A nerve fiber signifies an axon and its envelopes. Two types of nerve fiber exist—myelinated and unmyelinated. Myelinated, rapidly conducting nerve fibers have a diameter of 1–20 μm and are up to 1 m long. In a transverse section stained to show the myelin sheath, the nerve fiber (Fig. A1) appears as a dark circle with a pale centrum, representing the axon (Figs. A2, B2). The Schwann's cells (Figs. A3, B3) surround the whole structure in the form of a signet ring. In routine preparations, the lipid-containing myelin sheath is dissolved, leaving only a sponglike neurokeratin material (Fig. B4), corresponding to the proteinaceous components of myelin. In longitudinal sections, the axon (Fig. C1), the myelin sheath (Fig. C2), and the Schwann's cell (Fig. C3) can be distinguished. Nodes of Ranvier (Fig. C4) are present in the peripheral (PNS) and central (CNS) nervous systems at points where the myelin sheath is interrupted. The internode (Fig. C5) is an approximately 50 μm–1-mm-long segment between two nodes of Ranvier and corresponds to one Schwann's cell (or one oligodendrocyte process in the CNS, see Plate 146). The pale, oblique lines within the myelin sheath, the Schmidt-Lanterman incisures (Fig. C6), are almost exclusively restricted to nerve fibers of the PNS.

In the electron microscope, transversely sectioned nerve fibers are seen to comprise, proceeding from the center to the exterior, the axon with neurofilaments (Fig. D1), neurotubules (Fig. D2), cisternae of smooth endoplasmic reticulum (Fig. D3), and mitochondria (Fig. D4). The axon is delimited by the axolemma (Fig. D5), separating it from the myelin sheath (Fig. D6). The myelin sheath is composed of numerous myelin lamellae, which originate from the plasmalemma of the Schwann's cell. The exact manner in which these lamellae wrap around the axon is not precisely known. It is clear that the myelin sheath is a component of the Schwann's cell.

Schwann's cells (Fig. D7), which represent the inner envelope of the nerve fibers, sometimes called the neurolemma, belong to the peripheral glia and have an ellipsoidal nucleus, poorly developed organelles, but a large number of free ribosomes. Two closely apposed cell membranes of the Schwann's cell on the left form the external mesaxon (Fig. D8), which runs through the Schwann's cell cytoplasm. The outer nerve fiber sheath or endoneurial sheath, which only occurs in the PNS, is made up of the basal lamina (Fig. D9) of the Schwann's cell and a network of reticular and collagen microfibrils (Fig. D10). Part of the basal lamina has been lifted back so that the fingerlike processes (Fig. D11) of Schwann's cells are exposed in the region of the node of Ranvier (Fig. D12). Whereas in myelinated nerve fibers only one axon is contained within one Schwann's cell, in unmyelinated nerve fibers this cell embraces several axons (Fig. D13). The axons usually possess a mesaxon (Fig. D14), though many occur as so-called naked axons (Fig. D15). Unmyelinated fibers are not segmented (see Plate 146), but in the PNS they have an endoneurial sheath consisting of a basal lamina (Fig. D9) and interlaced collagen and reticular microfibrils (Fig. D10). There are no morphological criteria that allow a differentiation to be made between afferent and efferent nerve fibers. (See plates 86–88 in Kestin 1979.)

Magnifications: Figs. A–C, ×2,000; Fig. D, ×14,000

REFERENCES
Plate 165. Nerve Fiber. Node of Ranvier

The small drawings at the bottom right show the light-microscopic appearance of the node of Ranvier following azan staining (Fig. A), osmium fixation (Fig. B), and silver staining (Fig. C). In the latter method, diffusion of the silver nitrate produces a cross (Ranvier’s cross, Fig. C1) in the region of the node.

Between the myelin-free paranodal end portions of two Schwann’s cells (Fig. D1), the axon (Fig. D2) becomes slightly thickened. At this point, the axolemma (Fig. D3) comes into contact with the interdigitating processes (Fig. D4) of Schwann’s cells and of the basal lamina (Fig. D5) of nerve fibers. Thus, in this region the axon directly contacts the endoneurial sheath. The interior of the axon contains neurofilaments (Fig. D6), neurotubules (Fig. D7), and cisternae of smooth endoplasmic reticulum (Fig. D8). (Mitochondria are not depicted.) Cytoplasmic processes (Fig. D9) from the Schwann’s cells appose the external surface of the axon. These processes are separated from one another by mesaxons (Fig. D10) and connected with the axolemma by means of dense bars (Fig. D11). On the external surface of the axon, the cytoplasmic processes are fluted in a spiral fashion (Fig. D12). In the upper Schwann’s cell, a few mesaxons and processes have been partially removed. Here it is apparent that the innermost myelin lamellae are the shortest, and thus it may be assumed that the rolling of the myelin lamellae proceeds roughly according to the mechanism depicted in Plate 155. In both Schwann’s cells, the external mesaxons (Fig. D13) and the fibrous elements of the endoneurial sheath (Fig. D14) outside the basal lamina (Fig. D5) are evident.

The velocity of propagation of stimuli varies between 0.5 and 120 m/s in myelinated nerve fibers. It is dependent on the structure of the particular nerve fiber. In myelinated nerve fibers, all excitatory and conducting processes of the action potentials occur at the nodes of Ranvier. The action potential jumps from one node to the next, a phenomenon termed saltatory conduction. The myelin sheaths of the internodal segments can thus be regarded as a form of insulation. (See Plate 88 in KRSTIĆ 1979 and physiology texts for further information.)

Magnifications: Figs. A–C, ×900; Fig. D, ×55,000

REFERENCES
Plate 166. Nerve Fiber. Schmidt-Lanterman Incisures

As already seen in Plate 164, Schmidt-Lanterman incisures are found within the myelin sheath of peripheral nerve fibers. The morphology of these incisures is dependent on the preparation and staining techniques employed. Thus, for example, Fig. A shows the incisures following OsO₄ fixation and Fig. B after iron hematoxylin staining. In Fig. B, the incisures correspond to the so-called Golgi funnels, which delimit the Schmidt-Lanterman segments (Fig. B).

In the electron microscope, the Schmidt-Lanterman incisures appear as zones in which the myelin lamellae (Fig. C1) run separately. Cytoplasm of the Schwann's cell occurs between the lamellae. An external mesaxon (Fig. C2), the basal lamina (Fig. C3), and the endoneurial sheath (Fig. C4) are also represented. The function of the Schmidt-Lanterman incisures is still uncertain. It remains to be clarified whether they impart plasticity to nerve fibers during bending, stretching, etc. The fact that these structures almost never appear in the CNS, i.e., where nerve fibers are not subject to mechanical force, would support this hypothesis.

Magnifications: Figs. A, B, x 2,000; Fig. C, x 55,000

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Severing of nerve fibers immediately leads to loss of the ability to conduct impulses and within a few weeks the fibers degenerate. Nonetheless, nerve fibers are capable of regeneration under certain circumstances. The process is depicted in this plate.

Following separation of an axon (Figs. A1-E1) from the body of the nerve cell (Figs. A2-E2), the myelin sheath becomes fragmented during the first 3 days and after about 2-3 weeks transforms into plaqulike fatty droplets (Figs. A3, B3). Simultaneously, the severed axon disintegrates. This secondary or Wallerian degeneration extends as far as the sensory and motor nerve endings (e.g., motor end plates, Figs. A4-E4). Schwann's cells (Figs. A5-E5), on the other hand, do not degenerate. Cross sections through the disintegrating nerve fibers appear in small drawings to the left of the main figures. Severance of the axon can affect the perikaryon of the nerve cell, causing it to swell. The Nissl bodies disappear (chromatolysis or tigrolysis), and the nucleus is displaced toward the cell membrane ("fish-eye cells"). Provided the damage does not occur in the immediate vicinity of the perikaryon, the nerve cells recover rapidly from the trauma. The ascending degeneration of the nerve fibers extends to the next node of Ranvier (R).

From the 2nd week to the 2nd month after injury, the myelin sheath lipids gradually become broken down, phagocytized by microglia in the CNS or by macrophages (Fig. B6) in the PNS, and transported away. The Schwann's cells at the ends of the proximal and distal stumps begin dividing and approach one another as early as the 1st week (arrows). This gives rise to the bands of Büngner (Fig. B7), which as tubular glial strands bridge the gaps. The axon (Fig. C1) growing from the proximal stump utilizes these glial strands to locate the target organ. As the axon advances - about 1-2 mm/day - through the glial strands, it becomes invested by a myelin sheath. During this regeneration phase, which can last up to 3 months, muscle fibers (Fig. C8) as well as other effectors atrophy owing to inactivity.

Contact with the target organ is initially reestablished by a thin, weak, myelinated axon (Fig. D1). In the course of the maturation phase, which can last a few months, the diameter and performance of the regenerating nerve fiber increase.

In the case of amputation or large-scale destruction of nerve fibers without surgical intervention, connective tissue inserts itself between the stumps, such that the glial strands cannot form a bridge over the gap. The proximal Schwann's cells then proliferate and, with the outgrowing axon and adjacent connective tissue, form a swollen structure, the so-called amputation neuroma (Fig. E9).

In humans, nerve fibers of the CNS are incapable of regeneration.

REFERENCES

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Plate 168. Synapses. Classification

The intercellular contact sites where impulses are transmitted from one neuron to another, or from a neuron to the target organ, are termed synapses. They are classed according to their mode of function into electrical (Fig. A) and chemical (Figs. B—F) synapses. The latter type is the more widely distributed.

Electrical or electrotonic synapses (Fig. A), the morphology of which corresponds to that of a nexus, are particularly frequent in muscular tissue (see Plates 119, 120, 136, 137), though relatively uncommon in nervous tissue. Where these synapses occur, the electrical resistance of the plasmalemma is very low, and this favors impulse conduction.

The relatively rare chemical synapses, synaptic bars (Fig. B), are found, as already indicated in Plate 158, in the receptor cells of the vestibulocochlear organ and otoliths (Fig. D). They are made up of an osmiophilic, 180- to 320-nm-long and about 35-nm-wide bar (Fig. B2), surrounded by synaptic vesicles (Fig. B1). It is not known what transmitter substance is contained in these bar vesicles (Fig. B3). According to some sources, it could be gamma-aminobutyric acid (GABA).

Synaptic ribbons (Fig. C1) are also a rare type of chemical synapse found in the axon endings of the rod and cone cells of the retina (Fig. C2). The nature of the transmitter in the surrounding synaptic vesicles has not been defined with certainty.

The most widely distributed chemical synapses are those with boutons terminalis. The synapse here consists of a broad presynaptic portion of axon, the bouton terminal itself (Fig. D1), a synaptic cleft (Fig. D2), and a postsynaptic element (Fig. D3). The widened terminal portion of the axon contains mitochondria, cisternae of smooth endoplasmic reticulum, neurofilaments (Fig. D4), neurotubules (Fig. D5), and two types of synaptic vesicle. One kind of vesicle is small and apparently empty (Fig. D6), the other type is significantly larger (Fig. D7), but much less frequent and filled with a fine-granular, highly osmiophilic substance. The neurotransmitter acetylcholine has been identified in the former, and 5-hydroxytryptamine (serotonin) or possibly dopamine in the latter. A presynaptic density (Fig. D8) borders the synaptic cleft.

The synaptic cleft is approximately 20 nm wide and filled with a fine-granular, weakly osmiophilic material. The adjacent postsynaptic membrane (Fig. D9) features a feltlike dense region, the postsynaptic density (Fig. D10). Since the vesicles in these synapses are spherical, they are referred to as S-type or type I synapses (after Gray).

In the F-type of synapse with a narrower and almost completely empty synaptic cleft (Fig. E1), the synaptic vesicles are predominantly flattened (hence F-type synapse), slightly biconcave, and with an unknown transmitter. This type of synapse is also referred to as type II (after Gray).

In the synapses thus far described, impulses are only transmitted in one direction, i.e., from the presynaptic portion to the postsynaptic portion. In reciprocal synapses (Fig. E), however, the impulses can travel in both directions. This latter type of synapse is rare, it has been described in the olfactory bulb of dogs.

The mode of action of chemical synapses may be summarized as follows. When an impulse arrives, the synaptic vesicles release their neurotransmitter into the synaptic cleft. The postsynaptic membrane thus becomes depolarized and the information from one cell is transferred to the other. The morphological appearance of the vesicles does not allow a definitive conclusion to be made regarding the function of the particular synapse. It is now known that the majority of acetylcholine-containing type I synapses have excitatory effects. Conversely, the tempting hypothesis of an inhibitory action of type II synapses requires further investigation. (See Plates 119-128 in Kandel's 1979 and physiology texts for further information.)

Magnifications: Fig. A, x 100,000; Fig. B, x 40,000; Fig. C, x 30,000; Figs. D—F, x 33,000

REFERENCES


Plate 169. Simplified Classification of Interneuronal Synapses
(Modified from Andres 1975)

The boutons terminaux are basically capable of ending on the body or soma (S), dendrites (D), and axons (A) of a nerve cell, and accordingly it is possible to distinguish axosomatic, axodendritic, and axoaxonic synapses. These, in turn, can be subdivided into various combinations depending on the morphology of the point of contact and the relationship with the boutons terminaux.

Thus, the following can be found on the soma:
1. Simple axosomatic synapses
2. Invaginated axosomatic synapses
3. Axosomatic spinous synapses;

On the dendrites:
4. Simple axodendritic synapses
5. Axodendritic spinous synapses
6. Crest synapses
7. Branched spinous synapses
8. “En passant” synapses
9. Axodendritic reciprocal synapses
10. Polysynaptic endings
11. Interdigitated spinous synapses; On the axon hillock:
12. A xoaxonic synapses
13. A xoaxonic inhibitory synapses (morphologically difficult to distinguish);
14. A xoaxonic synapses
15. “En passant” synapses.

It should here be stated that this classification of synapses is not exhaustive. (See Plates 119-125 in Kristić 1979.)

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Plate 170. Structural Elements of the Peripheral Nervous System

From a histological point of view, the following parts of the PNS are important:
1. Spinal ganglia
2. Spinal nerves
3. Peripheral nerve endings
   3a. Efferent (motor end plates, autonomic nerve endings)
   3b. Afferent (neuromuscular spindles, Golgi tendon organ, terminal corpuscle)
4. Sympathetic trunk with its ganglia (4a) and prevertebral sympathetic ganglia (4b).

The following is a brief description of the neuronal connections between components of the PNS. Arrows indicate the direction of impulse conduction.

Axons (5) of the large, multipolar motor neurons (6) in the anterior gray column of the spinal cord make up the major portion of the peripheral nerves (2) and innervate the skeletal musculature as efferent nerve fibers.

From the sympathetic nerve cells (7) in the intermediolateral nucleus of the lateral gray column of the spinal cord, axons run through the white rami communicantes (9) to the ganglia of the sympathetic trunk (4a) or continue further to the prevertebral ganglia (4b). Axons of the sympathetic neurons (7) of the spinal cord synapse with dendrites of multipolar nerve cells (10) in the ganglia of the sympathetic trunk (4a). From here, the postganglionic unmyelinated axons of the multipolar nerve cells enter the spinal nerve via the gray rami communicantes (11). These axons (interrupted line) assure the autonomic innervation of glands, muscles, etc. (3a).

Postganglionic nerve fibers run from the prevertebral ganglia (4b), e.g., celiac ganglion, superior mesenteric ganglion, etc. to the inner organs (e.g., intestinal tract), where they synapse with intramural ganglion cells (12).

From the periphery, i.e., via sensory nerve endings (3b) of various types (free and encapsulated nerve endings, neuromuscular spindle, Golgi tendon organ), afferent impulses are transmitted along nerve fibers to pseudounipolar ganglion cells (13), located in the spinal ganglia (1). From here, the stimuli are transmitted via the celluli- fugal branch (14) of the T-process to the spinal cord, where a few collaterals (15) join the motor neurons (6). In this way, a simple reflex arc is formed. (See anatomy texts for further information.)

REFERENCES
A spinal ganglion (Fig. A1) is included within the posterior root (Fig. A2) of the spinal nerve and possesses a bilaminar capsule. The inner layer is a continuation of the arachnoid membrane (see Plate 174), which as the perineurial epithelium (Fig. A3) extends over the spinal ganglion and nerve. The outer capsule layer (Fig. A4), composed of dense connective tissue, stems from the dura mater (see Plate 174) and is gradually continuous with the perineurial connective tissue and epineurium (Fig. A5) of spinal nerves. The anterior (Fig. A6) and posterior roots together form a spinal nerve (Fig. A7). The perineurial epithelium (Fig. A3) has been partially removed so as to expose its lamination and the flattened cells (Fig. A8) of the surface facing the ganglion. The space (Fig. A9) between the capsule and tissue of the ganglion has been drawn wider for the sake of clarity. The spinal ganglion cells (Fig. A10) occur in clusters in the ganglion interior. Many nerve fibers (Fig. A11) run between the groups of cells. After routine staining, ganglion cells (Fig. B1) appear round with a diameter of up to 100 µm. They are characterized by a spherical, clear nucleus (Fig. B2) with a very well-developed nucleolus (Fig. B3), and the cytoplasm contains Nissl bodies and lipofuscin granules (Fig. B4). Sections occasionally reveal a pale axon hillock (Fig. B5). Satellite cells or amphotocytes (Fig. B6) encapsulate the ganglion cells. Since the contact between the two is not particularly firm, ganglion cells sometimes become detached from the amphotocytes as a result of the shrinkage (Fig. B7) induced by fixation. Loose connective tissue of the endoneurium (Fig. B8), containing unmyelinated and myelinated nerve fibers (Fig. B9), is found outside the satellite cells. Following silver staining, many neurofibrils (Fig. C1) and, in particular, their forked T-processes (Fig. C2) can be seen in the perikarya of the spinal ganglion cells. Numerous nerve fibers (Fig. C3) appear as black lines in the endoneurium.

Magnifications: Fig. A, ×20; Figs. B, C, ×350

REFERENCES
The body of a nerve cell contains a large nucleus with a nucleolus, scattered Nissl bodies (1), very extensive Golgi fields (2), and numerous mitochondria and lysosomes. Neurofilaments and neurotubules constitute cytoskeletal components. Satellite cells (3) closely surround the perikaryon of nerve cells and there is no intervening basal lamina. In profile, satellite cells appear flattened and in plan view are seen to be stellate, highly interdigitated cells with a heterochromatin-rich nucleus, osmiophilic cytoplasm, and sparse organelles. They are separated from the endoneurium by a basal lamina (4), to which the fibrous structures (5) of the loose endoneurial connective tissue adhere. In the direct vicinity of the nerve cells are scattered fibrocytes (6), capillaries (7), and several myelinated (8) and unmyelinated (9) nerve fibers. Each of these structures of course has its own basal lamina. As shown in the light-microscopic image of the previous plate, pseudounipolar nerve cells have a T-shaped process (10), partially covered by satellite cells. This process has been drawn considerably shorter here owing to lack of space.

It can be observed that the two horizontal T-branches are enveloped by a Schwann's cell (11), which supplies them with a myelin sheath (12). A pseudounipolar ganglion cell is thus morphologically a biaxonal element. The impulse-conducting (afferent) process deriving from the periphery can only be electrophysiologically defined as a dendrite (13), and that running into the spinal cord as an axon (14); this distinction cannot be made morphologically.

Magnification: \( \times 5,500 \)

REFERENCES


Plate 173. Bipolar Nerve Cell from Corti’s Ganglion

Unlike other ganglion cells of the organ-
ism, the bipolar nerve cells of Corti’s or
the spiral ganglion are invested by myelin
lamellae. These bipolar ganglion cells are
well protected by the bony pillar of the
cochlea, the modiolus (Fig. A1). Their
dendrites extend to the hair cells, and the
ascending axons contact the nerve cells of
the acoustic nuclei in the rhomboid fossa
(see anatomy texts for further informa-
tion).

Staining of the myelin sheaths (Fig. B1)
reveals that not all cells of the spiral
ganglion are myelinated. In the surround-
ing endoneurium (since although these
take cells are deeply embedded in skull
bone they belong to the PNS), myelinated
nerve fibers (Fig. B2), loose fibrous con-
nective tissue, and blood capillaries are
found.

Ganglion cells are spindle-shaped and
have only two processes – a dendrite
(Fig. C1) and an axon (Fig. C2). The cell
body contains a spherical, frequently in-
dented nucleus with dispersed chromatin
and a large nucleolus. As in every nerve
cell, Nissl bodies are numerous, spreading
into the dendrite but not into the axon hil-
lock (Fig. C3).

Large numbers of other organelles occur
in the bipolar ganglion cells. A few lyso-
somes and residual bodies are found be-
tween the ergastoplasmic cisternae.

The outer surface of bipolar cells is
covered by myelin lamellae (Fig. C4) fur-
nished by Schwann’s cells (Fig. C5). This
envelope continues over the dendrite and
axon and thus makes it morphologically
difficult to differentiate the two. As stated
previously, Schwann’s cells are separated
from the surrounding loose endoneurial
connective tissue by a basal lamina (Fig.
C6).

The purpose of this extremely good insu-
lolation of the bipolar ganglion cells is not
fully apparent. It is possible that it aids the
tonal “resolving power” (acuity) of the
ear. (See Plate 107 in Krstić 1979.)

Magnifications: Fig. A, × 20;
Fig. B, × 600; Fig. C, × 7,000

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Plate 174. Peripheral or Spinal Nerve. General View

As stated in Plate 170, union of the anterior (1) and posterior (2) roots gives rise to a peripheral or spinal nerve (3). The perspective in this drawing has been exaggerated for greater clarity. This plate also shows the transition from the envelopes of the spinal cord to the sheaths of a spinal nerve.

The spinal cord is, like all parts of the CNS, enveloped by the pia mater (4), which has been cut at the point of exit of the motor nerve roots and drawn back slightly on either side.

The second of the leptomeninges, the arachnoid membrane (5), continues as the perineurial epithelium (6) into the region of the spinal nerves, where several nerve fibers (7) unite to form a nerve fascicle (8).

The perineural sheath is made up of 3–15 concentric layers of very flattened cells of perineurial epithelium. Perineurial epithelial cells (9) appear clearly on the surface facing the spinal cord and nerve fibers. It is evident from the drawing that the subarachnoid space (10) communicates with the interior of every nerve fascicle [see arrow from the spinal ganglion (11) to the exposed bundle of nerve fibers].

The external surface of the arachnoid membrane lies close to the dura mater (12), which is continuous with the perineurial connective tissue and epineurium (13). The strong, slightly undulating, longitudinal collagen fibers (14) of the epineurium bind all the nerve fascicles together and form a nerve (3).

Sympathetic trunk ganglia (15) can also be seen in this plate. Myelinated white rami communicantes (16) run to the sympathetic trunk ganglia, and unmyelinated gray rami communicantes (17) leave the ganglia and join the spinal nerve (see Plate 170). Hence, it is the presence or absence of the myelin sheath that gives the rami communicantes a white or gray appearance upon macroscopic inspection.

Since all spinal nerves contain myelinated motor and sensory nerve fibers in addition to autonomic (sympathetic and parasympathetic) fibers, they are referred to as mixed peripheral nerves.

REFERENCES
Every peripheral nerve is made up of a variable number of rounded nerve fascicles (Fig. A1) and every fascicle comprises a variable number of nerve fibers (Fig. A2). The individual fascicles are ensheathed by concentric lamellae of the perineurium (Fig. A3). The nerve fibers are surrounded by a delicate fibrous connective tissue, the endoneurium (Fig. A4).

A surface nerve fascicle has been cut and its perineurium pulled back to expose the perineurial epithelium (Fig. A5) and the undulating course of the nerve fibers. The strong collagen fibers of the epineurium (Fig. A6) are longitudinally directed and also undulate, which gives the nerve a certain degree of elasticity. The epineurium holds the whole fascicle together, but also extends between the bundles of nerve fibers with its blood vessels (Fig. A7), lymphatics, and adipose tissue (Fig. A8).

A further layer made up of loose connective tissue, the paraneurium (Fig. A9), surrounds the nerve. The structures in the rectangular inset in Fig. A correspond to Fig. B, and those in the square to Fig. C. As already seen in Plate 164, axons (Fig. B2), myelin sheaths (Fig. B3), and nodes of Ranvier (Fig. B4) are evident in longitudinal sections of myelinated nerve fibers (Fig. B1). Blood capillaries (Fig. B5) occur in the endoneurium. Routine staining of a transverse section reveals the concentric layers of the perineurium (Fig. C1), the epineurium (Fig. C2), and, between the nerve fibers (Fig. C3), the loose endoneurium (Fig. C4) with blood capillaries (Fig. C5). Note the stellate neurokeratin network (Fig. C6) and axons (Fig. C7).

Magnifications: Fig. A, x35; Figs. B, C, x700

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NERVOUS TISSUE
Plate 175. Structure of a Spinal Nerve
Plate 176. Structure of the Perineurium. Transverse Section

The perineurium (1), as already stated in Plates 174 and 175, is made up of 3-15 concentric layers of very flattened epithelial cells (2), termed perineurial epithelium or endothelium, and perineurial connective tissue.

The epithelial cells, which are only about 0.1-0.3 μm thick, are joined to one another in the overlapping areas by four to five zonulae occludentes (3) and desmosomes (4). Each epithelial cell lamella is covered on both sides by a basal lamina (5). Longitudinally oriented collagen microfibrils (6) are largely found between the concentric perineurial layers. The epithelial cells themselves have very flattened nuclei with condensed chromatin, inconspicuous organelles, and an exceptionally large number of micropinocytotic vesicles (7) in the thin cytoplasmic extension.

The outermost perineurial epithelial lamella is in contact with the relatively thin perineural connective tissue sheath (8). Further toward the exterior are attached the longitudinal collagen fibers of the epineurium (9). These two connective tissue sheaths, which merge into one another without a sharp border, can, for all practical purposes, be regarded as a continuation of the dura mater. Within the nerve fascicle are found a myelinated (10) and an unmyelinated (11) nerve fiber and fibrous and cellular components of the endoneurium – collagen microfibrils (12), fibrocytes (13), etc. The endoneurial sheath (14) of both nerve fibers can also be seen.

Magnification: × 17,500

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The perineurium (1) of a nerve fascicle has been partially removed so as to provide a better impression of its layered structure. The epithelial lamellae (2) are made up of very flattened, elongated cells. One cell has been lifted back at the point where it overlaps another cell, revealing the characteristic structure of a zonula occludens (3). Numerous openings (4) are visible on the external and internal surfaces of the epithelial cells, corresponding to the micropinocytotic vesicles. Basal laminae (5) cover the epithelial cells, between which run many longitudinal collagen microfibrils (6). Myelinated (7) and unmyelinated (8) nerve fibers, which, like the blood capillaries (9), possess their own basal laminae, are located in the fascicle interior. The basal lamina (11) of a myelinated nerve fiber has been cut and partly pulled away (lower left) in order to expose the insertion of the outer mesaxon (10). Numerous longitudinally oriented collagen microfibrils (12) and fibrocytes (13) also occur in the endoneurium.

The outer covering of the nerve fascicle is composed of perineurial connective tissue (14). The epineurium has been omitted from this plate.

The multilamellar perineurial epithelium represents a highly selective diffusion barrier between the nerve fibers and the surrounding epineurial connective tissue. Morphological evidence of this is the presence of innumerable micropinocytotic vesicles in the firmly joined epithelial cells. Experiments have shown that, e.g., ferritin, horseradish peroxidase, and dyes are incapable of penetrating the perineural layers. For this reason, the term “blood-nerve barrier” (BNB), comparable with the blood-brain barrier, is employed.

Magnification: × 3,000

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NERVOUS TISSUE

Plate 178. Endings of Efferent Nerve Fibers. Motor End Plate

Motor end plates (Fig. A1) are barely visible in routine preparations but become distinct following gold chloride staining. In the vicinity of the motor end plates, the efferent nerve fibers branch in a grapelike manner ("en grappe") over the striated skeletal muscle fiber (Fig. A2). Nuclei (Fig. A3) belonging to the telogial cells, i.e., the specially differentiated Schwann's cells overlying the muscle fiber, appear between the ramifications of the nerve fibers. Other nuclei belong largely to the muscle fibers. An area corresponding to Fig. A is three-dimensionally presented in Fig. B. Three myelinated efferent nerve fibers (Fig. B1) with nodes of Ranvier (Fig. B2) contact the skeletal muscle fibers (Fig. B3). Flattened teloglia cells (Fig. B4) mark the points of contact. The middle nerve fiber has been cut so as to display its axon (Fig. B5) projecting into a depression of the muscle fiber. A nerve fiber can innervate a variable number of muscle fibers, depending on the region of the body. In muscles with very precise functions, e.g., in the extrinsic musculature of the eyes and the muscles of the larynx, one nerve fiber may innervate a single muscle fiber - as illustrated in this plate. In muscles where contraction demands less precision, one nerve fiber supplies a whole bundle of muscle fibers. A motor unit is therefore defined as the area of muscle innervated by a motor neuron.

Satellite cells (Fig. B6) and the endomysium (Fig. B7), which has been largely removed, are also evident in the drawing. Perpendicular to the muscle fiber run the precapillaries (Fig. B8), from which arise the longitudinally oriented capillaries (Fig. B9). The latter anastomose with one another by means of transverse branches (Fig. B10). (See Plate 129 in Krstic: 1979.)

Magnifications: Fig. A, ×750; Fig. B, ×2,000

REFERENCES
Every axon (1) loses its myelin sheath (2) in the vicinity of its terminal branching, and the Schwann's cells (3) flatten and transform into teloglia cells (4). The basal lamina (5) of the Schwann's cells simultaneously covers the teloglia cells and is continuous with the basal lamina (6) of the muscle fiber (7). In the slightly protruding sole plate of the muscle fiber, the axon ramifies into several short end branches (8), which become thicker toward the end and fit into the synaptic troughs. The axolemma does not, however, come into direct contact with the plasmalemma of the muscle fiber, since the fissure that separates them contains a glycoprotein-rich amorphous substance (arrowheads), which outside the synapse is continuous with the basal lamina (6) of the muscle fiber. The terminal portion of an axon branch (9) has been lifted back so that the synaptic clefts of the subneural apparatus (10) can be observed from above. On the underside of the end branch, the parallel arrangement of the membrane-bound particles of the so-called active zones (11) can be distinguished. The transversely sectioned axon ending at the base of the plate reveals numerous synaptic vesicles (12), which although they appear empty do in fact contain acetylcholine. The microfolds of the subneural apparatus (13), which are filled with a fine-granular amorphous substance, are evident below the end branch.

In the vicinity of the end plate, the sarcoplasm contains many mitochondria but is devoid of myofibrils (14). The function of a motor end plate can be summarized as follows. When an impulse reaches the terminal ramifications of a motor axon, the depolarizing acetylcholine is released into the synaptic cleft (15) between the axolemma and sarcolemma, thereby bringing about muscular contraction. Prior to each new transmission of impulses, the acetylcholine is destroyed by the enzyme cholinesterase. The openings of the T-tubules (16) and the fibrous feltwork of the endomysium (17) can be observed. (See Plate 130 in Krsic 1979 and physiology texts for further information.)

Magnification: × 20,000

REFERENCES
NERVOUS TISSUE

Plate 180. Endings of Autonomic Nerves in the Smooth Musculature

Following silver staining (Fig. A), the adrenergic autonomic nerve fibers and their endings in the smooth musculature appear to have a netlike arrangement. Fluorescent-microscopic analysis (Fig. B) reveals a higher concentration of catecholamines in the autonomic terminal branchings, especially in the small varicosities (Fig. B1).

In Fig. C, the ramification of a muscle cell bundle (Fig. C1) is depicted. The spindle-shaped smooth muscle cells (Fig. C2) are contained within a network of more or less transversely or longitudinally oriented collagen and reticular fibrils (Fig. C3).

The autonomic nerve endings (Fig. C4) have lost their Schwann's sheath and are "naked" between the muscle cells. Axo-axonal "en passant" synapses (Fig. C5) are frequent in the network of autonomic nerve fibers. Junctions between sympathetic and parasympathetic axons have also been detected. No differentiations comparable with motor end plates occur between muscle cells and autonomic fibers. It is only occasionally that the swollen axonal terminations contact indirectly (through the basal lamina) the sarcolemma. Even less frequently, the axonal terminations enter specially prepared depressions of the sarcolemma (see Plate 120).

A varicosity (Fig. C6) is shown at higher magnification in Fig. D. The presence of 50- to 80-nm-wide synaptic vesicles with osmiophilic cores (Fig. D1), which are distinct in the transmission electron microscope, characterizes both the varicose dilations and the axonal end branches (see Plate 120). Other vesicles (Fig. D2), fewer in number but up to 150 nm across, are found among the synaptic vesicles. Mitochondria (Fig. D3) and cisternae of smooth endoplasmic reticulum (Fig. D4) also occur in the axoplasm.

The small synaptic vesicles with the osmiophilic cores contain norepinephrine, and dopamine is found in the larger vesicles. Both transmitters are released from the endings as required and exert their effects on the whole sarcolemmal surface of the muscle cells. The excitatory waves produced are propagated between the muscle cells through nexus zones.

Cholinergic nerve endings are distinguished by a large number of apparently empty synaptic vesicles. It is, however, very difficult by means of morphological criteria to determine the nature of autonomic end branches. (See Plate 131 in KRSTIĆ 1979.)

Magnifications: Figs. A, B, x200; Fig. C, x2,000; Fig. D, x30,000

REFERENCES
Neuromuscular spindles are small organs, 2-10 mm long and 0.5 mm thick, embedded in the skeletal musculature. They are involved in proprioception. Figure A shows a transverse section through a neuromuscular spindle from the extraocular muscles, and Fig. B a neuromuscular spindle from the musculi lumbricales. Both structures are surrounded by a fairly thick capsule (Figs. A1, B1), in which the intrafusal muscle fibers (Figs. A2, B2) and nerve fibers (Figs. A3, B3) can be recognized under the light microscope. Skeletal muscle fibers (Figs. A4, B4) surround the neuromuscular spindles.

In a light-microscopic magnification of a longitudinal section (Fig. C), the capsule (Fig. C1) of the neuromuscular spindle is less easy to distinguish, though two types of intrafusal muscle fiber are now evident. The nuclei of the first type are stacked on top of one another and the fibers are thus termed nuclear chain fibers (Fig. C2). In the other type, the nuclei are clustered in a central saclike distension, and these fibers are called nuclear bag fibers (Fig. C3).

Following silver staining, the ramification of nerve fibers in the neuromuscular spindle can be traced. The annulospiral sensory nerve endings (Fig. D1) are conspicuous and entwine around every intrafusal muscle fiber over an approximately 300-μm-long section. Other nerve endings extend to the intrafusal muscle fibers and form motor end plates (Fig. D2). Outside the neuromuscular spindle, the extrafusal nerve fibers that innervate skeletal musculature are seen to have considerably larger motor end plates (Fig. D3). In the electron-microscopic image of a transversely sectioned neuromuscular spindle, the outer capsule (Fig. E1), which is regarded as an extension of the perineurium, can be clearly seen. The capsule (see also Plate 176) has a lamellar structure, and capillaries (arrows) run between the layers. The outer and inner capsules (Fig. E2) delimit the periaxial space (Fig. E3) with its unmyelinated (Fig. E4) and myelinated (Fig. E5) nerve fibers.

Nuclear chain fibers (Fig. E6) are narrow, whereas nuclear bag fibers (Fig. E7) are distinguished by several nuclei in the broader middle sections. Fibrocytes (Fig. E8) and myelinated and unmyelinated nerve fibers can be observed between intrafusal muscle fibers. The neuromuscular spindle also of course contains capillaries.

Magnifications: Figs. A–D, × 250; Fig. E, × 2,000

REFERENCES
In a neuromuscular spindle that has been opened along its longitudinal axis, an outer (1) and inner (2) capsule can be distinguished. The outer capsule represents a continuation of the perineurium (3). Thin, transversely striated intrafusal nuclear chain fibers (4) and nuclear bag fibers (5) are bound at their ends to the inner surface of the outer capsule by means of reticular and collagen microfibrils (6), originating from the connective envelope of these muscle fibers. Annulospiral endings of the thick, sensory nerve fibers (Ia or Aff. I) wind around the middle of each muscle fiber. The thin, likewise sensory, nerve fibers (II or Aff. II), the so-called flower-spray endings, are located almost exclusively on the terminal sections of nuclear chain fibers. In addition to sensory innervation, intrafusal and extrafusal muscle fibers receive motor innervation in the form of y-nerve fibers, which terminate on intrafusal muscle fibers as motor end plates (7, Eff. II) and grapelike endings (8, Eff. III). It should be mentioned here that in differentiating the various types of nerve fiber, metallic staining methods are superior to electron microscopy. Fibrocytes (9) also occur in the interior of the neuromuscular spindle. Outside the spindle capsule, a nerve fibers terminate on thick skeletal muscle fibers (10).

The endomysium (11) surrounds the neuromuscular spindle and connects it to the extrafusal muscle fibers. This fact is of great significance in the function of the neuromuscular spindle. Neuromuscular spindles are mechanoreceptors which provide information about the length of the muscle both to the cerebellum and, via a collateral, directly to the multipolar motor nerve cells of the gray matter of the spinal cord. Thus, for example, contraction of the intrafusal nerve fibers caused by y-nerve fibers is transmitted to the annulospiral endings, which then excite the motor neurons by their collaterals. As a response, the impulses are conducted from the motor neurons via x-fibers to the extrafusal muscle fibers, which bring about a contraction in accordance with the strain on the muscle involved. In the same way, sudden stretching of muscle leads to immediate muscular contraction (e.g., patellar reflex).

Magnification: × 1,500

REFERENCES
Plate 183. Endings of Afferent Nerve Fibers. Intrafusal Muscle Fibers

This plate shows a nuclear chain (Fig. A1) and a nuclear bag fiber (Fig. A2) at higher magnification and drawn to reveal the internal structure. In both types of muscle fiber, the myofibrils (Fig. A3) like those of the myotubes (see Plate 124) are displaced toward the plasmalemma and absent in central sections of the fibers. These regions are thus incapable of contraction. Leptomeric myofibrils (Fig. A, arrows; Fig. B), which frequently occur in intrafusal muscle fibers, contain structures that are reminiscent of Z-lines (Fig. B1). These lines run for a distance of 100 nm, mainly perpendicular to the orientation of the myofibrils. Since the leptomeric bands change their direction, a zebra pattern develops, which is visible in longitudinal sections. Leptomeric myofibrils are rarely found in skeletal and cardiac musculature, but are more common in muscle fibers that still bear some embryonic characteristics (Purkinje cells of the impulse-conducting system, intrafusal muscle fibers). The function of leptomeric fibrils remains to be established. It is believed that they are precursors of normal striated myofibrils, according to which the leptomeric bands would correspond to Z-lines. Among the nervous elements, it is possible to distinguish the annulospiral endings (Fig. A4), flower-spray fibers (Fig. A5), and the two types of motor y-fiber (Figs. A6, A7), described in Plate 182. The area contained within the circle in the upper right is enlarged in Fig. C. An annulospiral unmyelinated ending (Fig. C1) is separated from the plasmalemma of the muscle fiber by an approximately 20-nm-wide cleft. Zonulae adherentes (Fig. C2) are occasionally seen in this region. In the interior of the ending, numerous mitochondria, cisternae of smooth endoplasmic reticulum, and vesicles are found. The basal lamina (Fig. C3) covering the muscle fiber also coats the annulospiral ending. Unlike a motor end plate, therefore, the annulospiral ending is hypolemmal, i.e., it is located beneath the basal lamina of the muscle fiber. The endings of the flower-spray fibers have a similar structure to annulospiral fibers. All y-motor end plates have exactly the same morphology as that described in Plate 179. The collagen microfibrils (Fig. A8) of the lower section of the intrafusal muscle fibers continue into a fine tendon (Fig. 9) (see Plate 182).

Magnifications: Fig. A, ×4,000; Fig. B, ×10,000; Fig. C, ×25,000

REFERENCES
Plate 184. Endings of Afferent Nerve Fibers. 
Golgi Tendon Organ or Neurotendinal Spindle

At the point of transition between a muscle and a tendon, sporadic Golgi tendon organs are found. Following silver staining, a rich ramification of sensory nerve fibers (Fig. A1) becomes evident. In the upper part of the drawing, striated skeletal muscle fibers (Fig. A2) penetrate the tendon organ. Below, the capsule, which is difficult to differentiate under the light microscope, with its inner collagen fibers is continuous with the tendon (Fig. A3). In Fig. B, the capsule has been opened to expose the interior of the tendon organ.

As in the neuromuscular spindle, the lamellar structure of the capsule (Fig. B1) of the Golgi tendon organ is a direct continuation of the perineurium (Fig. B2). The extremely flattened cells of the perineural epithelium (Fig. B3) can be recognized both on the inner and outer surfaces of the capsule.

The entire Golgi tendon organ is invested by a feltwork made up of reticular and collagen microfibrils (Fig. B4). All fibrous structures are continuous with the tendon fibers (Fig. B5). Other tendon fibers (Fig. B6) surround the whole tendon organ.

Several anastomosing and loosely arranged collagen fibers (Fig. B7) run through the interior of the Golgi tendon organ. These collagen fibers are continuations of the connective envelope of muscle fibers (Fig. B8) that enter the tendon organ.

The myelinated nerve fibers (Fig. B9) that penetrate the Golgi tendon organ soon lose the myelin sheath but not the Schwann's sheath. The richly branched axons wrap around the collagen fibers and terminate in nodular thickenings (Fig. B10).

The relationship between the collagen fibers and nerve endings is shown three-dimensionally in Fig. C (modified after SCHULTZ and SWETT 1972). The collagen fibers (Fig. C1) press deep into the terminal thickenings of the axon (Fig. C2). It appears as if the neuronal elements occupy all the space between the collagen fibers. The axons are accompanied by Schwann's cells (Fig. C3).

The mode of function of the Golgi tendon organ can be summarized as follows. Muscular contraction causes the loosely arranged intrafusal collagen fibers to become taut. In this way, the fibers come closer to one another, in the direction of the arrows, and compress the axon thickenings and this induces stimulation of the nerve endings. The impulses are then conducted to the spinal cord.

Magnifications: Fig. A, x 150; Fig. B, x 500; Fig. C, x 22,000

REFERENCES
Plate 185. Endings of Afferent Nerve Fibers in Epithelial and Connective Tissues

Figure A shows a schematized section of skin, in which a detailed view of all layers other than the epidermis (Fig. A1) has been omitted. Endoepidermal nerve endings (Fig. A2) terminate both freely and on certain cells (Fig. A3). Other free nerve fibers are found associated with the hair follicle sheath (Fig. A4). In the connective tissue beneath the epidermis, encapsulated terminal corpuscles occur, of which only Meissner's (Fig. A5) and Vater-Pacini (Fig. A6) corpuscles are dealt with in this book. In addition to the nerve fibers, a hair shaft (Fig. A7), sebaceous (Fig. A8) and sweat (Fig. A9) glands, and the arrector muscle (Fig. A10) are presented in this drawing. The inset corresponds to Fig. B (modified after Halata 1975).

Nerve endings lose their myelin sheath as they enter the epidermis, and upon penetrating the epithelial basal lamina (Fig. B1) lose their Schwann's sheath (Fig. B2). The basal lamina of the Schwann's cells (Fig. B2) is continuous with that of the epidermis. Axons are located in the intercellular spaces and in their vertical path through the germinative layer almost extend as far as the stratum granulosum (Fig. B3). Similar endoepithelial nervous ramifications also occur in the cornea and various mucous membranes.

Perception of pain and temperature is very probably achieved through stimulation of the free nerve endings. Another form of endoepithelial ending found in glabrous and hairy skin is shown on the right in Fig. B. Two axons lose their myelin sheath (Fig. B4) and for a short distance are surrounded only by the Schwann's cells (Fig. B2). The axons penetrate the epidermis as unmyelinated fibers and run to the specially differentiated Merkel's cells (Fig. B5). Here, each nerve ending becomes broader, creating a Merkel's disc (Fig. B6), which forms a synapse-like junction (Fig. B7) with the adjacent Merkel's cell. Merkel's cells form several digitiform processes and attach to adjacent cells by small desmosomes; their cytoplasm contains electron-dense, approximately 100-nm-wide, membrane-bound granules, the significance of which is unknown.

Merkel's discs respond to pressure and vibration stimuli, and so are classed among the mechanoreceptors.

Magnifications: Fig. A, ×70; Fig. B, ×1,200

REFERENCES


NERVOUS TISSUE

Plate 186. Endings of Afferent Nerve Fibers Around the Hair Follicle
(Modified from ANDRES and DÜHRING 1973; HALATA 1975;
MUNGER 1971)

Every hair follicle with its sheaths is surrounded by several longitudinally arranged afferent nerve endings. A transverse section through a hair follicle reveals first of all the hair shaft (Fig. A1) and then the inner (Fig. A2) and outer (Fig. A3) epithelial root sheaths. Between the outer epithelial and connective tissue sheaths (Fig. A4) is found a basal lamina (Fig. A5).

The connective tissue sheath encloses several sensory nerve fibers (Fig. A6), running parallel to the axis of the hair. The basal lamina (Fig. A7) of the nerve fibers is continuous with that of the outer epithelial root sheath (see also Fig. B6).

The nerve fibers terminate in a cylindrical portion (Fig. A8), where a flattened nerve ending (Fig. A9) is sandwiched between two Schwann's cells (Fig. A10). A narrow belt of the compressed axon protrudes between the Schwann's cells. A few collagen microfibrils (Fig. A11) and elastic fibers (Fig. A12) of the connective tissue root sheath can be seen between the nerve endings.

Figure B depicts the sandwiching of an axon in cross section. In the upper part of the drawing, peripheral cell regions (Fig. B1) belonging to the outer epithelial root sheath can be seen. The basal lamina (Fig. B2) is attached to the cells by means of numerous hemidesmosomes (Fig. B3). Schwann's cells (Fig. B4) flanking the axons are characterized by a pale cytoplasm and several micropinocytotic vesicles. The flattened nerve ending (Fig. B5) contains a remarkably large number of mitochondria and is located only 100-200 nm from the hair shaft epithelium. A three-dimensional reconstruction of the sensory nerve endings is given in Figs. C and D.

In the lower part of Fig. C, the penultimate normally structured Schwann's cell (Figs. C1, D1) ends in series of cytoplasmic processes (Fig. C2) described in Plate 165. The cell is of course enveloped by a basal lamina (Figs. C3, D3). The line of origin of the outer mesaxon (Fig. D4) is evident.

After it leaves the penultimate Schwann's cell, the axon (Figs. C5, D5) becomes shaped by the last two glial cells into a spearhead form. In Fig. D, where the nerve ending (Fig. D5) has been partially removed, micropinocytotic vesicles (Fig. D6) on the surface facing the axon and the nucleus (Fig. D7) of a Schwann's cell can be observed.

Every movement of the hair stimulates the nerve endings and the impulses are conducted to the CNS.

Magnifications: Fig. A, x 2,500; Fig. B, x 18,000; Figs. C, D, x 14,000

REFERENCES


NERVOUS TISSUE

Plate 187. Endings of Afferent Nerve Fibers. Meissner's Corpuscle (Modified from ANDRES and DÖHRING 1973)

Meissner's corpuscles belong to the so-called encapsulated end organs. Following metallic staining, the corpuscles (Fig. A; see Plate 185), which occur at the tip of a connective tissue papilla, appear as ovoid, 50- to 150-μm-long and 60-μm-wide structures. They are made up of stacked, partially flattened, pear-shaped tactile cells (Fig. A1), whose nuclei are predominantly located at the periphery of the corpuscle. Between the tactile cells, there is a network of unmyelinated nerve fibers (Fig. A2), which become myelinated upon leaving the corpuscle (Fig. A3).

Meissner's corpuscles are surrounded by a capsule (Fig. A4). Collagen fibrils (Fig. A5) irradiate from the capsule to the basal cells of the epidermis, and blood capillaries (Fig. A6) are always found in the vicinity of the capsule.

In Fig. B, prepared from electron-microscopic observations, the Meissner's corpuscle appears like an egg in an eggcup. A large number of flattened cytoplasmic layers (Fig. B1) of the tactile cells (Fig. B2) form the ovoid structure. Tactile cells are sometimes considered specially differentiated Schwann's cells. Closer study reveals that many cytoplasmic lamellae leave the peripheral nuclear regions and that these lamellae interdigitate in a fairly complex manner with similar processes of the opposite tactile cells.

Myelinated nerve fibers (Fig. B3) enter the corpuscles from below, lose their myelin sheath, and thread between the cytoplasmic lamellae in tortuous and repeatedly branching spirals (Fig. B4). Within the corpuscle, the axons are enveloped only by a Schwann's sheath. Every axon terminates in a flattened, clublike swelling (Fig. B5), which can synapse with the tactile cells. The transversely cut nerve fiber indicated by an arrow is three-dimensionally presented in Fig. C.

A mitochondria-rich axon (Fig. C1) is encased within flattened Schwann's cells (Fig. C2), which in turn are invested by a basal lamina (Fig. C3). Tactile cells are contained within an incomplete capsule (Fig. C4) belonging to the perineurium. Like all hitherto described perineurial capsules, it is composed of several layers of perineurial epithelial cells. The space between the tactile cells and the capsule has been drawn significantly broader for greater clarity.

Many collagen microfibrils and fibers (Fig. B7) join the tactile and capsule cells with the branched basal processes of the basal epithelial cells. The Meissner's corpuscle thus appears to hang from the epidermis. These connections between the terminal corpuscle and epidermis are important in the function of the former. Every deformation of the epidermis induced by pressure is transferred to Meissner's corpuscles. Since these corpuscles are particularly numerous in the tips of the fingers and toes, it is supposed that they are responsible for touch and pressure perception.

Magnifications: Fig. A, x 800; Fig. B, x 3,500; Fig. C, x 15,000

REFERENCE
NERVOUS TISSUE

Plate 188. Endings of Afferent Nerve Fibers. Vater-Pacini Corpuscle

Vater-Pacini corpuscles are the largest of all encapsulated nerve endings; they can attain a length of 3-4 mm and a width of 2 mm. They are found in various inner organs and in the subcutis. Vater-Pacini corpuscles are particularly frequent in the skin of the finger pads and palm. A large number of these bodies have also been identified along arteriovenous anastomoses.

Under the light microscope, a transverse section through a terminal corpuscle reveals first a capsule (Fig. A 1) and then an onionlike lamellar outer core (Fig. A 2). In the center is an inner core (Fig. A 3) with the axon.

In Fig. B, which is based on the results of ultrastructural analysis, the lamellar structure of the capsule (Fig. B 1), surrounded by blood capillaries (Fig. B 2), and connective tissue fibers can be observed. The outer core is made up of 10-60 thin, concentric, impervious cell lamellae (Fig. B 3), formed of flattened fibrocytes. The liquid-filled spaces between the lamellae contain collagen microfibrils (Fig. B 4) and occasional blood capillaries (Fig. B 5).

The capsule and lamellae are a direct continuation of the perineurium (Fig. B 6), however, unlike the perineurium of a nerve fascicle the spaces between the epithelial cells here are exceptionally narrow (see Plate 176).

On the right of the picture, a nerve fiber (Fig. B 7) and two blood capillaries (Fig. B 8) can be seen entering the corpuscle. The axon (Fig. B 9) loses its myelin sheath (Fig. B 10) in this region, but continues to be accompanied by Schwann’s cells, which form the inner core (Fig. B 11). Only the portion of axon located within the inner core has receptor properties. The axon terminates in a nodular thickening (Fig. B 12). A simplified cross section is shown in Fig. C to clarify the complex structure of the inner core.

The inner core is made up of two symmetrical systems of tightly interdigitating half lamellae (Fig. C 1) of Schwann’s cells. The lamellae are partially separated by a radial cleft (Fig. C 2). In the center of the inner core is the sensitive portion of the axon (Fig. C 3).

Every pressure-induced deformation of the Vater-Pacini corpuscle is transmitted by the liquid-filled spaces between the lamellae of the outer core, and this stimulates the unmyelinated axon segments of the inner core.

The ability of Vater-Pacini corpuscles to react to pressure explains why they occur not only in skin but also in the vicinity of arteriovenous anastomoses, where they are thought to regulate blood pressure. Vater-Pacini corpuscles are stimulated by vibrations as well as by pressure.

Magnifications: Fig. A, x 70; Fig. B, x 1,200; Fig. C, x 1,700

REFERENCE
Plate 189. Sympathetic Trunk. Light-Microscopic Appearance of Autonomic Ganglion and Its Nerve Cells

A schematic representation of the connections between the spinal cord and the sympathetic ganglia has already been given in Plate 170. Branches project from the sympathetic trunk ganglia (Fig. A1) to the prevertebral ganglia (Fig. A2). A horizontal section through a prevertebral ganglion (arrow) is shown in Fig. B.

Like all parts of the peripheral nervous system, the sympathetic ganglia and their branches are surrounded by perineurium (Fig. B1), which is supported on its outer surface by a fibrous network predominantly made up of collagen fibers. The interior of the ganglion is dominated by a well-developed endoneurium (Fig. B2), which groups the nerve cells in small clusters (Fig. B3). A few rami communicantes (Fig. B4) can be seen at the periphery of the ganglion. The two insets in Fig. B are enlarged in Figs. C and D.

Routinely stained sections (Fig. C) reveal the capsule (Figs. C, D1) and, in the interior of the ganglion, the vascular endoneurium (Figs. C2, D2) containing many myelinated and unmyelinated nerve fibers. The spindle-shaped or polygonal sympathetic cells (Figs. C3, D3) are smaller than spinal ganglion cells. The nuclei of sympathicus cells are spherical and clear but have one or two relatively large nucleoli. Nissl bodies and lipofuscin granules occur more frequently in sympathetic ganglion cells than in spinal ganglion cells. A somewhat irregular layer of satellite cells (Fig. C4) separates the nerve cells from the endoneurium.

Following silver staining (Fig. D), the precise form of the sympathetic ganglion cells can be discerned, and it is evident that they are multipolar nerve cells. The cell interior is seen to contain many neurofibrils (Fig. D4). Dendrites and axons of the multipolar nerve cells are difficult to distinguish. Some observations indicate that sympathetic nerve cells may even have several axons. The cell processes near the perikaryon form a fairly dense convoluted network. Many nerve fibers (Fig. D5) in synaptic contact with the ganglion cells can also be seen in the endoneurium. Amphocytes do not appear so clearly after silver staining.

Magnifications: Fig. B, × 20; Figs. C, D, × 350

REFERENCES
NERVOUS TISSUE

Plate 190. Sympathetic Trunk. Multipolar Autonomic Nerve Cell

The stellate body of a sympathetic autonomic neuron contains a large nucleus with a well-developed nucleolus. Polyneuronal autonomic nerve cells are also occasionally found. Nissl bodies (1), the most conspicuous element of the neuroplasm, are very well developed in the vegetative cells and extend into the dendrites (2). They are absent only in the axon hillock (3). The Golgi apparatus is variously developed and around it occur granules and vesicles. Vegetative nerve cells also contain numerous mitochondria. Lipofuscin granules are seen in older individuals. Some data, though not fully corroborated, suggest that vegetative nerve cells may even be capable of division after birth. However, centrioles have as yet to be detected in vegetative ganglion cells. Neurotubules and neurofilaments run in various directions through the cytoplasm. Several cell extensions leave the perikaryon. Boutons terminaux (4) of other autonomic axons, either naked (5) or accompanied by a Schwann’s sheath (6), contact the dendrites. Axosomal synapses (7) are of course also present. The outer surface of the perikaryon is surrounded by several satellite cells (8). The investment of an autonomic nerve cell by satellite cells becomes less complete the greater the distance from the sympathetic trunk. In the sympathetic trunk, the satellite cell envelope appears practically uninterrupted, as in the cell presented here, whereas intramural ganglion cells are only surrounded by an endoneurial sheath. There is no basal lamina between the satellite cell and nerve cell. Occasionally, however, satellite cells cover axosomatic synapses (9). The basal lamina (10) of satellite cells is continuous with that of Schwann’s cells (11). Numerous autonomic nerve fibers (12) run through the endoneurium in the vicinity of the autonomic neurons. It is not possible morphologically to differentiate between autonomic nerve cells of the sympathetic and parasympathetic nervous systems. (See Plates 119, 120 in Krstić 1979.)

Magnification: ×10,000

REFERENCES