane and mitochondria are visible in the perinuclear region, which indicates the high activity of these cells. Mitochondria are usually round and contain intramitochondrial granules. The outer (not facing the neuron) surface of the satellite cell is covered with a loose basement membrane. The satellite cells in the ganglia of the autonomic nervous system and the Schwann cells in the non-me dulled nerves were found to have cilia and basal bodies. The nucleus of a satellite cell is usually smaller and appears denser than the nucleus of a neuron. It sometimes contains lysosomes and pigment [4,23,28]. For the functional interaction of the satellite cell and the neuron, the nature of the adjacent surfaces of the cytoplasm underlying them and the intercellular space is of great importance. Between the neuron and the satellite cell that envelops it, there is a gap about 200 A wide, usually transparent to electrons and structureless. In these areas, the plasma membrane of the neuron is denser than the satellite membrane and sometimes has an irregular wavy contour. It is possible that this is due to differences in the structure of the membranes of these two cells. On the surface adjacent to the neuron, the plasmalemma of the satellite cell often forms deep invaginations. Similar blind invaginations can also be seen in the surface of the neuron; they are closely associated with subsurface cisterns [4,23,28]. In the perinuclear cytoplasm of the satellite cell, as well as in the processes of the Schwann cells around the axon, still parallel threads are visible, similar in appearance and thickness (100 A) to neurofilaments [4].

C. Processes of a neuron

1. Dendrite. The dendrites of the neurons of the autonomic ganglia are in many respects similar to the perikaryon in the organization of their cytoplasm [17]. Here, organelles such as mitochondria, granular endoplasmic reticulum and vesicles are found in abundance - both small (300-500 A) and large (700-1000 A). In some dendrites, a large fibrous body 1-3 microns in diameter was found, which consists of an accumulation of filaments 70 A thick, apparently connected at certain intervals by transverse bridges. Dendrites, like the bodies of neurons, are surrounded by a sheath of satellite cells that separate them from the extracellular space [17,20].

2. Axon. The axoplasm of the peripheral nerves has an extremely characteristic appearance on the cut [7]. This applies equally to the axons of myelinated and unmyelinated nerve fibers, and their most striking feature is the presence of many axoplasmic filaments [10]. These longitudinally running filaments are about 100 A thick and, apparently, are identical to those described in the body of the neuron. In the axoplasm one can often see formations of another type, arranged in the same way, these are either filaments or tubules. Their diameter is 200-300 A, and the contours are ring-shaped in cross section [7,10,16]. Along with these components, we find in the axoplasm many small, round or elongated mitochondria with a dense matrix, small vesicles, as well as cisterns and tubules of the agranular endoplasmic reticulum [10]. In many areas, the irregularly shaped cisterns seem to merge with each other, forming a continuous system of channels running along the axon [7,16].

3. Relationship between axon and Schwann cells. Axons are myelinated and non-myelinated. In the latter case, the relationship between the axon and the Schwann cell is very peculiar [27]. These relationships are fundamental to understanding the nature of the myelin sheath and myelin formation [13]. Understanding of these relationships was achieved only when an electron microscope was involved in their study. True, the general nature of the structure of the myelin sheath was predicted even before that on the basis of early studies of the birefringent properties of myelin in polarized light and X-ray diffraction analysis of a fresh nerve, but these were only indirect data, and, of course, they could not contain any information on the mechanism of formation of the myelin sheath. and the role of Schwann cells in this process [13,27]. The first electron micrographs of non-fleshy nerve fibers were presented by Gasser, who showed that, although the Schwann cell completely surrounds the axon, these are two completely independent formations separated by their own plasma membranes. Axons are embedded in deep grooves in the surface of the Schwann cell [13,27]. The edges of the Schwann Ian cytoplasm and its plasma membrane, covering the axon on both sides, close over it, and in this case, a paired membrane structure is formed, which Gasser called "mesaxonic" [27]. Such relationships are the general rule, and very few exceptions have been found in the study of a wide variety of peripheral nerves. Except for the endings and end sections, the non-fleshy fibers are encased in sheaths of Schwann cells throughout their entire length and therefore do not come into direct contact with the extracellular environment. Although it has not yet been clarified how things stand at the border of the Schwann cells located one behind the other along the fiber, the same close connection probably takes place here [13,27].

The degree of complexity of the relationship between the axon and the Schwann cell enveloping it can be very different. In some nerves, especially cutaneous nerves, only a few axons may be associated with each Schwann cell. In these cases, the me Saxons (M) may be short and straight, or strongly twisted and sinuous [8,27]. In other places, for example, in the posterior roots and olfactory nerves, large bundles of axons are sometimes found, and a separate branch of the mesaxonic goes to each such bundle [13]. Each of the main me Saxons branches many times, covering a large number of such bundles. In the intramural plexuses of the intestine, Schwann cells envelop many such axons, and each mesaxonic, branching many times, surrounds small groups of axons [8,13]. The axolemma of the unmyelinated axon, like the plasma membrane of the Schwann cell, is an elementary membrane 75 A thick. These membranes are separated by a gap 100-150 A wide. The accuracy of determining these dimensions is essential for the problem of myelin formation and for understanding the nature of the myelin sheath.

D. Myelin formation

After clarifying the fundamental nature of the relationship between the Schwann cell and the unmyelinated axon, the problem of the formation of the myelin sheath remained unresolved. Guerin's observations on the myelination of nerves in the chick embryo, confirmed by Robertson in other animal species, led to her decision. During the formation of myelin, the following process occurs in general terms. At an early stage of its differentiation, the future myelinated axon is located in the deepening of the surface of the Schwann cell. The process of its "wrapping" by the Schwann cell begins, and in the end the axon is wrapped in this cell and connected to its surface by the mesaxonic. Thus, at this stage, we see the same picture as was described for the myeline’s fiber, but with the essential difference that each Schwann cell usually encloses only one axon here. The extracellular space between the two sheets of the plasma membrane, which form the mesaxonic, still retains a width of about 100-150 A at the early stages. Soon this gap closes, and the outer surfaces of the plasma membrane of the Schwann cell come into contact with each other, forming a five-layer

structure like a double elementary membrane about 150 A thick - the so-called outer complex membrane [5,19,25].

Subsequent steps in this process involve the growth and elongation of the mesaxonic, which spirals around the axon in many roll-like layers. Initially, the mesaxonic coils are separated from each other by the cytoplasm of the Schwann cell, which creates another gap, this time cytoplasmic. Soon this gap closes and successive turns come into close contact with each other. The resulting layer of tightly adjacent cytoplasmic surfaces of the Schwann cell membranes forms the “main dense line” of the mature myelin sheath [19,25]. The layer formed as a result of the contact of the outer surfaces of these membranes constitutes the "intermediate" line. Thus, compact myelin consists of spirally laid plates that form a repeating structure in the radial direction with a period of about 120 A (the distance between the axes of the main dense lines). This period is divided into two equal parts by an intermediate line [25]. The outer mesaxonic is preserved so that the myelin plates continue to pass without interruption into the plasma membrane of the Schwann cell. One of the most important findings from these observations is that the myelin sheath is formed directly from the plasma membrane of the Schwann cell. As we shall now see, this is of great importance in connection with the problem of the structure of the plasma membrane [5,25].

There are still a number of questions concerning the specific nature of the mechanisms of myelin formation. First of all, the question arises of how the mesaxonic coils of the Schwann cell around the axon are formed. The true rotation of this cell around the axon is very unlikely, especially since there can be several myelinated axons in one Schwann cell. The most plausible explanation is that the mesaxonic itself grows and this leads to its introduction into the cytoplasm of the Schwann cell along a spiral path and, thus, to winding it around the axon. The location and mechanism of this membrane growth remains the subject of much conjecture, and the lack of a complete solution to this question has led to a divergence of opinion regarding the structure of the plasma membrane [5,19,24,25.

E. Myelin sheath of the peripheral nerve

With this knowledge of the process of myelin sheath formation, we can now better understand the structure of the fully formed myelin sheath, as well as draw some conclusions about the structure of the elementary membrane.

The optical properties of the myelin sheath in polarized light have long been known. In a series of detailed studies, Schmidt put forward the idea that the myelin sheath consists of thin layers of lipid molecules, the long axes of which are oriented radially with respect to the axon. Between these lipid molecules, according to Schmidt, are protein molecules with long axes directed tangentially with respect to the axon. Later quantitative studies in polarized light largely confirmed these assumptions [19,24,25].

Based on the analysis of X-ray diffraction at small angles, it was possible to develop this concept and determine the exact dimensions of the radial repeating unit. For a fresh peripheral nerve of a mammal, a period of about 180 A was found. In a dried nerve, this period is approximately 20-30 A less. As a result of optical studies, a model of a repeating period was proposed - a structure of two bimolecular lipid layers separated by protein monolayers. Finian put forward another similar idea about the repeating structural unit of myelin; according to this idea, there are two bimolecular lipid layers, the polar surfaces of which are covered with protein monolayers. To explain the measured value - 171 A (the peripheral nerve of the frog) - Finian included an unknown "difference factor" in the structure, which would otherwise be symmetrical and thus create a period equal to half the actually measured value [19,24,25].

The first electron microscopic studies of the myelin sheath were carried out by Fernandez-Moran and Sjostrand. As a result of a number of subsequent works, the now generally accepted idea of the structure of the fully formed myelin sheath of the peripheral nerve has developed. This idea is based on the study of preparations fixed both with O3O4 and with permanganate; in both cases very similar images are obtained. The strikingly regular structure of the myelin sheath consists of a series of dense lines about 30 A thick; the distance between their axes, i.e., the value of the repeating period, is about 120 A (on some preparations up to 150 A). These are the main dense lines. In favorable cases, especially after permanganate fixation, it can be seen that this main period is subdivided by a less dense intermediate line about 30 Å thick. as a result of the closure of its outer surfaces. This is where the discrepancy is observed: the addition of two membranes with a thickness of 75 A each should create a repeating period of not 120 A, as established by measurements, but 150 A. Although there is still no definite solution to this problem, it has been suggested that the plasmalemma is partially merge and this leads to a decrease in the total thickness [5,19,24,25].

Another discrepancy is found when comparing the period found from the data of X-ray diffraction analysis (180 A) with the electron microscopic image (120 A). This difference was explained by compression occurring during fixation, dehydration, embedding, and sectioning [8,24,25].

Because myelin is derived from the plasma membrane of the Schwann cell, the putative molecular structure of the myelin sheath has been extrapolated back to the corresponding layers of the plasma membrane. The models proposed for the structure of an elementary membrane basically consist of a bimolecular layer of lipids, the polar groups of which are adjacent to protein layers or one protein layer and one polysaccharide layer. This latter is probably due to Finean's "difference factor"; but instead, the model can be made more asymmetric by adding a third layer of protein near the cytoplasmic surface. When evaluating hypothetical ideas about the elementary membrane based on data on the structure of the myelin sheath, a certain caution is necessary, as Fawcett pointed out. It is possible that during the formation of a new membrane material during myelination, some components of the usual plasma membrane are lost or, conversely, something is added [5,19,24,25].

The structure of the node of Ranvier follows quite logically from the way the myelin sheath is formed. To understand the structure of the intercept, you need to understand that the length of the myelin helix (along the axis of the fiber) changes from one turn to another. The coil adjacent to the axon is the shortest, and as it approaches the surface of the myelin sheath, the length of the coils gradually increases. Thus, near the junction, the myelin plates sequentially peel off from the compact mass of myelin, starting from the innermost one. At the intercept, the outermost layer ends, and here only the cytoplasm of the Schwann cell remains above the axon [8,25].

In each of those areas where the plates, bending, depart towards the axon, the main dense line splits and the cytoplasm of the Schwann cell (SC) appears in the gap. Here, in essence, the relations that took place in the process of development after the formation of the mesaxonic until the closure of the cytoplasmic gap are preserved. In this gap of the Schwann Ian cytoplasm there is little o and it often contains small sweat granules of about 100-150 A [24]. Between the Schwannian Maspalomas and the axolemma there is a small gap less than 100 A wide, and in some places one or two light

intermediate lines can be seen here, as in a "tight connection ". In a peripheral nerve in the interception area, the surface of the axon is usually not bare, since two adjacent Schwann cells, linked by their processes, form a continuous sheath around it [24]. In smaller fibers, this axolemma almost directly contacts the extracellular space. In addition, in thicker fibers, the non-myelinated area in the interception area may be about 0.5 microns thick, while in thinner axons, its length can reach 2-3 microns. Thus, in the nodes of Ranvier, the axolemma is either separated from the extracellular space only by a plexus of processes of Schwann cells, or, in the case of thinner axons, is in almost direct contact with it. The significance of these morphological facts for ideas about the mechanism of bringing the action potential is obvious [8,24,25].

Near the point where myelin ends, the thickness of the axon usually changes slightly, while in the region of the intercept itself, the axon may be thicker. In the axoplasm, clusters of small mitochondria, neurofilaments, small vesicles, elements of the agranular reticulum of small granules are visible here [8,10,16,24,25].

Schmidt-Lanterman notches, which have long been controversial, are now recognized as real structures; they are actually funnel-shaped tears in the myelin sheath. The axon is enclosed in a sheath of Schwann cells (SCs) [24]. The section was "stained" with phosphotungstic acid; therefore, the collagen fibrils of the endoneurium look very dense. The endoneurium is surrounded by bodies and flattened processes of fibroblasts. In these structures, the myelin plates are stratified along the main dense line, and the cytoplasm of the Schwann cell appears in the gaps. Thus, although ruptures are possible in myelin, the plasmalemma and cytoplasm of the Schwann cell retain their continuity. For this structure, no obvious functional significance can be established, and it is inclined to be considered a defect that occurs in the course of development due to mechanical stress experienced by the nerve fiber [24].

Here we should mention another type of myelin sheath - the myelin sheaths of the bodies of neurons in the nucleus of the VIII cranial nerve. This sheath, formed by satellite cells, differs in some respects from the myelin of nerve fibers. First of all, it has a very irregular structure - typical myelin plates, interspersed here with thin layers of cytoplasm. Myelin plates split in places, suddenly end in blind loops or turn in the opposite direction. They are compact or loose. In addition, myelin layers are formed by more than one satellite cell. These facts seem to indicate that this type of myelin is not formed from a single satellite cell in an orderly manner, as occurs in the internodes. Although the precise mode of its formation is not known, it is certain that this process is associated with a complex irregular intertwining of several satellite cells and with incomplete fusion of their membranes into myelin plates [8,24,25].

F. Peripheral nerve endings

1. Synapses. The detailed structure, varieties, and functional significance of synapses and synaptic structures will be more fully considered in the next chapter. In the peripheral nervous system, the structural elements of synapses have been studied in the sympathetic ganglia, the ciliary ganglion, intramural intestinal plexuses, and other places [8,15]. In all these cases, whether it is an axon ending on a soma or a dendrite, or a postganglionic ending, a striking uniformity of structure is observed [15]. Two plasma membranes in a synapse or in a nerve ending are separated by a gap of 60 to 200 A or more, depending on localization. Occasionally, vague seals can be seen in this gap. One or both membranes adjacent to each other may have an increased density [8,15]. Usually, the terminal section of the axon expands and contains a group of small vesicles 300-500 A in diameter - the so-called synaptic vesicles. In addition, in many places, but in a smaller number, larger bubbles (about 1000 A in diameter) containing a dense central mass are found [15]. These bubbles with a dense "core" are especially noteworthy in the postganglionic endings; they are believed to have something to do with the catecholamines. Small mitochondria, although usually present, are not as ubiquitous as the vesicular elements of the cytoplasm. Axons are covered with Schwann sheaths to the very endings [15].

2. General sensitivity receptors. Receptors of general sensitivity have endings of a peculiar type. While it cannot be said that true synapses exist here, the structure of the nerve endings bears a strong resemblance to what we see in synapses. Usually, these receptors are characterized by the presence of one or more supporting or receptor cells. Nerve fibers, losing their myelin sheath (if any), enter the receptor and form terminal extensions on the receptor cells present here. These extensions contain many small vesicles and small, dense mitochondria. As we saw in the previous section, these are the two hallmarks of a synapse [3,8].

An example of such a structure is the taste bud. It is made up of two types of cells [3,8.14,22]. One type of cell is the supporting cell, so named because it envelops the nerve fibers from where they enter the kidney to where they end. In this respect, the supporting cell is completely analogous to the Schwann one in its function. It is possible that it even represents a derivative of the Schwann cell. The second type of cells are taste receptor cells, equipped with apical microvilli and densely granular cytoplasm. The fiber of the trigeminal nerve ends on this cell in the form of an extension containing many small (300-600 A) vesicles and mitochondria. This area, on the basis of its ultramicroscopic morphology, is considered as a synapse, although this is not consistent with the strict physiological definition of the concept of a synapse, since there is no impulse transmission here. It is interesting, however, to note that the characteristic synaptic structures are located in that of the contact formations, which would be the postsynaptic element [3,8,14].

The structure of the olfactory epithelium is in many respects much simpler than that of the taste bud, since the primary neuron, the olfactory receptor cell, lies within the mucosa. The dendritic region of the receptor cell, heading towards the surface of the epithelium, ends in the form of a rod covered with cilia. The proximal processes of these cells are axons that form olfactory filaments [22]. Within the epithelium, these axons are sheathed by two other types of cells, supporting and basal. In the basal layer of the epithelium, axon bundles are surrounded by Schwann cells, which form a typical structure with a mesaxonic [3,8,14].

We find a great resemblance to the taste bud in the Pacini corpuscles [1,9,12]. These little bodies consist of numerous cytoplasmic plates located concentrically in the outer zone, and bilaterally in the inner zone. These lamellar structures are thought to originate from fibroblasts and not from Schwann cells. The myelinated nerve fiber, approaching the body of Pacini, first loses its myelin sheath, and then the sheath of Schwann cells, so that its expanded ending is in direct contact with the most centrally located plate of the inner flask of the body. The axoplasmic components of these endings also resemble the structures contained in the true presynaptic element. Along the entire perimeter of the nerve fiber, there are numerous small mitochondria and many bubbles 500 A in diameter. Thus, we find here the morphological features of the synapse, with both characteristic components (mitochondria and vesicles) contained in the putative postsynaptic element. Of course, in the absence of decisive physiological data, the relationship between the unmyelinated nerve ending and the lamellar cell in the Pacini body cannot be called a synapse [1,9,12].

Meissner's corpuscles consist of a "package" of flattened tactile (lamellar) cells that form a series of transverse layers. Nerve fibers, losing their myelin sheaths upon entering the body, pass in winding paths between flat cells. Nerve endings are surrounded by a complex interweaving of processes of tactile cells. The terminal nerve fiber can form several successive extensions [1,8,9,12].

Expanded terminal sections of nerve fibers contain many small dense mitochondria and small vesicles (400-500 A). Groups of small bubbles are scattered inside the nerve ending, and in the tactile cell, some bubbles are located along the plasma membrane. The axolemmas of these nerve endings seem to be closely attached to the plasma membranes of the tactile cells. In some cases, both adjacent membranes are thickened, and near these thickenings there is a concentration of small bubbles - both in the tactile cell and in the nerve ending. Such a picture, as in the previously described receptors, has morphological signs of a synapse. However, we do not have data on the transfer of the membrane potential through this compound. An interesting fact is that the distribution of small "synaptic" vesicles on both sides of the proposed synapse does not reveal a mutual correspondence [8].

The sensitive endings of the muscle spindle are also characterized by a terminal expansion filled with small mitochondria and many small vesicles. The axolemma comes into close contact with the sarcolemma. As in the previous cases, if here one can "talk about" a "synapse", then the characteristic structures are in the postsynaptic element. Thus, the morphological polarity is reversed. The current level of our knowledge of general sensitivity receptors does not allow us to more closely connect the available morphological, physiological and pharmacological data. However, in view of their size and accessibility, these nerve formations, apparently, can serve as a convenient object for appropriate studies [1,8,9].

Conclusion

Thus, the main contribution of electron microscopy was the solution of problems concerning Nissl's substance, the Golgi apparatus, neurofibrils, myelin sheath and synapses. However, many problems remain unresolved due to the special nature of the neuron and the complexity of the structure of its processes. The use of an electron microscope led to the emergence of ideas about the structure and functions of the endoplasmic reticulum, protein, myelin sheath, Schwann cells, nodes of Ranvier, synapses, and the contents of presynaptic endings. This article presents the elements of the peripheral nervous system, new information about them and functions that can be further used in the study of the mechanisms of the occurrence of diseases and methods of treatment. Also, with the knowledge of the process of myelin sheath formation, we can now better understand the structure of the fully formed myelin sheath, as well as draw some conclusions about the structure of the elementary membrane.

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