

Peripheral Nervous System



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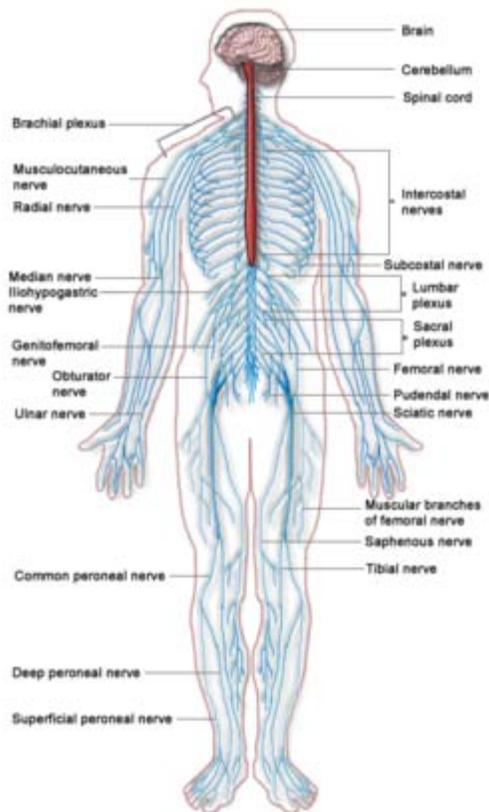
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Introduction

Brain: Peripheral nervous system



The Human Nervous System. Blue is PNS while red is CNS.

Latin *Pars peripherica; Systema nervosum periphericum*

The **peripheral nervous system**, or PNS, consists of the nerves and ganglia outside of the brain and spinal cord. The main function of the PNS is to connect the central nervous system (CNS) to the limbs and organs. Unlike the CNS, the PNS is not protected by the bone of spine and skull, or by the blood–brain barrier, leaving it exposed to toxins and

mechanical injuries. The peripheral nervous system is divided into the somatic nervous system and the autonomic nervous system; some textbooks also include sensory systems.

The cranial nerves are part of the PNS.

General classification

By direction

There are two types of neurons, carrying nerve impulses in different directions. These two groups of neurons are:

- The sensory neurons are afferent neurons which relay nerve impulses toward the central nervous system.
- The motor neurons are efferent neurons which relay nerve impulses away from the central nervous system.

By function

The peripheral nervous system is functionally as well as structurally divided into the somatic nervous system and autonomic nervous system. The somatic nervous system is responsible for coordinating the body movements, and also for receiving external stimuli. It is the system that regulates activities that are under conscious control. The autonomic nervous system is then split into the sympathetic division, parasympathetic division, and enteric division. The *sympathetic nervous system* responds to impending danger, and is responsible for the increase of one's heartbeat and blood pressure, among other physiological changes, along with the sense of excitement one feels due to the increase of adrenaline in the system. ("fight or flight" responses). The *parasympathetic nervous system*, on the other hand, is evident when a person is resting and feels relaxed, and is responsible for such things as the constriction of the pupil, the slowing of the heart, the dilation of the blood vessels, and the stimulation of the digestive and genitourinary systems. ("rest and digest" responses). The role of the *enteric nervous system* is to manage every aspect of digestion, from the esophagus to the stomach, small intestine and colon.

Specific nerves and plexi

Ten out of the twelve cranial nerves originate from the brainstem, and mainly control the functions of the anatomic structures of the head with some exceptions. The nuclei of cranial nerves I and II lie in the forebrain and thalamus, respectively, and are thus not considered to be true cranial nerves. CN X (10) receives visceral sensory information from the thorax and abdomen, and CN XI (11) is responsible for innervating the sternocleidomastoid and trapezius muscles, neither of which is exclusively in the head.

Spinal nerves take their origins from the spinal cord. They control the functions of the rest of the body. In humans, there are 31 pairs of spinal nerves: 8 cervical, 12 thoracic, 5

lumbar, 5 sacral and 1 coccygeal. In the cervical region, the spinal nerve roots come out *above* the corresponding vertebrae (i.e. nerve root between the skull and 1st cervical vertebrae is called spinal nerve C1). From the thoracic region to the coccygeal region, the spinal nerve roots come out *below* the corresponding vertebrae. It is important to note that this method creates a problem when naming the spinal nerve root between C7 and T1 (so it is called spinal nerve root C8). In the lumbar and sacral region, the spinal nerve roots for travel within the dural sac and they travel below the level of L2 as the cauda equina.

Cervical spinal nerves (C1–C4)

The first 4 cervical spinal nerves, C1 through C4, split and recombine to produce a variety of nerves that subserve the neck and back of head.

Spinal nerve C1 is called the suboccipital nerve which provides motor innervation to muscles at the base of the skull. C2 and C3 form many of the nerves of the neck, providing both sensory and motor control. These include the greater occipital nerve which provides sensation to the back of the head, the lesser occipital nerve which provides sensation to the area behind the ears, the greater auricular nerve and the lesser auricular nerve. The phrenic nerve arises from nerve roots C3, C4 and C5. It innervates the diaphragm, enabling breathing. If the spinal cord is transected above C3, then spontaneous breathing is not possible.

Brachial plexus (C5-T1)

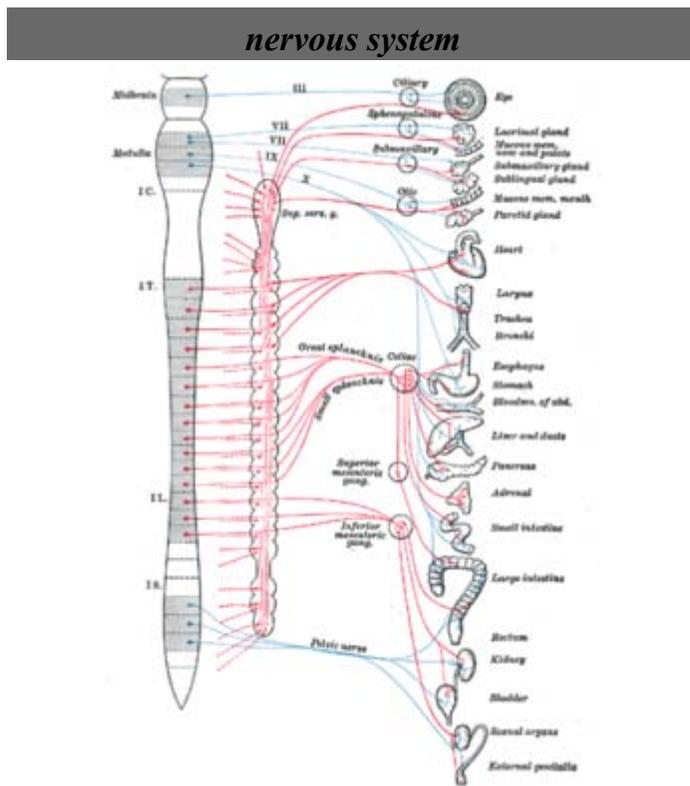
The last four cervical spinal nerves, C5 through C8, and the first thoracic spinal nerve, T1, combine to form the brachial plexus, or plexus brachialis, a tangled array of nerves, splitting, combining and recombining, to form the nerves that subserve the arm and upper back. Although the brachial plexus may appear tangled, it is highly organized and predictable, with little variation between people.

Neurotransmitters

The main neurotransmitters of the peripheral nervous system are acetylcholine and noradrenaline. However, there are several other neurotransmitters as well, jointly labeled Non-noradrenergic, non-cholinergic (NANC) transmitters. Examples of such transmitters include non-peptides: ATP, GABA, dopamine, NO, and peptides: neuropeptide Y, VIP, GnRH, Substance P and CGRP.

Chapter 1

Autonomic Nervous System



The autonomic nervous system

Blue = parasympathetic

Red = sympathetic

Latin *divisio autonmica systematis nervosi peripherici*

The **autonomic nervous system** (ANS or **visceral nervous system**) is the part of the peripheral nervous system that acts as a control system functioning largely below the

level of consciousness, and controls visceral functions. The ANS affects heart rate, digestion, respiration rate, salivation, perspiration, diameter of the pupils, micturition (urination), and sexual arousal. Whereas most of its actions are involuntary, some, such as breathing, work in tandem with the conscious mind.

It is classically divided into two subsystems: the parasympathetic nervous system and sympathetic nervous system. Relatively recently, a third subsystem of neurons that have been named 'non-adrenergic and non-cholinergic' neurons (because they use nitric oxide as a neurotransmitter) have been described and found to be integral in autonomic function, particularly in the gut and the lungs.

With regard to function, the ANS is usually divided into sensory (afferent) and motor (efferent) subsystems. Within these systems, however, there are inhibitory and excitatory synapses between neurons.

The enteric nervous system is sometimes considered part of the autonomic nervous system, and sometimes considered an independent system.

Anatomy

ANS innervation is divided into sympathetic nervous system and parasympathetic nervous system divisions. The sympathetic division has thoracolumbar “outflow”, meaning that the neurons begin at the thoracic and lumbar (T1-L2) portions of the spinal cord. The parasympathetic division has craniosacral “outflow”, meaning that the neurons begin at the cranial nerves (CN 3, CN7, CN 9, CN10) and sacral (S2-S4) spinal cord.

The ANS is unique in that it requires a sequential two-neuron efferent pathway; the preganglionic neuron must first synapse onto a postganglionic neuron before innervating the target organ. The preganglionic, or first, neuron will begin at the “outflow” and will synapse at the postganglionic, or second, neuron’s cell body. The post ganglionic neuron will then synapse at the target organ.

Sympathetic division

The sympathetic division (thoracolumbar outflow) consists of cell bodies in the lateral horn of spinal cord (intermediolateral cell columns) of the spinal cord from T1 to L2. These cell bodies are GVE (general visceral efferent) neurons, and are the preganglionic neurons. There are several locations upon which preganglionic neurons can synapse for their postganglionic neurons:

- Paravertebral ganglia of the sympathetic chain (these run on either side of the vertebral bodies)
- Prevertebral ganglia (celiac ganglia, superior mesenteric ganglia, inferior mesenteric ganglia)
- Chromaffin cells of adrenal medulla (this is the one exception to the two-neuron pathway rule: synapse is direct onto cell bodies)

These ganglia provide the postganglionic neurons from which innervation of target organs follows. Examples of splanchnic (visceral) nerves are:

- Cervical cardiac nerves & thoracic visceral nerves which synapse in the sympathetic chain
- Thoracic splanchnic nerves (greater, lesser, least) which synapse in the prevertebral ganglion
- Lumbar splanchnic nerves which synapse in the prevertebral ganglion
- Sacral splanchnic nerves which synapse in the inferior hypogastric plexus

These all contain afferent (sensory) nerves as well, also known as GVA (general visceral afferent) neurons.

Parasympathetic division

The parasympathetic division (craniosacral outflow) consists of cell bodies from one of two locations: brainstem (Cranial Nerves III, VII, IX, X) or sacral spinal cord (S2, S3, S4). These are the preganglionic neurons, which synapse with postganglionic neurons in these locations:

- Parasympathetic ganglia of the head (Ciliary (CN III), Submandibular (CN VII), Pterygopalatine (CN VII), Otic (CN IX))
- In or near wall of organ innervated by Vagus (CN X), Sacral nerves (S2, S3, S4)

These ganglia provide the postganglionic neurons from which innervations of target organs follows. Examples are:

- The preganglionic parasympathetic splanchnic (visceral) nerves
- Vagus nerve, which wanders through the thorax and abdominal regions innervating, among other organs, the heart, lungs, liver and stomach

Sensory neurons

The sensory arm is made of “primary visceral sensory neurons” found in the peripheral nervous system (PNS), in “cranial sensory ganglia”: the geniculate, petrosal and nodose ganglia, appended respectively to cranial nerves VII, IX and X. These sensory neurons monitor the levels of carbon dioxide, oxygen and sugar in the blood, arterial pressure and the chemical composition of the stomach and gut content. (They also convey the sense of taste, a conscious perception). Blood oxygen and carbon dioxide are in fact directly sensed by the carotid body, a small collection of chemosensors at the bifurcation of the carotid artery, innervated by the petrosal (IXth) ganglion. Primary sensory neurons project (synapse) onto “second order” or relay visceral sensory neurons located in the medulla oblongata, forming the nucleus of the solitary tract (nTS), that integrates all visceral information. The nTS also receives input from a nearby chemosensory center, the area postrema, that detects toxins in the blood and the cerebrospinal fluid and is essential for chemically induced vomiting or conditional taste aversion (the memory that ensures

that an animal which has been poisoned by a food never touches it again). All these visceral sensory informations constantly and unconsciously modulate the activity of the motor neurons of the ANS

Motor neurons

Motor neurons of the ANS are also located in ganglia of the PNS, called “autonomic ganglia”. They belong to three categories with different effects on their target organs: sympathetic, parasympathetic and enteric.

Sympathetic ganglia are located in two sympathetic chains close to the spinal cord: the prevertebral and pre-aortic chains. Parasympathetic ganglia, in contrast, are located in close proximity to the target organ: the submandibular ganglion close to salivary glands, paracardiac ganglia close to the heart etc... Enteric ganglia, which as their name implies innervate the digestive tube, are located inside its walls and collectively contain as many neurons as the entire spinal cord, including local sensory neurons, motor neurons and interneurons. It is the only truly autonomous part of the ANS and the digestive tube can function surprisingly well even in isolation. For that reason the enteric nervous system has been called “the second brain”.

The activity of autonomic ganglionic neurons is modulated by “preganglionic neurons” (also called improperly but classically "visceral motoneurons") located in the central nervous system. Preganglionic sympathetic neurons are in the spinal cord, at thoraco-lumbar levels. Preganglionic parasympathetic neurons are in the medulla oblongata (forming visceral motor nuclei: the dorsal motor nucleus of the vagus nerve (dmnX), the nucleus ambiguus, and salivatory nuclei) and in the sacral spinal cord. Enteric neurons are also modulated by input from the CNS, from preganglionic neurons located, like parasympathetic ones, in the medulla oblongata (in the dmnX).

The feedback from the sensory to the motor arm of visceral reflex pathways is provided by direct or indirect connections between the nucleus of the solitary tract and visceral motoneurons.

Function

Sympathetic and parasympathetic divisions typically function in opposition to each other. But this opposition is better termed complementary in nature rather than antagonistic. For an analogy, one may think of the sympathetic division as the accelerator and the parasympathetic division as the brake. The sympathetic division typically functions in actions requiring quick responses. The parasympathetic division functions with actions that do not require immediate reaction. Consider sympathetic as "fight or flight" and parasympathetic as "rest and digest".

However, many instances of sympathetic and parasympathetic activity cannot be ascribed to "fight" or "rest" situations. For example, standing up from a reclining or sitting position would entail an unsustainable drop in blood pressure if not for a compensatory

increase in the arterial sympathetic tonus. Another example is the constant, second to second modulation of heart rate by sympathetic and parasympathetic influences, as a function of the respiratory cycles. More generally, these two systems should be seen as permanently modulating vital functions, in usually antagonistic fashion, to achieve homeostasis. Some typical actions of the sympathetic and parasympathetic systems are listed below.

Sympathetic nervous system

Promotes a "fight or flight" response, corresponds with arousal and energy generation, and inhibits digestion.

- Diverts blood flow away from the gastro-intestinal (GI) tract and skin via vasoconstriction.
- Blood flow to skeletal muscles and the lungs is enhanced (by as much as 1200% in the case of skeletal muscles).
- Dilates bronchioles of the lung, which allows for greater alveolar oxygen exchange.
- Increases heart rate and the contractility of cardiac cells (myocytes), thereby providing a mechanism for the enhanced blood flow to skeletal muscles.
- Dilates pupils and relaxes the ciliary muscle to the lens, allowing more light to enter the eye and far vision.
- Provides vasodilation for the coronary vessels of the heart.
- Constricts all the intestinal sphincters and the urinary sphincter.
- Inhibits peristalsis.
- Stimulates orgasm.
- Inhibits peristalsis

Parasympathetic nervous system

Promotes a "rest and digest" response, promotes calming of the nerves return to regular function, and enhances digestion.

- Dilates blood vessels leading to the GI tract, increasing blood flow. This is important following the consumption of food, due to the greater metabolic demands placed on the body by the gut.
- The parasympathetic nervous system can also constrict the bronchiolar diameter when the need for oxygen has diminished.
- Dedicated cardiac branches of the Vagus and thoracic Spinal Accessory nerves impart Parasympathetic control of the Heart or Myocardium.
- During accommodation, the parasympathetic nervous system causes constriction of the pupil and contraction of the ciliary muscle to the lens, allowing for closer vision.
- The parasympathetic nervous system stimulates salivary gland secretion, and accelerates peristalsis, so, in keeping with the rest and digest functions,

appropriate PNS activity mediates digestion of food and indirectly, the absorption of nutrients.

- Is also involved in erection of genitals, via the pelvic splanchnic nerves 2–4.
- Stimulates sexual arousal.

Neurotransmitters and pharmacology

At the effector organs, sympathetic ganglionic neurons release noradrenaline (norepinephrine), along with other cotransmitters such as ATP, to act on adrenergic receptors, with the exception of the sweat glands and the adrenal medulla:

- Acetylcholine is the preganglionic neurotransmitter for both divisions of the ANS, as well as the postganglionic neurotransmitter of parasympathetic neurons. Nerves that release acetylcholine are said to be cholinergic. In the parasympathetic system, ganglionic neurons use acetylcholine as a neurotransmitter, to stimulate muscarinic receptors.
- At the adrenal cortex, there is no postsynaptic neuron. Instead the presynaptic neuron releases acetylcholine to act on nicotinic receptors.
- Stimulation of the adrenal medulla releases adrenaline (epinephrine) into the bloodstream which will act on adrenoceptors, producing a widespread increase in sympathetic activity.

The following table reviews the actions of these neurotransmitters as a function of their receptors.

Circulatory system

Heart

Target	Sympathetic (adrenergic)	Parasympathetic (muscarinic)
cardiac output	β_1 , (β_2): increases	M2: decreases
SA node: heart rate (chronotropic)	β_1 , (β_2): increases	M2: decreases
Atrial cardiac muscle: contractility (inotropic)	β_1 , (β_2): increases	M2: decreases
Ventricular cardiac muscle	β_1 , (β_2): increases contractility (inotropic) increases cardiac muscle automaticity	---
at AV node	β_1 : increases conduction increases cardiac muscle automaticity	M2: decreases conduction Atrioventricular block

Blood vessels

Target	Sympathetic (adrenergic)	Parasympathetic (muscarinic)
vascular smooth muscle	α 1: contracts; β 2: relaxes	M3: relaxes
renal artery	α 1: constricts	---
larger coronary arteries	α 1 and α 2: constricts	---
smaller coronary arteries	β 2: dilates	---
arteries to viscera	α : constricts	---
arteries to skin	α : constricts	---
arteries to brain	α 1: constricts	---
arteries to erectile tissue	α 1: constricts	M3: dilates
arteries to salivary glands	α : constricts	M3: dilates
hepatic artery	β 2: dilates	---
arteries to skeletal muscle	β 2: dilates	---
Veins	α 1 and α 2 : constricts β 2: dilates	---

Other

Target	Sympathetic (adrenergic)	Parasympathetic (muscarinic)
platelets	α 2: aggregates	---
mast cells - histamine	β 2: inhibits	---

Respiratory system

Target	Sympathetic (adrenergic)	Parasympathetic (muscarinic)
smooth muscles of bronchioles	β 2: relaxes (major contribution) α 1: contracts (minor contribution)	M3: contracts

The bronchioles have no sympathetic innervation, but are instead affected by circulating adrenaline

Nervous system

Target	Sympathetic (adrenergic)	Parasympathetic (muscarinic)
Pupil dilator muscle	α 1: contracts (causes mydriasis)	M3: contracts circular muscle (causes miosis)
Ciliary muscle	β 2: relaxes (causes long-range focus)	M3: contracts (causes short-range focus)

Digestive system

Target	Sympathetic (adrenergic)	Parasympathetic (muscarinic)
salivary glands: secretions	β : stimulates viscous, amylase secretions $\alpha 1$: stimulates potassium cation	M3: stimulates watery secretions
lacrimal glands (tears)	β : stimulates protein secretion	---
kidney (renin)	$\beta 1$: secretes	---
parietal cells	---	M1: Gastric acid secretion
liver	$\alpha 1, \beta 2$: glycogenolysis, gluconeogenesis	---
adipose cells	$\beta 1, \beta 3$: stimulates lipolysis	---
GI tract (smooth muscle) motility	$\alpha 1, \alpha 2, \beta 2$: decreases	M3, (M1) : increases
sphincters of GI tract	$\alpha 1, \alpha 2, \beta 2$: contracts	M3: relaxes
glands of GI tract	no effect	M3: secretes

Endocrine system

Target	Sympathetic (adrenergic)	Parasympathetic (muscarinic)
pancreas (islets)	$\alpha 2$: decreases secretion from beta cells, increases secretion from alpha cells	M3 increases stimulation from alpha cells and beta cells
adrenal medulla	N (nicotinic ACh receptor): secretes epinephrine and norepinephrine	---

Urinary system

Target	Sympathetic (adrenergic)	Parasympathetic (muscarinic)
Detrusor urinae muscle of bladder wall	$\beta 2$: relaxes	M3: contracts
urethral sphincter (internal)	$\alpha 1$: contracts	relaxes
sphincter	$\alpha 1$: contracts; $\beta 2$ relaxes	M3: relaxes

Reproductive system

Target	Sympathetic (adrenergic)	Parasympathetic (muscarinic)
uterus	$\alpha 1$: contracts (pregnant) $\beta 2$: relaxes (non-pregnant)	---
genitalia	$\alpha 1$: contracts (ejaculation)	M3: erection

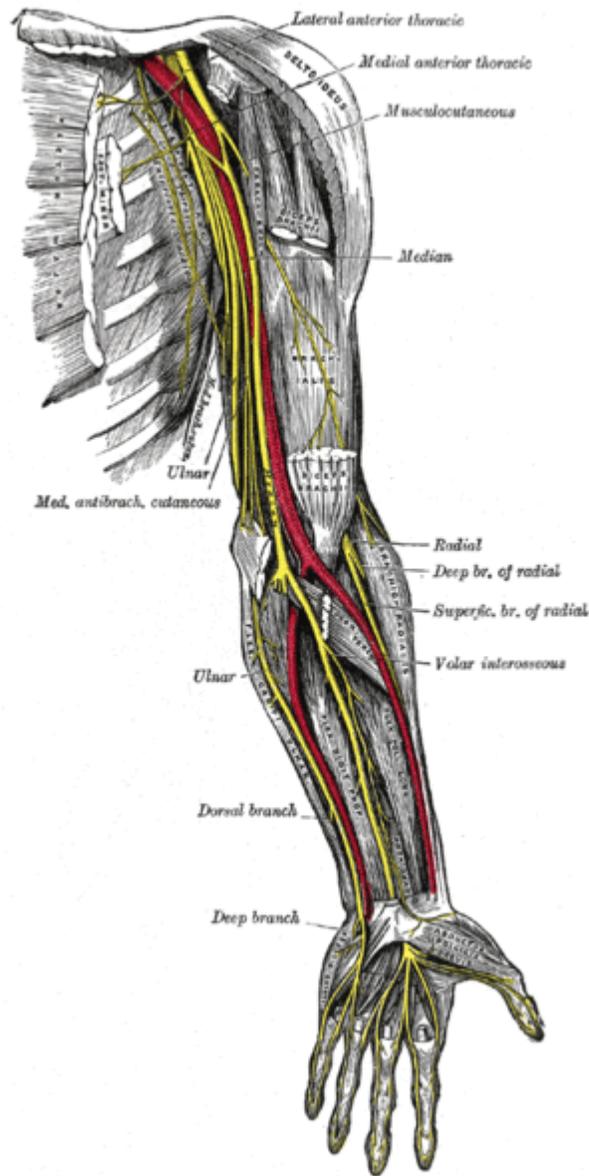
Integumentary system

Target	Sympathetic (muscarinic and adrenergic)	Parasympathetic (muscarinic)
sweat gland secretions	M: stimulates (major contribution); α 1: stimulates (minor contribution)	has no effect on sweating ---
arrector pili	α 1: stimulates	---

Chapter 2

Peripheral Nerve and Spinal Nerve

Peripheral nerve



Nerves (yellow)

A **peripheral nerve**, or simply **nerve** is an enclosed, cable-like bundle of peripheral axons (the long, slender projections of neurons). A nerve provides a common pathway for the electrochemical nerve impulses that are transmitted along each of the axons. Nerves are found only in the peripheral nervous system. In the central nervous system, the analogous structures are known as tracts. Neurons are sometimes called *nerve cells*, though this term is potentially misleading since many neurons do not form nerves, and nerves also include non-neuronal Schwann cells that coat the axons in myelin.

Each nerve is a cordlike structure that contains many axons. These axons are often referred to as “fibres”. Within a nerve, each axon is surrounded by a layer of connective tissue called the endoneurium. The axons are bundled together into groups called fascicles, and each fascicle is wrapped in a layer of connective tissue called the perineurium. Finally, the entire nerve is wrapped in a layer of connective tissue called the epineurium.

Anatomy

Nerves are categorized into three groups based on the direction that signals are conducted:

- *Afferent nerves* conduct signals from sensory neurons to the central nervous system, for example from the mechanoreceptors in skin.
- *Efferent nerves* conduct signals from the central nervous system along motor neurons to their target muscles and glands.
- *Mixed nerves* contain both afferent and efferent axons, and thus conduct both incoming sensory information and outgoing muscle commands in the same bundle.

Nerves can be categorized into two groups based on where they connect to the central nervous system:

- *Spinal nerves* innervate much of the body, and connect through the spinal column to the spinal cord. They are given letter-number designations according to the vertebra through which they connect to the spinal column.
- *Cranial nerves* innervate parts of the head, and connect directly to the brainstem. They are typically assigned Roman numerals from 1 to 12, although cranial nerve zero is sometimes included. In addition, cranial nerves have descriptive names.

Each nerve is covered externally by a dense sheath of connective tissue, the epineurium. Underlying this is a layer of flat cells, the perineurium, which forms a complete sleeve around a bundle of axons. Perineurial septae extend into the nerve and subdivide it into several bundles of fibres. Surrounding each such fibre is the endoneurium. This forms an unbroken tube which extends from the surface of the spinal cord to the level at which the axon synapses with its muscle fibers, or ends in sensory receptors. The endoneurium consists of an inner sleeve of material called the glycocalyx and an outer, delicate, meshwork of collagen fibres. Nerves are bundled along with blood vessels, since the

neurons of a nerve have fairly high energy requirements. Within the endoneurium, the individual nerve fibres are surrounded by a low protein liquid called endoneurial fluid. The endoneurium has properties analogous to the blood-brain barrier, in that it prevents certain molecules from crossing from the blood into the endoneurial fluid. In this respect, endoneurial fluid is similar to cerebro-spinal fluid in the central nervous system. During the development of nerve edema from nerve irritation or (injury), the amount of endoneurial fluid may increase at the site of irritation. This increase in fluid can be visualized using magnetic resonance neurography, and thus MR neurography can identify nerve irritation and/or injury.

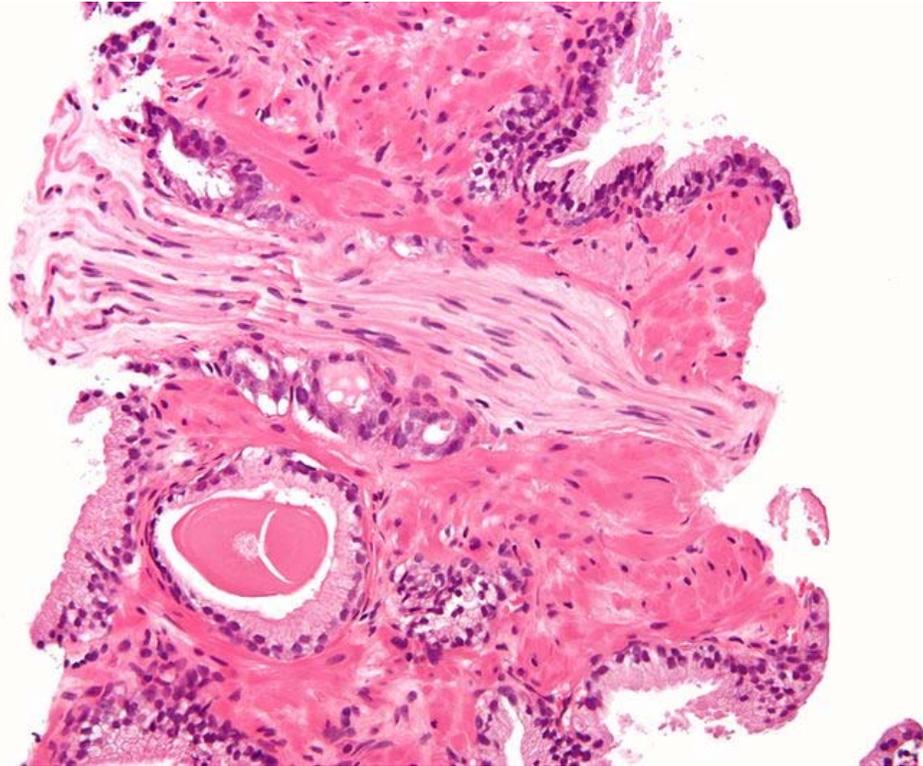
Physiology

A nerve conveys information in the form of electrochemical impulses (known as nerve impulses or action potentials) carried by the individual neurons that make up the nerve. These impulses are extremely fast, with some myelinated neurons conducting at speeds up to 120 m/s. The impulses travel from one neuron to another by crossing a synapse, the message is converted from electrical to chemical and then back to electrical.

Nerves can be categorized into two groups based on function:

- *Sensory nerves* conduct sensory information from their receptors to the central nervous system, where the information is then processed. Thus they are synonymous with *afferent nerves*.
- *Motor nerves* conduct signals from the central nervous system to muscles. Thus they are synonymous with *efferent nerves*.

Clinical importance



Micrograph demonstrating perineural spread of prostate cancer. H&E stain.

Damage to nerves can be caused by physical injury or swelling (e.g. carpal tunnel syndrome), autoimmune diseases (e.g. Guillain-Barré syndrome), infection (neuritis), diabetes or failure of the blood vessels surrounding the nerve. A *pinched nerve* occurs when pressure is placed on a nerve, usually from swelling due to an injury or pregnancy. Nerve damage or pinched nerves are usually accompanied by pain, numbness, weakness, or paralysis. Patients may feel these symptoms in areas far from the actual site of damage, a phenomenon called **referred pain**. Referred pain occurs because when a nerve is damaged, signalling is defective from all parts of the area from which the nerve receives input, not just the site of the damage. Neurologists usually diagnose disorders of the nerves by a physical examination, including the testing of reflexes, walking and other directed movements, muscle weakness, proprioception, and the sense of touch. This initial exam can be followed with tests such as nerve conduction study and electromyography (EMG).

Cancer

Cancer can spread along nerves; this is known as *perineural spread* and often is associated with a worse prognosis.

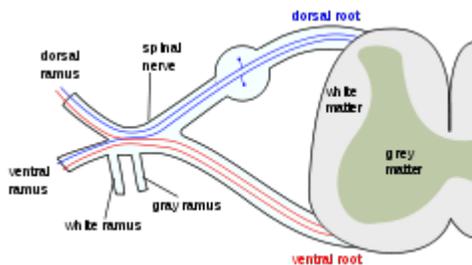
Nerve Growth & stimulation

Nerve growth normally ends in adolescence, but can be re-stimulated with a molecular mechanism known as "Notch signaling", working on a Notch receptor:

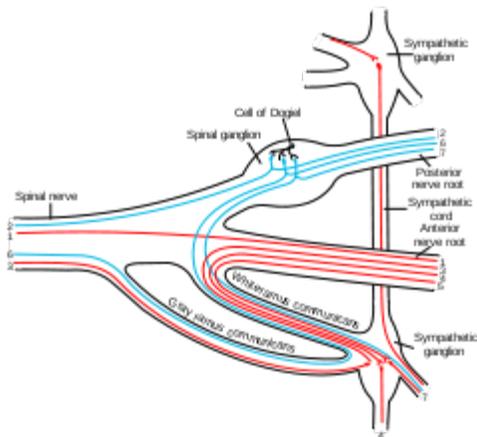
Yale Study Shows Way To Re-Stimulate Brain Cell Growth ScienceDaily (Oct. 22, 1999) — Results Could Boost Understanding Of Alzheimer's,

Spinal nerve

Nerve: Spinal nerve



The formation of the spinal nerve from the dorsal and ventral roots



Scheme showing structure of a typical spinal nerve.

1. Somatic efferent.
2. Somatic afferent.
- 3,4,5. Sympathetic efferent.
- 6,7. Sympathetic afferent.

Latin	<i>nervi spinales</i>
Gray's	<i>subject #208 916</i>
MeSH	<i>Spinal+nerves</i>

The term **spinal nerve** generally refer to a mixed spinal nerve, which carries motor, sensory, and autonomic signals between the spinal cord and the body. Humans have 31 left-right pairs of spinal nerves, each roughly corresponding to a segment of the vertebral column: 8 cervical spinal nerve pairs (C1-C8), 12 thoracic pairs (T1-T12), 5 lumbar pairs (L1-L5), and 5 sacral pairs (S1-S5) and 1 coccygeal pair. The spinal nerves are part of the peripheral nervous system (PNS).

Anatomy

Each spinal nerve is formed by the combination of nerve fibers from the dorsal and ventral roots of the spinal cord. The dorsal roots carry afferent sensory axons, while the ventral roots carry efferent motor axons. The spinal nerve emerges from the spinal column through an opening (intervertebral foramen) between adjacent vertebrae. This is true for all spinal nerves except for the first spinal nerve pair, which emerges between the occipital bone and the atlas (the first vertebra).

Outside the vertebral column, the nerve divides into branches. The dorsal ramus contains nerves that serve the dorsal portions of the trunk carrying visceral motor, somatic motor, and sensory information to and from the skin and muscles of the back. The ventral ramus contains nerves that serve the remaining ventral parts of the trunk and the upper and lower limbs carrying visceral motor, somatic motor, and sensory information to and from the ventrolateral body surface, structures in the body wall, and the limbs. The meningeal branches (recurrent meningeal or sinuvertebral nerves) branch from the spinal nerve and re-enter the intervertebral foramen to serve the ligaments, dura, blood vessels, intervertebral discs, facet joints, and periosteum of the vertebrae. The rami communicantes contain autonomic nerves that serve visceral functions carrying visceral motor and sensory information to and from the visceral organs.

Some ventral rami merge with adjacent ventral rami to form a nerve plexus, a network of interconnecting nerves. Nerves emerging from a plexus contain fibers from various spinal nerves, which are now carried together to some target location. Major plexuses include the cervical, brachial, lumbar, and sacral plexuses.

Clinical significance

The muscles that one particular spinal root supplies are that nerve's myotome, and the dermatomes are the areas of sensory innervation on the skin for each spinal nerve. Lesions of one or more nerve roots result in typical patterns of neurologic defects (muscle weakness, abnormal sensation, changes in reflexes) that allow localization of the causeing lesion.

Chapter 3

Connective Tissue in the Peripheral Nervous System and Dorsal Root Ganglion

Connective tissue in the peripheral nervous system

A peripheral nerve contains two types of tissue:(1) nerve fibers, and (2) connective tissue. Dendrites and axons with schwann cells and myelin sheath are surrounded by connective tissue. A nerve fiber in the peripheral nervous system consists of an axon or long dendrite, myelin sheath (if existence) and their schwann cells. Peripheral sensory fibers contain long dendrites, but peripheral motor fibers have long axons. Long dendrites of sensory fibers have structural properties as motor axons.

Layers of connective tissue in the peripheral nerve

Three layers of connective tissue surround each peripheral nerve that include:

- Epineurium
- Perineurium
- Endoneurium

Epineurium

The epineurium surrounds the peripheral nerve trunk (i.e. Superficial epineurium). This is considered the outermost layer. The epineurium separates the nerve fascicles, but lies outside the perineurium (i.e. Interfascicular epineurium).

Perineurium

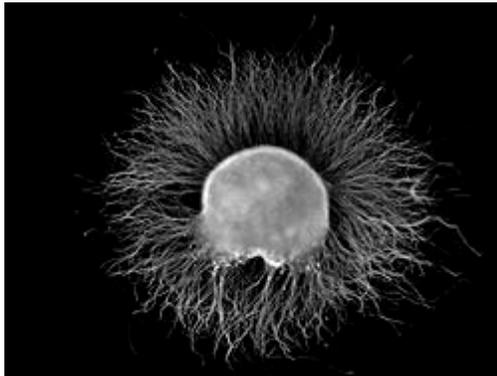
Each nerve fascicle is surrounded by the perineurium that includes a group of nerve fibers. The perineurium has very important role in the protection and support from nerve fibers. This section of connective tissue is an important factor in preventing the passing of large molecules from the epineurium into a fascicle.

Endoneurium

Each nerve fiber is surrounded by the endoneurium. This section is a thin layer of connective tissue. The endoneurium is the tube that places the components of a nerve fiber such as axon, the myelin sheath and Schwann cells into itself. Thus, the endoneurium separates nerve fibers of a fascicle.

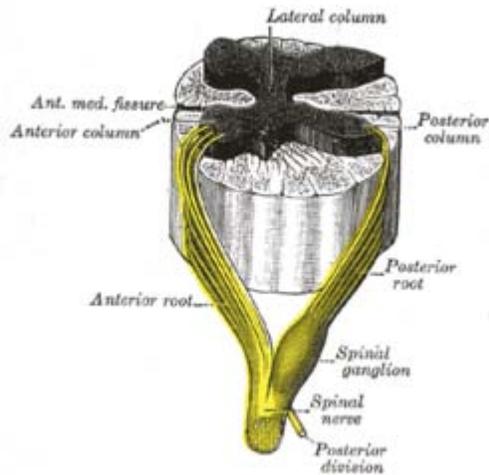
Dorsal root ganglion

Dorsal root ganglion



This is a dorsal root ganglion (DRG) from a chicken embryo (around stage of day 7) after incubation overnight in NGF growth medium stained with anti-neurofilament antibody.

Axons growing out of the ganglion are visible.



A spinal nerve with its anterior and posterior roots. The dorsal root ganglion is the "spinal ganglion", following the posterior/dorsal root.

Latin *ganglion sensorium nervi spinalis*

Gray's *subject #185 750*

Precursor neural crest

MeSH *Spinal+Ganglia*

In anatomy and neurology, a **dorsal root ganglion** (or **spinal ganglion**) is a nodule on a dorsal root that contains cell bodies of neurons in afferent spinal nerves.

Unique unipolar structure

The axons of dorsal root ganglion neurons are known as afferents. In the peripheral nervous system, afferents refer to the axons that relay sensory information into the central nervous system (i.e. the brain and the spinal cord). These neurons are of the pseudo-unipolar type, meaning they have an axon with two branches that act as a single axon, often referred to as a *distal process* and a *proximal process*.

Note: the neuron can consist of three parts:

1. Dendrite that receives the information and relays it to the Soma), or cell body.
2. Soma - the cell body of the neuron
3. Axon: which relays information from the soma.

In a neuron, the dendrite receives information from another neuron's axon at the synapse, and the axon sends information to the next neuron's dendrites, even though the dendrite may be covered with myelin.

Unlike the majority of neurons found in the central nervous system, an action potential in dorsal root ganglion neuron may initiate in the *distal process* in the periphery, bypass the cell body, and continue to propagate along the *proximal process* until reaching the synaptic terminal in the dorsal horn of the spinal cord.

Distal section

The distal section of the axon may either be a bare nerve ending or encapsulated by a structure that helps relay specific information to nerve. For example, a Meissner's corpuscle or Pacinian corpuscle may encapsulate the nerve ending, rendering the *distal process* sensitive to mechanical stimulation, such as stroking or vibration, respectively.

Location

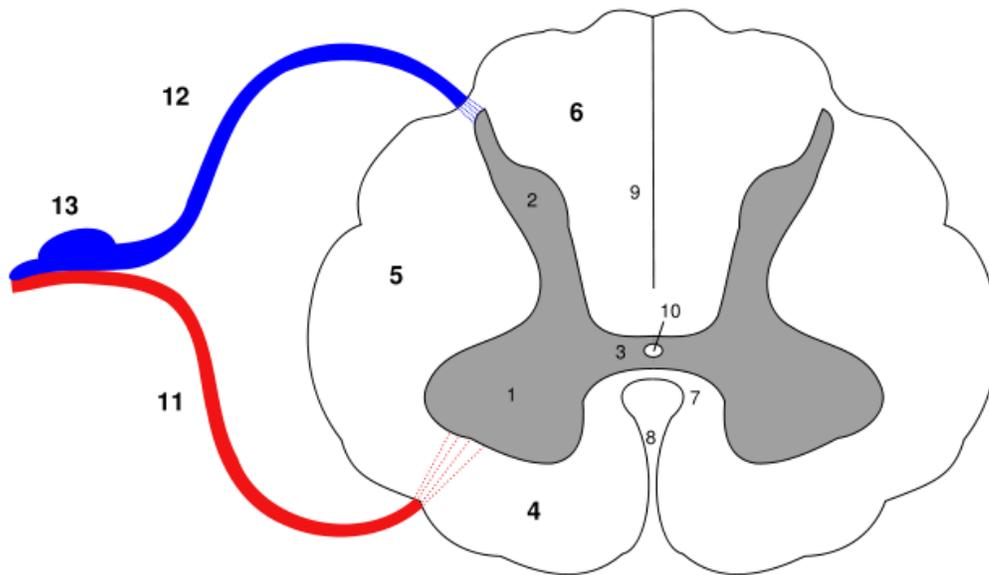
The dorsal root ganglia lie along the vertebral column by the spine.

Embryology

The dorsal root ganglia develops in the embryo from neural crest cells, not neural tube. Hence, the spinal ganglia can be regarded as gray matter of the spinal cord that became translocated to the periphery.

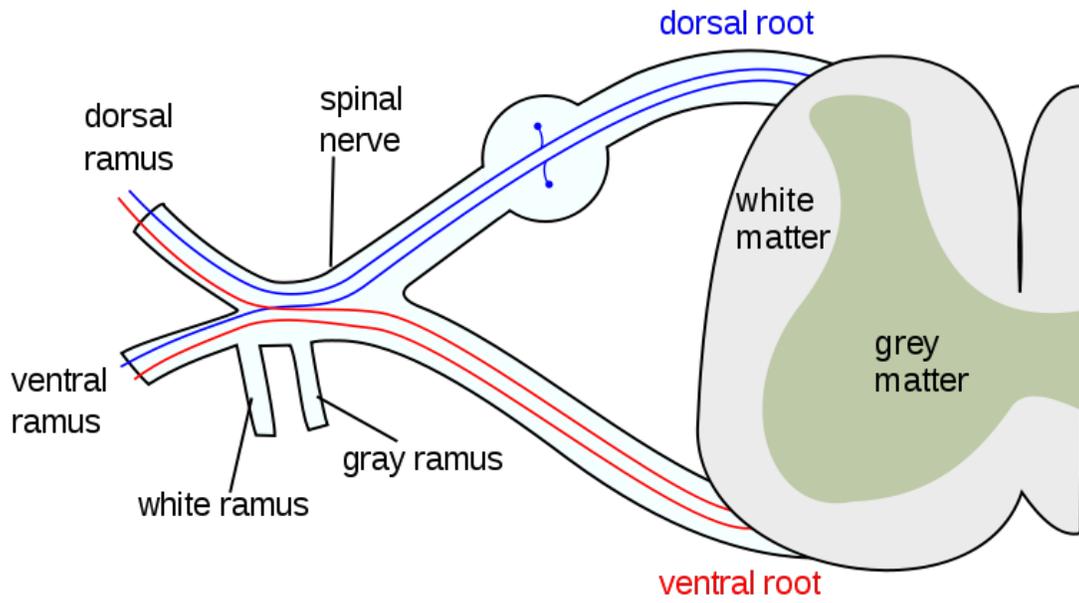
Nociception

Proton-sensing G protein-coupled receptors are expressed by DRG sensory neurons and might play a role in acid-induced nociception.

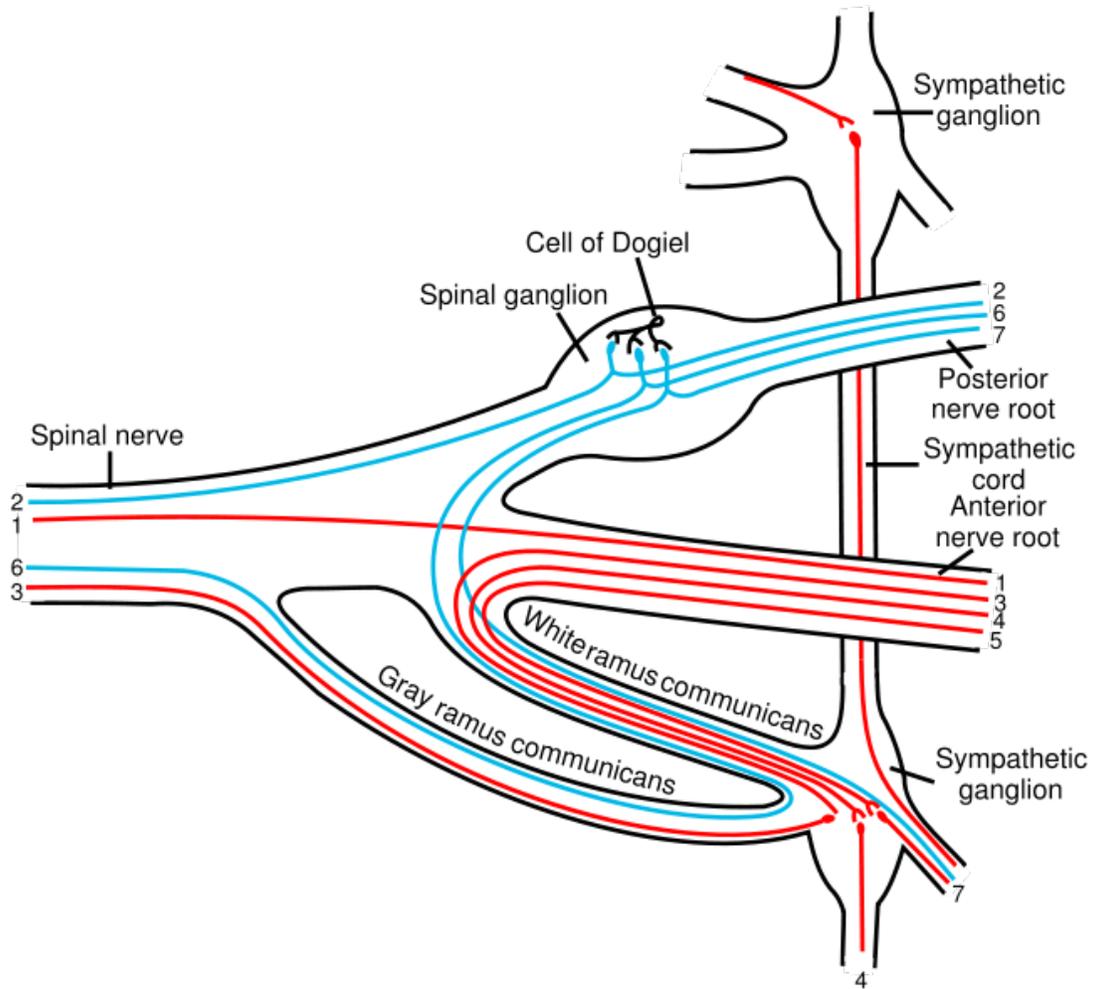


Gray matter	White matter	
1. Anterior horn	4. Anterior funiculus	10. Central canal
2. Posterior horn	5. Lateral funiculus	11. Anterior root
3. Gray commissure	6. Posterior funiculus	12. Posterior root
	7. Anterior commissure	13. Dorsal root ganglion
	8. Anterior median fissure	
	9. Posterior median sulcus	

Medulla spinalis



The formation of the spinal nerve from the dorsal and ventral roots |



Scheme showing structure of a typical spinal nerve.

Chapter 4

Efferent Nerve Fiber and General Visceral Afferent Fibers

Efferent nerve fiber

Nerve: Efferent nerve fiber

Latin *neurofibrae efferentes*

In the nervous system, **efferent nerves** – otherwise known as motor or effector neurons – carry nerve impulses *away* from the central nervous system to effectors such as muscles or glands (and also the ciliated cells of the inner ear). The term can also be used to describe relative connections between nervous structures (for example, a neuron's efferent synapse provides input to another neuron, and not vice-versa). The opposite activity of direction or flow is **afferent**.

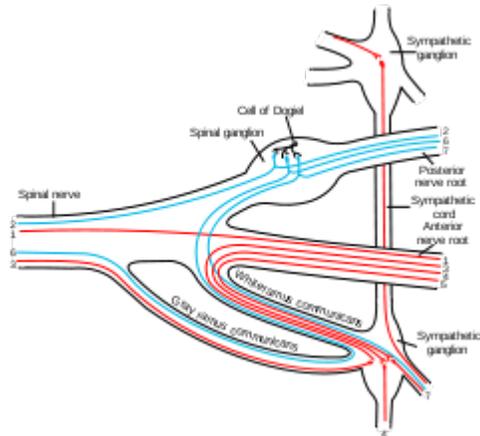
The motor nerves are efferent nerves involved in muscular control. The cell body of the efferent neuron is connected to a single, long axon and several shorter dendrites projecting out of the cell body itself. This axon then forms a neuromuscular junction with the effectors. The cell body of the motor neuron is satellite-shaped. The motor neuron is present in the grey matter of the spinal cord and medulla oblongata, and forms an electrochemical pathway to the effector organ or muscle. Besides motor nerves, there are efferent sensory nerves that often serve to adjust the sensitivity of the signal relayed by the afferent sensory nerve.

Etymology and Mnemonics

Both **afferent** and **efferent** come from French, evolved from Latin (the basis of many terms in medicine and biology) for the terms, respectively, *ad ferens* (Latin verb *ferre*: carry), meaning *carrying into*, and *ex ferens*, meaning *carrying away*. *Ad* and *ex* give an easy mnemonic device for remembering the relationship between *afferent* and *efferent*: *afferent connection arrives* and an *efferent connection exits*.

General visceral afferent fibers

General visceral afferent fibers



Scheme showing pathways (white/grey rami are spatially reverse, possibly for clarity?) of a typical spinal nerve.

1. Somatic efferent.
2. Somatic afferent.
- 3,4,5. Sympathetic efferent.
- 6,7. Parasympathetic afferent.

Note that this image merely depicts pathways in a schematic fashion - it is not anatomically correct. The efferent sympathetics exit in a loop - entering the more lateral white and either exiting the more medial grey or traveling up/down the chain to exit ganglia.

Gray's *subject #190 849*

The **general visceral afferent fibers (GVA)**, conduct sensory impulses (usually pain or reflex sensations) from the viscera, glands, and blood vessels to the central nervous system. They are considered to be part of the autonomic nervous system. However, unlike the efferent fibers of the autonomic nervous system, the afferent fibers are not classified as either sympathetic or parasympathetic.

Examples of nerves containing GVA fibers include the glossopharyngeal nerve and the vagus nerve.

Pathway

Abdomen

In the abdomen, general visceral afferent fibers usually accompany sympathetic efferent fibers. This means that a signal traveling in an afferent fiber will begin at sensory receptors in the afferent fiber's target organ, travel up to the ganglion where the sympathetic efferent fiber synapses, continue back along a splanchnic nerve from the ganglion into the sympathetic trunk, move into a ventral ramus via a white ramus communicans, and finally move into the mixed spinal nerve between the division of the rami and the division of the roots of the spinal nerve. The GVA pathway then diverges from the sympathetic efferent pathway, which follows the ventral root into the spinal column, by following the dorsal root into the dorsal root ganglion, where the cell body of the sympathetic visceral afferent nerve is located. Finally, the signal continues along the dorsal root from the dorsal root ganglion to a region of gray matter in the dorsal horn of the spinal column where it is transmitted via a synapse to a neuron in the central nervous system.

The only GVA nerves in the abdomen that do not follow the above pathway are those that innervate structures in the distal half of the sigmoid colon and the rectum. These afferent fibers, instead, follow the path of parasympathetic efferent fibers back to the vertebral column, where the afferent fibers enter the S2-S4 sensory ganglia followed by the spinal cord.

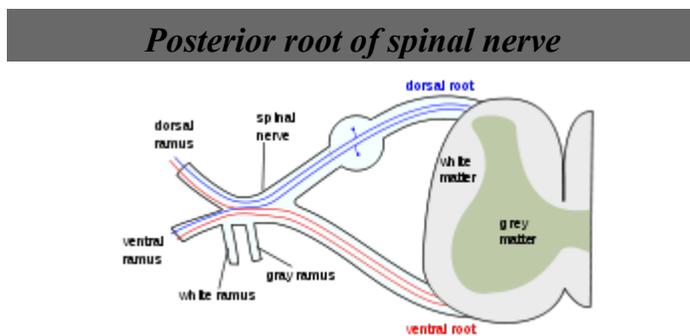
Pelvis

The course of GVA fibers from organs in the pelvis, in general, depends on the organ's position relative to the pelvic pain line. An organ, or part of an organ, in the pelvis is said to be "above the pelvic pain line" if it is in contact with the peritoneum, except in the case of the large intestine, where the pelvic pain line is said to be located in the middle of the sigmoid colon. GVA fibers from structures above the pain line follow the course of the sympathetic efferent fibers, and GVA fibers from structure below the pain line follow the course of the parasympathetic efferents. Pain from the latter fibers is less likely to be consciously experienced.

Chapter 5

Posterior Root of Spinal Nerve and General Somatic Efferent Fibers

Posterior root of spinal nerve



The formation of the spinal nerve from the dorsal and ventral roots

Latin *radix posterior*

Gray's *subject #208 916*

MeSH *Dorsal+Roots*

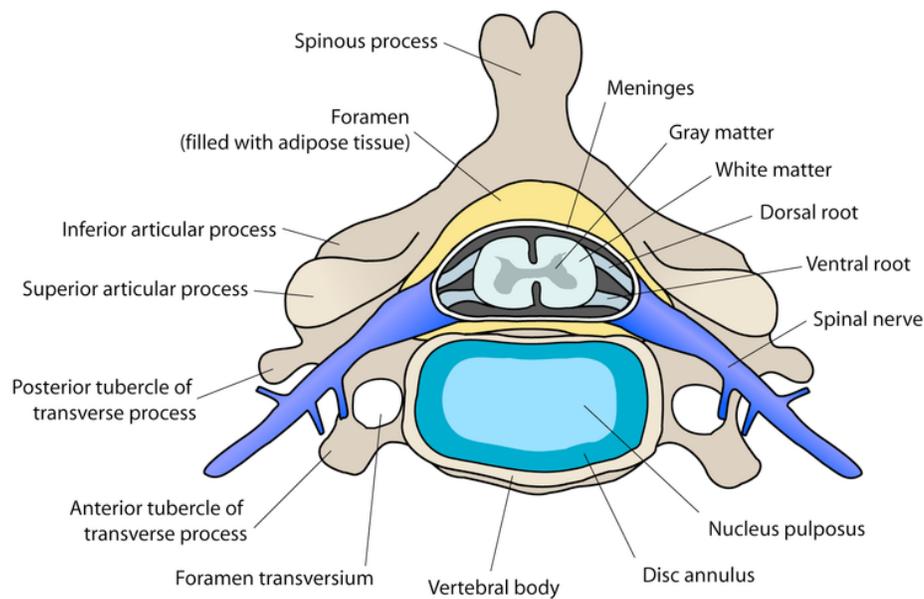
In anatomy and neurology, the **dorsal root** (or **posterior root**) is the afferent sensory root of a spinal nerve.

At the distal end of the dorsal root is the dorsal root ganglion, which contains the neuron cell bodies of the nerve fibres conveyed by the root.

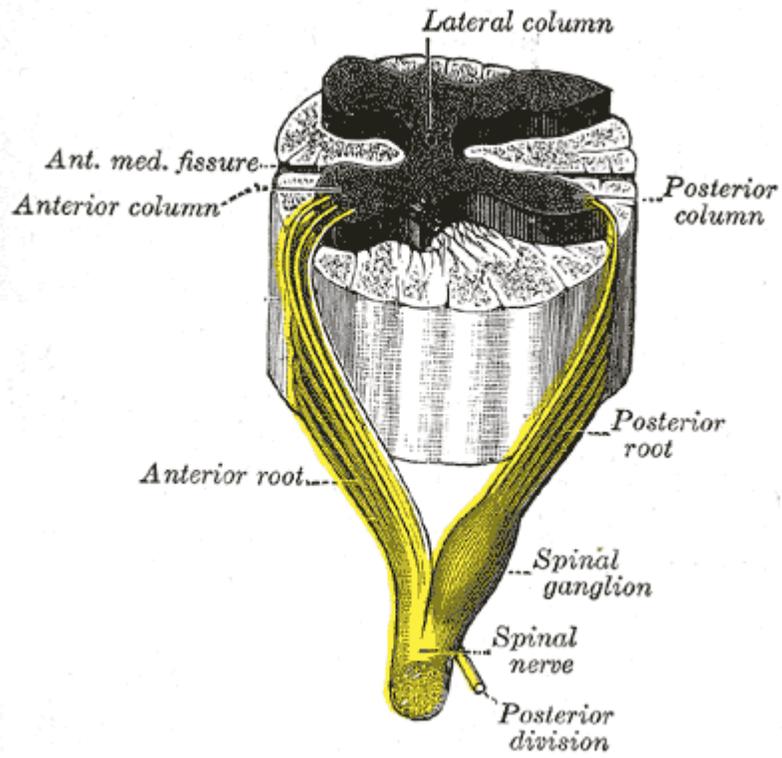
If the dorsal root of a spinal nerve were severed it would lead to numbness in certain areas of the body.

The lateral division of the dorsal root contains lightly myelinated and unmyelinated axons of small diameter. These transmit pain and temperature sensation from the body. These fibers cross through the anterior white commissure to form the Anterior lateral system in the lateral funiculus.

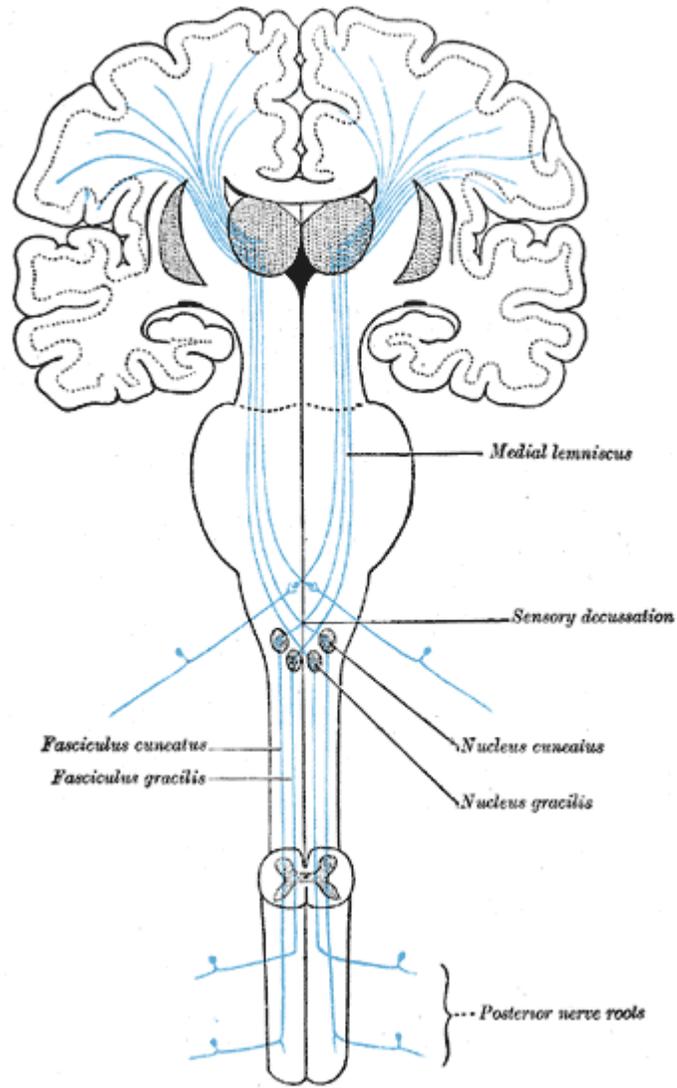
The medial division of the dorsal root contains myelinated axons of larger diameter. These transmit information of discriminative touch, pressure, vibration, and conscious proprioception originating from spinal levels C2 through S5. These fibers are pushed in towards the posterior medial sulcus to form the fasciculus gracilis and the fasciculus cuneatus.



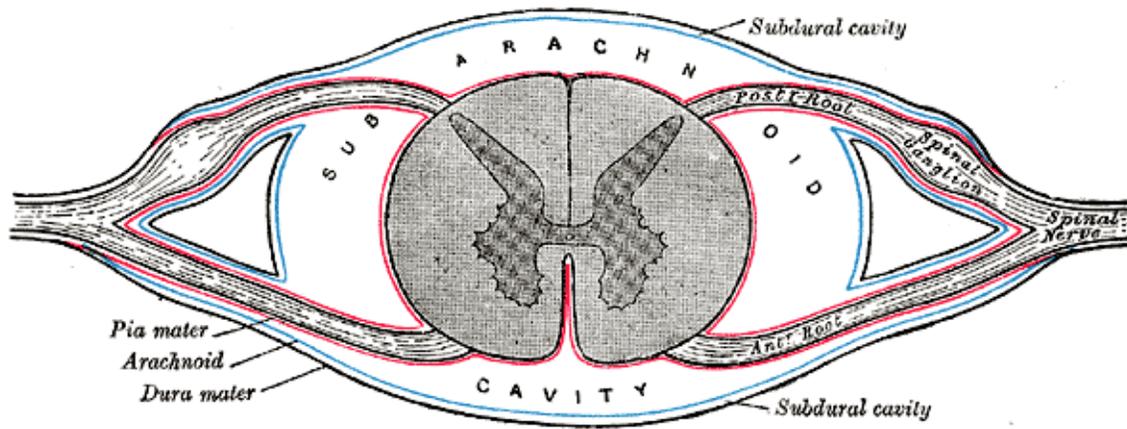
Cervical vertebra



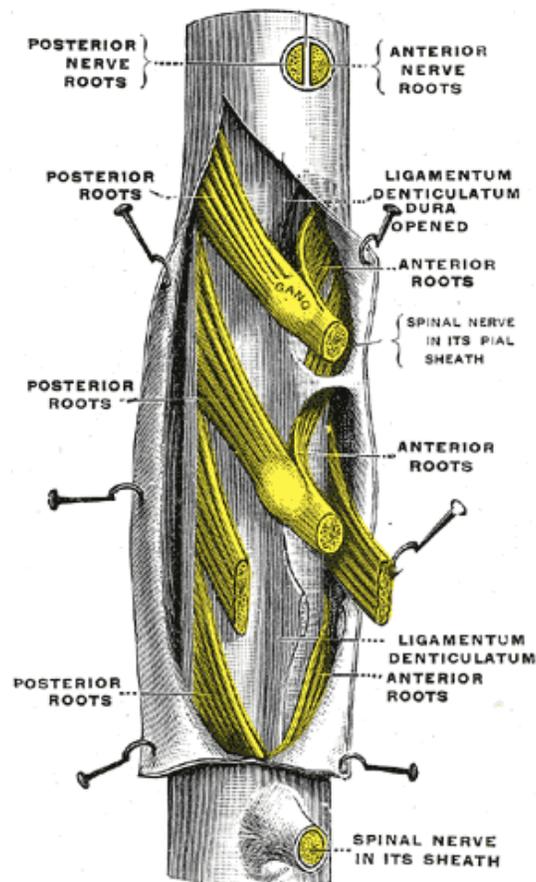
A spinal nerve with its anterior and posterior roots.



The sensory tract.



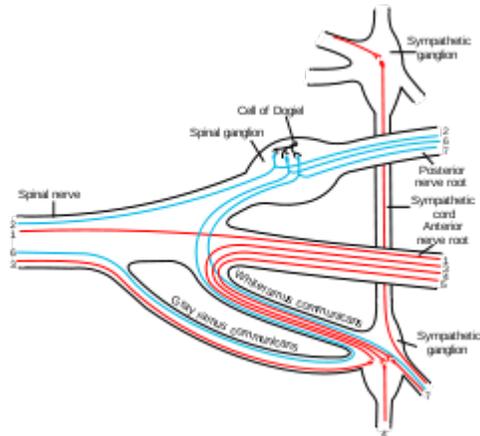
Diagrammatic transverse section of the medulla spinalis and its membranes.



A portion of the spinal cord, showing its right lateral surface. The dura is opened and arranged to show the nerve roots.

General somatic efferent fibers

General somatic efferent fibers



Scheme showing structure of a typical spinal nerve.

1. Somatic efferent.
2. Somatic afferent.
- 3,4,5. Sympathetic efferent.
- 6,7. Sympathetic afferent.

Gray's *subject #190 849*

The *spinal* **somatic efferent neurons (GSE, 'somatomotor, or somatic motor fibers)**, arise from motor neuron cell bodies in the ventral horns of the gray matter within the spinal cord. They exit the spinal cord through the ventral roots, carrying motor impulses to skeletal muscle.

Of the somatic efferent neurons, there exist subtypes.

- Alpha motor neurons (α) target extrafusal muscle fibers.
- Gamma motor neurons (γ) target intrafusal muscle fibres

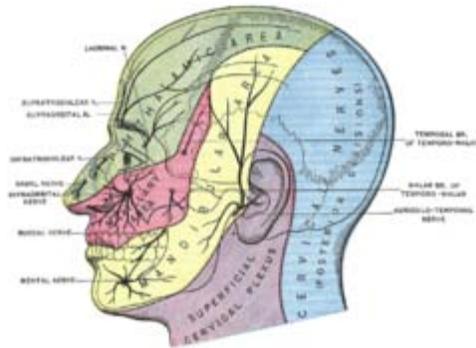
Cranial nerves also supply their own somatic efferent neurons to the extraocular muscles and some of the muscles of the tongue.

Chapter 6

Cervical Plexus and Lumbar Plexus

Cervical plexus

Nerve: Cervical plexus



Dermatome distribution of the trigeminal nerve (Superficial cervical plexus visible in purple, at center bottom.)

Latin *plexus cervicalis*

Gray's *subject #210 925*

From C1-C4

The **cervical plexus** is a plexus of the ventral rami of the first four cervical spinal nerves which are located from C1 to C5 cervical segment in the neck. They are located laterally to the transverse processes between prevertebral muscles from the medial side and vertebral (m.scalenus, m.levator scapulae, m.splenius cervicis) from lateral side. There is anastomosis with accessory nerve, hypoglossal nerve and sympathetic trunk.

It is located in the neck, deep to sternocleidomastoid. Nerves formed from the cervical plexus innervate the back of the head, as well as some neck muscles. The branches of the

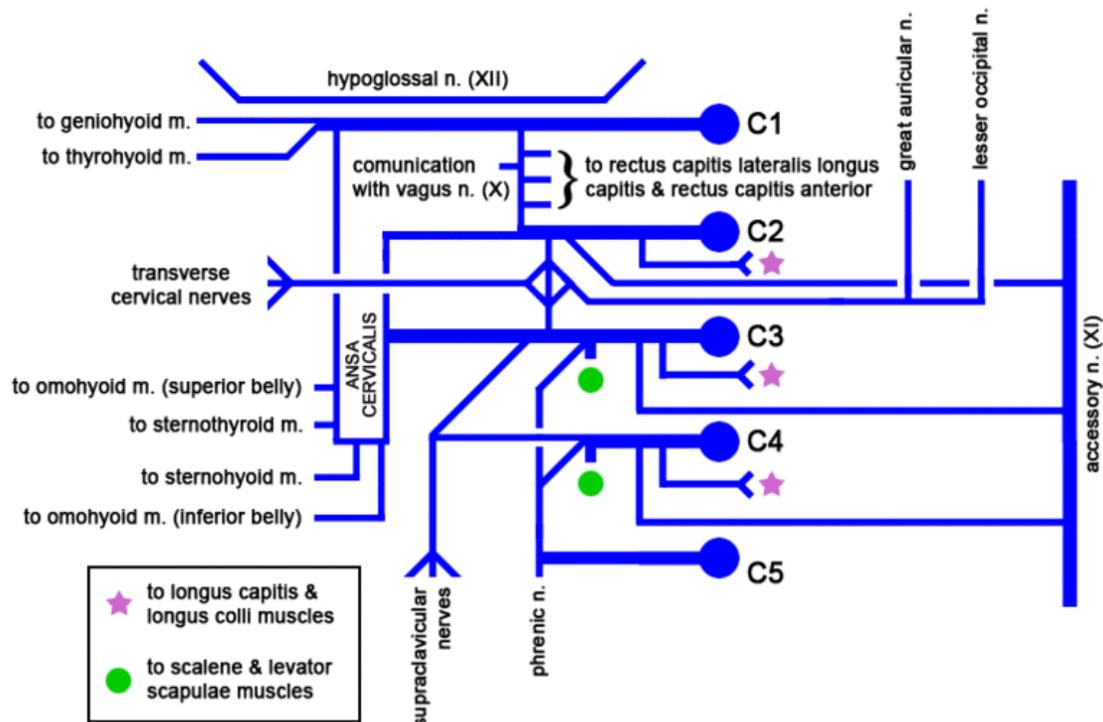
cervical plexus emerge from the posterior triangle at the nerve point, a point which lies midway on the posterior border of the Sternocleidomastoid.

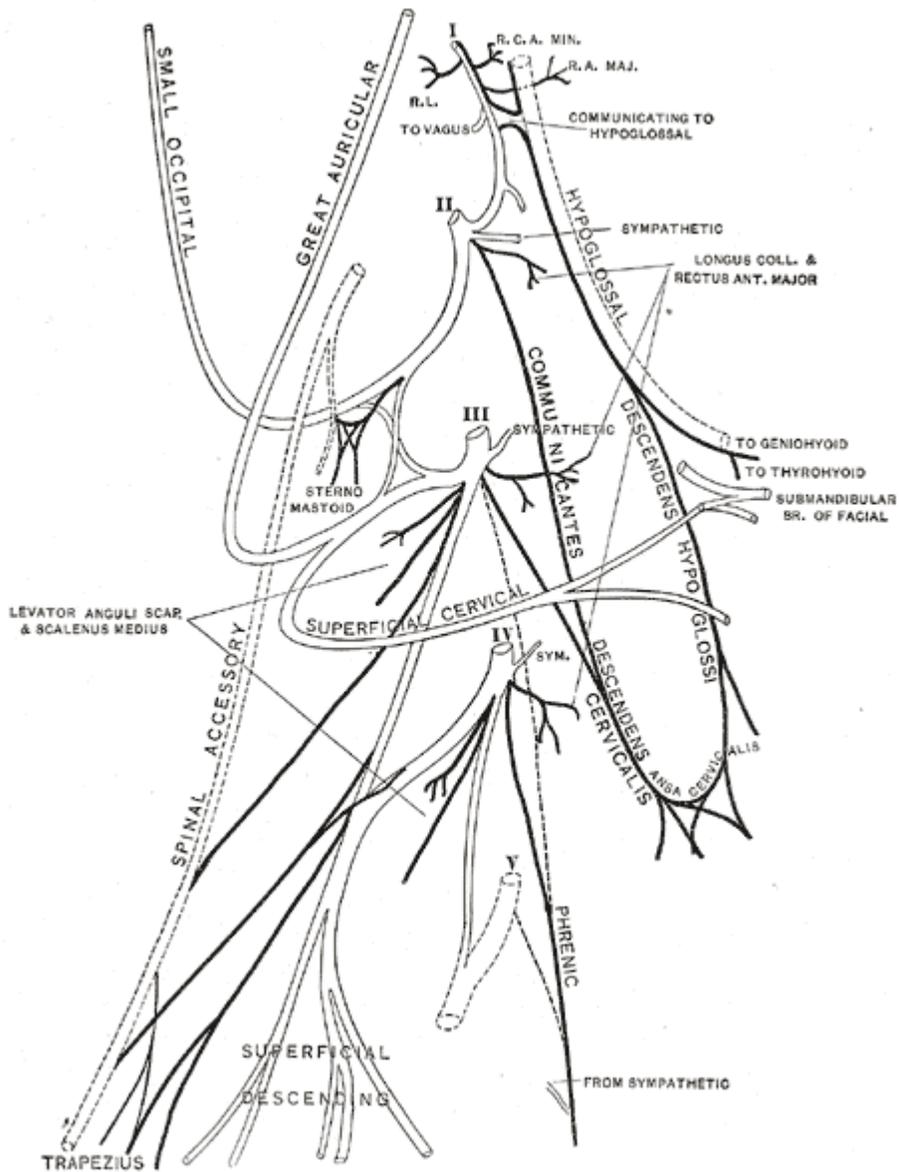
Branches

The cervical plexus has two types of branches: cutaneous and muscular.

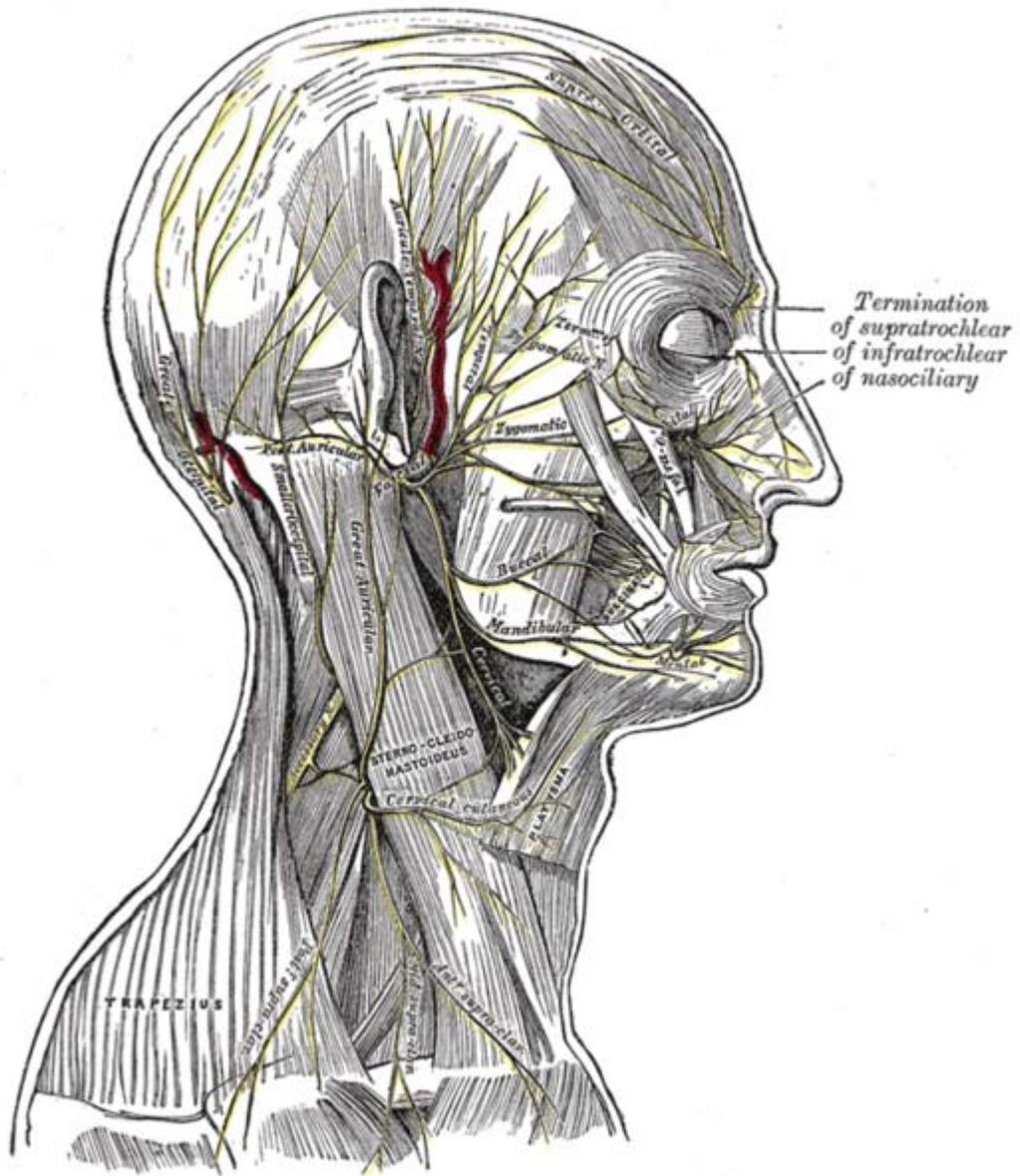
- Cutaneous (4 branches):
 - Lesser occipital nerve - innervates lateral part of occipital region (C2 ONLY)
 - Great auricular nerve - innervates skin near concha auricle and external acoustic meatus (C2&C3)
 - Transverse cervical nerve - innervates anterior region of neck (C2&C3)
 - Supraclavicular nerves - innervate region of suprascapularis, shoulder, and upper thoracic region (C3,C4)
- Muscular
 - Ansa cervicalis (loop formed from C1-C3), etc. (geniohyoid (C1 only), thyrohyoid (C1 only), sternothyroid, sternohyoid, omohyoid)
 - Phrenic (C3-C5 (primarily C4))-innervates diaphragm and the pericardium
 - Segmental branches (C1-C4)- innervates anterior and middle scalenes

Diagram

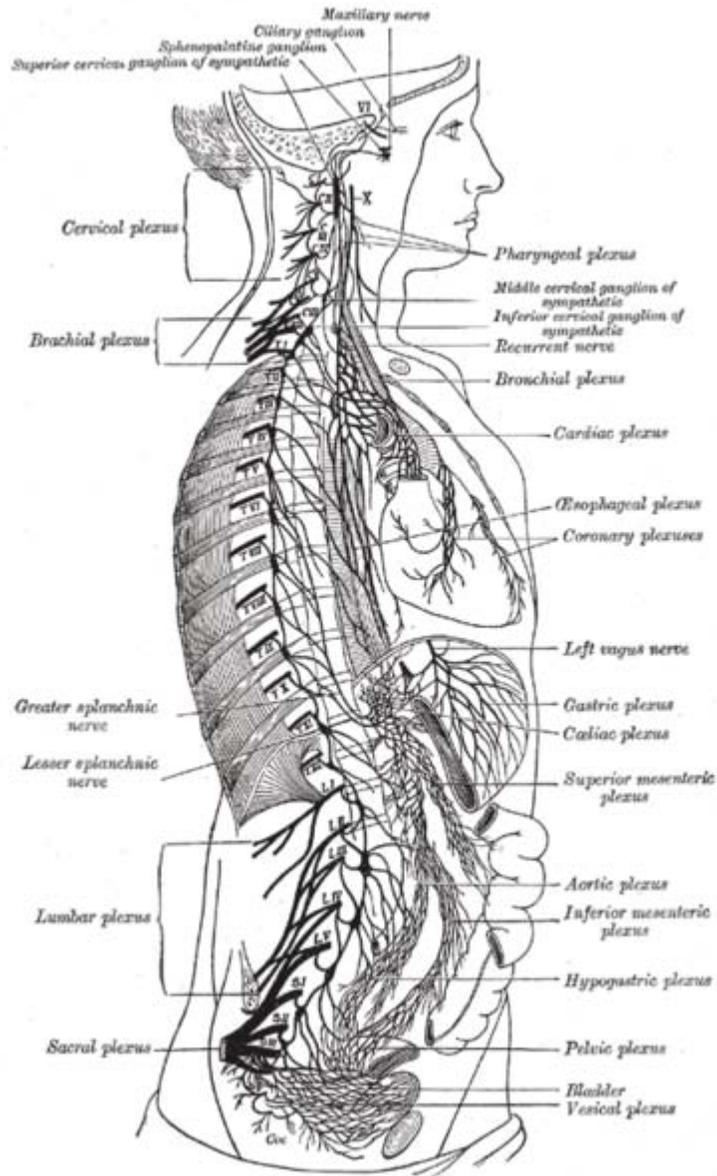




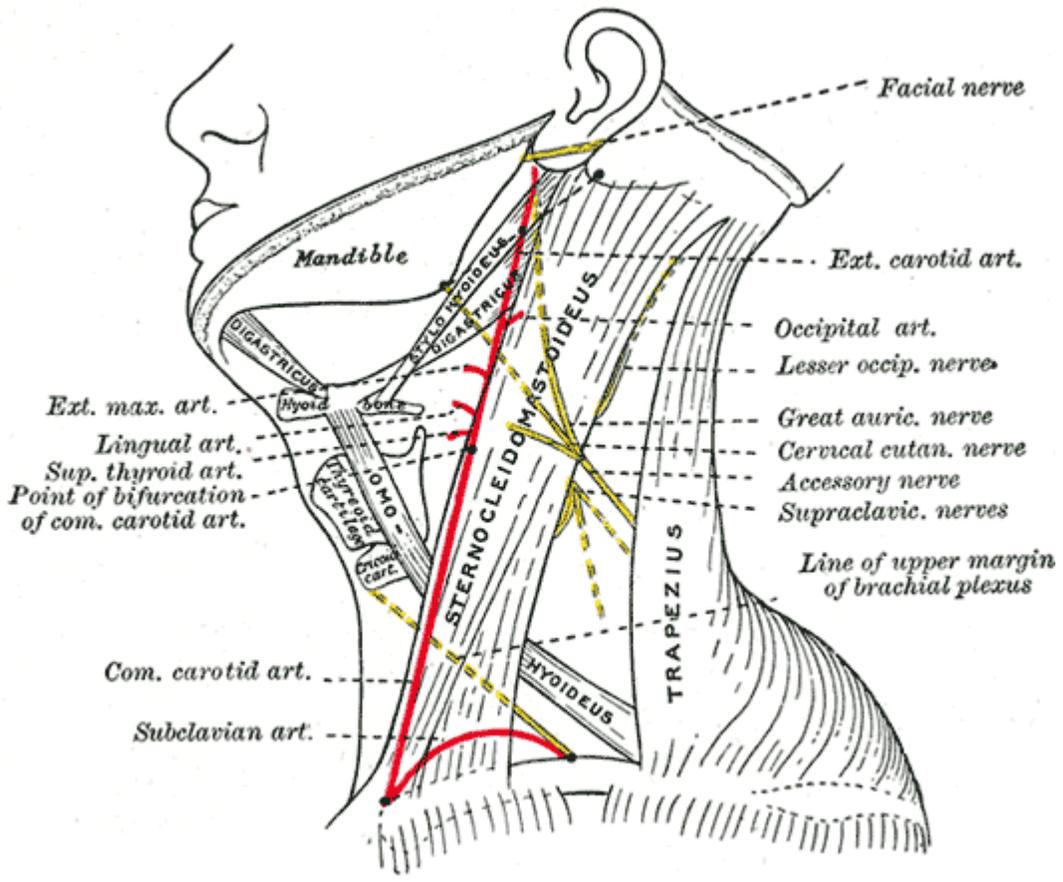
Plan of the cervical plexus.



The nerves of the scalp, face, and side of neck.



The right sympathetic chain and its connections with the thoracic, abdominal, and pelvic plexuses.

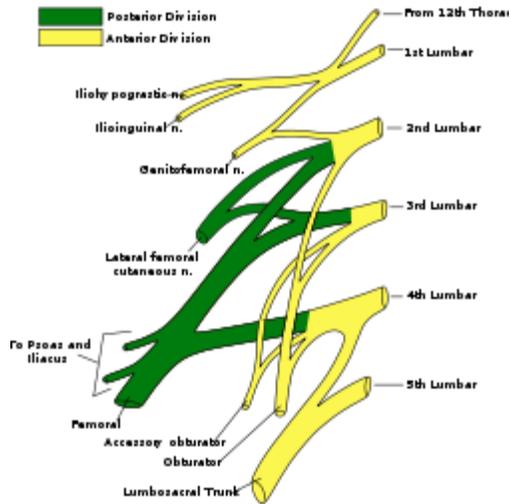


Side of neck, showing chief surface markings.

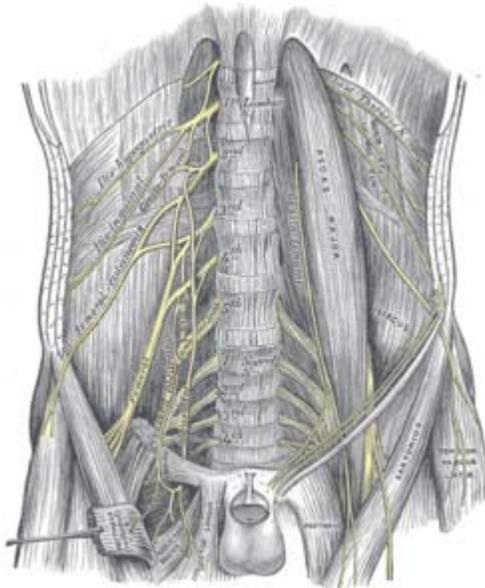
Lumbar plexus

Nerve: Lumbar plexis

Latin = plexus lumbalis



Plan of lumbar plexus.



The lumbar plexus and its branches.

Gray's *subject #212 949*

From T12, L1-L4

MeSH *Lumbosacral+Plexus*

The **lumbar plexus** is a nervous plexus in the lumbar region of the body which forms part of the lumbosacral plexus. It is formed by the ventral divisions of the first four

lumbar nerves (L1-L4) and from contributions of the subcostal nerve (T12), which is the last thoracic nerve. Additionally, the ventral rami of the fourth lumbar nerve pass communicating branches, the lumbosacral trunk, to the sacral plexus. The nerves of the lumbar plexus pass in front of the hip joint and mainly support the anterior part of the thigh.

The plexus is formed lateral to the intervertebral foramina and pass through psoas major. Its smaller motor branches are distributed directly to psoas major, while the larger branches leave the muscle at various sites to run obliquely downward through the pelvic area to leave the pelvis under the inguinal ligament, with the exception of the obturator nerve which exits the pelvis through the obturator foramen.

Branches

The iliohypogastric nerve runs anterior to the psoas major on its proximal lateral border to run laterally and obliquely on the anterior side of quadratus lumborum. Lateral to this muscle, it pierces the transversus abdominis to run above the iliac crest between that muscle and abdominal internal oblique. It gives off several motor branches to these muscles and a sensory branch to the skin of the lateral hip. Its terminal branch then runs parallel to the inguinal ligament to exit the aponeurosis of the abdominal external oblique above the external inguinal ring where it supplies the skin above the inguinal ligament (i.e. the hypogastric region) with the anterior cutaneous branch.

The ilioinguinal nerve closely follows the iliohypogastric nerve on the quadratus lumborum, but then passes below it to run at the level of the iliac crest. It pierces the lateral abdominal wall and runs medially at the level of the inguinal ligament where it supplies motor branches to both transversus abdominis and sensory branches through the external inguinal ring to the skin over the pubic symphysis and the lateral aspect of the labia majora or scrotum.

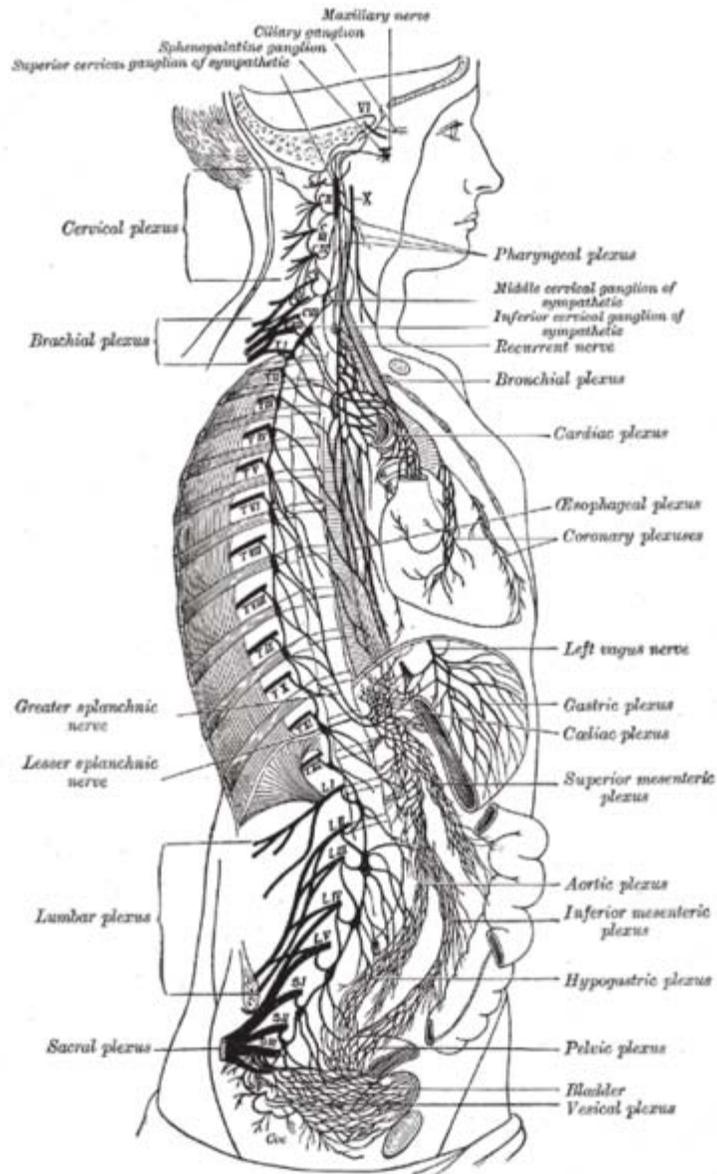
The genitofemoral nerve pierces psoas major anteriorly below the former two nerves to immediately split into two branches that run downward on the anterior side of the muscle. The lateral femoral branch is purely sensory. It pierces the vascular lacuna near the saphenous hiatus and supplies the skin below the inguinal ligament (i.e. proximal, lateral aspect of femoral triangle). The genital branch differs in males and females. In males it runs in the spermatic cord and in females in the inguinal canal together with the teres uteri ligament. It then sends sensory branches to the scrotal skin in males and the labia majora in females. In males it supplies motor innervation to the cremaster.

The lateral cutaneous femoral nerve pierces psoas major on its lateral side and runs obliquely downward below the iliac fascia. Medial to the anterior superior iliac spine it leaves the pelvic area through the lateral muscular lacuna. In the thigh it briefly passes under the fascia lata before it breaches the fascia and supplies the skin of the anterior thigh.

The obturator nerve leaves the lumbar plexus and descends behind psoas major on its medial side, then follows the linea terminalis into the lesser pelvis, and finally leaves the pelvic area through the obturator canal. In the thigh, it sends motor branches to obturator externus before dividing into an anterior and a posterior branch, both of which continue distally. These branches are separated by adductor brevis and supply all thigh adductors with motor innervation: pectineus, adductor longus, adductor brevis, adductor magnus, adductor minimus, and gracilis. The anterior branch contributes a terminal, sensory branch which passes along the anterior border of gracilis and supplies the skin on the medial, distal part of the thigh.

The femoral nerve is the largest and longest of the plexus' nerves. It gives motor innervation to iliopsoas, pectineus, sartorius, and quadriceps femoris; and sensory innervation to the anterior thigh, posterior lower leg, and hindfoot. In the pelvic area, it runs in a groove between psoas major and iliacus giving off branches to both muscles, and exits the pelvis through the medial aspect of muscular lacuna. In the thigh it divides into numerous sensory and muscular branches and the saphenous nerve, its long sensory terminal branch which continues down to the foot.

Nerves of the lumbar plexus			
Nerve	Segment	Innervated muscles	Cutaneous branches
Iliohypogastric	T12-L1	<ul style="list-style-type: none"> • Transversus abdominis • Abdominal internal oblique 	<ul style="list-style-type: none"> • Anterior cutaneous ramus • Lateral cutaneous ramus • Anterior scrotal nerves in males • Anterior labial nerves in females
Ilioinguinal	L1		<ul style="list-style-type: none"> • Femoral ramus • Genital ramus
Genitofemoral	L1, L2	<ul style="list-style-type: none"> • Cremaster in males 	<ul style="list-style-type: none"> • Lateral femoral cutaneous
Lateral femoral cutaneous	L2, L3		
Obturator	L2-L4	<ul style="list-style-type: none"> • Obturator externus • Adductor longus • Adductor brevis • Gracilis • Pectineus • Adductor magnus 	<ul style="list-style-type: none"> • Cutaneous ramus
Femoral	L2-L4	<ul style="list-style-type: none"> • Iliopsoas • Pectineus • Sartorius • Quadriceps femoris 	<ul style="list-style-type: none"> • Anterior cutaneous branches • Saphenous
Short, direct muscular branches	T12-L4	<ul style="list-style-type: none"> • Psoas major • Quadratus lumborum • Iliacus • Lumbar intertransverse 	

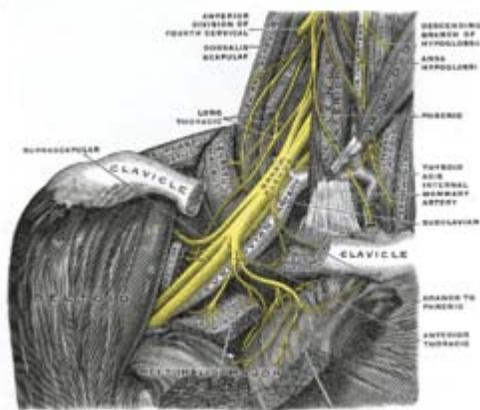


The right sympathetic chain and its connections with the thoracic, abdominal, and pelvic plexuses.

Chapter 7

Brachial Plexus

Nerve: Brachial plexus



The right brachial plexus with its short branches, viewed from in front.

Latin *plexus brachialis*

Gray's *subject #210 930*

Innervates Sensory and motor innervation to the upper limb

From C5, C6, C7, C8, T1

MeSH *Brachial+plexus*

The **brachial plexus** is an arrangement of nerve fibers, running from the spine, formed by the ventral rami of the lower four cervical and first thoracic nerve roots (C5-T1). It proceeds through the neck, the axilla (armpit region), and into the arm.

Function

The brachial plexus is responsible for cutaneous and muscular innervation of the entire upper limb, with two exceptions: the trapezius muscle innervated by the spinal accessory nerve (CN XI) and an area of skin near the axilla innervated by the intercostobrachial nerve.

Lesions can lead to severe functional impairment.

Anatomy

Path

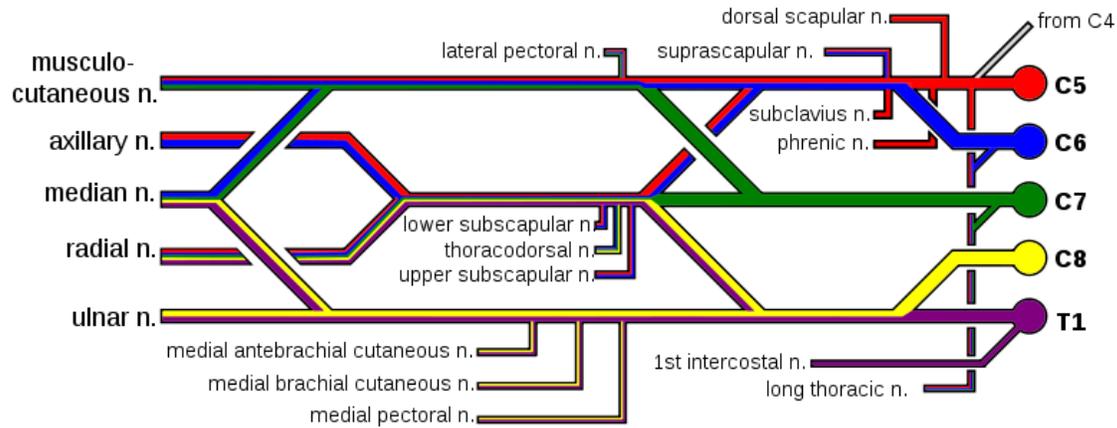
The brachial plexus is divided into Roots, Trunks, Divisions, Cords, and Branches. There are five "terminal" branches and numerous other "pre-terminal" or "collateral" branches that leave the plexus at various points along its length.

- The five **roots** are the five anterior rami of the spinal nerves, after they have given off their segmental supply to the muscles of the neck.
- These roots merge to form three **trunks**:
 - "superior" or "upper" (C5-C6)
 - "middle" (C7)
 - "inferior" or "lower" (C8-T1)
- Each trunk then splits in two, to form six **divisions**:
 - anterior divisions of the upper, middle, and lower trunks
 - posterior divisions of the upper, middle, and lower trunks
- These six divisions will regroup to become the three **cords**. The cords are named by their position with respect to the axillary artery.
 - The *posterior cord* is formed from the three posterior divisions of the trunks (C5-T1)
 - The *lateral cord* is the anterior divisions from the upper and middle trunks (C5-C7)
 - The *medial cord* is simply a continuation of the anterior division of the lower trunk (C8-T1)
- The **branches** are listed below. Most branch from the cords, but a few branch (indicated in italics) directly from earlier structures. The five on the left are considered "terminal branches".

Some mnemonics for remembering the order of the brachial plexus:

- **Real Texans Drink Cold Beer**
- **Read The Darn Cadaver Book**

- Real Teachers Drink Chilled Beer
- Randy Travis Drinks Cold Beer



Diagrammatic representation of the brachial plexus using colour to illustrate the contributions of each nerve root to the branches

Specific branches

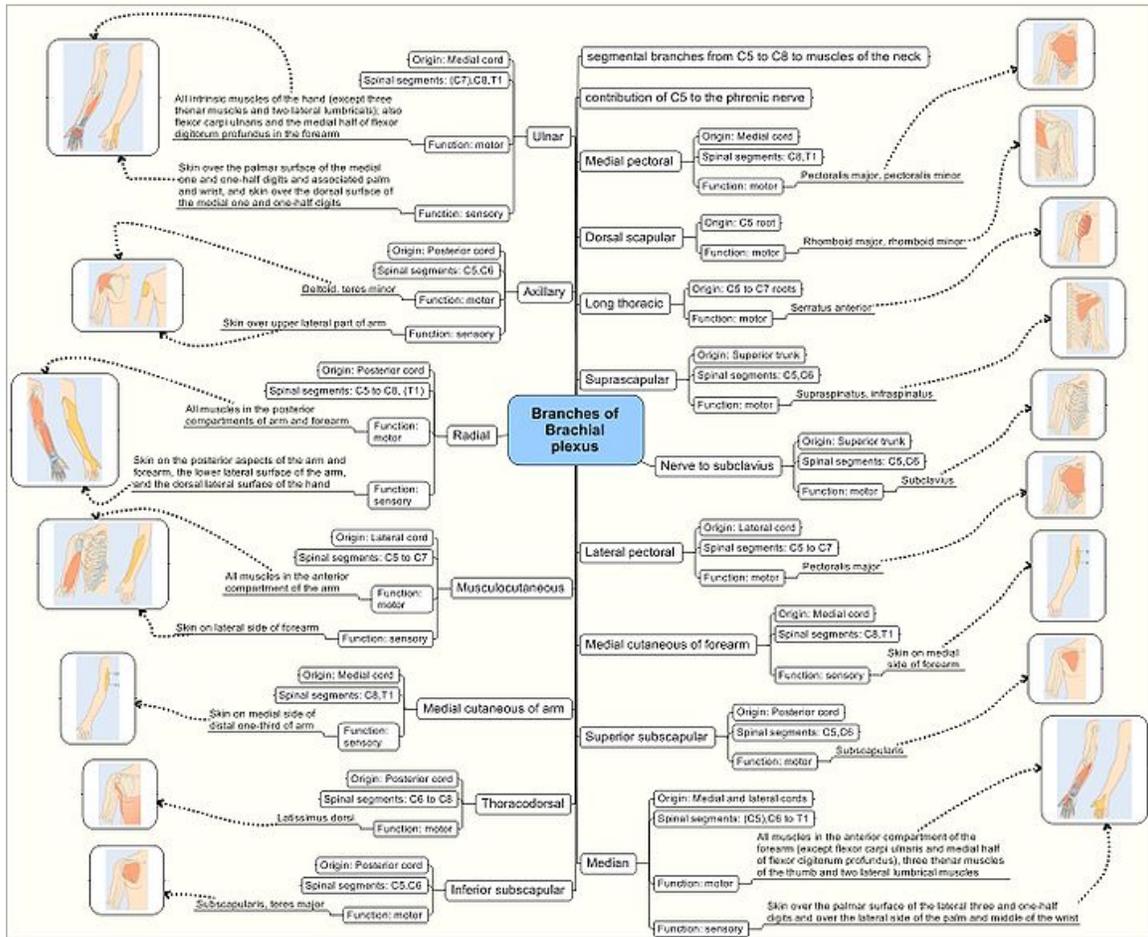
From	Nerve	Roots	Muscles	Cutaneous
roots	dorsal scapular nerve	C5	rhomboid muscles and levator scapulae	-
roots	long thoracic nerve	C5, C6, C7	serratus anterior	-
upper trunk	nerve to the subclavius	C5, C6	subclavius muscle	-
upper trunk	suprascapular nerve	C5, C6	supraspinatus and infraspinatus	-
lateral cord	lateral pectoral nerve	C5, C6, C7	pectoralis major (by communicating with the medial pectoral nerve)	-
lateral cord	musculocutaneous nerve	C5, C6, C7	coracobrachialis, brachialis and biceps brachii	becomes the lateral cutaneous nerve of the forearm
lateral cord	lateral root of the median nerve	C5, C6, C7	fibres to the median nerve	-
posterior cord	upper subscapular nerve	C5, C6	subscapularis (upper part)	-

posterior cord	thoracodorsal nerve (middle subscapular nerve)	C6, C7, C8	latissimus dorsi	-
posterior cord	lower subscapular nerve	C5, C6	subscapularis (lower part) and teres major	-
posterior cord	axillary nerve	C5, C6	anterior branch: deltoid and a small area of overlying skin posterior branch: teres minor and deltoid muscles	posterior branch becomes upper lateral cutaneous nerve of the arm
posterior cord	radial nerve	C5, C6, C7, C8, T1	triceps brachii, supinator, anconeus, the extensor muscles of the forearm, and brachioradialis	skin of the posterior arm as the posterior cutaneous nerve of the arm
medial cord	medial pectoral nerve	C8, T1	pectoralis major and pectoralis minor	-
medial cord	medial root of the median nerve	C8, T1	fibres to the median nerve	portions of hand not served by ulnar or radial
medial cord	medial cutaneous nerve of the arm	C8, T1	-	front and medial skin of the arm
medial cord	medial cutaneous nerve of the forearm	C8, T1	-	medial skin of the forearm
medial cord	ulnar nerve	C8, T1	flexor carpi ulnaris, the medial two bellies of flexor digitorum profundus, the intrinsic hand muscles except the thenar muscles and the two most lateral lumbricals	the skin of the medial side of the hand and medial one and a half fingers on the palmar side and medial two and a half fingers on the dorsal side

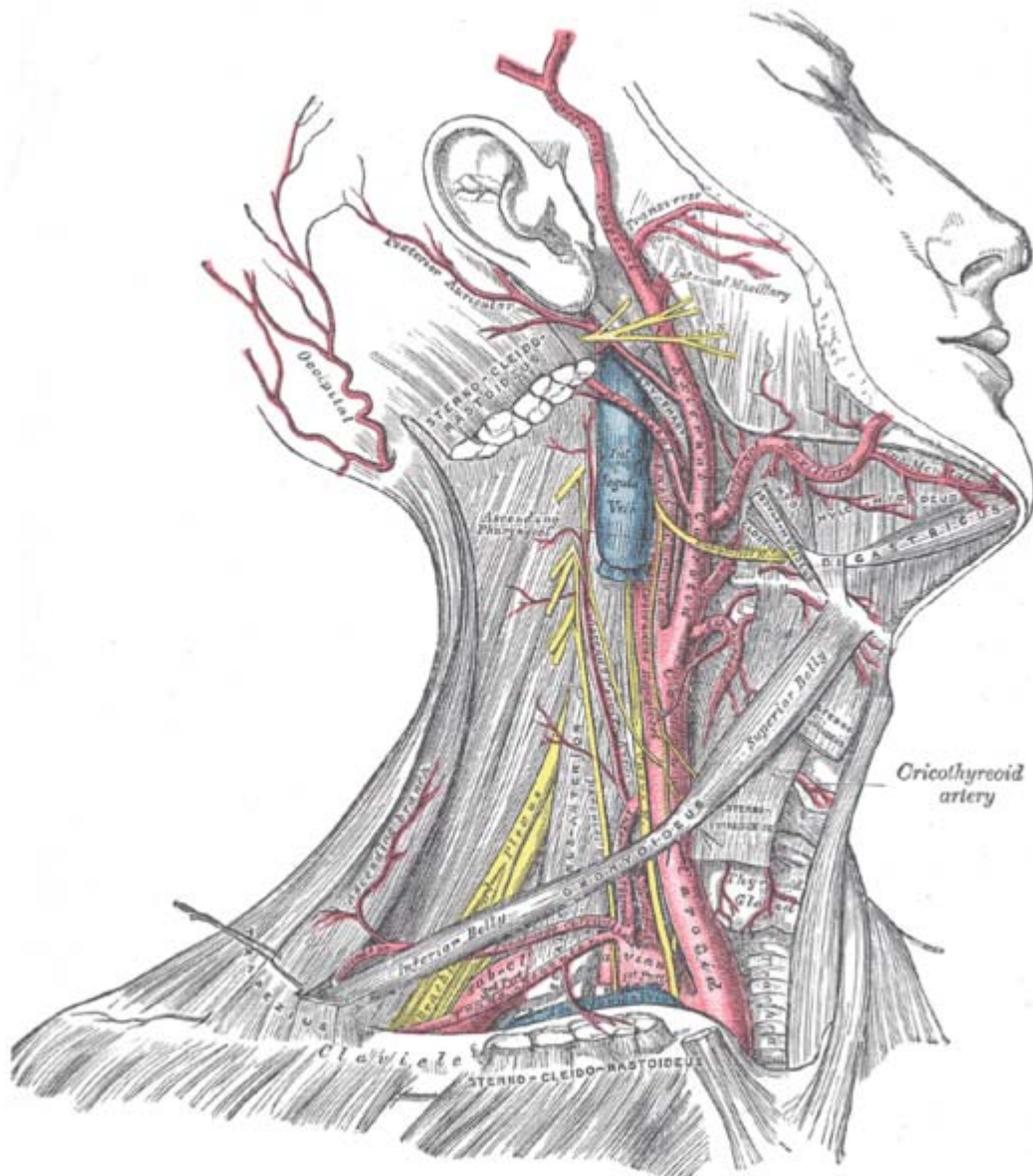
Some mnemonics for remembering the branches:

- Posterior cord branches
 - STAR - subscapular (upper and lower), thoracodorsal, axillary, radial
 - ULTRA - upper subscapular, lower subscapular, thoracodorsal, radial, axillary
- Lateral Cord Branches
 - LLM "Lucy Loves Me" - lateral pectoral, lateral root of the median nerve, musculocutaneous
- Medial Cord Branches

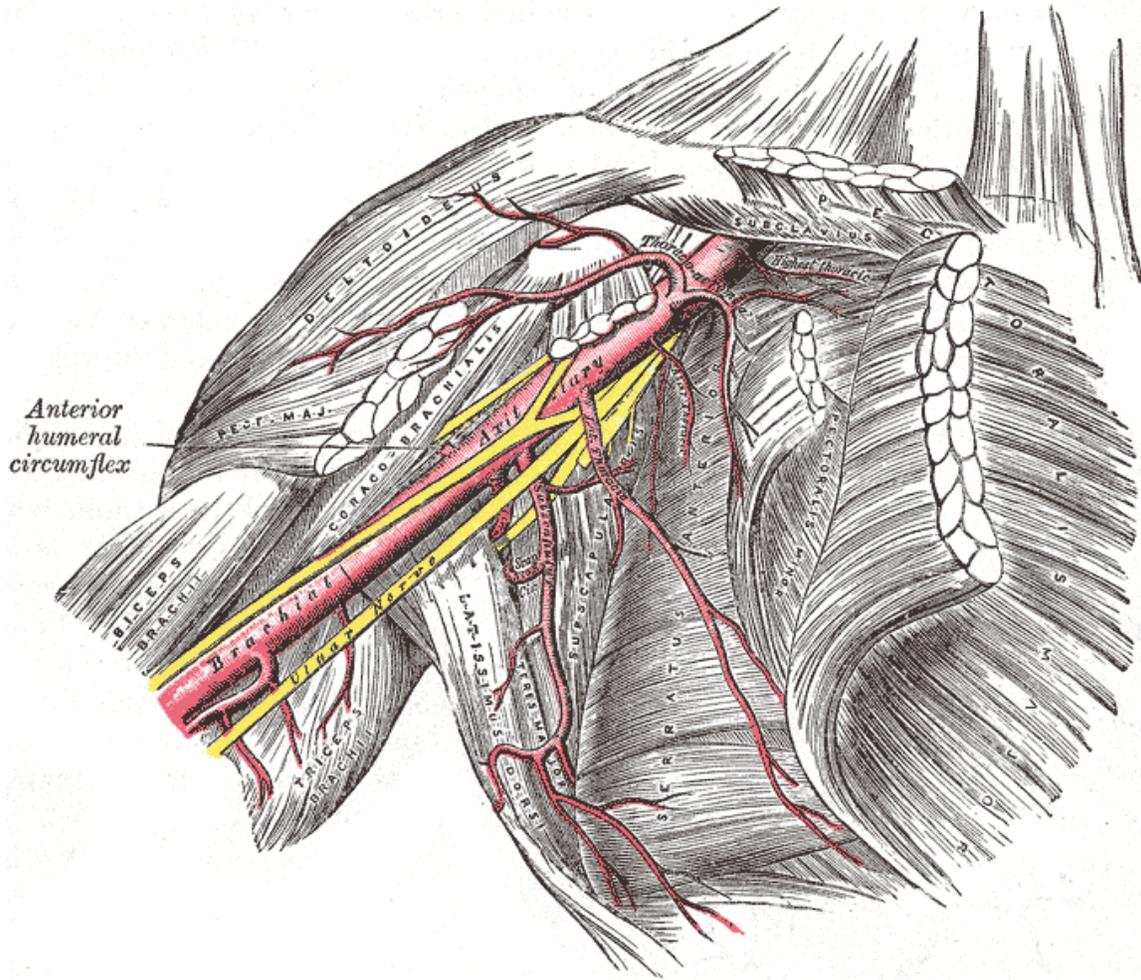
- MMMUM "Most Medical Men Use Morphine" - medial pectoral, medial cutaneous nerve of arm, medial cutaneous nerve of forearm, ulnar, medial root of the median nerve



Mind map showing branches of brachial plexus



Superficial dissection of the right side of the neck, showing the carotid and subclavian arteries.



The axillary artery and its branches.

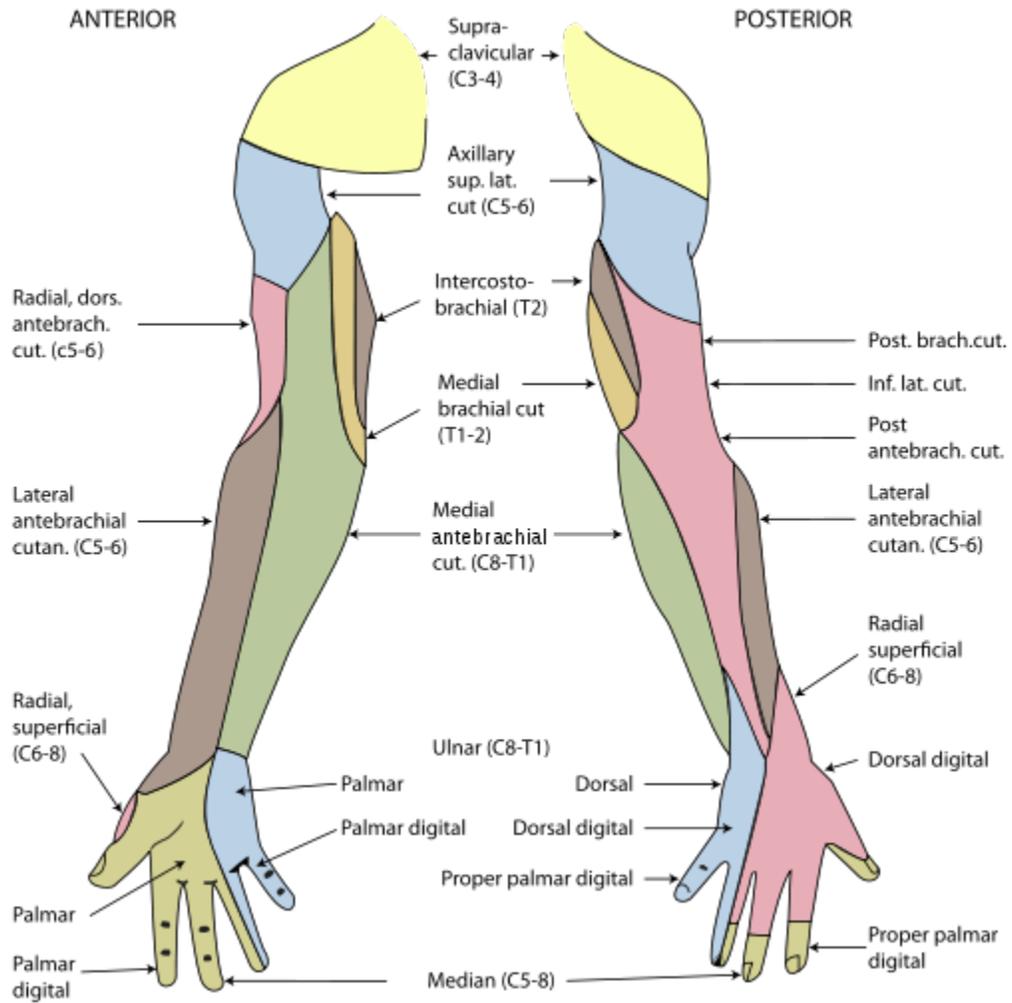
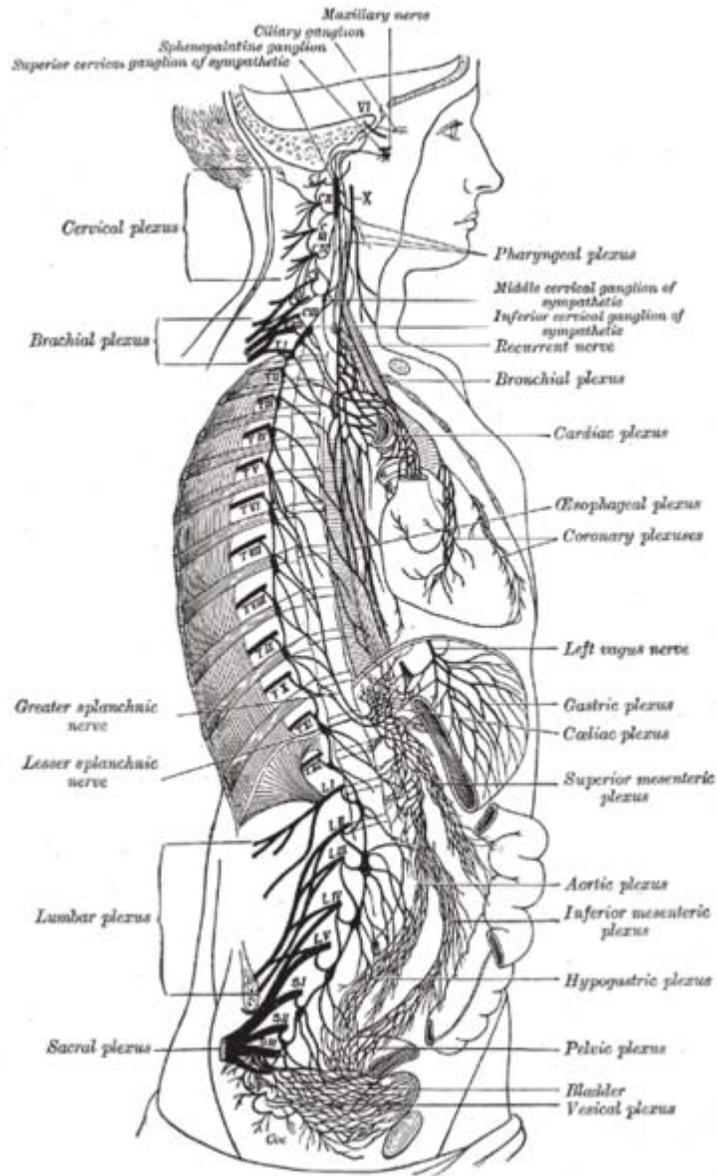
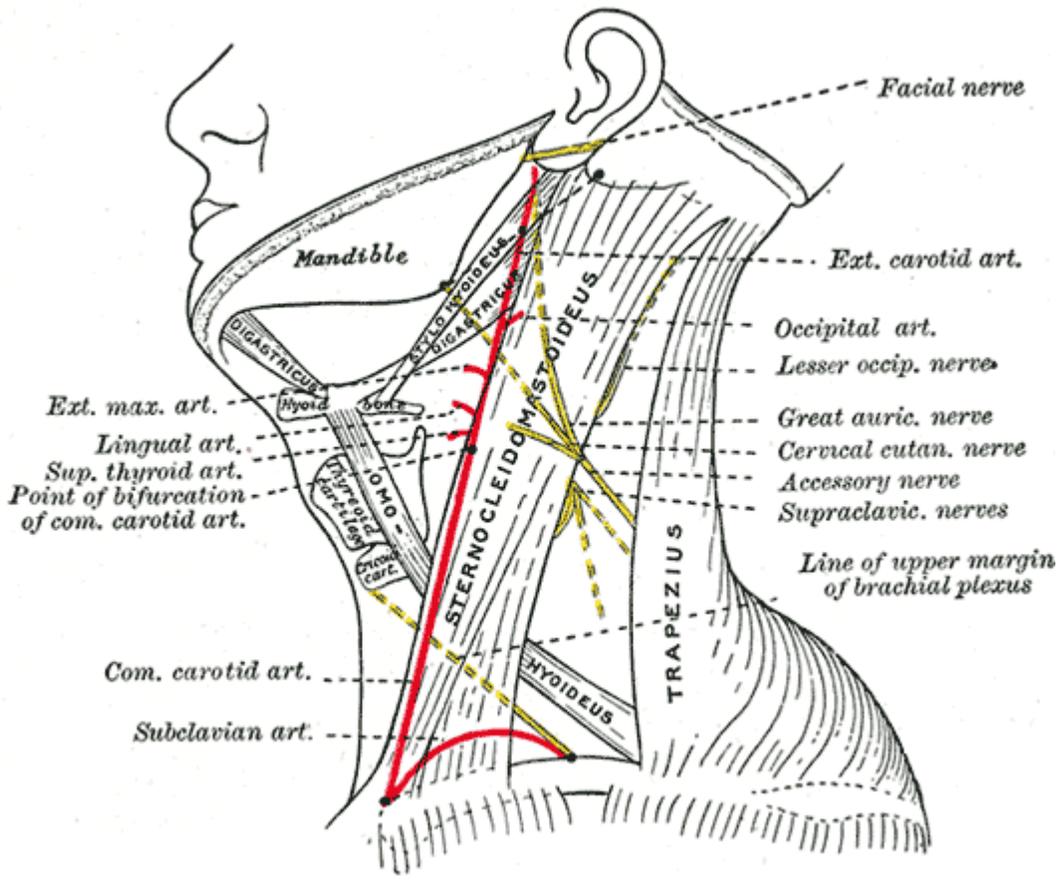


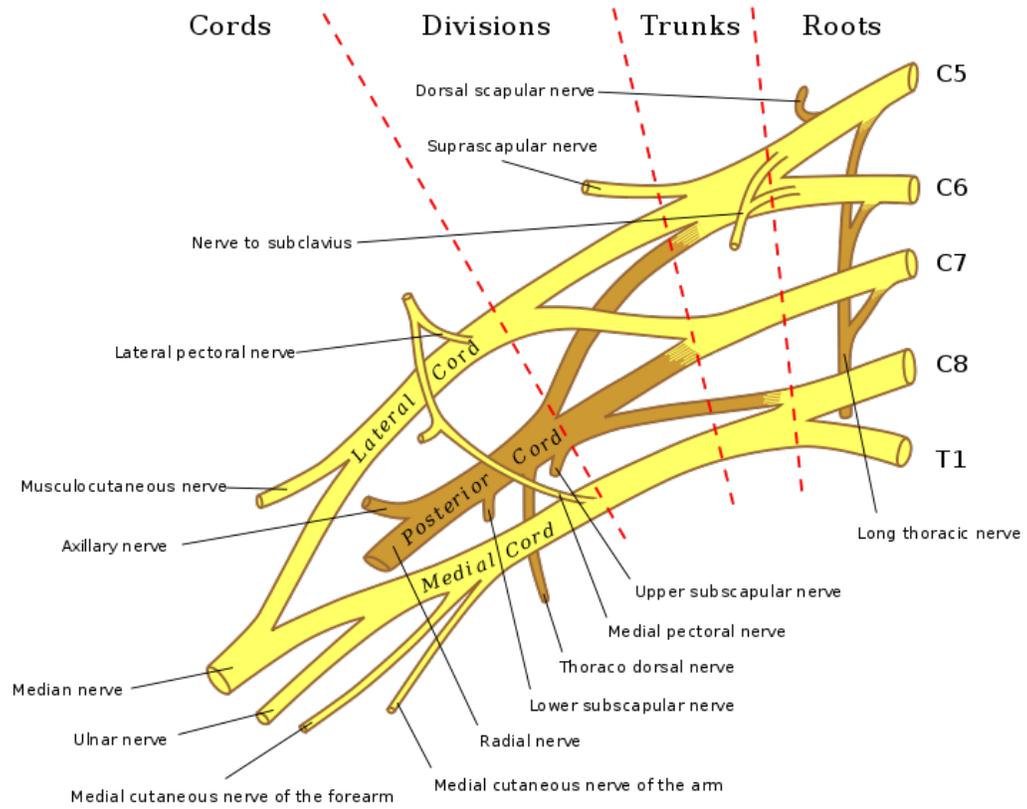
Diagram of segmental distribution of the cutaneous nerves of the right upper extremity.



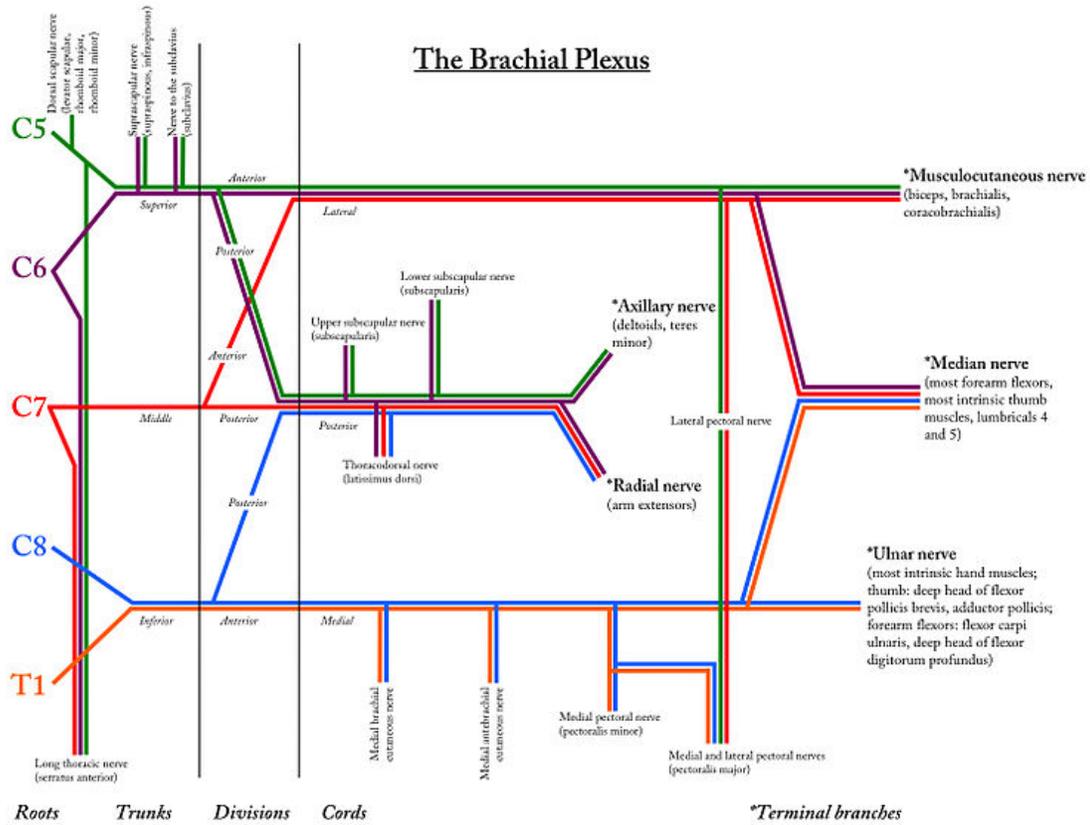
The right sympathetic chain and its connections with the thoracic, abdominal, and pelvic plexuses.



Side of neck, showing chief surface markings.



Brachial plexus with areas of roots, trunks, divisions and cords marked.



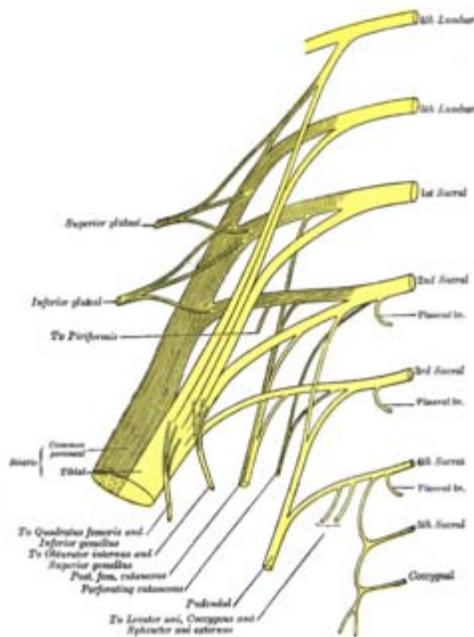
Color-coded diagram of brachial plexus illustrating roots of associated nerves.

Chapter 8

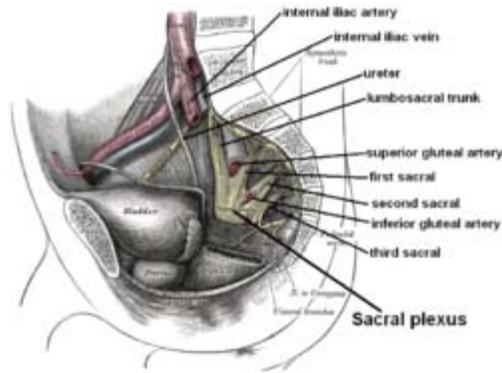
Sacral Plexus and Celiac Plexus

Sacral plexus

Nerve: Sacral plexus



Plan of sacral and pudendal plexuses.



Relations of the sacral plexus. Dissection of side wall of pelvis showing sacral and pudendal plexuses.

Latin *plexus sacralis*

Gray's *subject #213 957*

From L4-L5, S1-S4

In human anatomy, the *sacral plexus* is a nerve plexus which provides motor and sensory nerves for the posterior thigh, most of the lower leg, the entire foot, and part of the pelvis. It is part of the lumbosacral plexus and emerges from the sacral vertebrae (S2-S4).

Composition

The sacral plexus is formed by::

- the lumbosacral trunk
- the anterior division of the first sacral nerve
- portions of the anterior divisions of the second and third sacral nerves

The nerves forming the sacral plexus converge toward the lower part of the greater sciatic foramen, and unite to form a flattened band, from the anterior and posterior surfaces of which several branches arise.

The band itself is continued as the sciatic nerve, which splits on the back of the thigh into the tibial nerve and common fibular nerve; these two nerves sometimes arise separately from the plexus, and in all cases their independence can be shown by dissection.

Often, the sacral plexus and the lumbar plexus are considered to be one large nerve plexus, the lumbosacral plexus. The lumbosacral trunk connects the two plexuses.

Relations

The sacral plexus lies on the back of the pelvis between the piriformis muscle and the pelvic fascia. In front of it are the internal iliac artery, internal iliac vein, the ureter, and

the sigmoid colon. The superior gluteal artery and vein run between the lumbosacral trunk and the first sacral nerve, and the inferior gluteal artery and vein between the second and third sacral nerves.

Nerves formed

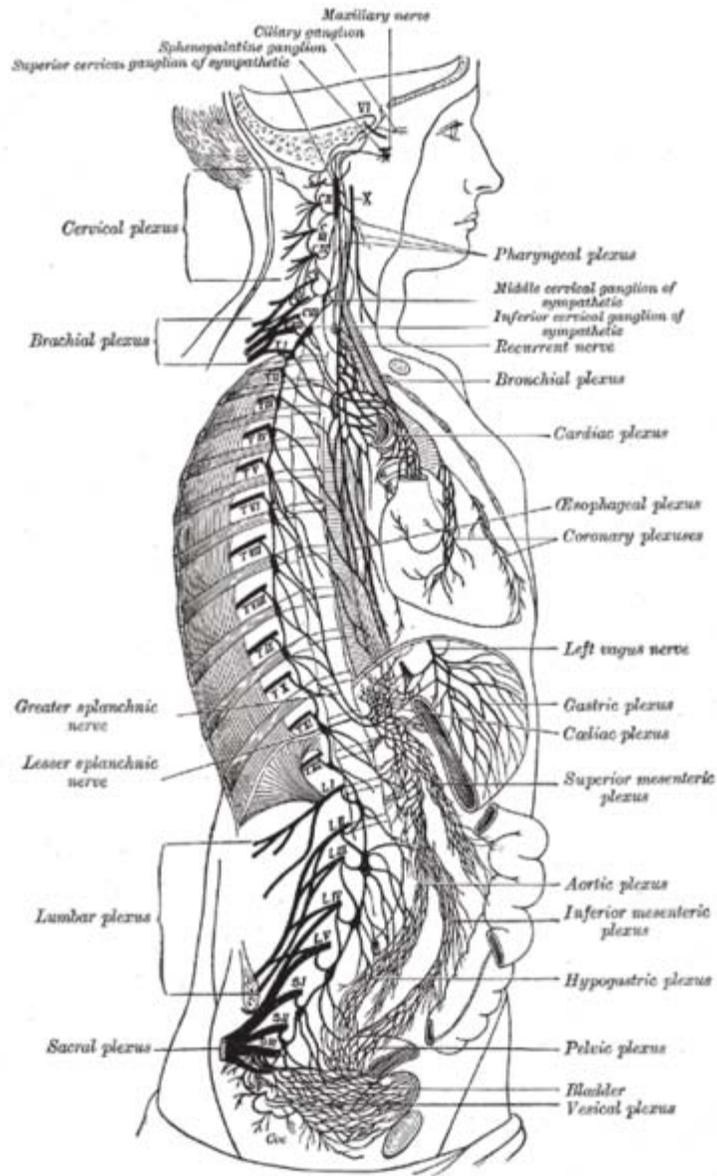
All the nerves entering the plexus, with the exception of the third sacral, split into ventral and dorsal divisions, and the nerves arising from these are as follows of the table below:

Nerves of the sacral plexus			
Nerve	Segment	Innervated muscles	Cutaneous branches
Superior gluteal	L4-S1	Gluteus medius Gluteus minimus Tensor fascia latae	
Inferior gluteal	L5-S2	Gluteus maximus	
Posterior cutaneous femoral	S1-S3		Posterior cutaneous femoral • Inferior cluneal nerves • Perineal branches
Direct branches from plexus			
• Piriformis	L5, S2	Piriformis	
• Obturator internus	L5, S1	Obturator internus	
• Quadratus femoris	L4-S1	Quadratus femoris	
Sciatic			
Sciatic	L4-S3	Semitendinosus (Tib) Semimembranosus (Tib) Biceps femoris • Long head (Tib) • Short head (Fib)	
Common fibular	L4-S2	Adductor magnus (medial part, Tib)	Lateral sural cutaneous Communicating fibular Medial dorsal cutaneous Intermediate dorsal cutaneous Lateral cutaneous nerve
• Superficial fibular		Peroneus longus Peroneus brevis	
• Deep fibular		Tibialis anterior	

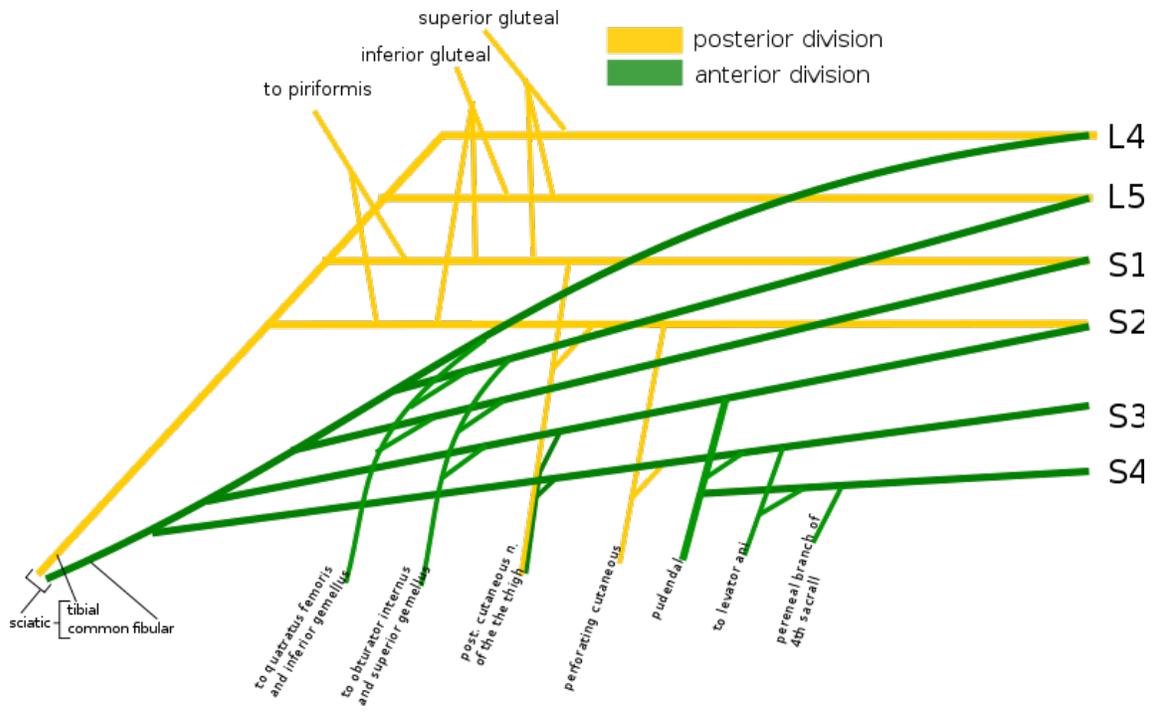
		Extensor digitorum longus	of big toe
		Extensor digitorum brevis	Intermediate dorsal cutaneous
		Extensor hallucis longus	
		Extensor hallucis brevis	
		Peroneus tertius	
		Triceps surae	
		Plantaris	Medial sural cutaneous
		Popliteus	Lateral calcaneal
		Tibialis posterior	Medial calcaneal
		Flexor digitorum longus	Lateral dorsal cutaneous
		Flexor hallucis longus	
		Abductor hallucis	
		Flexor digitorum brevis	
		Flexor hallucis brevis (medial head)	Proper digital plantar
		Lumbrical (first and second)	
		Flexor hallucis brevis (lateral head)	
		Quadratus plantae	
		Abductor digiti minimi	
		Flexor digiti minimi	
		Opponens digiti minimi	
		Lumbrical (third and fourth)	Proper plantar digital
		Plantar interossei (first to third)	
		Dorsal interossei (first to fifth)	
		Adductor hallucis	

Pudendal and coccygeal

		Muscles of the pelvic floor:	
		Levator ani	Inferior rectal
		Superficial transverse perineal	Perineal
		Deep transverse perineal	• Posterior scrotal/labial
		Bulbospongiosus	• Dorsal penis/clitoris
		Ischiocavernosus	
		Sphincter anus externus	
		Urethral sphincter	
		Pudendal (Pudendal plexus)	
	S1-S4		
		Coccygeal (Coccygeal plexus)	
	S5-Co1	Coccygeus	Anococcygeal Dorsal branches



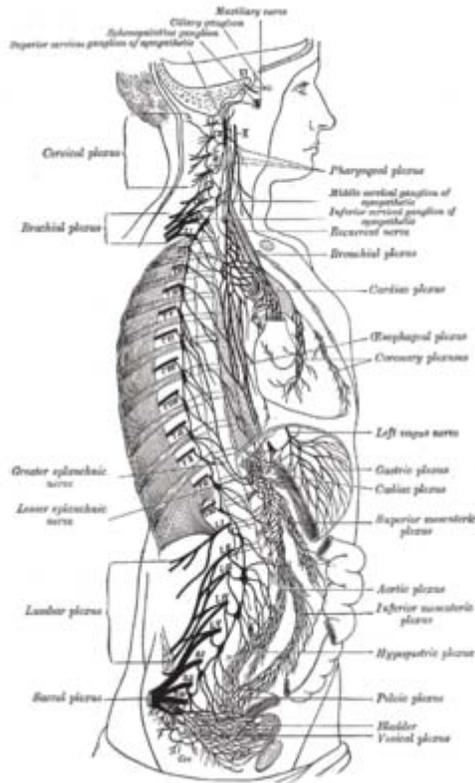
The right sympathetic chain and its connections with the thoracic, abdominal, and pelvic plexuses.



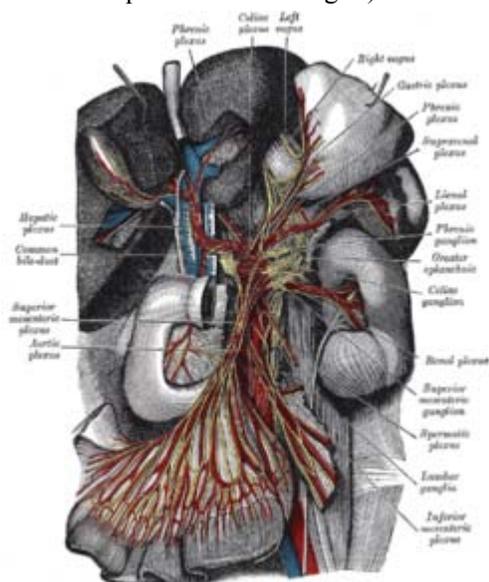
A schematic depiction.

Celiac plexus

Nerve: Celiac plexus



The right sympathetic chain and its connections with the thoracic, abdominal, and pelvic plexuses. (Label for celiac plexus at center right.)



The celiac ganglia with the sympathetic plexuses of the abdominal viscera radiating from the ganglia. (Label for celiac plexus at top center.)

Latin *plexus coeliacus*

Gray's *subject #220 985*

From celiac branches of vagus nerve

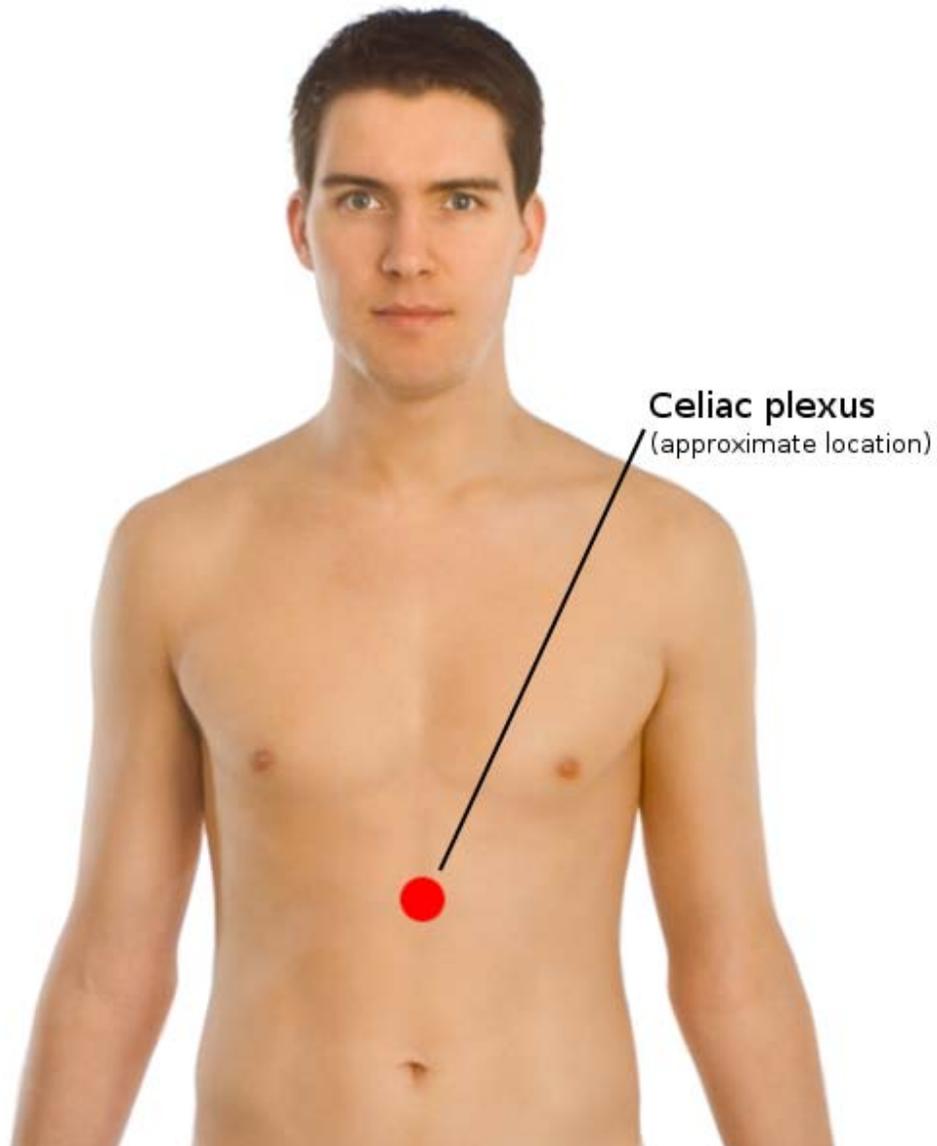
MeSH *Celiac+Plexus*

The **celiac plexus**, also known as the **solar plexus**, is a complex network of nerves (a plexus) located in the abdomen, where the celiac trunk, superior mesenteric artery, and renal arteries branch from the abdominal aorta. It is in back of the stomach and the omental bursa, and in front of the crura of the diaphragm, on the level of the first lumbar vertebra, L1.

The plexus is formed (in part) by the greater and lesser splanchnic nerves of both sides, and also parts of the right vagus nerve.

The celiac plexus proper consists of the celiac ganglia with a network of interconnecting fibers. The aorticorenal ganglia are often considered to be part of the celiac ganglia, and thus, part of the plexus.

Related plexuses



Approximate location of the celiac plexus on the coronal plane

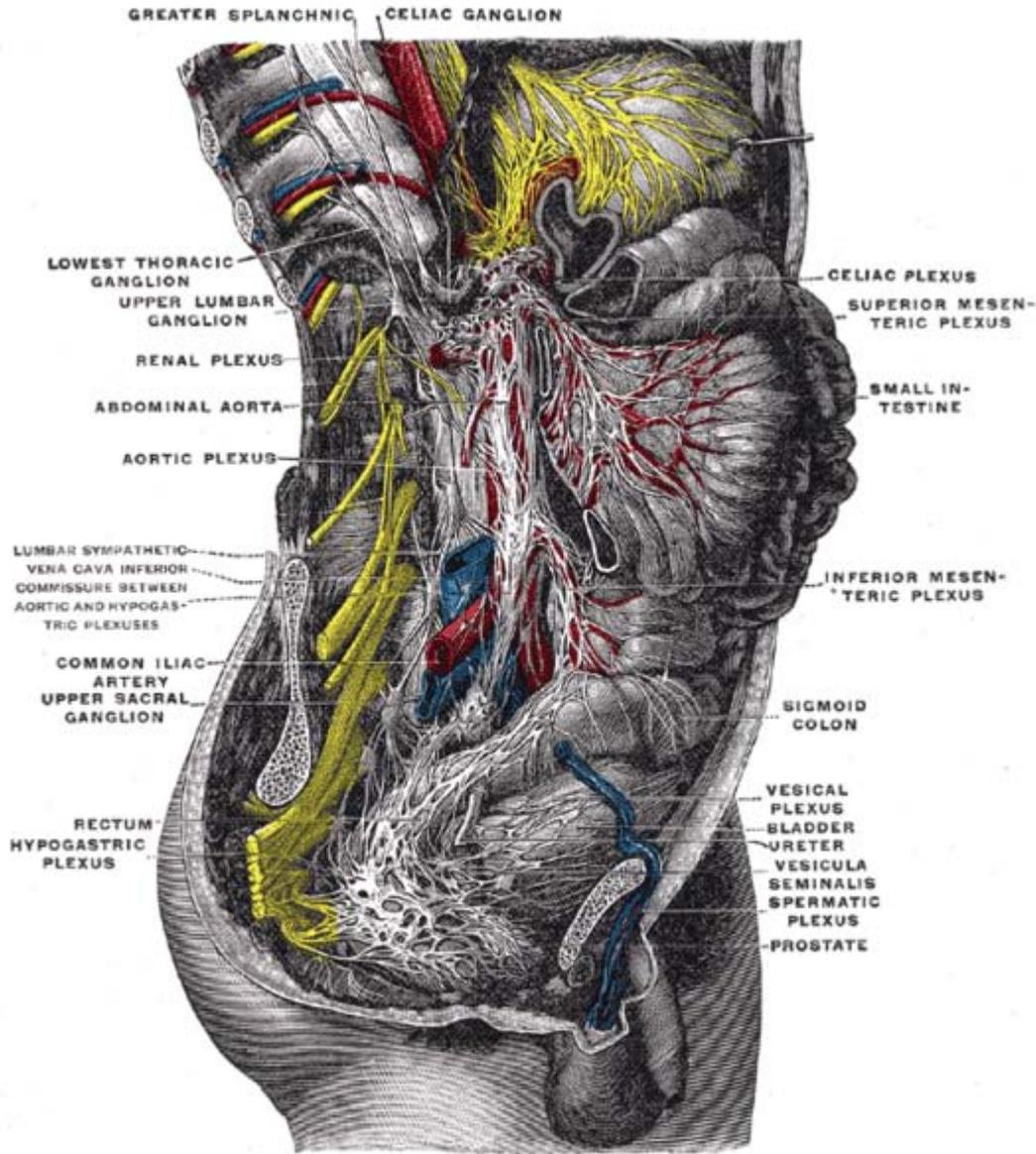
The celiac plexus includes a number of smaller plexuses:

- Hepatic plexus
- Splenic plexus
- Gastric plexuses
- Pancreatic plexus
- Suprarenal plexus

Other plexuses that are derived from the celiac plexus:

- Renal plexus
- Testicular plexus / ovarian plexus
- Superior mesenteric plexus
- Inferior mesenteric plexus

Clinical significance



Lower half of right sympathetic cord

The celiac plexus is often popularly referred to as the solar plexus, generally in the context of a blow to the stomach. In many of these cases, it is not the celiac plexus itself being referred to, but rather the region where it is located. A blow to the stomach can upset this region. This can cause the diaphragm to spasm, resulting in difficulty in

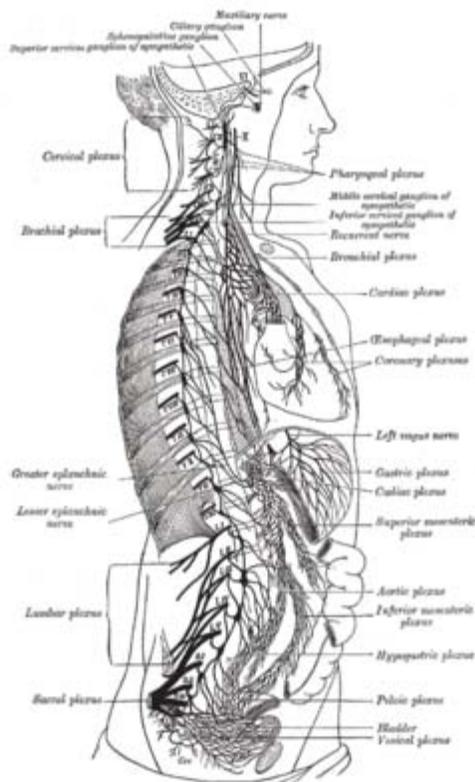
breathing—a sensation commonly known as "getting the wind knocked out of you". A blow to this region can also affect the celiac plexus itself, possibly interfering with the functioning of the viscera, as well as causing great pain.

A celiac plexus block by means of fluoroscopically guided injection is sometimes used to treat intractable pain from cancers such as pancreatic cancer. Frequently celiac plexus block performed by pain management specialists and radiologists is performed via CT guidance. Intractable pain related to chronic pancreatitis is an important indication for celiac plexus ablation.

Chapter 9

Sympathetic Nervous System

Brain: Sympathetic nervous system



The sympathetic nervous system extends from the thoracic to lumbar vertebrae and has connections with the thoracic, cardiac, and pelvic plexuses.

Latin *Pars sympathica divisionis autonomici systematis nervosi*

The (**ortho-**) **sympathetic nervous system (SNS)** is one of the three parts of the autonomic nervous system, along with the enteric and parasympathetic systems. Its general action is to mobilize the body's resources under stress; to induce the fight-or-flight response. It is, however, constantly active at a basal level to maintain homeostasis.

Overview

Alongside the other two components of the autonomic nervous system, the sympathetic nervous system aids in the control of most of the body's internal organs. Stress - as in the flight-or-flight response - and so may be thought to counteract the parasympathetic system, which generally works to promote maintenance of the body at rest. In truth, the functions of both systems are not so straightforward, but this is a useful rule of thumb.

There are two kinds of neurons involved in the transmission of any signal through the sympathetic system; pre- and post- ganglionic. The shorter preganglionic neurons originate from the thoracolumbar region of the spinal cord (levels T1 - L2, specifically) and travel to a ganglion, often one of the paravertebral ganglia, where they synapse with a postganglionic neuron. From there, the long postganglionic neurons extend across most of the body.

At the synapses within the ganglia, preganglionic neurons release acetylcholine, a neurotransmitter that activates nicotinic acetylcholine receptors on postganglionic neurons. In response to this stimulus postganglionic neurons - with two important exceptions - release norepinephrine, which activates adrenergic receptors on the peripheral target tissues. The activation of target tissue receptors causes the effects associated with the sympathetic system.

The two exceptions mentioned above are postganglionic neurons innervating sweat glands—which release acetylcholine for the activation of muscarinic receptors - and the adrenal medulla. The adrenal medulla develops in tandem with the sympathetic nervous system, and acts as a modified sympathetic ganglion: synapses occur between pre- and post- ganglionic neurons within it, but the post ganglionic neurons do not leave the medulla; instead they directly release norepinephrine and epinephrine into the blood.

Function

Organ	Effect
Eye	Dilates pupil
Heart	Increases rate and force of contraction
Lungs	Dilates bronchioles
Digestive tract	Inhibits peristalsis
Kidney	Increases renin secretion
Penis	Promotes ejaculation

The sympathetic nervous system is responsible for up- and down-regulating many homeostatic mechanisms in living organisms. Fibers from the SNS innervate tissues in almost every organ system, providing at least some regulatory function to things as diverse as pupil diameter, gut motility, and urinary output. It is perhaps best known for mediating the neuronal and hormonal stress response commonly known as the *fight-or-flight response*. This response is also known as *sympatho-adrenal response* of the body, as the preganglionic sympathetic fibers that end in the adrenal medulla (but also all other sympathetic fibers) secrete acetylcholine, which activates the great secretion of adrenaline (epinephrine) and to a lesser extent noradrenaline (norepinephrine) from it. Therefore, this response that acts primarily on the cardiovascular system is mediated directly via impulses transmitted through the sympathetic nervous system and indirectly via catecholamines secreted from the adrenal medulla.

Some evolutionary theorists suggest that the sympathetic nervous system operated in early organisms to maintain survival as the sympathetic nervous system is responsible for priming the body for action. One example of this priming is in the moments before waking, in which sympathetic outflow spontaneously increases in preparation for action.

Organization

Sympathetic nerves originate inside the vertebral column, toward the middle of the spinal cord in the intermediolateral cell column (or lateral horn), beginning at the first thoracic segment of the spinal cord and are thought to extend to the second or third lumbar segments. Because its cells begin in the thoracic and lumbar regions of the spinal cord, the SNS is said to have a *thoracolumbar outflow*. Axons of these nerves leave the spinal cord through the anterior rootlet/root. They pass near the spinal (sensory) ganglion, where they enter the anterior rami of the spinal nerves. However, unlike somatic innervation, they quickly separate out through white rami connectors (so called from the shiny white sheaths of myelin around each axon) that connect to either the paravertebral (which lie near the vertebral column) or prevertebral (which lie near the aortic bifurcation) ganglia extending alongside the spinal column.

To reach target organs and glands, the axons must travel long distances in the body, and, to accomplish this, many axons relay their message to a second cell through synaptic transmission. The ends of the axons link across a space, the synapse, to the dendrites of the second cell. The first cell (the presynaptic cell) sends a neurotransmitter across the synaptic cleft where it activates the second cell (the postsynaptic cell). The message is then carried to the final destination.

Presynaptic nerves' axons terminate in either the paravertebral ganglia or prevertebral ganglia. This can occur through one of four methods:

1. The nerve enters the paravertebral ganglion at the level of its originating spinal nerve, and then ascends to a more superior paravertebral ganglion, where it synapses with the postsynaptic cell.

2. The nerve enters the paravertebral ganglion at the level of its originating spinal nerve and synapses with the postsynaptic cell at that level.
3. The nerve enters the paravertebral ganglion at the level of its originating spinal nerve, and then descends to a more inferior paravertebral ganglion, where it synapses with the postsynaptic cell.
4. The nerve enters the paravertebral ganglion at the level of its originating spinal nerve and then descends to a prevertebral ganglion, where it synapses with the postsynaptic cell.

The postsynaptic cell then goes on to innervate the targeted end effector (ie gland, smooth muscle, etc.). Because paravertebral and prevertebral ganglia are relatively close to the spinal cord, presynaptic neurons are generally much shorter than their postsynaptic counterparts, which must extend throughout the body to reach their destinations.

A notable exception to the routes mentioned above is the sympathetic innervation of the suprarenal (adrenal) glands. In this case, presynaptic neurons pass through paravertebral ganglia, on through prevertebral ganglia and then synapse directly with suprarenal tissue. This tissue consists of cells that have pseudo-neuron like qualities in that when activated by the presynaptic neuron, they will release their neurotransmitter (epinephrine) directly into the blood stream.

In the SNS and other components of the peripheral nervous system, these synapses are made at sites called ganglia. The cell that sends its fiber is called a preganglionic cell, while the cell whose fiber leaves the ganglion is called a postganglionic cell. As mentioned previously, the preganglionic cells of the SNS are located between the first thoracic segment and third lumbar segments of the spinal cord. Postganglionic cells have their cell bodies in the ganglia and send their axons to target organs or glands.

The ganglia include not just the sympathetic trunks but also the cervical ganglia (superior, middle and inferior), which sends sympathetic nerve fibers to the head and thorax organs, and the celiac and mesenteric ganglia (which send sympathetic fibers to the gut).

Information transmission

Messages travel through the SNS in a bidirectional flow. Efferent messages can trigger changes in different parts of the body simultaneously. For example, the sympathetic nervous system can accelerate heart rate; widen bronchial passages; decrease motility (movement) of the large intestine; constrict blood vessels; increase peristalsis in the esophagus; cause pupillary dilation, piloerection (goose bumps) and perspiration (sweating); and raise blood pressure. Afferent messages carry sensations such as heat, cold, or pain.

The first synapse (in the sympathetic chain) is mediated by nicotinic receptors physiologically activated by acetylcholine, and the target synapse is mediated by adrenergic receptors physiologically activated by either noradrenaline (norepinephrine) or adrenaline (epinephrine). An exception is with sweat glands, which receive sympathetic innervation but have muscarinic acetylcholine receptors, which are normally characteristic of Parasympathetic nervous system. Another exception is with certain deep muscle blood vessels, which dilate (rather than constrict) with an increase in sympathetic tone. This is because of the presence of more beta2 receptors (rather than alpha1, which are frequently found on other vessels).

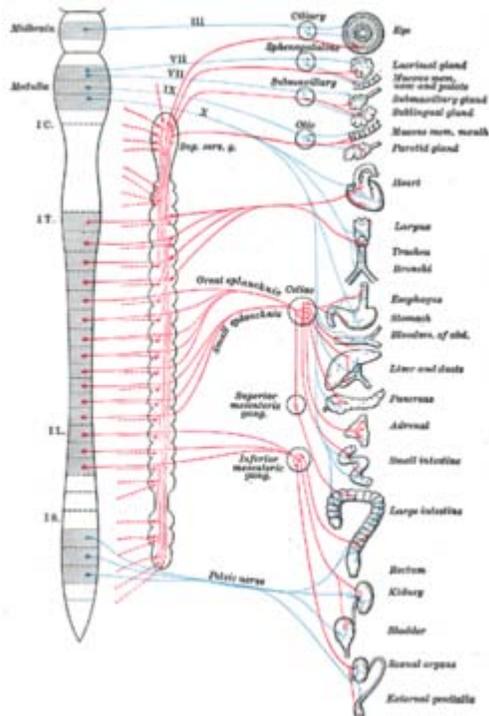
Sympathicotonia

Sympathicotonia is a stimulated condition of the sympathetic nervous system, marked by vascular spasm, elevated blood pressure, and goose bumps.

Chapter 10

Parasympathetic Nervous System

Brain: Parasympathetic nervous system



Autonomic nervous system innervation, showing the sympathetic and parasympathetic (craniosacral) systems, in red and blue, respectively

Latin *Pars parasympathica divisionis autonomici systematis nervosi*

The **parasympathetic nervous system (PSNS)** is one of the two main divisions of the autonomic nervous system (ANS). The ANS is responsible for regulation of internal

organs and glands, which occurs unconsciously. The parasympathetic system specifically is responsible for stimulation of activities that occur when the body is at rest, including sexual arousal, salivation, lacrimation (tears), urination, digestion and defecation. Its action is described as being complementary to that of one of the other main branches of the ANS, the sympathetic nervous system, which is responsible for stimulating activities associated with the fight-or-flight response. Because of this relationship, the action of the parasympathetic nervous system is often described as "rest and digest".

Relation to sympathetic nervous system

Sympathetic and parasympathetic divisions typically function in opposition to each other. This natural opposition is better understood as complementary in nature rather than antagonistic. For an analogy, one may think of the sympathetic division as the accelerator and the parasympathetic division as the brake. The sympathetic division typically functions in actions requiring quick responses. The parasympathetic division functions with actions that do not require immediate reaction. A useful acronym to summarize the functions of the parasympathetic nervous system is SLUDD (salivation, lacrimation, urination, digestion and defecation).

Physical location

The parasympathetic nerves (PSNS) are autonomic (aka "visceral") branches of the peripheral nervous system (PNS). Parasympathetic nerve fibers arise from the central nervous system with the S2, S3, and S4 spinal nerves and from the third, seventh, ninth, and tenth cranial nerves. Because of its location the parasympathetic system is commonly referred to as having "craniosacral outflow", which stands in contrast to the sympathetic nervous system which is said to have "thoracolumbar outflow".

The parasympathetic nerves that arise from the S2, S3, and S4 spinal nerves are commonly referred to as the pelvic splanchnic nerves or the "nervi erigentes".

Pathways

As is true in the sympathetic nervous system, efferent parasympathetic nerve signals are carried from the central nervous system to their targets by a system of two neurons. The first neuron in this pathway is referred to as the preganglionic or presynaptic neuron. Its cell body sits in the central nervous system and its axon usually extends to a ganglion somewhere else in the body where it synapses with the dendrites of the second neuron in the chain. This second neuron is referred to as the postganglionic or postsynaptic neuron.

The axons of presynaptic parasympathetic neurons are usually long: they extend from the CNS into a ganglion that is either very close to or embedded in their target organ. As a result, the postsynaptic parasympathetic nerve fibers are very short.

In the **cranium**, preganglionic PSN (CN III, CN VII, and CN IX) usually arise from specific nuclei in the Central Nervous System (CNS) and synapse at one of four

parasympathetic ganglia: ciliary, pterygopalatine, otic, or submandibular. From these four ganglia the PSN complete their journey to target tissues via CN V (trigeminal) branches (ophthalmic nerve CN V₁, maxillary nerve CN V₂, mandibular nerve CN V₃).

The **vagus nerve** (CN X) does not participate in these cranial ganglia as most of its PSN fibers are destined for a broad array of ganglia on or near thoracic viscera (esophagus, trachea, heart, lungs) and abdominal viscera (stomach, pancreas, liver, kidneys). It travels all the way down to the midgut/hindgut junction, which occurs just before the splenic flexure of the transverse colon at a point called "cannon bohm".

The **pelvic splanchnic** efferent preganglionic nerve cell bodies reside in the lateral gray horn of the spinal cord at the S2-S4 spinal levels. Their axons continue away from the CNS to synapse at an autonomic ganglion. The PSN ganglion where these preganglionic neurons synapse will be close to the organ of innervation. This differs from the sympathetic nervous system, where synapses between pre- and post-ganglionic efferent nerves generally occur at ganglia that are farther away from the target organ.

Sensation

The afferent fibers of the autonomic nervous system, which transmit sensory information from the internal organs of the body back to the central nervous system, are not divided into parasympathetic and sympathetic fibers as the efferent fibers are. Instead, autonomic sensory information is conducted by general visceral afferent fibers.

General visceral afferent sensations are mostly unconscious visceral motor reflex sensations from hollow organs and glands that are transmitted to the CNS. While the unconscious reflex arcs normally are undetectable, in certain instances they may send pain sensations to the CNS masked as referred pain. If the peritoneal cavity becomes inflamed or if the bowel is suddenly distended your body will interpret the afferent pain stimulus as somatic in origin. This pain is usually non-localized. The pain is also usually referred to dermatomes that are at the same spinal nerve level as the visceral afferent synapse.

Cranial Nerve Parasympathetic Paths and Control

The oculomotor nerve is responsible for several parasympathetic functions related to the eye. The oculomotor PNS fibers originate in the Edinger-Westphal nucleus in the CNS and travel through the superior orbital fissure to synapse in the ciliary ganglion located just behind the orbit (eye). From the ciliary ganglion the postganglionic PSN fibers leave via short ciliary nerve fibers, a continuation of the nasociliary nerve (a branch of ophthalmic division of the trigeminal nerve, CN V₁). The short ciliary nerves innervate the orbit to control the ciliary muscle (responsible for accommodation) and the sphincter pupillae muscle which is responsible for miosis or constriction of the pupil (in response to light or accommodation).

The parasympathetic aspect of the facial nerve controls secretion of the sublingual and submandibular salivary glands, the lacrimal gland, and the glands associated with the nasal cavity. The preganglionic fibers originate within the CNS in the superior salivatory nucleus and leave as the intermediate nerve (which some consider a separate cranial nerve altogether) to connect with the facial nerve just distal (further out) to it surfacing the CNS. Just after the facial nerve geniculate ganglion (general sensory ganglion) in the temporal bone, the facial nerve gives off two separate parasympathetic nerves. The first is the greater petrosal nerve and the second is the chorda tympani. The greater petrosal nerve travels through the middle ear and eventually combines with the deep petrosal nerve (sympathetic fibers) to form the nerve of the pterygoid canal. The PSN fibers of the nerve of the pterygoid canal synapse at the pterygopalatine ganglion, which is closely associated with the maxillary division of the trigeminal nerve (CN V₂). The postganglionic PSN fibers leave the pterygopalatine ganglion in several directions. One division leaves on the zygomatic division of CN V₂ and travels on a communicating branch to unite with the lacrimal nerve (branch of the ophthalmic nerve of CN V₁) before synapsing at the lacrimal gland. These PSN to the lacrimal gland control tear production.

A separate group of PSN leaving from the pterygopalatine ganglion are the descending palatine nerves (CN V₂ branch) which include the greater and lesser palatine nerves. The greater palatine PSN synapse on the hard palate and regulate mucus glands located there. The lesser palatine nerve synapses at the soft palate and controls sparse taste receptors and mucus glands. Yet another set of divisions from the pterygopalatine ganglion are the posterior, superior, and inferior lateral nasal nerves; and the nasopalatine nerves (all branches of CN V₂, maxillary division of the trigeminal nerve) that bring PSN to glands of the nasal mucosa. The second PSN branch that leaves the facial nerve is the chorda tympani. This nerve carries secretomotor fibers to the submandibular and sublingual glands. The chorda tympani travels through the middle ear and attaches to the lingual nerve (mandibular division of trigeminal, CN V₃). After joining the lingual nerve the preganglionic fibers synapse at the submandibular ganglion and send postganglionic fibers to the sublingual and submandibular salivary glands.

The glossopharyngeal nerve, CNIX, has parasympathetic fibers that innervate the parotid salivary gland. The preganglionic fibers depart CNIX as the tympanic nerve and continue to the middle ear where they make up a tympanic plexus on the cochlear promontory of the mesotympanum. The tympanic plexus of nerves rejoin and form the lesser petrosal nerve and exit through the foramen ovale to synapse at the otic ganglion. From the otic ganglion postganglionic parasympathetic fibers travel with the auriculotemporal nerve (mandibular branch of trigeminal, CN V₃) to the parotid salivary gland.

The vagus nerve, named from the Latin word *vagus* means literally "Wandering", since the nerve controls such a broad range of target tissues, has PSN that originate in the dorsal nucleus of the vagus nerve and the nucleus ambiguus in the CNS. The vagus nerve is an unusual cranial PSN in that it doesn't join the trigeminal nerve in order to get to its target tissues. Another peculiarity is that the vagus has an autonomic ganglion associated with it at approximately the level of C1 vertebra. The vagus gives no PSN to the cranium. The vagus nerve is hard to track definitively due to its ubiquitous nature in the thorax and

abdomen so the major contributions will be discussed. Several PSN nerves come off the vagus nerve as it enters the thorax. One nerve is the recurrent laryngeal nerve, which becomes the inferior laryngeal nerve. From the left vagus nerve the recurrent laryngeal nerve hooks around the aorta to travel back up to the larynx and proximal esophagus while, from the right vagus nerve, the recurrent laryngeal nerve hooks around the right subclavian artery to travel back up to the same location as its counterpart. These different paths are a direct result of embryological development of the circulatory system. Each recurrent laryngeal nerve supplies the trachea and the esophagus with parasympathetic secretomotor innervation for glands associated with them (and other fibers that are not PSN).

Another nerve that comes off the vagal nerves approximately at the level of entering the thorax are the cardiac nerves. These cardiac nerves go on to form cardiac and pulmonary plexuses around the heart and lungs. As the main vagus nerves continue into the thorax they become intimately linked with the esophagus and sympathetic nerves from the sympathetic trunks to form the esophageal plexus. This is very efficient as the major function of the vagus nerve from there on will be control of the gut smooth muscles and glands. As the esophageal plexus enter the abdomen through the esophageal hiatus anterior and posterior vagal trunks form. The vagal trunks then join with preaortic sympathetic ganglion around the aorta to disperse with the blood vessels and sympathetic nerves throughout the abdomen. The extent of the PSN in the abdomen include the pancreas, kidneys, liver, gall bladder, stomach and gut tube. The vagal contribution of PSN continues down the gut tube until the end of the midgut. The midgut ends 2/3 of the way across the transverse colon near the splenic flexure.

Pelvic Splanchnic Control

The pelvic splanchnic nerves, S2-4, work in tandem to innervate the pelvic viscera. Unlike in the cranium, where one PSN was in charge of one particular tissue or region, for the most part the pelvic splanchnics each contribute fibers to pelvic viscera by first traveling to one or more plexuses before being dispersed to the target tissue. These plexuses are composed of mixed autonomic nerve fibers (PSN and SN) and include the vesical, prostatic, rectal, uterovaginal and inferior hypogastric plexus. The preganglionic neurons in the neurons do not synapse in named ganglion as in the cranium but rather in the walls of the tissues or organs that they innervate. The fiber paths are variable and each individual's autonomic nervous system in the pelvis is unique. The visceral tissues in the pelvis that the PSN control include: urinary bladder, ureters, urinary sphincter, anal sphincter, uterus, prostate, glands, vagina and penis. Unconsciously, the PSN will cause peristaltic movements of the ureters helping to move urine from the kidneys into the bladder and move feces down the intestinal tract and upon necessity, the PSN will assist excreting urine from the bladder or defecation. Stimulation of the PSN will cause the detrusor muscle (urinary bladder wall) to contract and simultaneously relax the internal sphincter urethrae muscle to relax allowing void of urine. Also, PSN stimulation to the internal anal sphincter will relax this muscle and allow defecation. There are other skeletal muscles involved with these processes but the PSN play a huge role in continence.

Another role that the PSN play in the pelvis is in sexual activity. In males, the cavernous nerves from the prostatic plexus stimulate smooth muscle in the fibrous trabeculae of the coiled helicine arteries to relax and allow blood to fill the corpora cavernosum and the corpus spongiosum of the penis, making it rigid to prepare for sexual activity. Upon emission of ejaculate, the sympathetics participate and cause peristalsis of the ductus deferens and closure of the internal urethral sphincter to prevent semen from entering the bladder. At the same time, parasympathetics cause peristalsis of the urethral muscle, and the pudendal nerve causes contraction of the bulbospongiosus (skeletal muscle is not via PSN), to forcibly emit the semen. During remission the penis becomes flaccid again. In the female, there is erectile tissue analogous to the male yet less substantial that plays a large role in sexual stimulation. The PSN cause release of secretions in the female that decrease friction. Also in the female, the parasympathetics innervate the fallopian tubes which helps peristaltic contractions and movement of the oocyte to the uterus for implantation. The secretions from the female genital tract aids in semen migration. The PSN (and SN to a lesser extent) play a huge role in reproduction.

Clinical Significance

The parasympathetic nervous system promotes digestion and the synthesis of glycogen, and allows for normal function and behavior.

Receptors

The parasympathetic nervous system uses chiefly acetylcholine (ACh) as its neurotransmitter, although other peptides (such as cholecystokinin) may act on the PSNS as a neurotransmitter. The ACh acts on two types of receptors, the muscarinic and nicotinic cholinergic receptors. Most transmissions occur in two stages: When stimulated, the preganglionic nerve releases ACh at the ganglion, which acts on nicotinic receptors of postganglionic neurons. The postganglionic nerve then releases ACh to stimulate the muscarinic receptors of the target organ.

Types of muscarinic receptors

The five main types of muscarinic receptors:

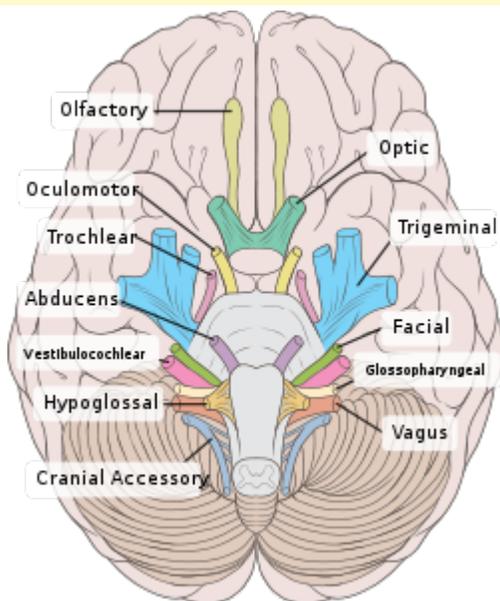
- The M1 muscarinic receptors (*CHRM1*) are located in the neural system.
- The M2 muscarinic receptors (*CHRM2*) are located in the heart, and act to bring the heart back to normal after the actions of the sympathetic nervous system: slowing down the heart rate, reducing contractile forces of the atrial cardiac muscle, and reducing conduction velocity of the sinoatrial node (SA node) and atrioventricular node (AV node). Note, they have a minimal effect on the contractile forces of the ventricular muscle due to sparse innervation of the ventricles from the parasympathetic nervous system.

- The M3 muscarinic receptors (*CHRM3*) are located at many places in the body, such as the endothelial cells of blood vessels, as well as the lungs causing bronchoconstriction. The net effect of uninnervated M3 receptors on blood vessels is vasodilation, as acetylcholine causes endothelial cells to produce nitric oxide, which diffuses to smooth muscle and results in vasodilation. They are also in the smooth muscles of the gastrointestinal tract (GIT), which help in increasing intestinal motility and dilating sphincters. The M3 receptors are also located in many glands that help to stimulate secretion in salivary glands and other glands of the body. They are also located on the detrusor muscle of the bladder, causing contraction of the bladder.
- The M4 muscarinic receptors: Postganglionic cholinergic nerves, possible CNS effects
- The M5 muscarinic receptors: Possible effects on the CNS

Chapter 11

Cranial Nerve

Nerve: Cranial nerves



Inferior view of the brain and brain stem showing **cranial nerves**. An unlabelled version is here

Latin *nervus cranialis* (plural: *nervi craniales*)

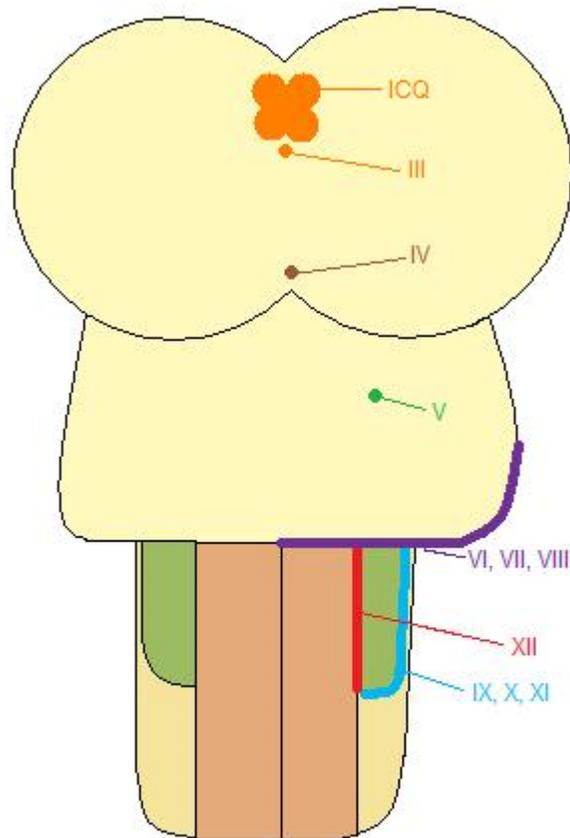
Cranial nerves are nerves that emerge directly from the brain, in contrast to spinal nerves which emerge from segments of the spinal cord. In humans, there are 12 pairs of cranial nerves. Only the first and the second pair emerge from the cerebrum; the remaining 10 pairs emerge from the brainstem.

Cranial nerves in non-human vertebrates

Human cranial nerves are nerves similar to those found in many other vertebrates. Cranial nerves XI and XII evolved in other species to amniotes (non-amphibian tetrapods) thus totaling twelve pairs. In some primitive cartilaginous fishes, such as the spiny dogfish or mud shark (*Squalus acanthias*), there is a terminal nerve numbered zero (as it exits the brain before the traditionally designated first cranial nerve).

List of cranial nerves

APPARENT ORIGINS FOR CRANIAL NERVES II - XII



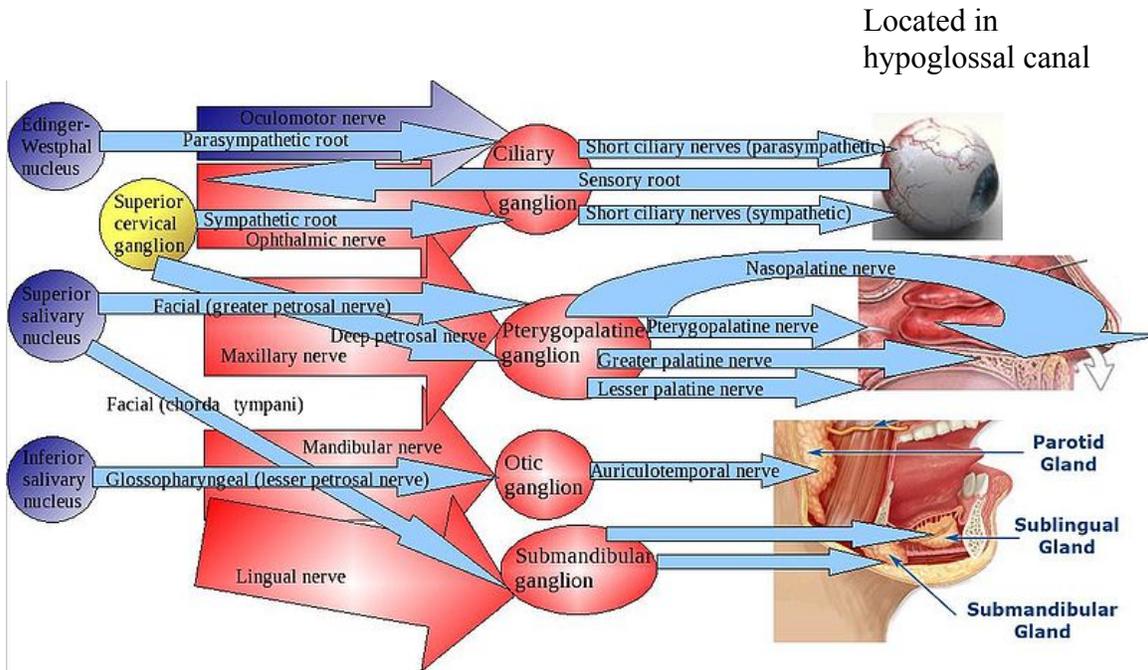
- III - Under the inferior corpora quadrigemina (dorsal)
- IV - In the interpeduncular fossa
- V - In the pons
- VI, VII, VIII - In the pontomedullary junction
- IX, X, XI - In the retroolivary sulcus
- XII - in the preolivary sulcus

#	Name	Sensory, Motor or Both	Origin	Nuclei	Function
0	Cranial nerve zero (<i>CN0 is not traditionally recognized.</i>)	Sensory		olfactory trigone, medial olfactory gyrus, and lamina terminalis	New research indicates CN0 may play a role in the detection of pheromones Linked to olfactory system in human embryos
I	Olfactory nerve	Purely Sensory	Telencephalon	Anterior olfactory nucleus	Transmits the sense of smell; Located in olfactory foramina in the Cribriform plate of ethmoid
II	Optic Nerve	Purely Sensory	Diencephalon	Ganglion cells of retina	Transmits visual information to the brain; Located in optic canal Innervates levator palpebrae superioris, superior rectus, medial rectus, inferior rectus, and inferior oblique, which collectively perform most eye movements; Also innervates m. sphincter pupillae. Located in superior orbital fissure
III	Oculomotor nerve	Mainly Motor	Midbrain	Oculomotor nucleus, Edinger-Westphal nucleus	Innervates the superior oblique muscle, which depresses, rotates laterally (around the optic axis), and intorts the eyeball; Located in superior orbital fissure
IV	Trochlear nerve	Mainly Motor	Midbrain	Trochlear nucleus	depresses, rotates laterally (around the optic axis), and intorts the eyeball; Located in superior orbital fissure

V	Trigeminal nerve	Both Sensory and Motor	Pons	Principal sensory trigeminal nucleus, Spinal trigeminal nucleus, Mesencephalic trigeminal nucleus, Trigeminal motor nucleus	Receives sensation from the face and innervates the muscles of mastication; Located in superior orbital fissure (ophthalmic nerve - V ₁), foramen rotundum (maxillary nerve - V ₂), and foramen ovale (mandibular nerve - V ₃)
VI	Abducens nerve	Mainly Motor	Posterior margin of Pons	Abducens nucleus	Innervates the lateral rectus, which abducts the eye; Located in superior orbital fissure Provides motor innervation to the muscles of facial expression, posterior belly of the digastric muscle, and stapedius muscle, receives the special sense of taste from the anterior 2/3 of the tongue, and provides secretomotor innervation to the salivary glands (except parotid) and the lacrimal gland; Located and runs through internal acoustic canal to facial canal and exits at stylomastoid foramen
VII	Facial nerve	Both Sensory and Motor	Pons (cerebellopontine angle) above olive	Facial nucleus, Solitary nucleus, Superior salivary nucleus	

VIII	Vestibulocochlear nerve (or <i>auditory-vestibular nerve</i> or <i>statoacoustic nerve</i>)	Mostly sensory	Lateral to CN VII (cerebellopontine angle)	Vestibular nuclei, Cochlear nuclei	Senses sound, rotation and gravity (essential for balance & movement). More specifically, the vestibular branch carries impulses for equilibrium and the cochlear branch carries impulses for hearing.; Located in internal acoustic canal
IX	Glossopharyngeal nerve	Both Sensory and Motor	Medulla	Nucleus ambiguus, Inferior salivary nucleus, Solitary nucleus	Receives taste from the posterior 1/3 of the tongue, provides secretomotor innervation to the parotid gland, and provides motor innervation to the stylopharyngeus. Some sensation is also relayed to the brain from the palatine tonsils. Sensation is relayed to opposite thalamus and some hypothalamic nuclei. Located in jugular foramen Supplies branchiomotor innervation to most laryngeal and all pharyngeal muscles (except the stylopharyngeus, which is innervated by the glossopharyngeal); provides parasympathetic
X	Vagus nerve	Both Sensory and Motor	Posterolateral sulcus of Medulla	Nucleus ambiguus, Dorsal motor vagal nucleus, Solitary nucleus	Supplies branchiomotor innervation to most laryngeal and all pharyngeal muscles (except the stylopharyngeus, which is innervated by the glossopharyngeal); provides parasympathetic

				<p>fibers to nearly all thoracic and abdominal viscera down to the splenic flexure; and receives the special sense of taste from the epiglottis. A major function: controls muscles for voice and resonance and the soft palate. Symptoms of damage: dysphagia (swallowing problems), velopharyngeal insufficiency. Located in jugular foramen</p> <p>Controls sternocleidomastoid and trapezius muscles, overlaps with functions of the vagus. Examples of symptoms of damage: inability to shrug, weak head movement; Located in jugular foramen</p> <p>Provides motor innervation to the muscles of the tongue (except for the palatoglossus, which is innervated by the vagus) and other glossal muscles. Important for swallowing (bolus formation) and speech articulation.</p>
XI	<p>Accessory nerve (or <i>cranial accessory nerve</i> or <i>spinal accessory nerve</i>)</p>	Mainly Motor	Cranial and Spinal Roots	<p>Nucleus ambiguus, Spinal accessory nucleus</p>
XII	Hypoglossal nerve	Mainly Motor	Medulla	<p>Hypoglossal nucleus</p>



Some of the major cranial nerves and their ganglia and fiber connections

Mnemonic devices

As the list is important to keep in mind during the examination of the nervous system, there are many mnemonic devices in circulation to help remember the names and order of the cranial nerves. Because the mind recalls rhymes well, the best mnemonics often use rhyming schemes. Three of the best known examples are, "On Old Olympus's Towering Tops, A Fine-Vested German Viewed Some Hops," "Oh, Oh, Oh To Take A Family Vacation! Go Vegas After Hours!", and "Oh, Oh, Oh, To Touch And Feel, A Good Velvet, Ahh, Heaven." A useful mnemonic for remembering which nerves are motor (M), sensory (S), or both (B) is, "Some Say Money Matters But My Brother Says Big Brains Matter Most". There are many more mnemonics from many sources, for example **OLD OPIe OCCasionally TRIes TRIGOnometry And Feels VErY GLOomy, VAGUe, And HYPOactive.**