CHAPTER

1

Functional Organization of Nervous Tissue

eSmartQuiz

Competencies

AN7.2: List components of nervous tissue and their functions.
AN7.3: Describe parts of a neuron and classify them based on number of neurites, size and function.
AN7.7: Describe various types of synapses.
AN68.1: Describe and identify multipolar and unipolar neurons, ganglia and peripheral nerves.
AN68.2: Describe the structure-function correlation of neuron.
AN68.3: Describe the ultrastructure of nervous tissue.

- The nervous system works in coordination with the entire body in harmony and as a divine mechanism. The nervous system is influenced by inputs from various other body systems and reciprocally controls and influences them.
- The nervous tissue is composed of neurons, their processes and supporting neuroglial cells and outer covering of meninges.

Functional Neuroanatomy

The nervous system performs the following functions:

1. It receives sensory stimuli from internal and external environment.
2. It integrates and analyze the sensory inputs.
3. It initiates and controls voluntary and involuntary functions of the body.
4. It stores the received information and experiences.
5. It utilizes the stored information for future responses.
6. It is a site of intelligence, memory, learning.
7. It is a site of thoughts and creativity.

Study Guide

- For understanding of the neuroanatomy, the student should know:
  1. Location of structure
  2. Function of structure
  3. From where it receives information (afferent fibers)
  4. To where it sends information (efferent fibers).

DIVISIONS OF NERVOUS SYSTEM

The nervous system can be studied or divided based on anatomical or structural classification and functional classification (Flowchart 1.1).

Anatomical or Structural Divisions

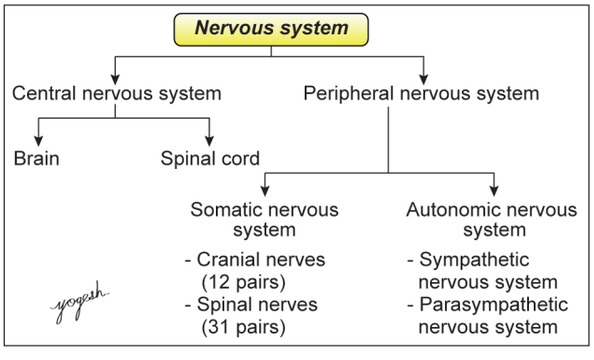
- Anatomically, the nervous system is divided into two parts:
  A. *Central nervous system*: It consists of brain and spinal cord.
  B. *Peripheral nervous system*: It consists of peripheral nerves and ganglia. The peripheral nerves include 12 pairs of cranial nerves, 31 pairs of spinal nerves and autonomic nerves. The ganglia include dorsal root ganglia of spinal nerves, cranial nerve root ganglia, and autonomic (sympathetic and parasympathetic) ganglia.

Functional Neuroanatomy

The central nervous system (CNS) integrates, processes, and coordinates sensory inputs, generating responses accordingly. It is the seat for intelligence, memory, learning, emotions and other higher functions.

The peripheral nervous system (PNS) carries sensation to CNS and supplies muscles, glands, blood vessels and viscera.

Flowchart 1.1: Divisions of nervous system



Functional (Physiological) Divisions

- On the physiological or functional basis, the nervous system is divided into two divisions: afferent or sensory and efferent or motor division.
  1. *Afferent or sensory division* brings the sensory information to the central nervous system.
  2. *Efferent or motor division* carries the motor stimuli away from the central nervous system.

Classification of efferent division: The efferent division of nervous system has two subsystems: somatic and autonomic, as follows:

1. *Somatic nervous system* (SNS) controls voluntary actions of skeletal muscles.
2. *Autonomic nervous system* (ANS) controls involuntary functions of heart, smooth muscles, glands, and blood vessels.

Functional Neuroanatomy

The CNS interprets the received sensory inputs and, based on that, it sends the efferent stimuli to control the body.

MAJOR COMPONENTS OF NERVOUS SYSTEM

The major components of nervous system and their cavities are listed in Table 1.1 (Fig. 1.1).

Enteric Nervous System

Functional Neuroanatomy

The enteric nervous system (ENS) receives sensory inputs from the stretching of the intestinal wall and chemical changes in the intestinal content. ENS sends signals that control the contraction of intestinal smooth muscles (peristaltic movements) and secretions of intestinal glands and cells.

- Enteric nervous system (ENS) is a network of neurons and ganglia located in the wall of gastrointestinal tract.
- It consists of the following components:
  1. *Myenteric (Auerbach's) plexus:* It is located in the wall of the intestine, between the inner and outer layers of the muscularis externa.
  2. *Submucosal (Meissner's) plexus:* It is located in the submucosal layer of gastrointestinal tract.

Functions of ENS

The enteric nervous system performs the following functions:

1. Regulates the motility of intestine.
2. Regulates the secretions of intestine.
3. Gives sensory inputs about stretching of wall of intestine.
4. Gives sensory inputs about chemical composition of content of intestine, such as pH, presence of fat, and so on.
5. Influences absorption of nutrients.

TABLE 1.1: Major components of nervous system

Part	*Cavity*	*Subparts*
Cerebral hemisphere	Lateral ventricle	Cerebral cortex: Frontal lobe, parietal, occipital, temporal lobes Basal ganglia, claustrum, insular cortex, limbic system
Diencephalon	3rd ventricle	Thalamus, hypothalamus, subthalamus, metathalamus, epithalamus
Brainstem	Cerebral aqueduct 4th ventricle	Midbrain Pons Medulla oblongata
Cerebellum	4th ventricle	Cerebellar cortex Cerebellar nuclei
Spinal cord	Central canal of spinal cord Terminal ventricle	Inner grey matter Outer white matter
Cranial nerve	–	12 pairs
Spinal nerves with dorsal root ganglia	–	31 pairs
Sympathetic ganglia	–	2 chains

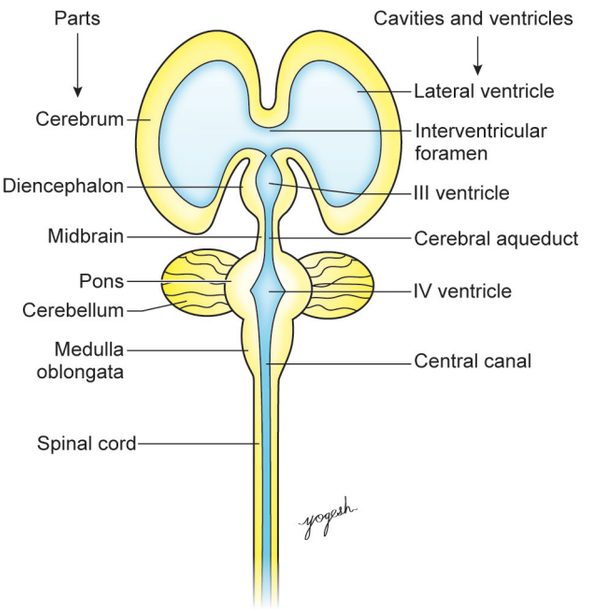


Fig. 1.1: Parts of the brain

CELLULAR ORGANIZATION OF NERVOUS SYSTEM

Functional Neuroanatomy

Mature neurons do not divide except for bipolar neurons of olfactory mucosa. Hence, most brain tumors arise from the uncontrolled growth of supporting neuroglial cells. Medulloblastoma of the cerebellum is a neuronal cell tumor.

The nervous system consists of:
1. Excitable cells – neurons
2. Non-excitable supporting cells – neuroglia and ependymal cells, Schwann cells, satellite cells.

NEURONS

Neurons are the structural and functional units of the nervous system. Neurons can receive and interpret sensory information, and they can transfer this information to other neurons or stimulate other non-neuronal cells.

Structure of Neuron

Each neuron has body, axon, dendrites and synaptic junctions (Fig. 1.2).

Cell body or soma

- It consists of a nucleus and surrounding cytoplasm.
- Nucleus of the neuron is large, vesicular and contains a prominent nucleolus. Most neurons have a central nucleus, except for those in sympathetic ganglia, which have an eccentric nucleus.
- In females, Barr body (*heterochromatin*) is present as plano-convex mass beneath the nuclear membrane.
- Mature neurons do not divide.

Cytoplasm

- It shows Nissl granules, numerous mitochondria, rough endoplasmic reticulum, and Golgi complex.

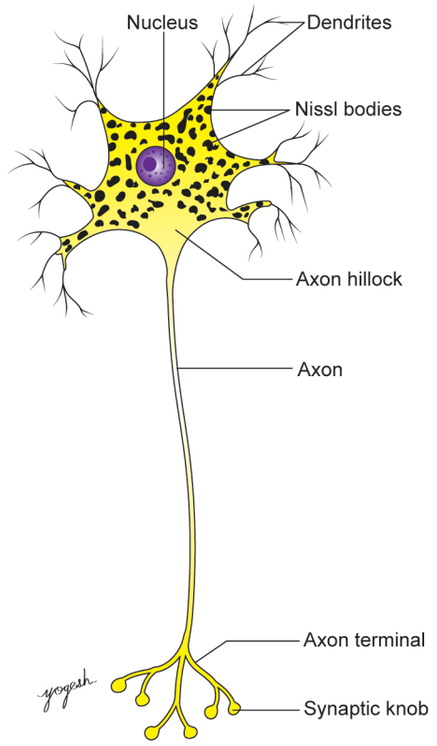


Fig. 1.2: Parts of neuron

- *Nissl bodies*

Functional Neuroanatomy

Nissl bodies are rough endoplasmic reticulum and produce proteins required for neurons and neurotransmission.

  - Nissl bodies or granules are deeply stained bodies with hematoxylin and other basic dyes.
  - They are present in cytoplasm and may extend into dendrites. They are absent at axon hillock – the site of beginning of axon from cytoplasm. They are also absent in the axon.
  - Nissl granules are numerous in motor neurons than in sensory neurons.
  - *Function*: Protein synthesis.

Clinical Neuroanatomy

Chromatolysis: It is a process where Nissl granules disappear. It occurs in injured or fatigued neurons. It is a reversible process.

Some Interesting Facts

Cytoplasmic organelles of neurons

- *Smooth endoplasmic reticulum*: It is present in cytoplasm, axon and dendrites.
  Function: It helps in transmission of neurotransmitters from cytoplasm to axon terminals and breaks up into synaptic vesicles at the axon terminal.
- *Mitochondria*: They are present throughout the cytoplasm and in all processes.
- *Golgi apparatus*: It is closely located to the nucleus. It helps in storage and release of neurosecretion.
- *Lysosomes*: They contain hydrolytic enzymes and acid phosphatase. They help in lysis of phagocytosed material.
- *Neurofilaments*: They are arranged in plexiform manner in the cell body. They extend into the axon and dendrites. They are crowded at the axon hillock; hence, Nissl granules are absent at the axon hillock. Neurofilaments support the cellular architecture of neurons.
- *Microtubules*: They are present in the body and neurites. They help regulate the contractility of neurons.
- *Centrioles*: They are present in neurons but do not divide in the postnatal life. Hence, neurons cannot divide after birth.
- *Pigments*:
  1. *Lipochrome*: These are yellow pigments and are more abundant in old age.
  2. *Neuromelanin:* They arise from degradation products of catecholamine synthesis. They are abundant in substantia nigra of midbrain.
  3. *Lipofuscin*: These are minor granular wear and tear pigments that increase with age. These are residual bodies of the cytoplasmic organelles.
  4. *Metallic elements*: Copper deposits give a bluish coloration and iron gives a pink color to the red nucleus and oculomotor nucleus.

Neurites

- These are processes arising from the body of the neuron. They are axons and dendrites.

Dendrites

> *Functional Neuroanatomy*
>
> Dendrites carry the received signals toward the cell body of neuron.

- These are multiple, short, thick and tapering processes.
- *Dendrite-free*: Branching pattern of dendrites form dendritic tree. All cell organelles, including Nissl granules, are present in dendrites except Golgi apparatus.
- Dendritic spines are numerous minute projections of the dendrites of some neurons.

Some Interesting Facts

Role of dendrites in memory and learning:

- Dendrites play an essential role in memory formation.
- Dendritic arborization or branching is the process of formation of dendritic connections. It plays a vital role in learning and memory. The formation of new connections between neurons, or the growth of new dendritic processes, enables new communication between neurons and provides a larger surface area for synapses.
- Dendritic spines or gemules are small projections of dendrites. The change in size and shape of dendritic spines produces a change in size and shape of synapse, called ***synaptic remodeling***.
- Thus, dendrite formation, plasticity/changing nature of dendritic branches, helps in learning and memory storage in brain.

Axons

- Axon is a single, long, thin process of neuron. It has uniform diameter.
- *Axoplasm* is the cytoplasm in the axon, and axolemma is its cell membrane.
- *Axon hillock* is the part of the neuronal cell body that gives rise to the axon. It contains numerous neurofibrils; hence, it is devoid of Nissl granules.
- Collateral branches may arise at right angle from the side of the axon. *Telodendrites* are the smaller branches at the terminal part of axon.
- ***Terminal knobs*** or ***boutons*** are the small swellings at the end of the terminal part of axon or its collateral branch. ***Motor end plate*** is terminal part of axon in the skeletal muscle.
- ***Preaxon*** is the initial segment of an axon that extends from axon hillock and the point of beginning of myelination.

> *Functional Neuroanatomy*
>
> Preaxon has synapses with excitatory and/or inhibitory neurons that modulate the transmission of nerve impulses along the axon.

Axonal transport:

- Axonal transport is the system of transport of substances within the axon. It is of two types:
  1. Anterograde or orthograde transport – transport away from the cell body.
  2. Retrograde transport – transport toward the cell body.
- Axonal transport examples:
  - Bodies of neurons of substantia nigra of midbrain produce dopamine, which is transported through axons to the corpus striatum.
  - Substances absorbed (pinocytosed) by the axon terminal may be transferred to the cell bodies of neuron.

Clinical Neuroanatomy

- *Rabies virus transport:* Rabies virus is present in the saliva of infected animals. Upon biting, this virus is deposited at the site of injury. Later, rabies virus enters the axons through synaptic knobs and moves toward the CNS by retrograde axonal transport.
- *Herpes zoster virus* is transported from neuronal cell bodies to the skin through anterograde axonal transport. This virus resides in sensory ganglia (bodies of sensory neurons) in its dormant phase.

CLASSIFICATION OF NEURONS

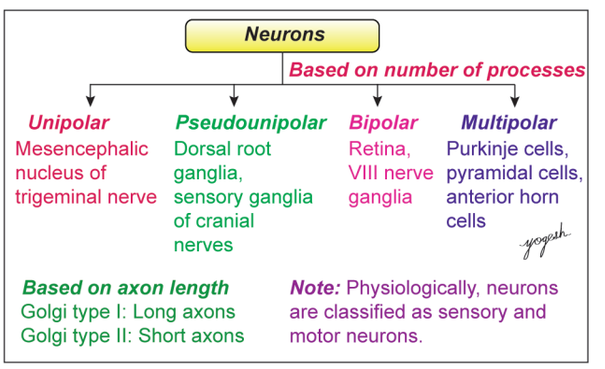
Q. Write a short note on classification of neurons.

Neurons can be classified based on the number of processes, size, and physiological functions.

Classification based on Number of Processes

- Neurons are classified structurally, that is, based on number of processes as unipolar, pseudounipolar, bipolar and multipolar. *Recent concept*: Unipolar and pseudounipolar neurons are considered under the same category (Fig. 1.3, Flowchart 1.2).
  1. *Unipolar neurons* have only one cell process, mostly dendrite. For example, neurons of mesencephalic nucleus of trigeminal nerve and certain neurons during embryonic life.

Flowchart 1.2: Classification of neurons



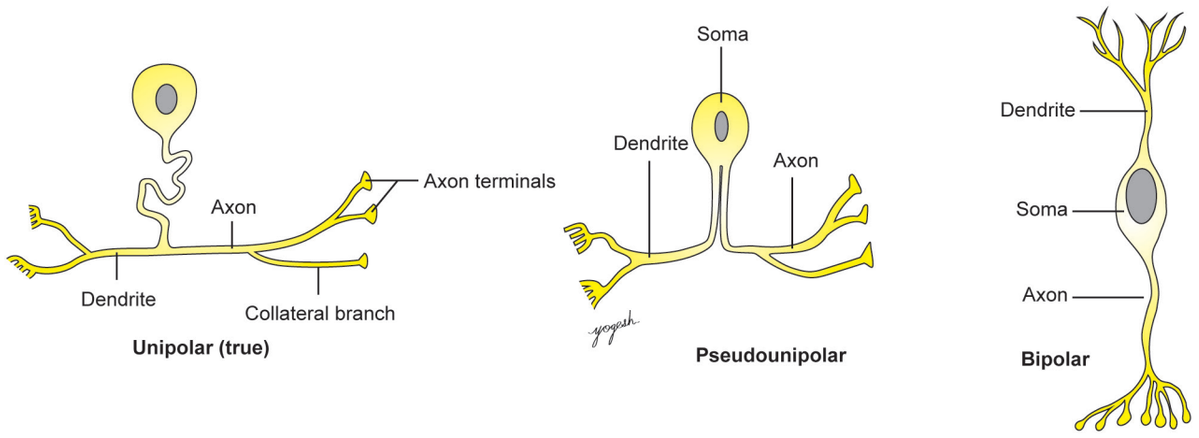


Fig. 1.3: Types of neurons (schematic)

2. *Pseudounipolar neurons* have one process that divides into two branches, central and peripheral. For example, neurons of dorsal root ganglia and sensory nerve ganglia.
3. *Bipolar neurons* have two processes, one axon and another dendrite. These processes arise from the cell body at its opposite ends, such as the retina, vestibular and spiral ganglia of the vestibulocochlear nerve, and the olfactory neuroepithelium.
4. *Multipolar neurons* have a single axon and multiple dendrites arising from the cell body. Examples: stellate neurons (star-shaped), Purkinje cells (flask-shaped), pyramidal cells (triangular-shaped).

Note: Axonic neurons do not have an axon. They have only dendrites, which conduct the signal in both directions.
For example, amacrine cells in the retina modulate photoreceptive signals, helping to perceive contrast movement in an image.

Classification based on Length of Axon

Based on the length of axon, the neurons are classified as Golgi type I and Golgi type II neurons.

Golgi type I neurons

They have a single long axon, which may be more than a meter in length. For example, spinal motor neurons, Purkinje cells of cerebellum, and pyramidal cells of cerebrum.

Golgi type II neurons

- They have short axons or do not even have axons.
- For example, stellate and granule cells of cerebellar cortex.

Physiological Classification of Neurons

Based on their physiological functions, neurons are classified into sensory, interneurons, and motor neurons.

1. *Sensory or afferent neurons:* These are capable of detecting various kinds of sensory stimuli such as pain, touch, temperature, and so on. They transmit the sensory information to the CNS.
2. *Interneurons:* They connect sensory and motor neurons. Approximately 90% of the body's neurons are interneurons. They lie within the CNS. They integrate the sensory inputs.
3. *Motor (efferent) neurons:* These carry motor stimuli from CNS to the muscles, glands and viscera. Motor neurons can be further classified as follows:
   A. *Somatic neurons*: They supply muscles. They are of two types:
      – *Upper motor neurons* are located in the motor area of cerebral cortex. Their axons terminate on the cranial nerve nuclei or anterior horn cells of spinal cord.
      – *Lower motor neurons*: They are located in the motor nuclei of cranial nerves and anterior horn cells of spinal cord.
   B. *Visceral (autonomic) neurons*: They stimulate cardiac and smooth muscles and glands. They are of two types:
      – *Preganglionic neurons*: They are located in the autonomic nuclei of cranial nerves (Edinger–Westphal nucleus, superior and inferior salivatory nucleus, lacrimatory nucleus, dorsal nucleus of vagus) and lateral horn of spinal cord.
      – *Postganglionic neurons*: They are located in the autonomic ganglia.

NEUROGLIA

These are supporting cells of the nervous system. They are classified as follows (Table 1.2):

1. Central neuroglia (neuroglia of the central nervous system)
   – Astrocytes
   – Oligodendrocytes
   – Microglia
   – Ependymal cells

TABLE 1.2: Glial cells

Cell	*Origin*	*Location*	*Functions*
Central neuroglia			
Fibrous astrocytes	Neural tube	White matter in CNS	Formation of blood–brain barrier
Protoplasmic astrocytes	Neural tube	Grey matter in CNS	Healing of injury by scar formation (gliosis)
Oligodendrocytes	Neural tube	Mostly white matter in CNS	Form myelin sheath in CNS
Microglia	Bone marrow	CNS	Phagocytosis
Ependymal cells	Neural tube	Lining of cavities of brain and spinal cord and choroid plexus	Produces CSF at choroid plexus Form Brain–CSF barrier
Peripheral neuroglia			
Schwann cells	Neural crest cells	Peripheral nerves	Myelination of axons and surrounding unmyelinated axons, nerve regeneration
Satellite cells	Neural crest cells	Sensory and autonomic ganglia	Protection and support for the neuronal cell bodies

2. Peripheral neuroglia (Neuroglial cells of peripheral nervous system)
   - Schwann cells
   - Satellite cells

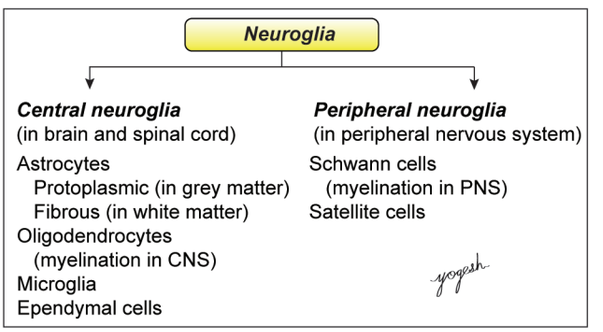
Functional Neuroanatomy

Neuroglial cells are supporting cells of neurons, and they form the insulation and the blood–brain barrier. These cells are non-excitable and undergo mitotic division.

Central Neuroglia

- These are neuroglial or supporting cells of the central nervous system.
- The central neuroglia includes (Fig. 1.4, Flowchart 1.3):
  - Astrocytes
  - Oligodendrocytes
  - Microglia
  - Ependymal cells
- On routine H&E staining, only nuclei of neuroglial cells are visible. They are about 5–10 times more than that of neurons. Heavy metal staining or immunohistochemistry is required for demonstration of the cell processes of neuroglia.

Flowchart 1.3: Types of neuroglia



Astrocytes

Functional Neuroanatomy

Astrocytes support the neurons. They regulate the movement of nutrients to and from the neurons and across the blood–brain barrier.

- Astrocytes are large, *star-shaped* cells with numerous star-like radiating cell processes
- *Classification*: There are two types of astrocytes: fibrous and protoplasmic.

Fibrous astrocytes

- They are present only in white matter.
- They have a few long and thin cell processes with expanded ends of processes as end feet or vascular feet.

Protoplasmic astrocytes

- They are mostly present in grey matter.
- They have numerous, thick processes and abundant cytoplasm.
- They form the blood–brain barrier.

- Histological identification: Both fibrous and protoplasmic astrocytes can be identified using immunohistochemistry. They both have glial fibrillary acidic protein (GFAP). Hence, astrocytes can be stained using anti-GFAP antibodies.

Functions

- Astrocytes support the neurons and microvasculature.
- They provide nutrients to the neurons and help in maintaining desired concentration of metabolites, ions and neurotransmitters.
- They store glycogen.
- Formation of blood–brain barrier: The end feet of processes of protoplasmic astrocytes have tight junctions, and they surround the blood vessels to form the blood–brain barrier.
- *Formation of glia limitations*: Protoplasmic astrocytes form a membrane-like barrier on external surface of brain and spinal cord as glia limitans. It lies just beneath the pia mater and ependymal lining. It forms a barrier between cerebrospinal fluid and ENS parenchyma.

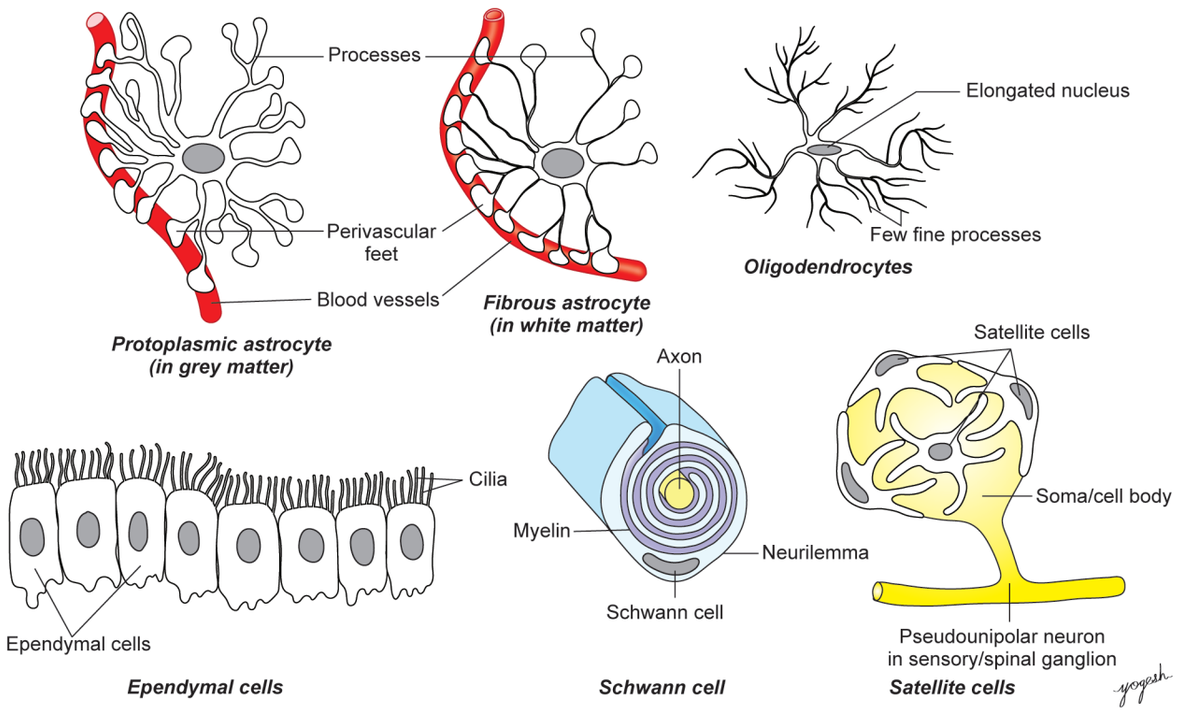


Fig. 1.4: Types of neuroglial cells

Clinical Neuroanatomy

- *Gliosis:* The damaged neurons that fail to heal in the brain and spinal cord are replaced by the proliferation of astrocytes. This is called gliosis. Thus, gliosis is a healing scar of CNS.
- *Fibrous astrocytoma:* It is a primary, slow-growing brain tumor that arises from astrocytes. It accounts for 80% of adult brain tumors. It can be localized using CT scan and MRI and can be confirmed with biopsy examination.

Some Interesting Facts

Pia-glial membrane and ependyma-glial membrane

- *Pia-glial membrane*: It is a glia limitans formed by processes of astrocytes on the outer surface of brain and spinal cord, just deep to the pia mater.
- *Ependyma-glial membrane*: It is a glia limitans formed by processes of astrocytes on the ventricular surface of brain and central canal of spinal cord, just deep to the ependymal lining.

Oligodendrocytes

Functional Neuroanatomy

Oligodendrocytes form myelin in CNS.

- Oligodendrocytes are small, rounded cells. They have few cytoplasmic processes (*oligo* = scanty, in Greek).
- One oligodendrocyte may myelinate multiple adjacent axons.
- *Node of Ranvier*: It is the gap between adjacent processes of oligodendrocytes that myelinate an axon.
- *Function:* Oligodendrocyte produces myelin sheaths in the brain and spinal cord.

Some Interesting Facts

Difference between the myelin sheath in CNS and PNS

- The myelin sheath in CNS has different protein expression than that of PNS.
- *Protein expressed in myelin sheath in CNS:* Proteolipid protein (PLP), myelin oligodendrocyte glycoprotein (MOG), oligodendrocyte myelin glycoprotein (OMGP).
- *Proteins expressed in myelin sheath in PNS:* Protein o(po), peripheral myelin protein (pm22), myelin basic protein.
- These proteins can be used in immunohistochemistry to stain and differentiate myelin in CNS and PNS.
- *Difference between oligodendrocytes and Schwann cells:* Oligodendrocytes do not have an external lamina, whereas it is present in Schwann cells. Oligodendrocytes do not cover nonmyelinated axons in the CNS, but Schwann cells enclose even non-myelinated axons in the PNS. Myelin in the CNS has fewer Schmidt-Lanterman clefts because astrocytes provide a favorable metabolic environment for neurons.
- Nodes of Ranvier in CNS are larger than those in PNS, and thus saltatory conduction in CNS is more efficient.

Microglia

Functional Neuroanatomy

Microglia are smallest neuroglia and they perform phagocytosis, especially in nerve tissue injuries and diseases. They remove bacteria, cancer cells and dead nerve cells.

- Microglia are the smallest neuroglial cells. They account for about 5% of all glial cells in CNS. These are phagocytic cells and form a part of mononuclear phagocytic system.
- *Development*: Microglia originate from granulocyte/monocyte progenitor (GMP) cells in bone marrow and enter the CNS through blood vessels.
- They are small cells with elongated nuclei. They have short, twisted processes with numerous spikes. Their cytoplasm contains numerous lysosomes, inclusions, and vesicles.
- *Functions:*
  1. Microglia are phagocytic cells that remove:
     - Dead cells, injured cells, cell debris
     - Cancerous cells
     - Invading microorganisms such as bacteria
     - Cancer (neoplastic) cells.
  5. Microglia play important role in inflammatory and degenerative diseases.

Some Interesting Facts

Gitter or Hortega cells: These are "*lipid-laden*" microglial cells. They are present at the edge of healing brain infarcts. These are also called *compound granule cells, Gitterzelle, Mesulica, or perivascular glial cells*.

Ependymal Cells

Functional Neuroanatomy

Ependymal cells are epithelium-like cells. They line the cavities of brain and spinal cord. They produce CSF and form brain–CSF barrier.

- Ependymal cells are the epithelium-like lining of fluid-filled cavities of brain and spinal cord. They are single-layered cuboidal to columnar cells.
- *Development*: They are derived from neural tube.
- *Types of ependymal cells:*
  1. *Ependymocytes*: They line the cavities of brain and spinal cord.
  2. *Choroid epithelial cells*: They line the choroid plexuses and produce CSF.
  3. *Tanycytes*: These are specialized ependymal cells that line that floor of third ventricle. They monitor the level of metabolites and are sensitive to changes in glucose level.
- Ependymal cells have tight junctions toward the apical surface. They show cilia and microvilli on the apical surface and numerous infoldings at basal surface.
- *Functions*:
  1. At choroid plexus, choroid epithelial cells (type of ependymal cells) secrete CSF.
  2. Ependymocytes form a component of the CSF-brain barrier.
  3. Tanycytes (modified ependymal cells) maintain metabolite levels.

Peripheral Neuroglia

- These are present in the PNS
- These are of two types:
  1. Schwann cells
  2. Satellite cells

Schwann Cells (Neurolemmocytes)

Functional Neuroanatomy

Schwann cells produce myelin in PNS and surround unmyelinated axons in PNS. They help in regeneration of axons in PNS.

- Schwann cells are present only in PNS. These are flattened cells with a flattened nucleus. It has abundant cytoplasm.
- *Development*: Schwann cells are derived from neural crest cells.
- Schwann cells produce myelin sheath around the axon. The nodes of Ranvier are the sites where adjacent Schwann cells meet along the myelinated axon. At these nodes, the axon is devoid of myelin.
- *Functions*:
  1. Schwann cells produce myelin and help in saltatory conduction of nerve impulses in PNS.
  2. They also enclose non-myelinated neurons.
  3. Schwann cells help in regeneration of damaged axons in PNS.

Satellite Cells

Functional Neuroanatomy

Satellite cells protect and support neurons in peripheral ganglia.

- Satellite cells are present in peripheral ganglia, both sensory and autonomic.
- These are single layer of small cuboidal cells. They surround the neuronal cell body. They form a complete capsule in sensory ganglia. This capsule gives passage to the nerve cell processes. In autonomic ganglia, the satellite cell capsule is incomplete, as these ganglia contain neuronal synapses.
- *Functions*
  1. They protect and support neurons in peripheral ganglia.
  2. They maintain microenvironment and help in metabolic exchange.
  3. They provide insulation.

SYNAPSE

Q. Write a short note on synapse.

- The nerve impulse is an electrical signal that travels across the neuron. This impulse is transmitted from one neuron to another through a specialized zone of cell contact called a *synapse*.
- Synapse is a specialized area of contact between two or more neurons. As well as with neurons, muscles, or glands.
- Synapses conduct an impulse by contiguity and not by continuity.

Classification of Synapse

Structural Classification of Synapse

Synapses are classified structurally as follows (Fig. 1.6):

1. Axodendritic synapse – between the axon of one neuron and the dendrite of another neuron
2. Axosomatic synapse – between axon of one neuron and body (soma) of another neuron
3. Axoaxonic synapse – between two axons
4. Dendroaxonic synapse – between dendrite of presynaptic neuron and axon of postsynaptic neuron
5. Dendrodendritic synapse – between two dendrites
6. Somatosomatic synapse – between bodies of two neurons
7. Somatodendritic synapse – between body (soma) of one neuron and dendrite of another neuron.

Chemical and Electric Synapses

Based on the mechanism of conduction of nerve impulses, the synapses are classified as follows (Flowchart 1.4):

1. *Chemical synapse*: It involves release of neurotransmitter (chemical) for conduction of nerve impulse.
2. *Electrical synapse*: It involves transfer of electric signal from one cell to another through the gap junctions.

Structure of Chemical Synapse

Chemical synapses are the most common type of synapse. It involves release of chemical neurotransmitter at the site of synapse during impulse transmission.

Components of chemical synapse

The chemical synapse consists of three components: Presynaptic knob, synaptic cleft, and postsynaptic membrane.

1. *Presynaptic knob*: It is a terminal part of presynaptic neuron. The presynaptic knob or terminal boutons contain all the components of the axon, including mitochondria and synaptic vesicles. These vesicles contain neurotransmitters, such as catecholamines (adrenaline, noradrenaline, dopamine), as well as acetylcholine and others.

   Synaptic vesicles are derived from Golgi apparatus or smooth endoplasmic reticulum. Some are even derived from the reuptake of neurotransmitters by endocytosis.

   Synaptic vesicles undergo exocytosis to release neurotransmitters.

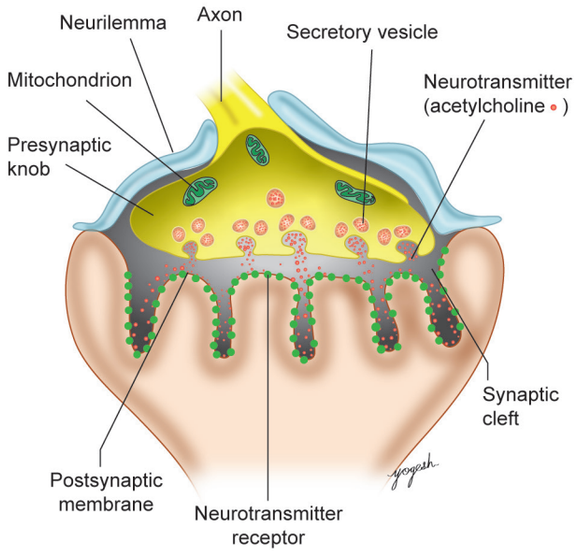


Fig. 1.5: Structure of a synapse neurotransmitter (acetylcholine)

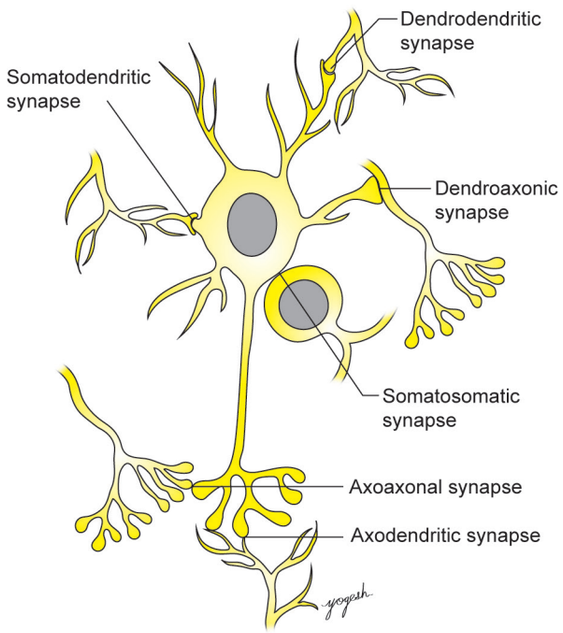
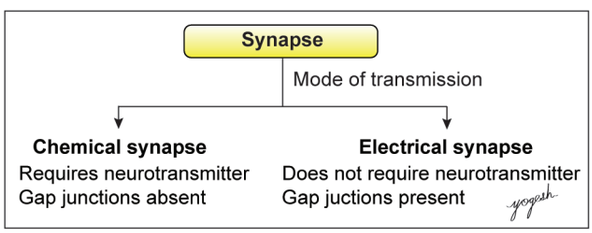


Fig. 1.6: Types of synapse

Flowchart 1.4: Classification of synapses based on mode of transmission



2. *Synaptic cleft*: It is a 20–30 nm wide gap between pre- and postsynaptic neurons. It permits the diffusion of the neurotransmitter.
3. *Postsynaptic membrane*: It is a thickened part of the postsynaptic membrane. It has receptor proteins that give attachment to neurotransmitters.

Some Interesting Facts

Type I and Type II synapses:

1. *Type I or asymmetric synapses:* In these synapses, the postsynaptic membrane is thicker than the presynaptic membrane. Most of the excitatory synapses are asymmetrical.
2. *Type II or symmetric synapses:* In these synapses, the postsynaptic membrane is not thicker than the presynaptic membrane. Most of the inhibitory synapses are symmetric.

Properties of Synapses

1. A single neuron may synapse with one or many (around 5500) different neurons.
   For example, bipolar neurons of the retina with only one ganglionic neuron. This is essential for accuracy of vision.
2. *Feed–forward inhibition:*

   Functional Neuroanatomy

   This is essential for progressive relaxation of the antagonist muscle during contraction of the agonist muscle. It enhances precision of action.

- Structure of feed–forward inhibition: One excitatory neuron (E) synapses with two excitatory neurons, A and B. Here, collateral from neuron E synapses with an inhibitory interneuron (I), which later inhibits the activity of neuron B. Thus, excitatory neuron (E) stimulates contraction of agonist muscle through neuron A and inhibits/relaxes antagonist muscle through neuron B.

3. *Feedback inhibition:*

   Functional Neuroanatomy

   The feedback inhibition is required to prevent excessive stimulation/muscle contraction.

- For example: **Renshaw cells** are inhibitory interneurons located in the anterior horn of spinal cord. Renshaw cells receive collateral from the lower motor neurons. On stimulation, it has received collateral (stimulus). Thus, the Renshaw cell provides feedback inhibition to the neuron. It helps prevent excessive stimulation of the lower motor neuron and excessive muscle contraction. Therefore, Renshaw cell helps for:
  a. Precise and coordinated movements
  b. Modulation of monosynaptic reflexes, such as the knee jerk reflex.

4. *Synaptic delay:*

   Functional Neuroanatomy

   Synaptic delay provides time to the postsynaptic neurons to integrate and process the information. It may provide time for summation or inhibition of multiple stimuli on postsynaptic neuron.

- Synaptic delay is a duration that is required to transfer impulse from one neuron to another. It involves time required to secrete neurotransmitter, traveling of neurotransmitter through synaptic cleft, it binding to receptors and so on.
- Average synaptic delay is 0.5 milliseconds.

Clinical Neuroanatomy

Tetanus and muscle spasm: In tetanus, *Clostridium tetani* bacteria release tetanus toxin in wounds that inhibits the activity of Renshaw cells in the spinal cord. Thus, there is loss of neuronal inhibition resulting into muscle rigidity and spasm.

NEUROTRANSMITTERS

Q. Write a short note on neurotransmitters.

Neurotransmitters are the substances released by the neurons at the site of synapse (Table 1.3).

TABLE 1.3: Neurotransmitters

Neurotransmitter	*Major location*
Acetylcholine	Motor neurons supplying skeletal muscles Parasympathetic postganglionic neurons Some sympathetic postganglionic neurons Some neurons of basal ganglia
Noradrenalin	Postganglionic neurons of sympathetic ganglia Locus coeruleus (located in the floor of 4th ventricle)
Adrenaline	Adrenal medulla
Dopamine	Substantia nigra Corpus striatum Limbic system
Serotonin	Raphe nuclei of brainstem
Histamine	Hypothalamus
GABA	Inhibitory neurons in brainstem and spinal cord (Renshaw cells)
Glutamate, Aspartate	Excitatory neurons from cerebral cortex
Glycine	Inhibitory neurons in brainstem and spinal cord
Nitric oxide	Autonomic and enteric synapses → smooth muscle relaxation Pelvic splanchnic nerves (nervi erigentes)
Neuropeptides	Pituitary gland, hypothalamus
Substance P	Spinal and trigeminal ganglia
Vasoactive intestinal polypeptide	Bipolar neurons of cerebral cortex Median eminence of hypothalamus

For example,

- Acetylcholine
- Monoamines: Noradrenalin, adrenaline, dopamine, serotonin, histamine
- Amino acids: Gamma aminobutyric acid (GABA), glutamate, aspartate, glycine, taurine
- Nitric oxide
- Neuropeptides
- Substance P
- Vasoactive intestinal polypeptides (VIP)
- Somatostatin
- B-endorphin
- Leu-enkephalin
- Met-enkephalin
- Dynorphins.

Notes