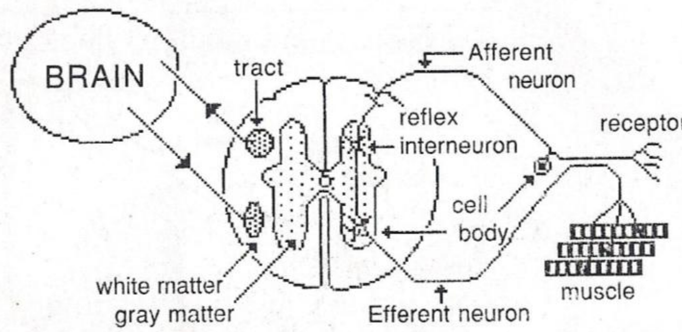
Spinal Cord Organization

The spinal cord . . .

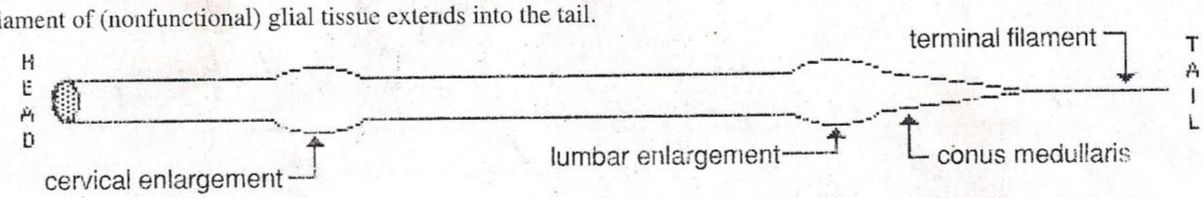
- connects with spinal nerves, through afferent & efferent axons in spinal roots;
- communicates with the brain, by means of ascending and descending pathways that form tracts in spinal white matter; and
- gives rise to spinal reflexes, pre-determined by interneuronal circuits.



Spinal Cord Section

Gross anatomy of the spinal cord:

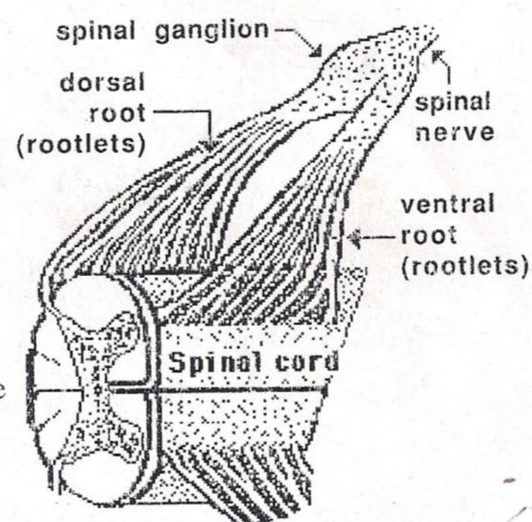
The spinal cord is a cylinder of CNS. The spinal cord exhibits subtle cervical and lumbar (lumbosacral) enlargements produced by extra neurons in segments that innervate limbs. The region of spinal cord caudal to the lumbar enlargement is *conus medullaris*. Caudal to this, a terminal filament of (nonfunctional) glial tissue extends into the tail.



A spinal cord **segment** = a portion of spinal cord that gives rise to a pair (right & left) of spinal nerves. Each spinal nerve is attached to the spinal cord by means of dorsal and ventral roots composed of rootlets. Spinal segments, spinal roots, and spinal nerves are all identified numerically by region. e.g., 6[th] cervical (C_6) spinal segment.

Sacral and caudal spinal roots (surrounding the conus medullaris and terminal filament and streaming caudally to reach corresponding intervertebral foramina) collectively constitute the cauda equina.

Both the spinal cord (CNS) and spinal roots (PNS) are enveloped by *meninges* within the vertebral canal. Spinal nerves (which are formed in intervertebral foramina) are covered by connective tissue (epineurium, perineurium, & endoneurium) rather than meninges.

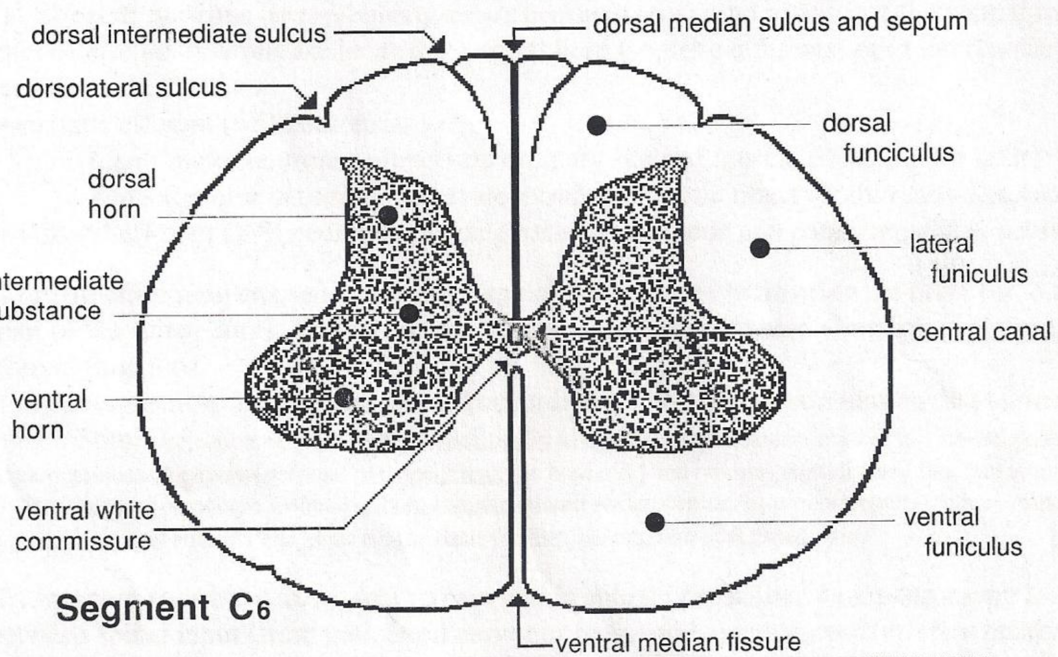


Spinal cord histology (transverse section):

Central canal (derived from embryonic neural cavity) is lined by ependymal cells & filled with cerebrospinal fluid. It communicates with the IV ventricle and ends in a dilated region (terminal ventricle).

Gray matter (derived from embryonic mantle layer) is butterfly-shaped. It has a high density of neuron cell bodies & gliocytes, a high capillary density, and sparse myelinated fibers. Gray matter regions include: dorsal horn, ventral horn, and *intermediate substance* — the latter features a lateral horn (sympathetic preganglionic neurons) in thoracolumbar spinal segments.

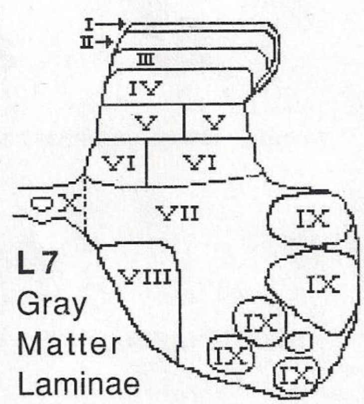
White matter (derived from embryonic marginal layer) is superficial to gray matter. It is composed of concentrated myelinated fibers, gliocytes, and low capillary density. White matter regions include: dorsal funiculus; ventral funiculus; lateral funiculus; and white commissure.



Gray matter organization:

Two schemes have evolved for organizing neuron cell bodies within gray matter. Either may be used according to which works best for a particular circumstance.

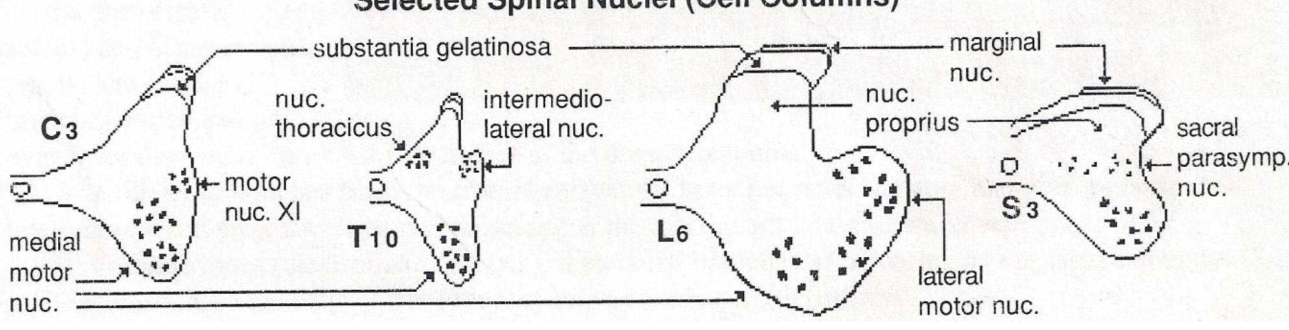
1] **Spinal Laminae**—spinal gray matter is divided into ten laminae (originally based on observations of thick sections in a neonatal cat). The advantage is that all neurons are included. The disadvantage is that laminae are difficult to distinguish.



L 7 Gray Matter Laminae

2] **Spinal Nuclei**—recognizable clusters of cells are identified as nuclei [a nucleus is a profile of a cell column]. The advantage is that distinct nuclei are generally detectable; the disadvantage is that the numerous neurons outside of distinct nuclei are not included.

Selected Spinal Nuclei (Cell Columns)



Types of spinal neurons:

All neurons in spinal cord gray matter have multipolar cell bodies. Based on axon destination, they can be divided into three major types, each of which has several subtypes:

1] **Efferent neurons** (embryologically derived from basal plate) send axons into the ventral root. Cell bodies of efferent neurons are located in ventral horn (somatic efferents) or in intermediate substance (visceral efferents).

- somatic efferent (SE) neurons:
  - *alpha* motor neurons— innervate ordinary skeletal muscle fibers (motor units);
  - *gamma* motor neurons—innervate intrafusal muscle fibers (within muscle spindles);
- visceral efferent (VE) neurons: preganglionic sympathetic and parasympathetic neurons.

2] **Projection neurons** send axons into spinal white matter to travel to the brain (or to a distant part of the spinal cord). The axons form *tracts* associated with ascending spinal pathways that have different functions.

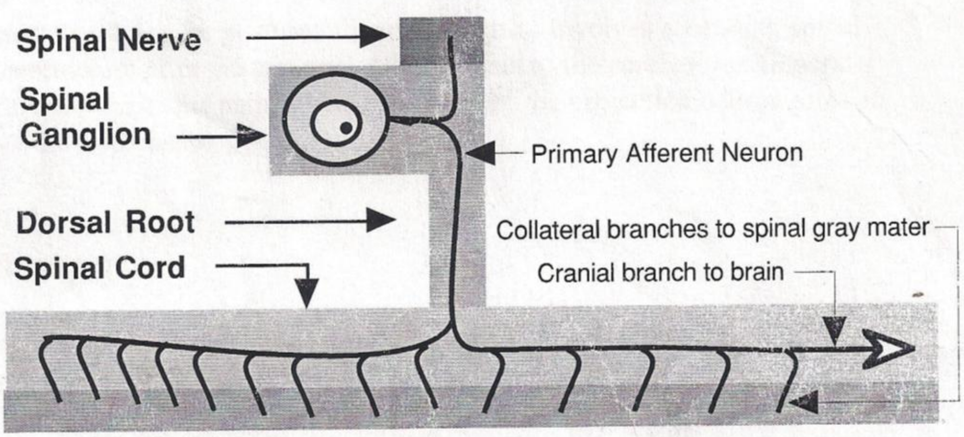
Projection neurons may be categorized according to the types of stimulation that ultimately excites them: Some projection neurons respond specifically to thermal or mechanical mild or noxious stimuli; however, many projection neurons respond non-specifically to both mild and noxious stimuli (they function to maintain alertness). Some projection neuron respond only to somatic stimuli (exteroceptors or proprioceptors); others respond to both somatic and visceral stimuli. The latter are the basis for the phenomenon of referred pain.

3] **Interneurons** have axons that remain within spinal gray matter. Interneurons are interposed between spinal input (from peripheral nerves or brain) and spinal output (efferent neurons). By establishing local circuits, interneurons "hardwire" input to output and thus determine the inherent reflex responses of the spinal cord (spinal reflexes).

Spinal Pathways

Primary Afferent Neuron = the first neuron in a spinal reflex or ascending spinal pathway.

Primary afferent neurons have their unipolar cell bodies in spinal ganglia. Receptors are found at the peripheral terminations of their axons. Their axons traverse dorsal roots, penetrate the spinal cord (at the dorsolateral sulcus) and bifurcate into cranial and caudal branches which extend over several segments within white matter of the dorsal funiculus.



Collateral branches from the cranial and caudal branches enter the gray matter to synapse on interneurons and projection neurons (or directly on efferent neurons for the myotatic reflex).

In some cases (discriminative touch), the cranial branches of incoming axons ascend directly to the brainstem where they synapse on projection neurons of the pathway.

> *Note:* **Pathway** = sequence (chain) of neurons synaptically linked to convey excitability changes from one site to another.

Ascending Pathways:

Chains of neurons carrying information from receptors to the brain (cerebral cortex).

Neuronal sequence:

Primary afferent neurons synapse on projection neurons typically located in spinal gray matter. The axons of projection neurons join *ascending tracts* and synapse on neurons in the brain. Ultimately, the pathway leads to thalamic neurons that project to the cerebral cortex.

The function of a particular pathway is determined by: 1] which primary afferent neurons synapse on the particular projection neurons of the pathway, and 2] where the projection neurons synapse in the brain.

In general, pathways may be categorized into three broad functional types:

1] *Conscious* discrimination/localization (e.g., pricking pain, warmth, cold, discriminative touch, kinesthesia) requires a specific ascending spinal pathway to the contralateral thalamus which, in turn, sends an axonal projection to the cerebral cortex. Generally there are three neurons in the conscious pathway and the axon of the projection neuron decussates and joins a contralateral tract (see the first two pathways on the following page; the third pathway is the one exception to the general rule).

2] *Affective* related (emotional & alerting behavior) information involves ascending spinal pathways to the brainstem. Projection neurons are non-specific. They receive synaptic input of different modalities and signal an ongoing magnitude of sensory activity, but they cannot signal where or what activity.

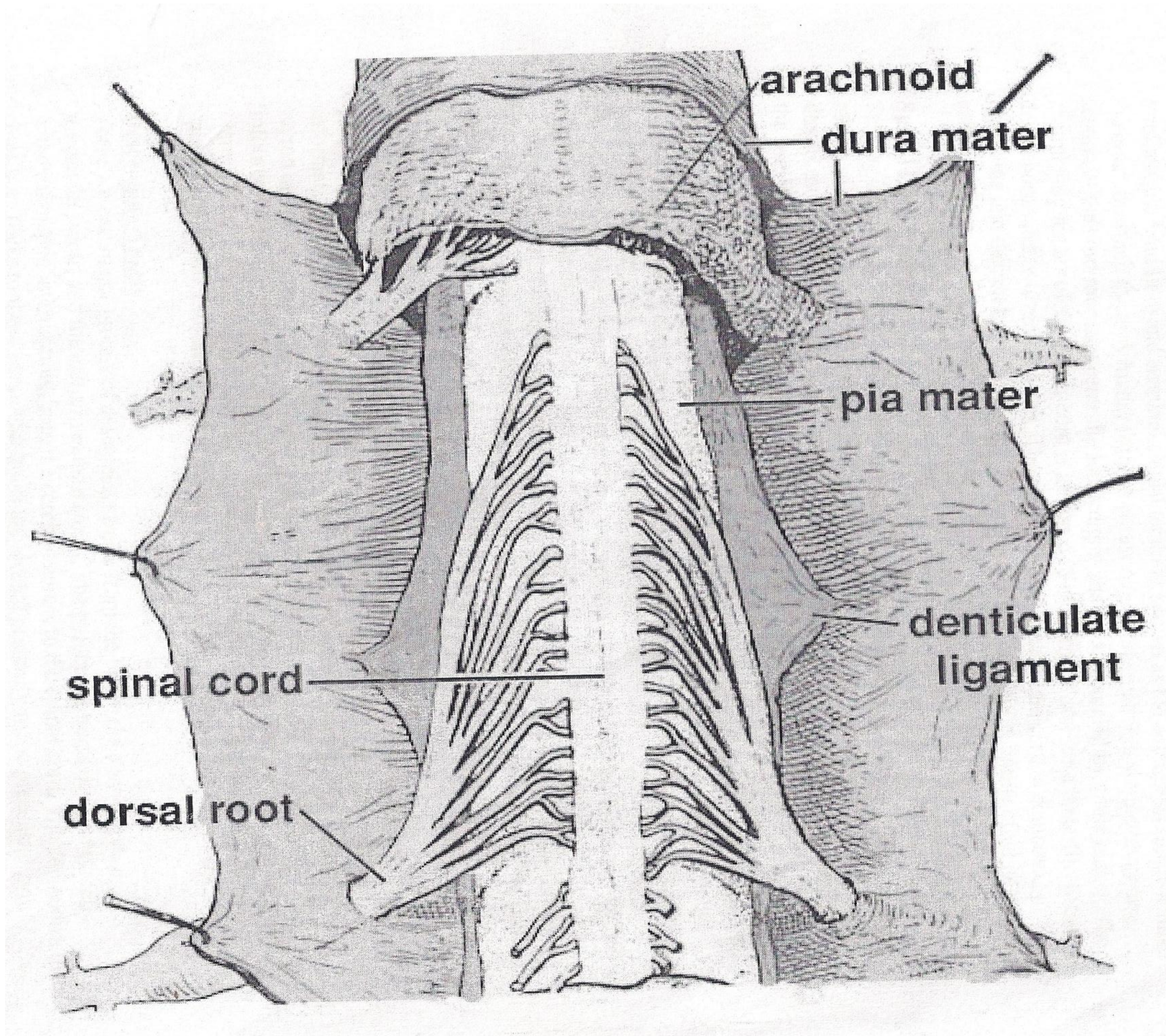
3] *Subconscious* sensory feedback for posture/movement control involves ascending spinal pathways principally to the cerebellum or brainstem nuclei that project to the cerebellum. Generally there are only two neurons in a subconscious pathway and the axon of the projection neuron joins an ipsilateral tract (see the last pathway on the following page).

Descending Spinal Pathways:

Axons of brain projection neurons travel in descending tracts in spinal white matter. They arise from various locations in the brain and synapse primarily on interneurons.

By synapsing on interneurons, descending tracts regulate:

1] spinal reflexes;
2] excitability of efferent neurons (for posture and movement); and
3] excitability of spinal projection neurons, i.e., the brain is able to regulate sensory input to itself. In some cases, descending tracts affect axon terminals of primary afferent neurons, blocking release of neurotransmitter (presynaptic inhibition).


arachnoid
dura mater
pia mater
denticulate ligament
spinal cord
dorsal root

THE SPINAL CORD (MEDULLA SPINALIS)

The spinal cord is an elongated nearly cylindrical structure which extends from the level of the foramen magnum of the skull to the first lumbar vertebra with some dorsoventral flattening and certain regional variations in form and dimensions along its course. The most important of these thickenings are the parts that give origin to the nerves that supplies the forelimb and hind limb and terminal caudal tapering known as the *conus medullaris.* Unlike the brain, in which the grey matter forms a cortex over white matter, a simple transverse section of the cord reveals a centrally located grey matter surrounded by white matter. The central grey matter of the spinal cord is arranged in the form of an H or a butterfly, with two dorsal horns and two ventral horns. The white matter of the spinal cord is composed of ascending and descending fibre tracts. These are arranged into six columns of white matter called funiculi.

Spinal Cord Tracts

Sensory information from receptors throughout most of the body is relayed to the brain by means of ascending tracts of fibres that conduct impulses up the spinal cord. When the brain directs motor activities, these directions are in the form of nerve impulses that travel down the spinal cord in descending tracts of fibres.

The fibre tracts within the white matter of the spinal cord are named to indicate whether they are ascending (sensory) or descending (motor) tracts. The names of the ascending tracts usually start with the prefix spino- and end with the name of the brain region where the spinal cord fibres first synapse. The dorsal spinothalamic tract, for example, carries impulses conveying the sense of touch and pressure, and synapses in the thalamus. From there it is relayed to the cerebral cortex. The names of descending motor tracts, conversely, begin with a prefix denoting the brain region that gives rise to the fibres and end with the suffix -spinal. The lateral corticospinal tracts, for example, begin in the cerebral cortex and descend the spinal cord.

Ascending Tracts

The ascending fibre tracts convey sensory information from cutaneous receptors, proprioceptors (muscle and joint senses), and visceral receptors. Most of the sensory information that originates in the right side of the body crosses over and eventually reach the region on the left side of the brain, which analyses this information. Similarly, the information arising in the left side of the body is ultimately analysed by the right side of the brain. This decussation occurs in the medulla oblongata for sensory modalities, or in the spinal cord for other modalities of sensation.

Descending Tracts

There are two major groups of descending tracts from the brain: *the corticospinal,* or *pyramidal tracts*, and the *extrapyramidal tracts*. The pyramidal tracts descend directly without synaptic interruption, from the cerebral cortex to the spinal cord. The cell bodies that contribute fibres to these pyramidal tracts are located primarily in the precentral gyrus (also called the motor cortex). Other areas of the cerebral cortex, however, also contribute to these tracts.

From 80%-90% of the corticospinal fibres decussate in the pyramids of the medulla oblongata (hence the name "pyramidal tracts") and descend in the lateral corticospinal tracts, which decussate in the spinal cord. Because of the crossing of fibres, the right cerebral hemisphere controls the musculature on the left side of the body, where the left hemisphere controls the right musculature. The corticospinal tracts are primarily concerned with the control of fine movement that requires dexterity.

The remaining descending tracts are extrapyramidal motor tracts, which originate in the midbrain and brain stem regions. If the pyramidal tracts of an experimental animal are cut, electrical stimulation of the cerebral cortex, cerebellum, and basal nuclei can still produce movements. The descending fibres that produce these movements must, by definition, be extrapyramidal tracts. The regions of the cerebral cortex, basal nuclei and cerebellum that participate in this motor control have numerous synaptic interconnections, and can influence movement only indirectly, by means of stimulation or inhibition of the nuclei that give rise to the extrapyramidal tracts. Notice that this motor control differs from that by the neurons of the precentral gyrus which send fibres directly down to the spinal cord in the pyramidal tracts.

The reticulospinal tracts are the major descending pathways of the extrapyramidal system. These tracts originate in the reticular formation of the brain stem which receives either stimulatory or inhibitory input from the cerebrum and the cerebellum. There are no descending tracts from the cerebellum; the cerebellum can influence motor activity only indirectly by its effect on the vestibular nuclei, red nucleus and basal nuclei (which sends axons to the reticular formation). These nuclei, in turn, send axons down the spinal cord via the vestibulospinal tracts, rubrospinal tracts and reticulospinal tracts respectively.

NERVES & NEURONS

The billions of tiny active units making up the nervous system are neurons or nerve cells - cells designed to communicate electrochemically with one another. Several kinds of non-communicating glial ("glue") cells support, nourish, insulate and far outnumber the neurons.

Each neuron receives and transmits signals through thousands of tiny "wires" linking it with other neurons in the nervous system. In fact these wires belong to the neurons themselves. Each neuron has three main parts: **cell body, axon and dendrites**.

The **cell body** is a minute blob made up of a central nucleus surrounded by cytoplasm - a rather sticky fluid containing special microscopic structures. Nutrients and waste products filtering in and out through the permeable cell wall keep the cell body alive.

The axonal and dendritic projections of neurons differentiate them from other cells that build our bodies. **An axon** ("axis") is a long, slim "tree-trunk" transmitting signals from the cell body to other cells via junctions known as synapses. Axons linking nearby regions of nerve tissue may be no more than a few millimetres long, while others sending signals from remote parts of the body to the brain or vice versa can measure more than a yard(about 1m).

Dendrites ("like trees") are networks of short fibres that branch out from an axon and synapse with the ends of axons from other neurons. Dendrites are receivers, bringing signals to their neuron's own cell body.

Neurons come in many varieties, but all may be grouped in one of several ways, according to their purpose, size or shape. For instance, **afferent (or sensory) neurons** bring signals to the central nervous system from elsewhere in the body. **Efferent (or motor) neurons** send signals out. **Interneurons** - 97 percent of all neurons, but found only in the brain and spinal cord - communicate between the two other groups.

The grey matter of the brain and spinal cord consists of cell bodies. White matter comprises the nerve fibres, or axons, sheathed in a white fatty substance (myelin) which wraps around them in a roll. Bundles of such insulated axons form **nerve fibres**. Most central nervous system nerves comprise cell bodies with short axon tracts or bundles. The longest axons are in the peripheral nervous system. Outside the central nervous system, cell bodies clumped together form ganglia.

PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system (PNS) consists of nerves (collection of axons) and their associated ganglia (collection of cell bodies). The CNS cannot function without the PNS. The central nervous system communicates with the body by means of nerves that exit the CNS from the brain (cranial nerves) and spinal cord (spinal nerves.) These nerves, collectively referred to as peripheral nerves, together with aggregations of cell bodies located outside the CNS, constitute the peripheral nervous system.

Cranial Nerves

There are twelve pairs of cranial nerves. Two of these pairs arise from neuron cell bodies located in the forebrain and hindbrain. The cranial nerves are designated by Roman numerals and by names *and not in figures* e.g. **Cranial nerve III** and ***not Cranial nerve 3***. The Roman numerals refer to the order in which the nerves are positioned rostrocaudally. Their names indicate structures innervated by these nerves (e.g. facial) or the principal function of the nerves (e.g. oculomotor).

Most cranial nerves are classified as mixed nerves. This term indicates that the nerve contains both sensory and motor fibres. Those cranial nerves associated with the special senses (e.g. olfactory, optic), however, consist of sensory fibres only. The cell bodies of these sensory neurons are not located in the brain, but instead are found in ganglia near the sensory organ.

I	Olfactory nerve	Sensory	Fibres join the convex surface of the olfactory bulb and give it a shaggy appearance in specimens which have been removed intact.
II	Optic nerve	Sensory	Converge through the optic foramen to the optic chiasm.
III	Oculomotor nerve	Motor	Arises from the medial part of the cerebral peduncle.
IV	Trochlear nerve	Motor	Smallest of the cranial nerves. Arises from the cranial cerebellar peduncle and emerges between the pons and the cerebral hemisphere. It supplies the dorsal oblique muscle.
V	Trigeminal nerve	Mixed	Largest of the cranial nerves. Connected with the lateral portions of pons. Divides into 3 primary branches: ***Ophthalmic n.**(*lacrimal, frontal & nasociliary nerves*); ****Maxillary n.**(*zygomatic, sphenopalatine & infraorbital nerves*); and *****Mandibular nerve**
VI	Abducens nerve	Motor	Emerges just behind the pons and lateral to the pyramid of the medulla. Innervates the retractor bulbi muscle.
VII	Facial nerve	Mixed	Arises close together with the eighth cranial nerve just behind the pons on the extremity of the corpus trapezoideum. Innervates muscles and other related structures of the face.
VIII	Vestibulocochlear nerve	Sensory	Origin: same as above. Divides at the internal acoustic meatus into its vestibular and cochlear parts which make their separate ways through the petrous temporal bone to the vestibular and cochlear components of the membranous labyrinth of the inner ear. Innervates the ear for hearing and balance.
IX	Glossopharyngeal nerve	Mixed	Connected by a root with the lateral aspect of the ventral surface of the medulla. Innervations of the tongue for gustatory function.
X	Vagus nerve	Mixed	Longest and the most widely distrtibuted of the cranial nerves. Origin: same as IX. Sometimes referred to as the pneumogastric nerve. It innervates the heart, larynx, lungs and stomach.
XI	Accessory nerve	Motor	Same as IX. Innervates the muscles of the neck.
XII	Hypoglossal nerve	Motor	Arises from the caudal part of the medulla along the lateral edge of the pyramid and emerges through the hypoglossal foramen. It innervates the muscles of the tongue and the genio-hyoideus.

Spinal Nerves

The total number of pairs of spinal nerves varies across species depending on their corresponding vertebral formula. The dog has 8 cervical, 13 thoracic, 7 lumbar, 3 sacral and about 5 caudal pairs.

Each spinal nerve is a mixed nerve composed of sensory and motor fibres. The fibres are packaged together in the nerve, but separate near the attachment of the nerve to the spinal cord. This produces two "roots" to each nerve. The orderly arrangement of the spinal nerves reveals the segmentation of the spinal cord. Each nerve is formed by the union of two roots (the dorsal and ventral roots). The **dorsal root** is almost exclusively composed of sensory (afferent) fibres. The central processes enter the cord along a dorsolateral furrow. They respond to a wide variety of somatic (exteroceptive and proprioceptive) and viscera (enteroceptive) stimuli. The **ventral root** is exclusively composed of motor (efferent) fibres originating from motor neurons within the ventral horn of the gray matter exiting the spinal cord along a ventrolateral strip – in transit to the effector organs (muscles & glands). The *dorsal root* contains an enlargement called the **dorsal root ganglion**, where the cell bodies of the sensory neurons are located. The motor neuron is a somatic motor neuron that innervates skeletal muscles; its cell body is not located in a ganglion, but instead is with the gray matter of the spinal cord. Some autonomic motor neurons (which innervate involuntary effectors), however, have their cell bodies in ganglia outside the spinal cord.

The dorsal and ventral roots unite peripheral to the dorsal root ganglion to form the mixed spinal nerve, which leaves the vertebral canal through the appropriate intervertebral foramen. In the cervical region, each nerve emerges cranial to the vertebra of the same numerical designation as the nerve, except the eighth, which emerges between the last cervical and firest thoracic vertebra; in other regions, each nerve emerges caudal to the vertebra of the same numerical designation.

The mixed trunk formed by the union of dorsal and ventral roots divides almost at once into dorsal and ventral rami.

- ***The dorsal branch*** is distributed to dorsal structures: epaxial muscles of the trunk and the skin over the back
- The much larger ***ventral branch*** is distributed to hypaxial muscles of the trunk, the muscles of the limbs (with a few exceptions) and the remaining part of the skin, including that of the limbs.

Both dorsal and ventral branches have connections with their neighbours that form continuous dorsal and ventral plexuses. These plexuses are neither obvious nor important except for enlarged portions of the ventral plexus opposite the origins of the limbs. The **brachial plexus** is for the enlarged portions of the ventral plexus opposite the origin of the forelimb and the **lumbosacral plexus** for that of the hind limb.

- **The brachial plexus**: usually formed by the contributions from the ventral branches of the last three cervical and first two thoracic nerves. The branches from this plexus innervates mostly the thoracic limb and partly the thoracic wall. There are about 11 branches that radiates from this plexus namely: *the suprascapular n., subscapular n., musculo-cutaneous n., radial n., median n., cranial thoracic/pectoral n., ulnar n., axillary n., long thoracic n., thoraco-dorsal n., and the external thoracic nerve.*

- **The lumbosacral plexus** is formed by the contributions from the ventral branches of the last three lumbar and the first two sacral nerves. It major branches are: *the femoral n., saphenous n., obturator n., cranial gluteal n., caudal gluteal n., sciatic n., common peroneal n., tibial n., and the plantar nerve.*

The limb plexuses allow for regrouping and reassociation of the consitutuent nerve fibers and the nerve trunks that emerge distally are each composed of fibers derived from two or three spinal segments; thus the median nerve is composed of fibers from spinal nerves C8 and T1, the femoral nerve of fibers from L4-L6.

The course of the major peripheral trunks must be known to avoid placing the nerves at unnecessary risk during surgery or drug administration. Their central connections are important in two contexts.

- ➢ Local anaesthetic solutions injected near selected spinal nerves have predictable effects in paralyzing muscles and in depriving skin areas of sensation.
- ➢ Also paralysis of particular muscles or absent or altered sensibility of specific skin areas may point to the precise locations of a central lesion.