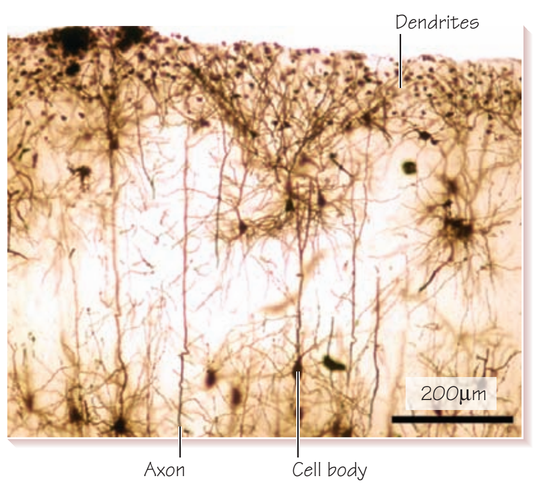
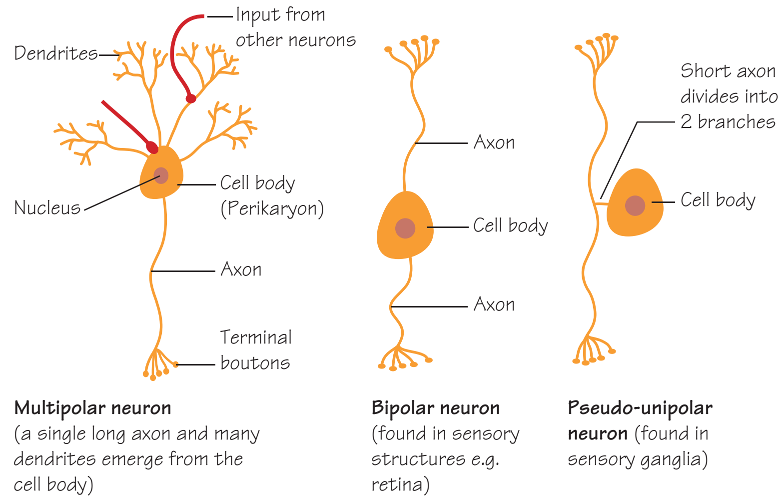
10 Nerves and supporting cells in the central nervous system

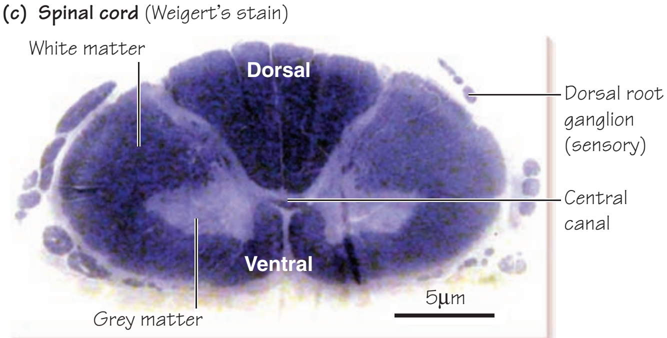
(a) Neurons in the brain, cerebrum (Golgi Cox stain)



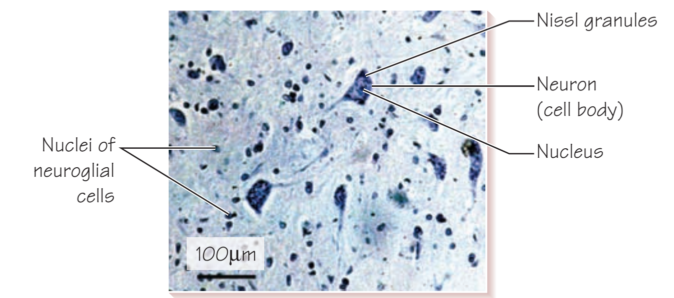
(b) Types of neurons



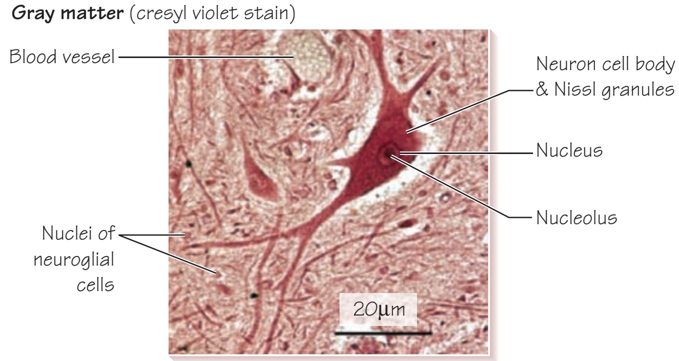
(c) Spinal cord (Weigert's stain)



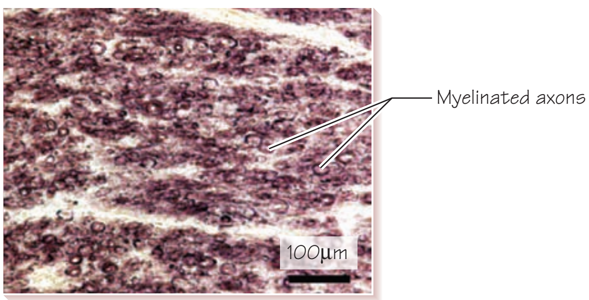
(d) Gray matter



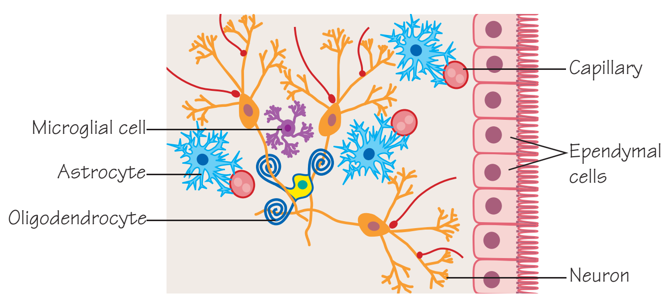
Gray matter (cresyl violet stain)



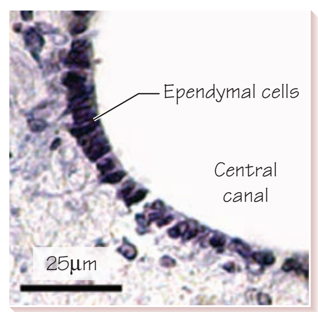
(e) White matter (TS)



(f) Neurons and supporting (neuroglial) cells in the spinal cord



(g) Ependymal cells



The **central nervous system** (CNS) consists of the brain and spinal cord. It contains gray and white matter (see below) made up of neurons and supporting cells.

The CNS is derived from surface ectoderm in the embryo, which folds up into a hollow cylinder (the neural tube).

The **somatic nervous system** controls voluntary functions and the **autonomic nervous system** involuntary functions.

Neurons

Many neurons (nerve cells) are very long and not easy to see in a single section. However, smaller neurons in the cerebrum can be seen (Fig. 10a), using heavy metal staining and thick sections. They consist of a cell body (perikaryon, or soma), a single axon and several dendrites. They range in diameter from 0.2 to 20 µm. They conduct electrical impulses.

The cell bodies of most neurons are located in the CNS. A few lie just outside the spinal cord in the ganglia, which are part of the peripheral nervous system (PNS).

The cell body contains the nucleus and is rich in Golgi, mitochondria, and rough endoplasmic reticulum (ER), also known as Nissl bodies. Proteins and mRNA are trafficked to and from the cell body along the axon along microtubules, using microtubule motors. Kinesins generally traffic substances away from the cell body and dyneins traffic substances back to the cell body.

There are **three main types of neuron** (Fig. 10b).

- **Multipolar neuron:** most common. Multiple short extensions of the cell body (dendrites), receive input from other neurons, and a single longer extension (axon), which transmits impulses to other neurons, or targets such as muscle.
- **Bipolar neuron:** a single axon and a single dendrite. Specialized neurons involved in sight, smell, and balance.
- **Pseudounipolar neuron:** a single axon and dendrite, which arise from a common stem. These are primary sensory neurons.

Synapses

Neurons make **synapses** (connections) with other neurons, or with their target organs (e.g., a muscle fiber) (see Chapter 11).

Synapses can form:

- between two axons (axoaxonic);
- between an axon and a dendrite (axodendritic); or
- between an axon and a cell body (axosomatic).

Electrical synapses (rare) are formed between two neurons, and the nerve impulse is transmitted directly via conduction of ions through gap junctions.

Chemical synapses (more common; see Chapter 10) connect neurons with their target organs, or neurons to other neurons.

Groups of neurons can be organized into:

- **layers** (strata), e.g., in the cerebral cortex;
- **bundles** (tracts or fasciculi), e.g., optic tract;
- **ganglia**, e.g., in the peripheral nervous system (PNS).

Axons of motor neurons exit the spinal cord in the nerves, and form synapses with their target organs such as skeletal muscle.

White and gray matter

A section through the spinal cord shows the central 'gray' matter surrounded by 'white' matter (Fig. 10c).

- **Gray matter** (Fig. 10d) contains all the cell bodies (**perikarya** or **soma**) of neurons, their unmyelinated dendrites, and all the cells that support the neurons (**neuroglia**).
- **White matter** (Fig. 10e) contains myelinated neurons, and a small number of cell bodies (from supporting cells only).

Supporting cells in the central nervous system (neuroglia)

Supporting cells (Fig. 10f) are the most common type of cell in the CNS and, unlike neurons, they are able to undergo mitosis, and proliferate.

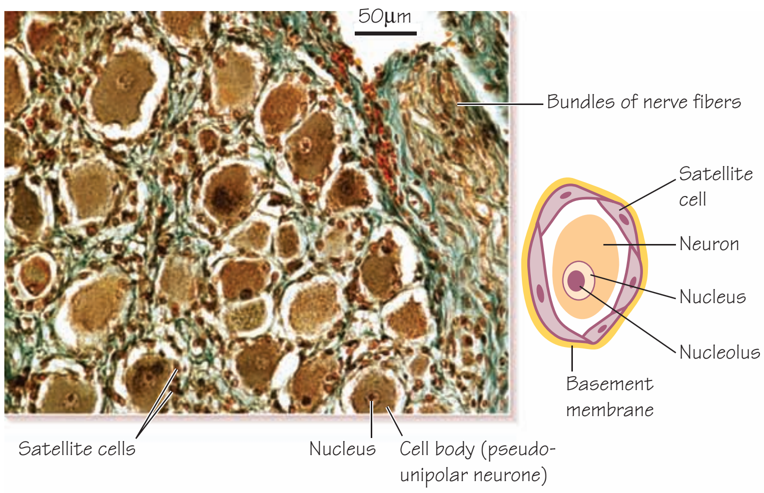
- **Astrocytes** are the most common type of supporting cell, and are mostly found in white matter. They make connections called 'end-feet' with capillaries, and they facilitate metabolic exchange between neurons and blood. They are star-shaped in appearance, when stains are used that show up the cell body and all its processes. They are derived from the neuroectoderm.
- **Oligodendrocytes** generate the myelin sheath for up to 50 axons. The myelin sheath (similar to that formed by Schwann cells in the PNS) insulates the nerve and increases the rate at which the axon conducts its action potential. In the disease, multiple sclerosis, the myelin sheath is damaged, and axons become demyelinated. Oligodendrocytes are derived from the neuroectoderm.
- **Microglia** (less common) play a role in immune defense, and can become phagocytic. These cells are derived from the mesoderm.

These three types of cells are difficult to distinguish in routine histological sections, but they can be distinguished by immunocytochemistry, using antibodies that recognize proteins specific to each cell type.

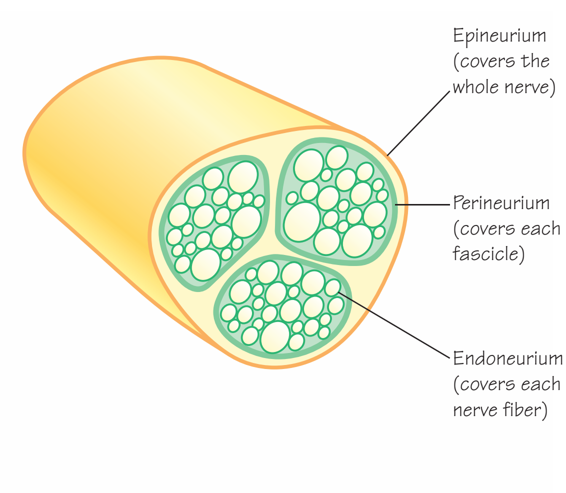
- **Ependymal cells** (Fig. 10g) make up the ependyma, which lines the ventricles of the brain and the central canal of the spinal cord. They contain microvilli and one or more cilia on their apical (lumenal) surface, and are made up of a tightly connected simple cuboidal epithelium.

11 Nerves and supporting cells in the peripheral nervous system

(a) Dorsal root ganglion (trichrome stain)

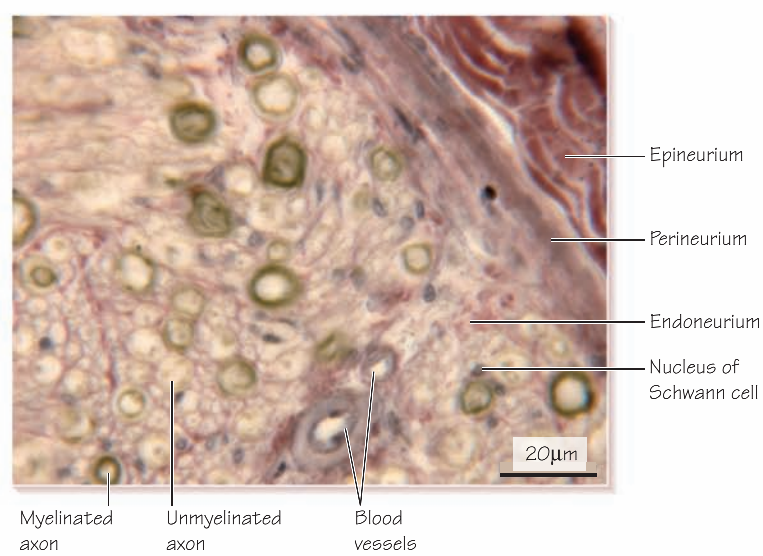


(b) Peripheral nerve structure (TS)

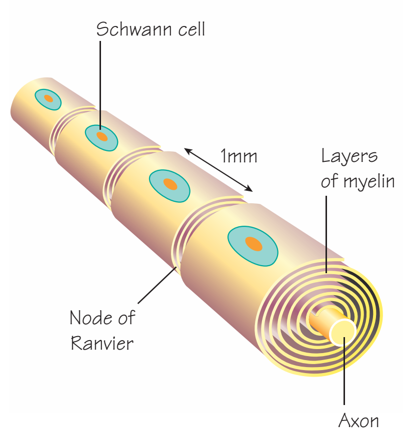


(c) Nerve (TS, low magnification)

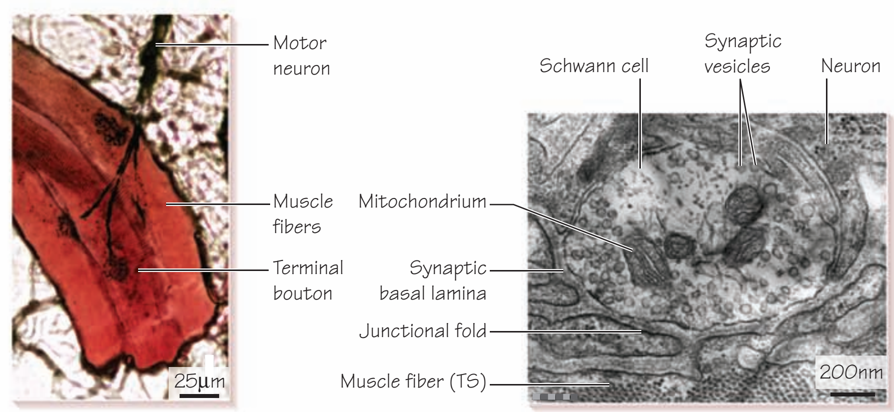
(d) Nerve (TS, high magnification)



(e) Myelination of axons by Schwann cells



(f) Neuromuscular junction



Muscle fiber and terminal boutons (stain: gold chloride)

Neuromuscular junction (EM)

Micrograph kindly provided by Joshua Sanes and Lin Mei

The **peripheral nervous system** (PNS) consists of all the nervous tissue outside the CNS, including cranial nerves, spinal nerves, and ganglia.

Nerve ganglia

These are nodular masses of neuronal cell bodies, together with their supporting neuroglia found just outside the CNS (e.g., dorsal root ganglia (Fig. 11a), which lie just outside the spinal cord, and cranial ganglia, in the head). They contain:

• **sensory neurons** in the **dorsal root** and **cranial ganglia** in the PNS;

• **sympathetic** and **parasympathetic motor neurons** in **autonomic ganglia** (PNS);

• **satellite cells**: epithelial Schwann-like cells that surround the neuron, and rest on a basement membrane are found in ganglia as shown here (Fig. 11a).

The neurons in the ganglia are derived from neural crest cells, which originate from a region just above the neural tube in the embryo.

The **dorsal root ganglia** contain the cell bodies of sensory neurons (sensory ganglia) and the cell bodies of afferent neurons from the autonomic nervous system. These neurons are pseudo-unipolar, and the fascicles of the nerves are myelinated.

The **sympathetic (autonomic) ganglia** contain multipolar neurons, most of which are not myelinated. They receive axons from presynaptic cells in the CNS.

Peripheral nerve structure

Neurons are bundled into **fascicles** inside nerves. There are three types of connective tissue coverings (Fig. 11b).

• **Endoneurium**: covers each neuron (nerve fiber) and its associated Schwann cells. It consists of bundles of collagen fibrils that run parallel to and around the nerve fibers. Endoneurium is secreted by a few fibroblasts and the Schwann cells.

• **Perineurium**: covers a bundles of fibers in a fascicle. It contains concentric layers of fibroblasts, which are tightly connected to each other by tight junctions, and which are surrounded by a basal lamina. This generates a protective 'blood–nerve' barrier, which only allows selected substances to pass across the barrier, and is analogous to the blood–brain barrier in the brain. This barrier is important in controlling diffusion of substances from the blood into the brain. It allows free transport of glucose and other selected molecules, but most substances cannot cross this barrier.

• **Epineurium**: covers the whole nerve (Fig. 11c,d), and is an example of dense connective tissue.

Supporting cells

Schwann cells are the main type of supporting cell in the PNS (Fig. 11e).

Schwann cells wrap their plasma membrane concentrically around the axon, forming a segment of myelin sheath about 1 mm long. One Schwann cell generates the myelin sheath around the axon between each node of Ranvier.

These tightly wrapped myelin layers are difficult to see in H&E sections due to their high lipid content, which is extracted by the tissue processing procedure. However, they can be seen if a stain such as osmium is combined with H&E (Fig. 11c,d).

Small gaps between each segment of sheath (nodes of Ranvier) allow saltatory conduction (the propagation of nerve impulses from one node to the next; Fig. 11e).

In **myelinated** axons, an individual Schwann cell envelops a single axon multiple times (Fig. 11d,e).

In so-called **unmyelinated** axons, in fact the axons are myelinated, but a single Schwann cell envelopes several axons, and does not form tightly wrapped layers around the axon. Instead the axons sit in grooves in the surfaces of the cells.

Both types of nerve fiber are present in nerves (Fig. 11d). In each nerve fiber, the axon appears as a central dot, surrounded by white space (which previously contained myelin, but has been lost during processing of the section).

If the neurons in the PNS are damaged, the axon distal to the site of the injury degenerates (Wallerian degeneration), and its myelin sheath also becomes fragmented. Schwann cells are stimulated to proliferate to repair the damage, and become phagocytic, engulfing these fragments, together with phagocytic white blood cells. The Schwann cells and connective tissue around the nerve form a scar. If the scar is not too great, the Schwann cells can bridge the scar, and the regenerating nerve can grow across this bridge and re-innervate their target organ.

In contrast, in the CNS (Chapter 10), the oligodendrocytes do not proliferate and they cannot repair any nerve damage.

Synapses

Most neurons synapse onto their target organs via a chemical synapse (Fig. 11f). At **chemical synapses**, a chemical neurotransmitter (e.g., acetylcholine, at neuromuscular junctions) is contained in synaptic vesicles in the terminal boutons of the nerve. When the nerve impulse reaches the terminal boutons, the vesicles release their contents into the narrow synaptic cleft between the synapse and the target organ. The neurotransmitter rapidly moves across the cleft, binds to receptors in the postsynaptic membrane of the target organ, and the target organ depolarizes.