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Neuroanatomy

FOR MEDICAL STUDENTS

As per the Indian Competency-Based Medical Curriculum

G.P. Pal

Second Edition

SUPPLEMENTARY VIDEOS ONLINE

Wolters Kluwer

Table of Contents at a Glance

2 Components of Nervous Tissue and Their Functions

CHAPTER OUTLINE [AN7.2]

The nervous tissue is one of the basic tissue of our body. The other basic tissues are epithelium, connective, and muscular. The nervous tissue is composed of nerve cells (neurons), nerve cell processes (axon and dendrites), and neuroglia. The nervous tissue is richly supplied by blood vessels.

NEURON [AN7.3]

A neuron consists of a cell body or soma and neuronal processes (Fig. 2.1). The neuronal processes that emerge from the cell body are called *dendrites* and *axons*. Dendrites are multiple cytoplasmic processes, but axon is a single process.

Nerve Cell Body or Soma

The nerve cell body has a typical pale staining euchromatic nucleus with a prominent dark nucleolus (Figs 2.1 and 2.2). The nucleus of the nerve cell is light staining (euchromatic) because chromatin material is extended as it is active chromatin. The cytoplasm of a neuron contains prominent basophilic material called *Nissl bodies* or *Nissl granules*. The cell body also contains Golgi apparatus, mitochondria, lysosomes, and smooth endoplasmic reticulum. The cytoskeleton of a neuron is formed by microtubules, neurofilaments, and microfilaments. Normally, neurons after birth are unable to replicate their DNA and thus do not undergo cell division.

Nerve Cell Processes

The elongated cytoplasmic processes originate from the cell body. These processes may travel long distances from the neuron. They are of two types: (i) dendrites and (ii) axons. Usually, a neuron consists of a single axon and multiple dendrites (Table 2.1).

Dendrites

Neurons usually have short, multiple dendrites, and each of these may branch extensively to form "dendritic tree" (Fig. 2.1). Dendrites are involved in receiving information from other cells. The cytoplasm of dendrites contains Nissl bodies, microtubules, microfilaments, and other organelles.

Axons

Axons are the nerve cell processes that send information in the form of electrical signals away from the nerve cell body to other cells. Usually, there is a single, extremely long axon (in some neurons, the length may reach up to 1 m) for each neuron. It originates in a conical region of the cell body known as axon hillock (Figs 2.1 and 2.2). Nissl bodies (granules) are absent in axon hillock and axon.

What is Axonal Transport?

The material produced in the cell body (usually proteins) can move within the axonal cytoplasm from the cell body to the distal region of the axon and back. This transport usually occurs at rates between 1 and 2 mm (slow transport) and 300 and 400 mm (rapid transport) per day.

Axonal transport occurs simultaneously in both directions, i.e. anterograde and retrograde. Rapid axonal transport involves particle-bound substances, microfilaments, and microtubules of the axoplasm. Within the axoplasm, different substances can move at different rates and in different directions. For example, the proteins of extracellular fluid can be taken up by the axon terminal as pinocytotic vesicles. These particles are then brought to the nerve cell body by retrograde transport. Viruses (of rabies, poliomyelitis, herpes), toxins, heavy metals, and some pathogenic bacteria are brought to the

AN7.2 List the components of nervous tissue and their functions.
AN7.3 Describe the parts of neuron and classify them based on the number of neurites, size, and function.

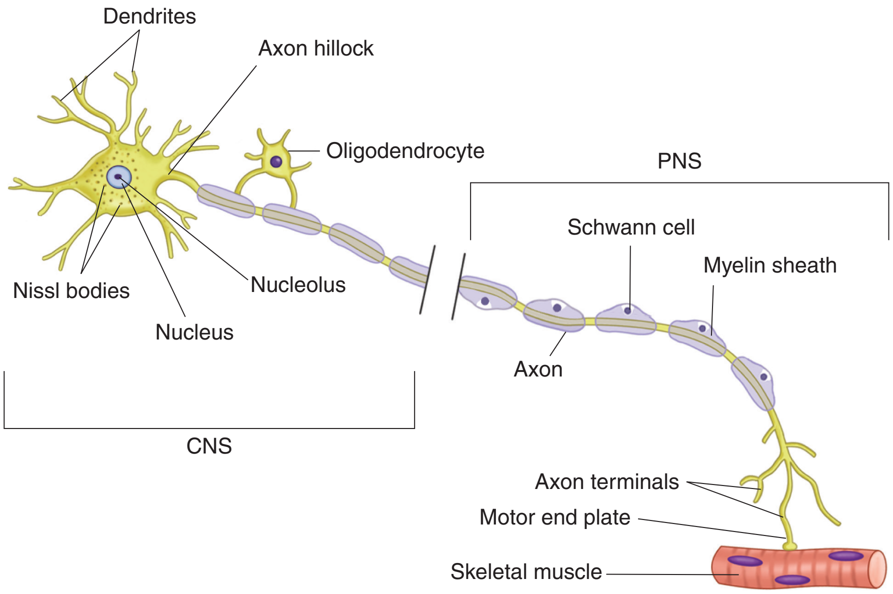

FIGURE 2.1 Various parts of a motor neuron. The oligodendrocytes form a myelin sheath around the axon in the central nervous system (CNS), while Schwann cells form a myelin sheath in the peripheral nervous system (PNS). Dendrites are multiple, short processes, while the axon is a single, long process.

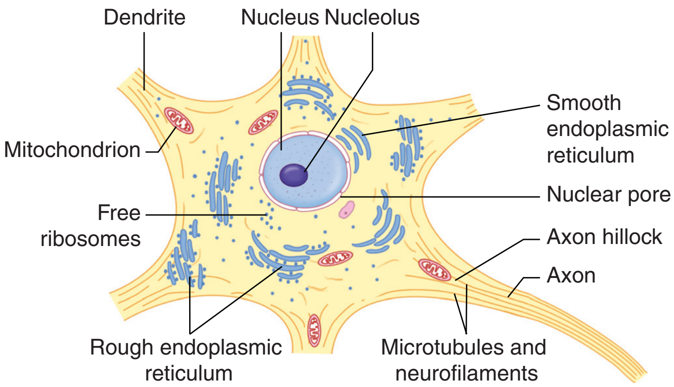

FIGURE 2.2 Semielectron microscopic view of a neuron. Notice the presence of multiple dendrites and a single axon. The nucleus is euchromatic, and the cytoplasm contains abundant rough endoplasmic reticulum. The axon is free of granules.

central nervous system (CNS) by retrograde axonal transport of both sensory and motor nerves.

Clinical Aspect

Dear students, throughout this book, the section of "Clinical Aspect" will deal to correlate your recently acquired anatomic knowledge to understand the basis of some related diseases or clinical conditions. This is just to make your anatomy study interesting. In no way, after going through "Clinical Aspect," you will be able to understand a disease in detail or will be able to solve a problem related to that disease. My intention is not to make you "Problem Solving" clinician at this stage. Do not be in hurry; you will learn about all these diseases or clinical conditions in great detail in your higher classes.

In this chapter, we shall learn about the anatomical basis of three different clinical conditions, i.e. rabies, herpes zoster, and tetanus.

TABLE 2.1 Difference Between Axons and Dendrites

Axon	Dendrites
Axon is a single, long, thin process of a nerve cell.	Dendrites are multiple, short, thick, and tapering processes of the nerve cell.
As the axon is a long process, it terminates away from the nerve cell body.	As dendrites are short processes, they terminate near the nerve cell body.
Axon rarely branches at the right angle (axon collaterals) but ends by dividing into many fine processes called axon terminals.	Dendrites are highly branching. Their branching pattern forms a dendritic tree.
Axon has uniform diameter and smooth surface.	The thickness of dendrite reduces as it divides repeatedly. Its surface is not smooth, but it bears many small spine-like projections for making synaptic contacts with the axons of other nerve cells.
Axon is free of Nissl granules.	Nissl granules are present in dendrites.
In axon, the nerve impulses travel away from the cell body.	In dendrites, the nerve impulses travel toward the cell body.

Rabies

Rabies is the viral disease of the CNS. It is transmitted to human through the bite of rabid animals (in India, mostly by the bite of street dogs having rabies infection). The virus is present in the saliva of these animals, which is absorbed by nerve terminals from the site of bite. The rabies virus is then transported to the CNS through retrograde axonal transport.

About 10 days to 2 months after bite, the symptoms appear. The patient may have fever to begin with but soon develops weakness and paralysis of various muscles. Due to paralysis of throat muscle, the patient is unable to drink and develops fear of water (hydrophobia). Paralysis of muscles is followed by loss of consciousness. Once the symptoms have developed, eventually the patient dies. However, vaccination has reduced the death rate due to rabies.

What might be done after animal bite?

Treatment should be started immediately which consists of injection of antibodies around the wound and a complete course of rabies vaccination. Preventive vaccination should be taken by persons who are at risk of animal bite.

Herpes Zoster

This is another example of disease along the axoplasmic flow. This infection is caused by varicella zoster virus. This virus causes chickenpox but then remains dormant in sensory nerve cells of cranial ganglia (usually trigeminal and vagus nerve ganglia) and spinal nerve ganglia (DRG) for long. The dormant virus may become reactivated in old age (usually 50–70 years) and causes herpes zoster. The disease is characterized by appearance of painful blisters along the path of a nerve (usually in the face, chest, or abdomen). The involvement of the face is due to cranial nerve trigeminal, and that of the chest or abdomen is due to involvement of spinal nerves.

Burning pain and itching along the path of nerve is followed by appearance of painful blisters. These blisters are formed along the path of nerve due to release of substance P and other peptides that cause the dilation of vessels leading to exudation of plasma.

Herpes zoster is self-limiting disease.

Tetanus

Tetanus is a wound infection caused by toxin produced by bacteria (*Clostridium tetani*). This infection acts on nerves controlling muscle activities. Symptom includes muscle stiffness in the jaw, arms, neck, and back. Spasm of muscles of respiration leads to breathlessness.

Previously, it was believed that the tetanus toxin is also transported from the site of wound to the CNS through retrograde axoplasmic flow. However, it is now believed that toxin travels through endoneurial space. Endoneurial space lies deep to endoneurial sheath, i.e. between myelin sheath and endoneurium. Refer to Chapter 3 for endoneurium. Vaccination against tetanus is highly effective.

CLASSIFICATION OF NEURONS

Neurons are classified on the basis of their structure, size, and function.

Classification Based on Structure

The structure and shape of a cell body are dependent on the number and orientation of cell processes arising from it (**Fig. 2.3a**). Depending on the number of processes emerging from the cell body, the neurons can be classified as follows:

1. Multipolar
2. Bipolar
3. Unipolar or pseudo-unipolar

Multipolar neurons: Multipolar neurons have a single axon and many dendrites extending from the cell body. Most of the neurons present in the CNS are multipolar.

Bipolar neurons: Bipolar neurons have two processes emerging from the cell body (e.g. bipolar neurons of retina and neurons of olfactory neuroepithelium).

Unipolar or pseudo-unipolar neurons: Unipolar or pseudo-unipolar neurons are found in the dorsal root ganglion of spinal nerves (sensory ganglion) and sensory root ganglia of cranial nerves. Such a neuron has a single process that extends from the cell body; this process then bifurcates to form a T-shaped process (**Fig. 2.3a**).

According to some authors, true unipolar neurons have only a single process extending from the cell body, usually the dendrite. These kinds of neurons are present in the *mesencephalic nucleus* of the trigeminal nerve.

Classification Based on Size

The neurons can also be classified on the basis of their size. According to this classification, the neurons are as follows:

1. Golgi type I neurons
2. Golgi type II neurons

Golgi type I neurons: Golgi type I neurons have a single, long axon, sometimes more than a meter in length. The axons of these neurons (e.g. pyramidal cells, Purkinje cells) extend long distances within the CNS (as part of the tracts) or in the peripheral nervous system (PNS) (as part of peripheral nerves, e.g. sciatic nerve; **Fig. 2.3b**).

Golgi type II neurons: Golgi type II neurons have short axons and terminate close to the cell body (e.g. stellate and granule cells of the cerebellar cortex).

Classification Based on Function

Functionally, the neurons are classified into *sensory*, *motor*, and *interneurons* (**Fig. 2.3c**).

Sensory or afferent neurons: Sensory neurons are specialized cells capable of detecting various kinds of stimuli, i.e. pain, touch, temperature, light, pressure, and chemicals.

Motor (efferent) neurons: Motor neurons carry efferent impulses and are responsible for the motor responses to sensory stimuli. Motor neurons are of two types: (i) somatic and (ii) visceral. These neurons send motor impulses to the muscles, which results in their contraction. Somatic motor neurons send impulses to the skeletal muscles while visceral motor neurons stimulate the smooth and cardiac muscles. The visceral motor neurons also send signals (secretomotor) to exocrine glands, which results in secretion from these glands.

Interneurons: Interneurons are located in between sensory and motor neurons. These neurons interconnect sensory and motor neurons. These neurons carry out the integrative function.

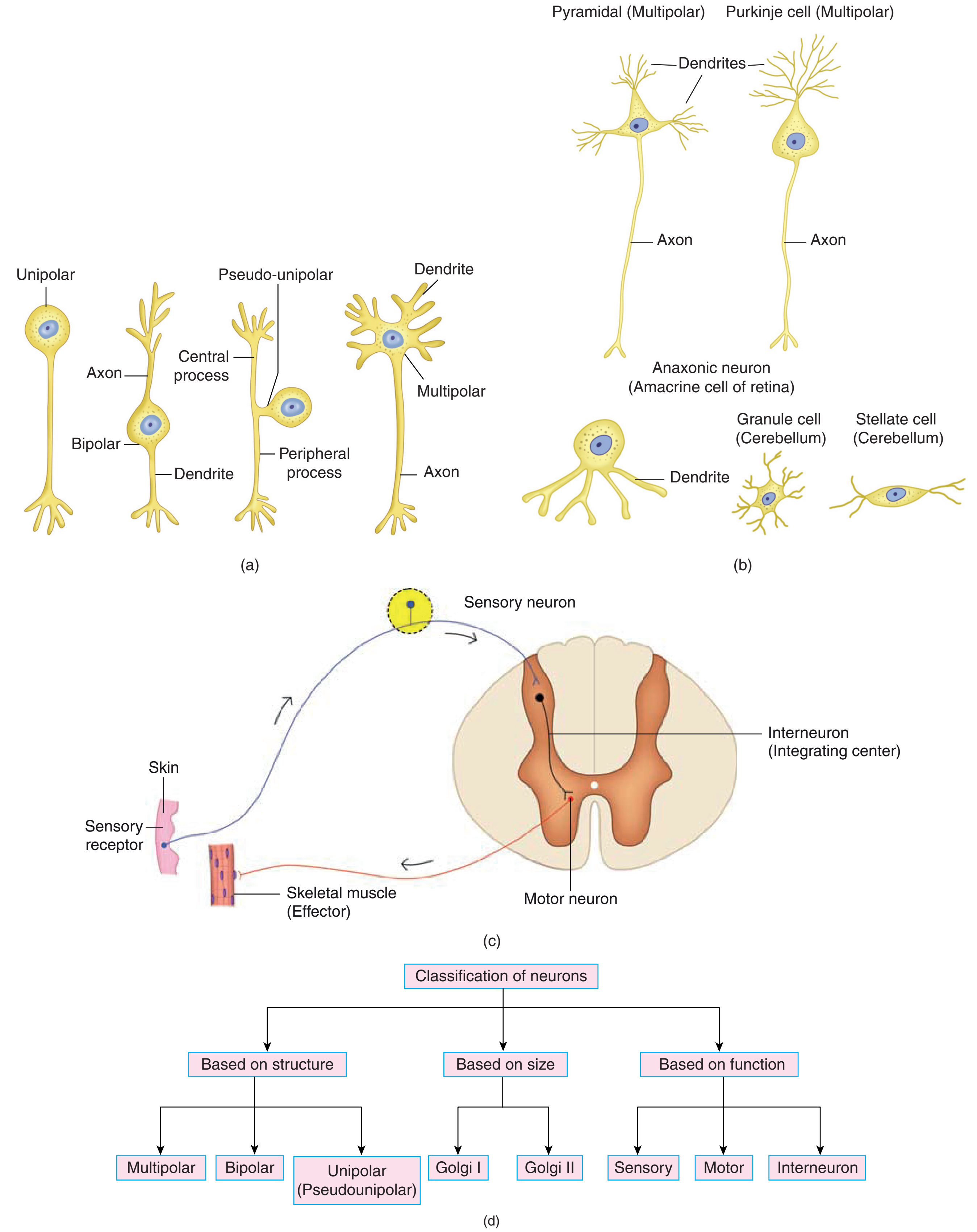

FIGURE 2.3 Types of neurons. (a) On the basis of cell processes arising from the cell body. (b) Various types of multipolar neuron. The pyramidal cells are found in cerebrum while Purkinje cells are present in the cerebellum. (c) All three functional neurons (sensory, motor, and interneuron) forming a reflex arc. (Reproduced, with permission, from Pal GP. *Illustrated Textbook of Neuroanatomy*. India, New Delhi: Wolters Kluwer (I) Pvt. Ltd.; 2013.) (d) Flowchart showing the classification of neurons.

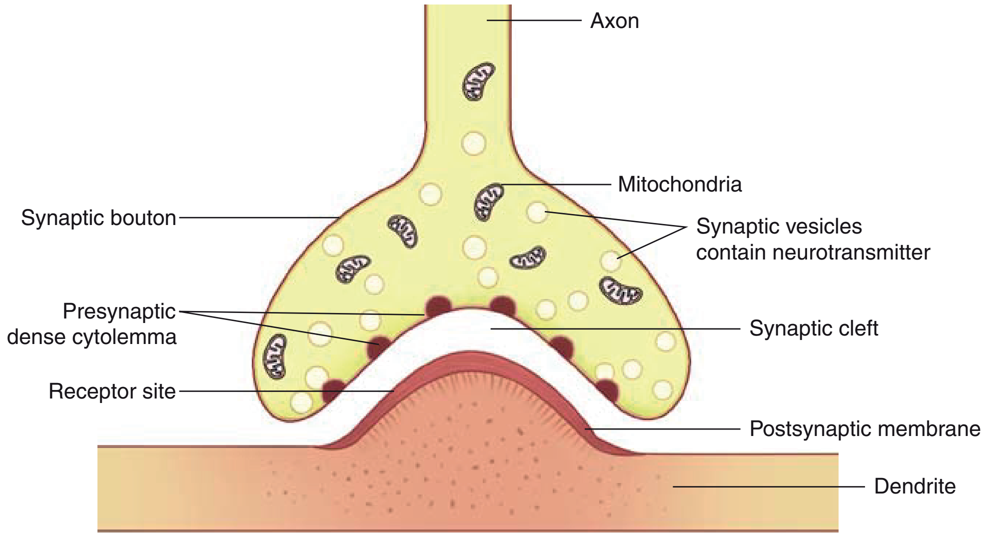

FIGURE 2.4 Simplified structure of a typical chemical synapse as seen by an electron microscope. The neurotransmitter is released by synaptic vesicles from presynaptic membrane and reaches the receptor on postsynaptic membrane after passing across the synaptic cleft. (Reproduced, with permission, from Pal GP. *Illustrated Textbook of Neuroanatomy.* India, New Delhi: Wolters Kluwer (I) Pvt. Ltd.; 2013.)

SYNAPSES [AN7.7]

The nervous system consists of a large number of neurons that communicate with each other through synapses. *Synapse* is defined as the point of contact between two neurons through which signals (messages/impulses) pass from one neuron to next.

Classification of Synapses

On the basis of communication between two neurons, synapses are classified as:

1. Chemical synapses
2. Electrical synapses

Chemical Synapses

Structure of Chemical Synapses

In this kind of synapses the communication between two neurons at a synapse occurs through neurotransmitters. Neurotransmitters are chemicals released by the presynaptic neuron that may excite the postsynaptic neuron. In this way impulse (signal) is relayed from one neuron to another. The transfer of nerve impulse at the synapse is always unidirectional, i.e. from presynaptic to postsynaptic neurons.

A synapse is formed by a specialized axon ending (axon terminal), which comes in contact with another neuron (**Fig. 2.4**). It is evident from **Figure 2.4** that though at synapse two neurons are close to each other, there is no structural continuity between them. At synapse one neuron sends message (signal) to another neuron that receives this message. The neuron that sends message is called as *presynaptic neuron* while the other neuron that receives this message (signal) is called as *postsynaptic neuron.*

There are three main parts (presynaptic part, synaptic cleft, and postsynaptic part) of a chemical synapse (**Fig. 2.4**). The presynaptic part of a synapse is the axon terminal of the first neuron containing mitochondria and thickened cell membrane (dense cytolemma). The axon terminal also contains presynaptic vesicles containing neurotransmitters in them. The postsynaptic membrane of the postsynaptic neuron presents a dense membrane that contains receptors.

Mechanism of Action of Chemical Synapse*

When a nerve impulse arrives at the presynaptic nerve terminal, the neurotransmitter is released in the synaptic cleft. The neurotransmitter binds to the receptors of the postsynaptic membrane. If a neurotransmitter depolarizes the postsynaptic membrane, it is excitatory. If a neurotransmitter causes hyperpolarization of the postsynaptic membrane, it is inhibitory in nature. Depolarizing postsynaptic potential triggers nerve impulse in the postsynaptic neuron (**Fig. 2.5**). Thus, the postsynaptic neuron receives a chemical signal and again converts it into an electrical signal.

In a chemical synapse, the axon of a nerve cell may form a synapse with a dendrite (axodendritic), with the cell body (axosomatic), and with the axon of another neuron (axoaxonic) (**Fig. 2.6**).

What are Neurotransmitters?

Neurotransmitters are chemicals responsible for transmission of an impulse across a synapse. These neurotransmitters are synthesized in neurons and present in synaptic vesicles. When the neurotransmitters are released in the synaptic cleft, they act on receptors on the postsynaptic membrane.

AN7.7 Describe various types of synapses.

*This is a simplified mechanism of action of a chemical synapse. For detail, refer to author's *Illustrated Textbook of Neuroanatomy* (Wolters Kluwer (I) Pvt. Ltd.).

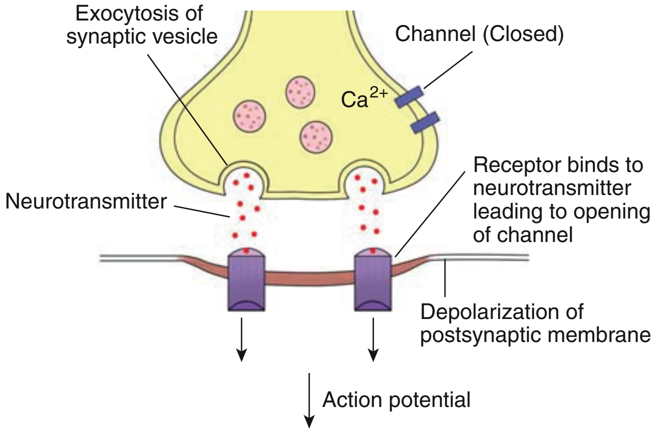

FIGURE 2.5 Mechanism of transmission of signal. Nerve impulse after arrival opens the Ca^{2+} channels to allow Ca^{2+} to enter the presynaptic neuron. Ca^{2+} leads to exocytosis of synaptic vesicles that release the neurotransmitter in the synaptic cleft. Molecules of neurotransmitter now bind to receptors on postsynaptic membrane. This allows opening of channels. Inflow of Na^+ takes place through these channels, which leads to depolarization of postsynaptic membrane and generation of action potential. (Reproduced, with permission, from Pal GP. *Illustrated Textbook of Neuroanatomy.* India, New Delhi: Wolters Kluwer (I) Pvt. Ltd.; 2013.)

These neurotransmitters may act in two different ways, i.e. excitatory or inhibitory:

- They may either depolarize the postsynaptic membrane (resulting in excitatory postsynaptic potential). These kinds of neurotransmitters are called excitatory neurotransmitters as they trigger the nerve impulse in the postsynaptic neuron. Thus the signals (messages) from one neuron are transmitted to the next.
- They may also cause hyperpolarization of the postsynaptic membrane. These kinds of neurotransmitter are inhibitory in nature. Thus, the transmission of signals (messages) is blocked.

The following chemicals act as neurotransmitters in the nervous system:

- Acetylcholine
- Amines
  - Norepinephrine and epinephrine
  - Dopamine
  - Serotonin and histamine
- Amino acids
- Nitric oxide gas
- Adenosine triphosphate
- Neuropeptides
  - Oxytocin and antidiuretic hormone (ADH)
  - Substance P
  - Enkephalin and endorphins
  - Cholecystokinin

Neuropeptides are long chain of amino acids and act as both excitatory and inhibitory peptides. At present more than 100 neurotransmitters are known.

Electrical Synapses

In this kind of synapses, transmission of impulses from one neuron to another occurs through *gap junctions* (**Fig. 2.7**). Each gap junction contains many tubules (connexons) that connect the cytosol of two adjacent neurons. Through these tubules, water, small molecules, and ions flow easily from one neuron to next. Thus through passage of ions, electrical impulse spreads from one neuron to the next. In an electrical

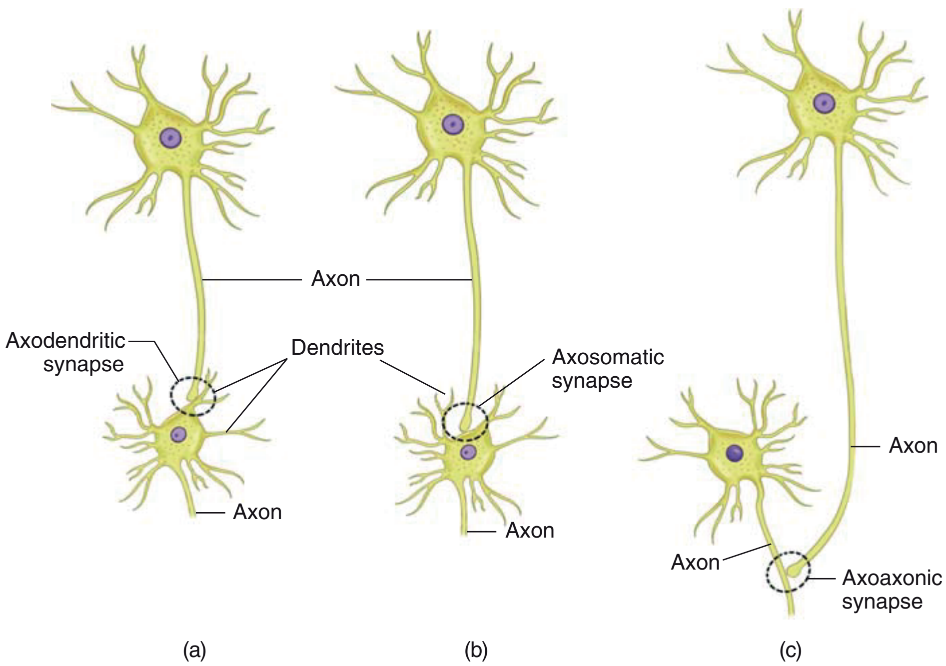

FIGURE 2.6 Various types of chemical synapses. (a) Axodendritic. (b) Axosomatic. (c) Axoaxonic. (Reproduced, with permission, from Pal GP. *Illustrated Textbook of Neuroanatomy.* India, New Delhi: Wolters Kluwer (I) Pvt. Ltd.; 2013.)

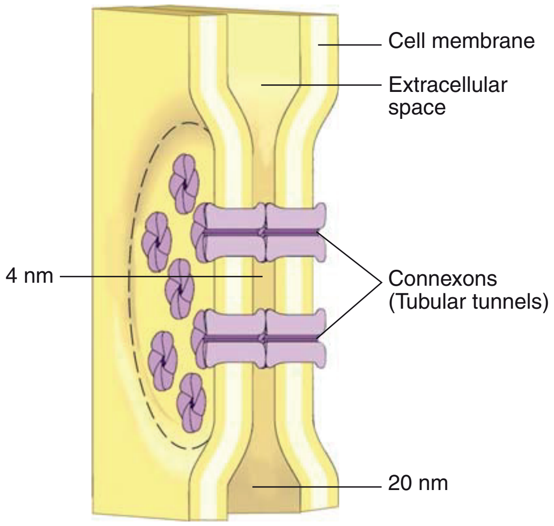

FIGURE 2.7 Electrical synapse (gap junction channels). Here transmission of impulse from one neuron occurs through gap junction. (Reproduced, with permission, from Pal GP. *Illustrated Textbook of Neuroanatomy*. India, New Delhi: Wolters Kluwer (I) Pvt. Ltd.; 2013.)

synapse, as compared to chemical synapse, the transmission of impulse is fast and passes in both the directions.

NEUROGLIA

Besides neurons, the nervous tissue also consists of supporting cells, known as *neuroglia* (glial cells). These cells and their processes fill up the space between neurons. Neuroglia provides insulation to neurons and their processes by completely enveloping them.

The size of neuroglial cells is much smaller than that of neurons. However, in the CNS, their number is 5–50 times more than that of neurons. The neuroglial cells are capable of multiplying in mature nervous tissue. Brain tumors may have their origin in glial cells and are called *gliomas*. In contrast to the nerve cells, neuroglial cells are unable to generate or transmit the impulse.

Neuroglial cells are classified as follows:

1. Neuroglial cells of the CNS
   (a) Ependymal cells
   (b) Astrocytes
   (c) Oligodendrocytes
   (d) Microglia
2. Neuroglial cells of the PNS
   (a) Schwann cells
   (b) Satellite cells

Neuroglial Cells of the CNS

Ependymal Cells

The ependymal cells are arranged in a single layer. They are cuboidal or columnar in shape. The microvilli/cilia are present on their apical surface (**Fig. 2.8a**). Ependymal cells line the ventricles of the brain and central canal of the spinal cord.

Function

Ependymal cells help in the formation and circulation of cerebrospinal fluid (CSF).

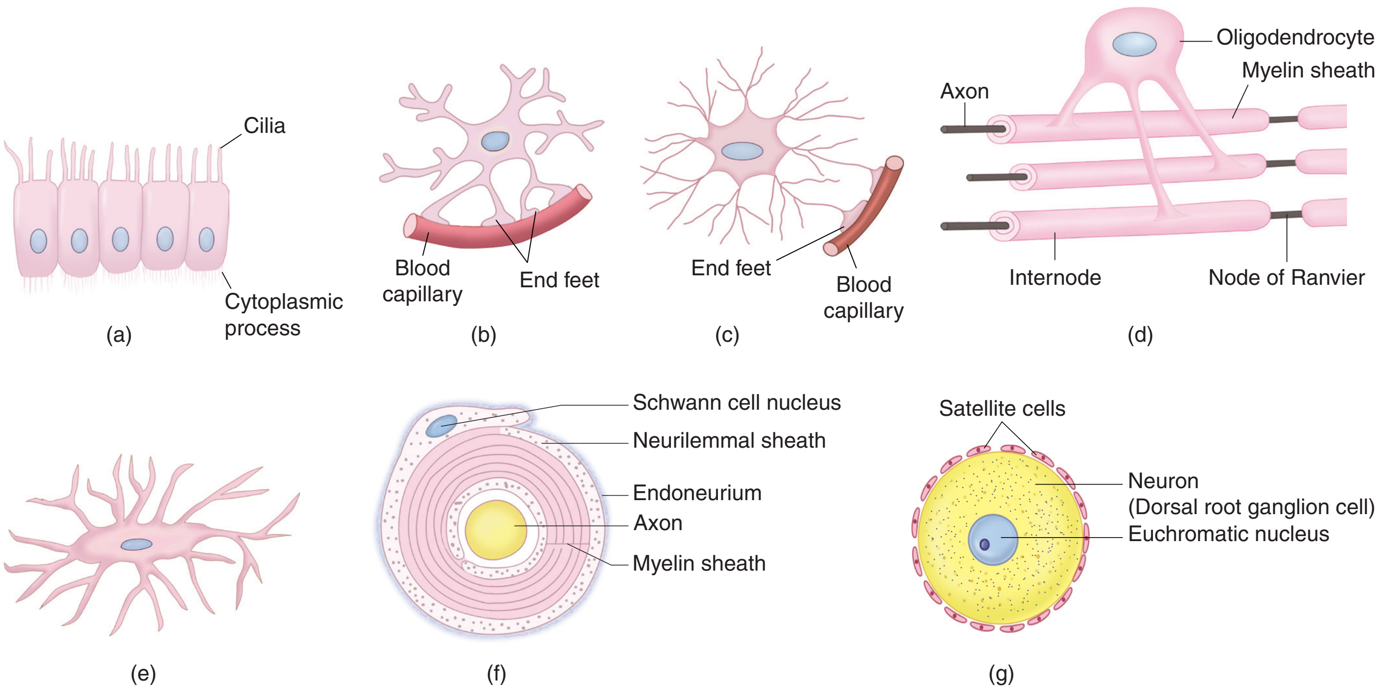

FIGURE 2.8 Different types of neurological cells. (a) Ependymal cells, (b) protoplasmic astrocyte, (c) fibrous astrocyte, (d) oligodendrocyte, forming myelin sheath in the CNS (e) microglia, (f) Schwann cell forming myelin sheath in PNS, and (g) satellite cells surrounding (encapsulating) a dorsal root ganglion cell.

Astrocytes

Astrocytes are so called because they are star-shaped. They have many star-like radiating processes. They are of two types: (i) protoplasmic astrocytes and (ii) fibrous astrocytes.

- Protoplasmic astrocytes have thick processes with abundant granular cytoplasm (**Fig. 2.8b**). They are mainly found in gray matter. Some of these are attached to the neighboring blood capillaries by bulbous "end-feet" or "vascular feet."
- Fibrous astrocytes have long, thin, and straight processes (**Fig. 2.8c**). These cells are present only in the white matter.

Function

Astrocytes completely cover brain surface by forming a subpial membrane. The blood–brain barrier is formed by astrocytes.

Oligodendrocytes

Oligodendrocytes are small, round, or oval cells with only a few cytoplasmic processes (**Fig. 2.8d**). These cells are present in the CNS only. Embryologically, oligodendrocytes develop from the neural tube.

Function

Oligodendrocytes produce myelin sheaths around the axons of multiple neurons in the CNS.

Microglia

Microglial cells are involved in phagocytic activities within the CNS. These cells are small with few tortuous processes (**Fig. 2.8e**).

Neuroglial Cells of the PNS

Schwann Cells

Schwann cells are flattened cells with a flattened nucleus that is surrounded by abundant cytoplasm. These cells are present in the PNS only.

Function

Schwann cells produce a myelin sheath along the axon of a neuron, in the PNS (**Fig. 2.8f**). They also participate in the regeneration of the PNS axon.

TABLE 2.2 Glial Cells and Their Functions

Glial Cells	Functions	Location
Astrocytes (protoplasmic and fibrous)	Provide a supportive framework for the CNS. Provide nutrients to neurons and secrete growth stimulants. Cover the brain surface and surface of neurons except at the site of synapse. Influence synaptic transmission by metabolizing neurotransmitters. Help in the formation of blood–brain barrier. Form hardened scar tissue after brain damage	CNS
Microglia	Removes micro-organisms, dead nervous tissue, and foreign matter by phagocytosis	CNS
Ependymal cells	Form and circulate CSF	CNS
Oligodendrocytes	Produce a myelin sheath around the axons in the CNS	CNS
Schwann cells	Form a myelin sheath and neurilemma around a nerve fiber in the PNS. They help in regeneration of nerve fibers	PNS
Satellite cells	Insulate and support neurons of ganglia and provide nutrition to them	PNS

Satellite Cells

Satellite cells surround the nerve cells of ganglia (spinal and autonomic ganglia). These are flattened cells with prominent nuclei (**Fig. 2.8g**). They are present only in the PNS.

Function

Satellite cells insulate and support neurons of ganglia (in the PNS).

The functions of glial cells are summarized in **Table 2.2.**

Summary

- The nervous tissue is composed of neurons, nerve cell processes (axon and dendrites), and neuroglia.
- Neurons are highly specialized cells and carry electrical signals from one cell to another.
- These cells have a typical pale staining achromatic nucleus, dark nucleolus, and Nissl granules (bodies) in the cytoplasm (**Fig. 2.2**).
- The elongated cytoplasmic processes originate from the nerve cell body. They are of two different types: (i) axon and (ii) dendrites (**Fig. 2.1**).
- Neurons usually have short, multiple, branching dendrites. They receive information from other cells and usually have only one extremely long axon. Axons send information away from the nerve cell body to other cells.
- The proteins (neurotransmitters) produced in cell are transported to the distal region of axon and back. This is known as *axonal transport*.
- The classification of neurons is based on their structure (multipolar, bipolar, etc.), size (Golgi types I and II), and functions (sensory neurons, motor neurons, and interneurons) (**Fig. 2.3c**).
- *Synapse* is defined as point of contact between two neurons. The nervous system consists of two types of synapses: chemical and electrical.
- A chemical synapse consists of three main parts: presynaptic part, synaptic cleft, and postsynaptic part (**Fig. 2.4**).
- When a nerve impulse arrives at presynaptic nerve terminals, the neurotransmitter is released in synaptic cleft. It binds to receptors on postsynaptic membrane. This leads to depolarization of postsynaptic membrane and generation of action potential (**Fig. 2.5**).

- Various types of chemical synapses are axodendritic, axosomatic, and axoaxonic (**Fig 2.6**).
- Neurotransmitters are chemicals responsible for transmission of impulse at synapse.
- In electrical synapses, transmission of impulse between two neurons occurs through gap junction (**Fig. 2.7**).
- Neuroglia (glial cells) are supporting cells of nervous tissue. They also provide insulation to neurons (satellite cells) and their processes (oligodendrocytes and Schwann cells) (**Fig. 2.8**).
- Ependymal cells help in the formation and circulation of the cerebrospinal fluid. The blood–brain barrier is formed by astrocytes while microglia are involved in phagocytic activities within the CNS.

Neuroanatomy

FOR

MEDICAL STUDENTS

As per the Indian Competency-Based Medical Curriculum

Second Edition

The second edition of this book is further streamlined and clinically focused from its previous edition. Text has been thoroughly revised to explain the concepts in simple and easy-to-understand language. Many improved and full-color new illustrations have been added to understand the basic concepts of this complicated subject.

Highlights

- This book is extensively revised as per the competency-based medical education (CBME) curriculum. All the competencies, as recommended by the National Medical Commission of India, have been included.
- A new chapter *Imaging of the Brain and Spinal Cord* has been included to help students understand the importance of X-rays, angiography, MRIs, CT, and PET scanning.
- The "Clinical Aspect" is now more explanatory for ease in understanding by first year students.
- Many new line diagrams and flowcharts have been included and existing line diagrams have been modified so that students are able to reproduce them easily.
- Language has been kept very simple and concise. Less important details are omitted.
- Chapter-end summaries have been included to help in quick revision.
- For the self-assessment of the topic, new MCQs with answers and explanations are included. At the end of each chapter, a list of important (frequently-asked) questions is also provided along with the hints to help students answer these questions.

G.P. Pal, MBBS, MS, DSc, FASI, FAMS, FNASc, FASc, Bhatnagar Laureate, is an eminent teacher with almost five decades of teaching experience in various medical colleges in India and USA. He is currently working as Director Professor, Department of Anatomy, Index Medical College, Indore, India. He has to his credit numerous research publications in journals of international repute. He has received several national awards and honors for his research work, which include Shakuntala Amir Chand Prize of ICMR, Shanti Swarup Bhatnagar Prize of CSIR, and several gold medals, oration awards, and Lifetime Achievement Award by the Anatomical Society of India. Dr Pal has been elected Fellow of various major academies in India—Anatomical Society of India, National Academy of Medical Sciences (New Delhi), National Academy of Sciences, (Allahabad), and Indian Academy of Sciences (Bengaluru). His research work is cited in more than 100 standard medical textbooks across the world. Recently, his name has featured in the list of top 2% scientists of the world (as per the survey conducted by Stanford University, USA, in 2020). He is ranked as #1 scientist in India and 102 in the world, in Anatomy.

Dr Pal has authored many well-received books such as *Textbook of Histology; Illustrated Textbook of Neuroanatomy; Medical Genetics; Genetics in Dentistry; General Anatomy; Basics of Medical Genetics; Human Osteology; Medical Genetics for Dental Students;* and *Thieme Dissector.* He has also edited the first South Asian edition of *Grant's Atlas of Anatomy* (in press). He has also co-authored Professor Inderbir Singh's *Human Embryology* from seventh to ninth editions.

For more information about the author and his work, search online for "Indian Anatomists – Wikipedia" or "Gaya Prasad Pal."

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