Spinal Cord and Spinal Nerves

Overview

The *spinal cord*, or **spinal medulla**, is located in the channel of the spinal column, the **vertebral canal**, and is surrounded by the *cerebrospinal fluid*. It has two spindle-shaped swellings: one in the neck region, the **cervical enlargement** (**C1**), and one in the lumbar region, the **lumbar enlargement** (**C2**). At the lower end, the spinal cord tapers into the **medullary cone** (**BC3**) and ends as a thin thread, the **terminal filament** (**C4**). The **anterior median fissure** at the ventral side and the **posterior median sulcus** (**BC5**) at the dorsal side mark the boundaries between the two symmetrical halves of the spinal cord. Nerve fibers enter dorsolaterally and emerge ventrolaterally at both sides of the spinal cord and unite to form the *dorsal roots*, **posterior roots**, and the *ventral roots*, **anterior roots**. The roots join to form short nerve trunks of 1 cm in length, the **spinal nerves**. Intercalated into the posterior roots are **spinal ganglia** (**B6**) containing *sensory nerve cells*. Only the posterior roots of the first cervical spinal nerves do not have a spinal ganglion, or only a rudimentary one.

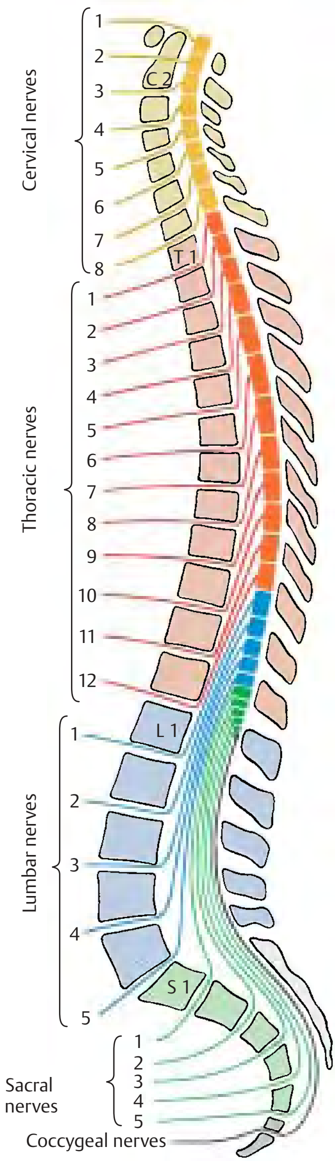
In humans, there are *31 pairs of spinal nerves* which emerge through the *intervertebral foramina* from the *vertebral canal*. Each spinal nerve pair supplies one body segment. The spinal cord itself is unsegmented. The impression of segmentation is created by the bundling of nerve fibers emerging from the foramina (p. 66).

The spinal nerves are subdivided into **cervical nerves**, **thoracic nerves**, **lumbar nerves**, **sacral nerves**, and **coccygeal nerves** (**A**). There are

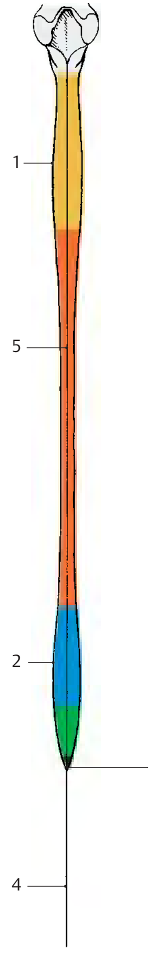
- *8 pairs of cervical nerves* (C1 – C8) (the first pair emerges between occipital bone and atlas)
- *12 pairs of thoracic nerves* (T1 – T12) (the first pair emerges between the first and second thoracic vertebrae
- *5 pairs of lumbar nerves* (L1 – L5) (the first pair emerges between the first and second lumbar vertebrae)
- *5 pairs of sacral nerves* (S1 – S5) (the first pair emerges through the upper sacral foramina)
- *one pair of coccygeal nerves* (emerging between the first and second coccygeal vertebrae)

Spinal cord and vertebral canal are initially of the same length so that each spinal nerve emerges from the foramen lying at its own level. During development, however, the vertebral column increases much more in length than does the spinal cord. As a result, the lower end of the spinal cord moves further up in relation to the surrounding vertebrae. In the newborn, the lower end of the spinal cord lies at the level of the third lumbar vertebra, and in the adult, at the level of the first lumbar or twelfth thoracic vertebra. Thus, the spinal nerves no longer emerge at their levels of origin; instead, their roots run down a certain distance within the vertebral canal to their foramen where they emerge. The more caudally the roots originate from the spinal cord, the longer their run within the vertebral canal. The levels where the spinal nerves emerge are therefore no longer identical with the corresponding levels of the spinal cord.

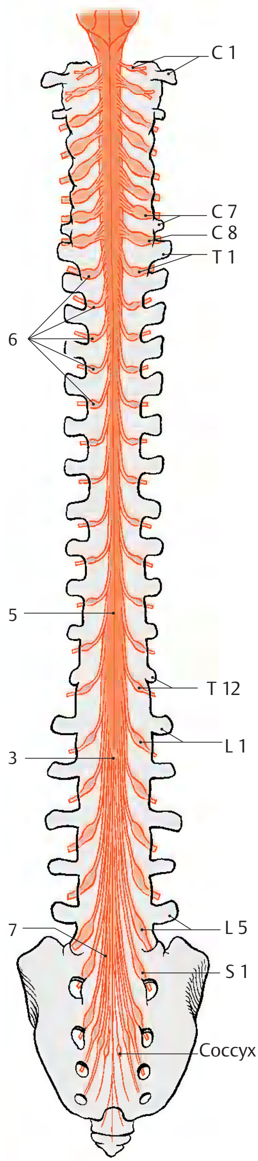
From the medullary cone (**BC3**) onward, the vertebral canal contains only a dense mass of descending spinal roots, known as the **cauda equina** (*tail of a horse*) (**B7**).



A Lateral view of the spinal nerves



C Spinal cord



B Dorsal view of the spinal ganglia

The Spinal Cord

Structure (A, B)

The **gray matter**, **substantia grisea** (nerve cells), appears in transverse section of the spinal cord as a butterfly configuration surrounded by the *white matter*, **substantia alba** (fiber tracts). We distinguish on either side a *dorsal horn* (**posterior horn**) (**AB1**) and a *ventral horn* (**anterior horn**) (**AB2**). Both form columns in the longitudinal dimension of the spinal cord, the **anterior column** and the **posterior column**. Between them lies the *central intermediate substance* (**A3**) with the obliterated central canal (**A4**). In the thoracic spinal cord, the *lateral horn* (**AB5**) is interposed between the anterior and posterior horns. The **lateral posterior sulcus** (**A6**) is the site where the posterior root fibers (**AB7**) enter. The anterior root fibers (**AB8**) leave the anterior side of the spinal cord as fine bundles.

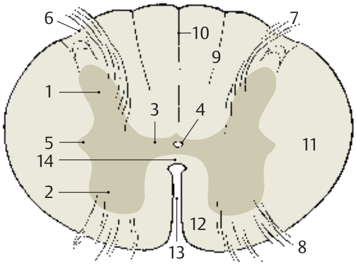
The posterior horn is *derived from the alar plate* (origin of sensory neurons) and contains neurons of the afferent system (**B**). The anterior horn is *derived from the basal plate* (origin of motor neurons) and contains the anterior horn cells, the efferent fibers of which run to the muscles. The lateral horn contains autonomic nerve cells of the *sympathetic nervous system* (p. 292).

The **white matter** is subdivided into the *dorsal column*, **or posterior funiculus** (**A9**), which reaches from the *posterior septum* (**A10**) to the posterior horn, the *lateral column*, or **lateral funiculus** (**A11**), which reaches from the posterior horn to the anterior root, and the *ventral column*, or **anterior funiculus** (**A12**), which reaches from the anterior root to the anterior fissure (**A13**). The latter two form the **anterolateral column**. The **white commissure** (**A14**) connects the two halves of the spinal cord.

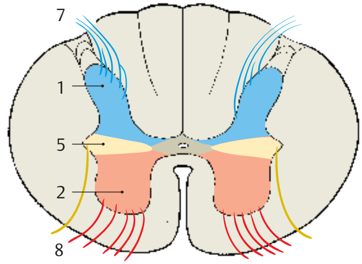
Reflex Arcs (C – G)

The afferent fibers of the posterior root, which originate from the nerve cells of the spinal ganglion, transmit sensory signals to the posterior horn cells of the spinal cord, and these pass them on to the brain (**C**). The relay may also take place in the medulla oblongata. However, the afferent fibers may also run to the anterior horn cells and transmit the signal directly to these cells. The resulting muscle reaction is called *reflex*, the underlying neuronal circuit is called *reflex arc* (**D**). In general, the afferent fibers do not run directly to the motor neuron (*monosynaptic reflex arc*) but via interneurons that are interposed (*multisynaptic reflex arc*) (**E**).

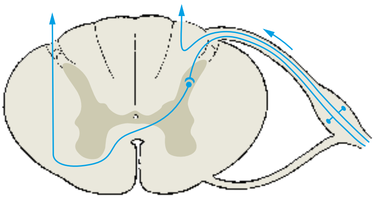
The monosynaptic intrinsic reflex (*stretch reflex*) and the multisynaptic extrinsic reflex (*withdrawal reflex*) are of clinical importance. In the **stretch reflex** (**F**), the muscle is briefly stretched by a tap on its tendon. Stimulation of the muscle receptors (p. 314) results in a momentary contraction of the muscle as a counter reaction. The reflex involves only a few neurons at any level of the spinal cord. In the **withdrawal reflex** (**G**), skin receptors are stimulated (pain); the withdrawal movement is brought about by the coordinated action of several muscle groups. The signal spreads through several levels of the spinal cord and involves many interneurons.



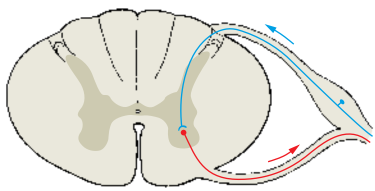
A Cross section of spinal cord



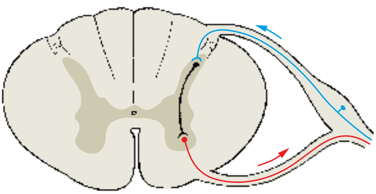
B Longitudinal zones of spinal cord



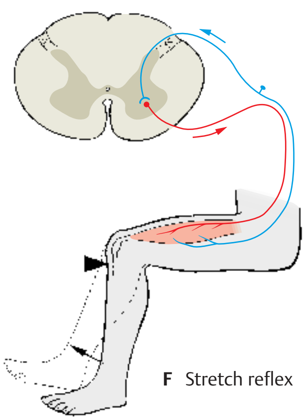
C Afferent fibers (ascending tracts)



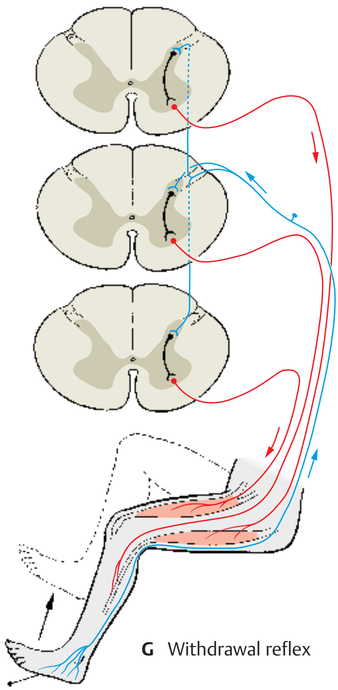
D Monosynaptic reflex arc



E Multisynaptic reflex arc



F Stretch reflex



G Withdrawal reflex

Gray Substance and Intrinsic System (A – E)

The **posterior horn** is formed by the **nucleus proprius** (**A1**), the major portion of the posterior horn from which the **dorsal nucleus** (*Clarke's nucleus*) (**A2**) is set apart. The **gelatinous substance** (*Rolando's substance*) (**A3**) borders dorsally on the nucleus proprius. On it sits like a cap the end of the posterior horn, the marginal zone (**nucleus posteromarginalis**) (**A4**). The posterior horn is separated from the surface of the spinal cord through the **posterolateral tract** (*Lissauer's tract*) (**A5**). Between posterior horn and anterior horn lies the *intermediate gray matter* (**A6**) and lateral to it the **lateral horn** (**A7**). The border to the white matter between posterior horn and lateral horn is diffuse (*reticular formation*) (**A8**).

In the **anterior horn**, the motor neurons are arranged in groups of nuclei.

Medial group of nuclei

- Anteromedial nucleus (**A9**)
- Posteromedial nucleus (**A10**)

Lateral group of nuclei

- Anterolateral nucleus (**A11**)
- Posterolateral nucleus (**A12**)
- Retroposterolateral nucleus (**A13**)

Central group of nuclei in the cervical spinal cord

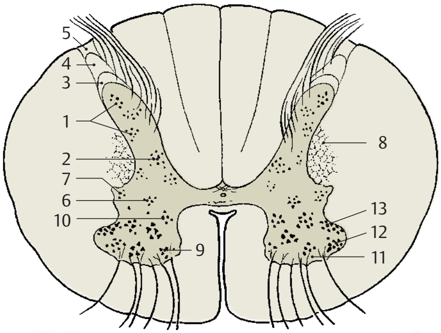
- Phrenic nucleus
- Accessory nucleus

For example, in the cervical spinal cord (**B**), the anterior horn is subdivided somatotopically so that the neurons of the medial group of nuclei supply neck and back muscles, intercostal, and abdominal muscles (**B14**). The neurons of the anterolateral nucleus supply the muscles of shoulder girdle and upper arm (**B15**), and the neurons of the posterolateral nucleus supply the muscles of lower arm and hand (**B16**). Finally, the retroposterolateral nucleus contains particularly large motor neurons that supply the small finger muscles (**B17**).

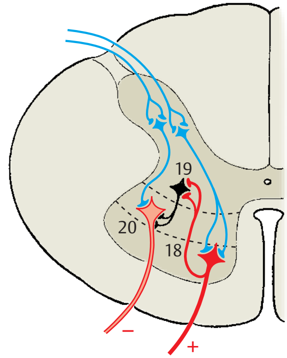
The neurons for the extensor muscles (**B18**) lie in the anterior field of the anterior horn, and those for the flexor muscles (**B20**) lie posterior to them. The somatotopic subdivisions do not occupy a single plane in the anterior horn but are spread over a certain height in such a way that the neurons for the shoulder girdle lie at a higher level, below them those for the upper arm, and still deeper those for the lower arm and hand. Diagram (**C**) illustrates the nerve supply to all body muscles.

To bring about an orderly movement during contraction of a muscle group, there must be simultaneous relaxation of the corresponding antagonists. This is achieved through inhibition of the corresponding anterior horn cells (**D**). For example, if an impulse is passed on by a neuron of the *extensor muscles* (**D18**), it is simultaneously transmitted by an axon collateral to inhibitory interneurons, the **Renshaw cells** (**D19**), which then inhibit the neurons of the *flexor muscles* (**D20**).

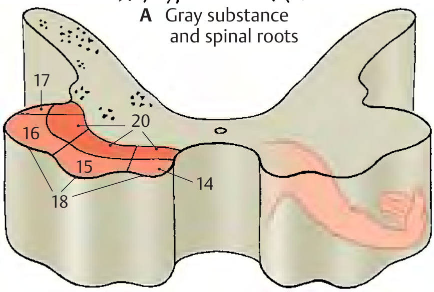
Intrinsic system of the spinal cord (E). Other interneurons mediate the spread of impulses over several levels, either on the same side or on the opposite side. Their ascending and descending fibers run in *basic bundles*, **fasciculi proprii** (**E21**), which border directly on the gray matter. In general, the ascending and descending fibers reach only one or two root levels. However, the fasciculi proprii also contain long fibers connecting the cervical spinal cord and the lumbar spinal cord (as shown in cats and monkeys). These fibers transmit excitatory and inhibitory impulses to anterior horn motor cells, a fact that is thought to be important for coordinated movement of the anterior and posterior extremities during locomotion. About half of the posterolateral tract (Lissauer's tract) (**E5**) consists of fibers of the intrinsic system.



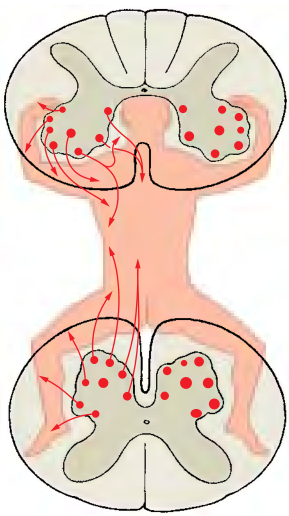
A Gray substance and spinal roots



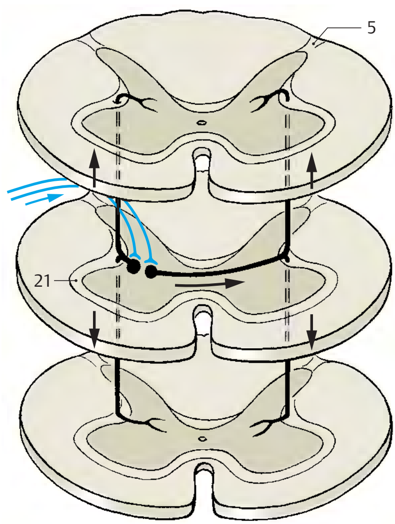
D Neuronal relay in the spinal cord



B Somatotopic organization of gray substance in the cervical spinal cord



C Somatotopic organization of gray substance, overview (according to *Bossy*)



E Fasciculi proprii

Cross Sections of the Spinal Cord (A – D)

Cross sections at different levels (left, myelin stain; right, cellular stain) vary considerably. In the regions of cervical enlargement and lumbar enlargement, the cross-sectional area is larger than in the rest of the spinal cord; it is largest at the C4 – C5 and L4 – L5 levels. In both swellings, the numerous nerves that supply the extremities cause an increase in gray matter.

The **white matter** is most extensive in the cervical region and diminishes gradually in caudal direction; the ascending sensory tracts increase in number from the sacral to the cervical region as more fibers are added, while the descending motor tracts decrease from the cervical to the sacral regions as fibers terminate at various levels.

The butterfly configuration of the **gray matter** changes in shape at the various levels, and so does the **posterolateral tract** (*Lissauer's tract*) (**A – D1**).

The **posterior horn** is narrow in the cervical spinal cord; its tip ends in the cap-shaped marginal zone (**nucleus posteromarginalis**) (**A2**). The lateral angle between the posterior and anterior horn is occupied by the reticular formation (**AD3**). The gelatinous substance (*Rolando's substance*) (**A – D4**) contains small, mostly peptidergic neurons where posterior root fibers of various calibers terminate; it also contains descending fibers from the brain stem (raphe nuclei, p. 108, B28; reticular formation, p. 146). Unmyelinated processes of neurons ascend or descend for one to four root levels within the posterolateral tract (*Lissauer's tract*) and then reenter into the gelatinous substance. Some of the processes run within the lateral spinothalamic tract to the thalamus (p. 324). The fibers of proprioceptive sensibility in the muscles (muscle spindles) terminate in the **posterior thoracic nucleus** (*dorsal nucleus of Clarke*) (**AB5**) where the tracts to the cerebellum begin. The reduced gray matter of the thoracic spinal cord has a slender posterior horn with a prominent dorsal nucleus. In the plump posterior horn of the lumbar and sacral spinal cords, the gelatinous substance (**CD4**) is much enlarged and borders dorsally on the narrow band of the marginal zone (**CD2**).

The **lateral horn** forms in the thoracic spinal cord the **lateral intermediate substance** (**B6**). It contains sympathetic nerve fibers mainly for the vasomotor system, the efferent fibers of which emerge via the anterior root. Sympathetic neurons also lie medially in the **intermediomedial nucleus** (**B7**). In the sacral spinal cord, parasympathetic neurons form the *intermediolateral nucleus* und *intermediomedial nucleus* (**D8**).

The **anterior horn** expands in the cervical spinal cord and contains several nuclei with large motor neurons, all of which are cholinergic.

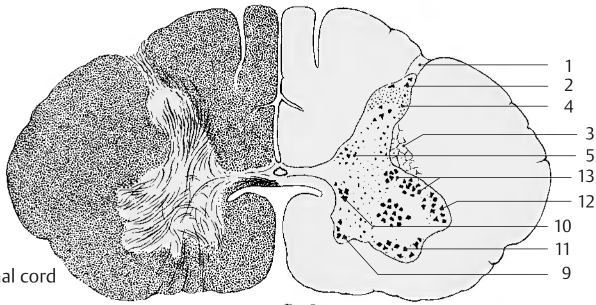
Medial group of nuclei

- Anteromedial nucleus (**A9**)
- Posteromedial nucleus (**A10**)

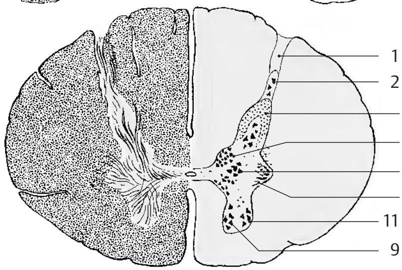
Lateral group of nuclei

- Anterolateral nucleus (**A11**)
- Posterolateral nucleus (**A12**)
- Retroposterolateral nucleus (**A13**)

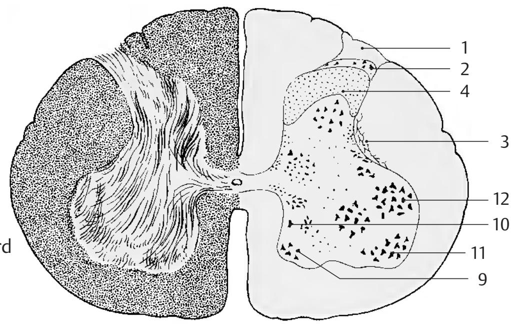
In the region supplying the upper limbs, the anterior horn is far more differentiated than in the thoracic spinal cord where only a few cell groups can be identified. The expanded, plump anterior horn of the lumbar and sacral spinal cords, which supplies the lower limbs, again contains several groups of nuclei.



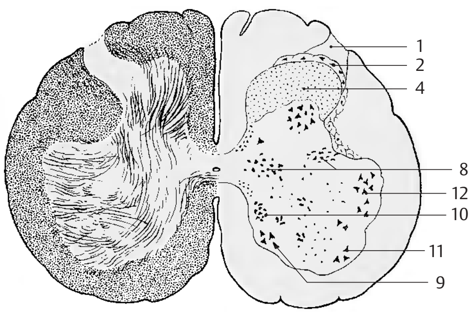
A Cervical spinal cord



B Thoracic spinal cord



C Lumbar spinal cord



D Sacral spinal cord

Ascending Pathways (A – D)

Tracts of the Anterolateral Funiculus (A)

Lateral spinothalamic tract (A1). The afferent, poorly myelinated posterior root fibers (**A2**) (first neuron of sensory pathway) bifurcate in the *posterolateral tract* (Lissauer's tract) and terminate at the cells of the *gelatinous substance* of the posterior horn. The fibers of the tract originate here, cross in the *white commissure* to the opposite side, and ascend in the lateral funiculus to the thalamus (second neuron). The pathway transmits *pain and temperature sensation*, *exteroceptive* and *proprioceptive impulses*. It is somatotopically subdivided; sacral (S) and lumbar (L) fibers are located dorsolaterally, while thoracic (T) and cervical (C) fibers are located ventromedially. Fibers for pain sensation probably lie superficially, while those for temperature sensation lie more deeply.

Anterior spinothalamic tract (A3). The afferent fibers (**A4**) (first neuron) bifurcate into ascending and descending branches and terminate at posterior horn cells, the fibers of which cross to the opposite side and ascend in the anterior funiculus to the thalamus (second neuron). They transmit *crude touch and pressure sensations.* Together with the lateral tract, they form the pathway of **protopathic sensibility** (p. 324).

The **spinotectal tract** (**A5**) carries pain fibers to the roof of the midbrain (contraction of pupils when in pain).

Pathways of the Posterior Funiculus (C, D)

Fasciculus gracilis (of Goll) **(C6)** and **fasciculus cuneatus** (of Burdach) **(C7)**. The thick heavily myelinated fibers ascend without relay in the ipsilateral posterior funiculi. They belong to the first neuron of the sensory pathway and terminate at the nerve cells of the posterior funiculus nuclei (second neuron) (p. 140, B5, B6). They transmit exteroceptive and proprioceptive impulses of the **epicritic sensibility** (*exteroceptive*, information on localization and quality of tactile sensation; *proprioceptive*, information on limb position and body posture). The posterior funiculi are somatotopically subdivided; the sacral fibers lie medially, followed laterally by the lumbar and thoracic fibers (*fasciculus gracilis*). The fibers from T3 to C2 lie laterally and form the *fasciculus cuneatus*.

Short ascending collaterals (**C8**) branch from the ascending fibers. They terminate at the posterior horn cells and form compact bundles, namely, the *comma tract of Schultze* (**D9**) in the cervical spinal cord, *Flechsig's oval field* (**D10**) in the thoracic spinal cord, and the *Phillippe – Gombault triangle* (**D11**) in the sacral spinal cord.

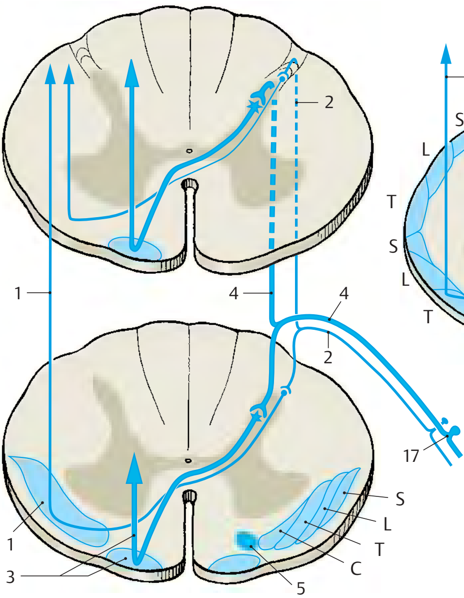
Cerebellar Pathways of the Lateral Funiculus (B)

Posterior spinocerebellar tract (Flechsig's tract) (B12). The afferent posterior horn fibers (first neuron) terminate at the cells of the *dorsal nucleus of Clarke* (**B13**) from where the tract (second neuron) originates. It runs along the margin of the ipsilateral lateral funiculus to the cerebellum and transmits mainly *proprioceptive impulses* (from joints, tendons, muscle spindles).

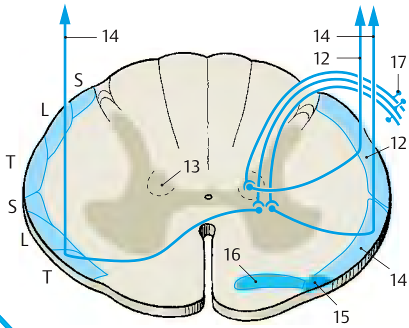
Anterior spinocerebellar tract (Gowers' tract) (B14). The cells of origin lie in the posterior horn. Their fibers (second neuron) ascend ipsilaterally as well as contralaterally along the anterolateral margin of the spinal cord to the cerebellum, to which they transmit *exteroceptive and proprioceptive impulses*. Both cerebellar pathways are somatotopically subdivided; the sacral fibers lie dorsally, the lumbar and thoracic fibers ventrally.

The **spino-olivary tract** (**B15**) and **vestibulospinal tract** (**B16**) arise from the posterior horn cells of the cervical spinal cord; they transmit mainly *proprioceptive impulses* to the inferior olive of the opposite side and to the vestibular nuclei.

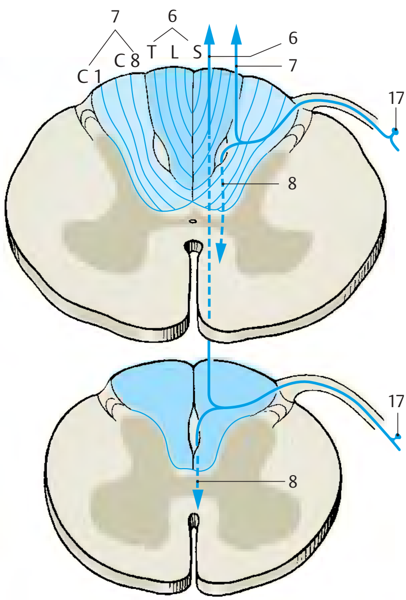
A – C17 Neurons in the spinal ganglion (first neuron) (p. 71, A7).



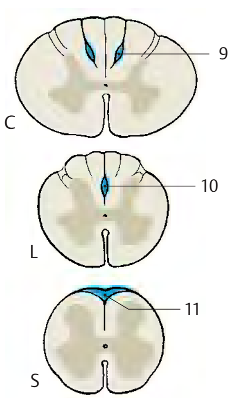
A Lateral and anterior spinothalamic tracts



B Anterior and posterior spinocerebellar tracts



C Fasciculus gracilis, fasciculus cuneatus



D Descending fibers of the posterior funiculi

Descending Pathways (A – C)

Corticospinal Tract, Pyramidal Tract (A)

The fibers of the pyramidal pathway originate mostly from the precentral gyrus and the cortex in front of it (areas 4 and 6) (p. 308, A1, A2). Furthermore, some of the fibers are thought to be derived from the cortical regions of the parietal lobe. Eighty percent of all fibers cross in the lower medulla oblongata to the collateral side (**pyramidal decussation**) (**A1**) and run as **lateral corticospinal tract** (**A2**) in the *lateral funiculus*. The remaining fibers run uncrossed as **anterior corticospinal tract** (**A3**) in the *anterior funiculus* and cross only at the level of their termination. More than half of the pyramidal tract fibers terminate in the cervical spinal cord to supply the upper limb, and one-fourth terminate in the lumbar spinal cord to supply the lower limb. The lateral funiculus is subdivided somatotopically, with the fibers for the lower limb lying at the periphery and those for the trunk and upper limb lying further inside. Most of the fibers terminate on interneurons that transmit impulses for the voluntary motor system to the anterior horn cells. However, the fibers not only conduct excitation to the anterior horn cells but also mediate cortical inhibition via interneurons (p. 308, p. 316).

Extrapyramidal Tracts (B)

The extrapyramidal tracts comprise descending systems from the brain stem that influence the motor system (p. 310):

- **Vestibulospinal tract** (**B4**) (*balance, muscle tone*)
- **Anterior and lateral reticulospinal tract** (**B5**) from the pons
- **Lateral reticulospinal tract** (**B6**) from the medulla oblongata
- **Tegmentospinal** tract (**B7**) from the midbrain

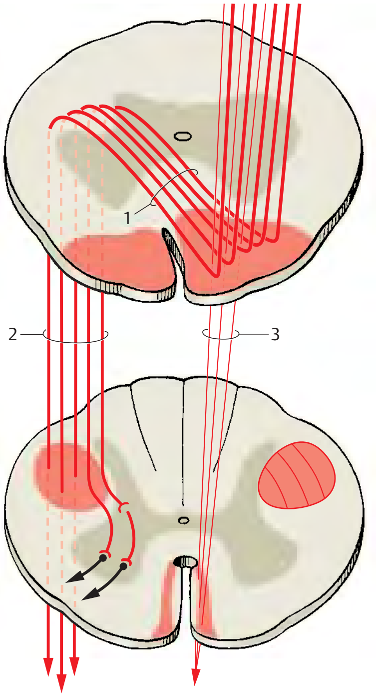
The **rubrospinal tract** (**B8**) (in humans largely replaced by the tegmentospinal tract) and the **tectospinal tract** (**B9**) terminate in the cervical spinal cord and influence only the *differentiated motor system of the head and upper limb*. The **medial longitudinal fascicle** (**B10**) contains various fiber systems of the brain stem (p. 142).

Autonomic Pathways (C)

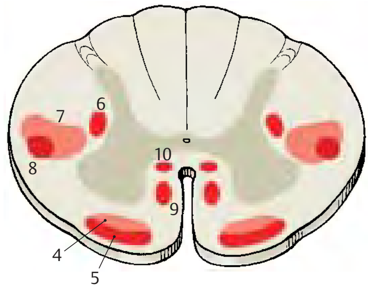
The autonomic pathways consist of poorly myelinated or unmyelinated fibers and rarely form compact bundles. The **parependymal tract** (**C11**) runs along both sides of the central canal. Its ascending and descending fibers can be traced back up to the diencephalon (hypothalamus) and are thought to transmit impulses for *genital function*, *micturition*, and *defecation*. Anterior to the lateral pyramidal tract runs the descending pathway for *vasoconstriction* and *sweating* (*Foerster*) (**C12**) with a somatotopic subdivision corresponding to that of the lateral pyramidal tract.

Visualization of Pathways (D – E)

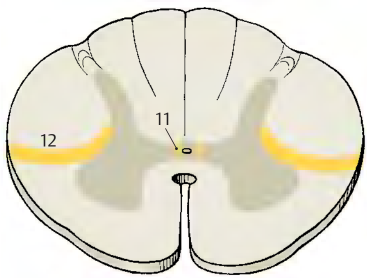
The various pathway systems cannot be identified on normal transverse sections of the spinal cord. Only under special circumstances (in experimental transection, in spinal cord injury, or during *development* when tracts become myelinated at different times), can they be distinguished from each sother, such as the late myelinating pyramidal tract (**D2**). In case *of injuries*, distal fibers separated from the perikaryon degenerate so that their area in the spinal cord becomes visible, such as the fasciculus gracilis (**E13**).



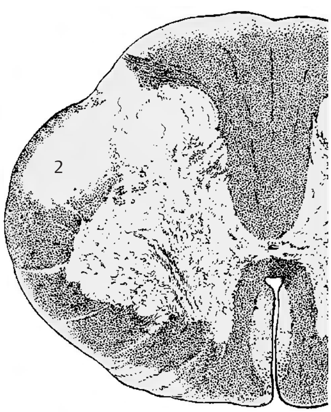
A Anterior and lateral corticospinal tract (pyramidal tract)



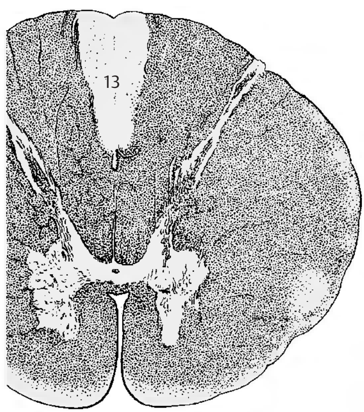
B Descending pathways



C Autonomic pathways



D Unmyelinated pyramidal tract in the newborn



E Degeneration of the fasciculus gracilis after injury to the spinal cord

Blood Vessels of the Spinal Cord (A – E)

The spinal cord is supplied with blood from two sources, the *vertebral arteries* and the *segmental arteries* (*intercostal arteries* and *lumbar arteries*).

Vertebral arteries (A1). Before they unite, they give off two thin *posterior spinal arteries* that form a network of small arteries along the posterior surface of the spinal cord. At the level of the pyramidal decussation, two additional branches of the vertebral arteries join to form the *anterior spinal artery* (**AD2**) which runs along the anterior surface of the spinal cord at the entrance to the anterior sulcus.

Segmental arteries (C3). Their posterior branches (**C4**) and the vertebral arteries give off **spinal branches** (**C5**) which enter through the intervertebral foramina and divide at the spinal roots into dorsal and ventral branches to supply the spinal roots and the spinal meninges. Of the 31 spinal arteries, only 8 to 10 extend to the spinal cord and contribute to its blood supply. The levels at which the radicular arteries approach the spinal cord vary, and so do the sizes of the vessels. The largest vessel approaches the spinal cord at the level of the lumbar enlargement between T12 and L3 (**large radicular artery**) (**A6**).

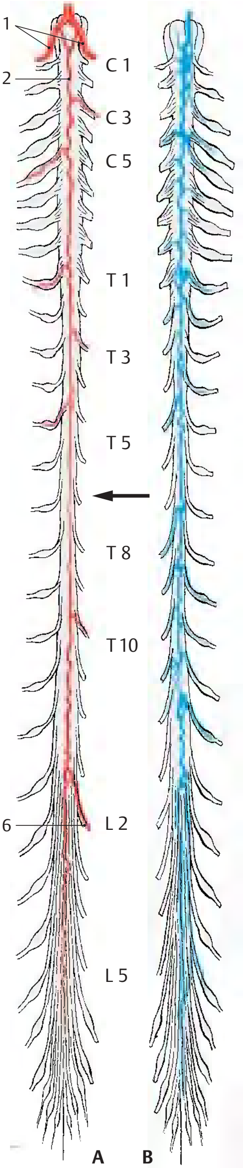
The **anterior spinal artery** is widest at the level of the cervical and lumbar enlargements. Its diameter is much reduced in the midthoracic region of the spinal cord. As this region is also the border area between two supplying radicular arteries, this segment of the spinal cord is especially at risk in case of circulatory problems (**A**, arrow). Depending on the variation of the radicular arteries, this may also apply to other segments of the spinal cord.

The anterior spinal artery gives off numerous small arteries into the anterior sulcus, the **sulcocommissural arteries** (**D7**). In the cervical and thoracic spinal cords, they turn alternately to the left and right halves of the spinal cord; in the lumbar and sacral spinal cords, they divide into two branches. In addition, anastomoses arise between the anterior and posterior spinal arteries, so that the spinal cord is surrounded by a vascular ring (**vasocorona**) (**D8**) from where vessels radiate into the white matter. Injection of tracers revealed that the gray matter is much more vascularized than the white matter (**D**).

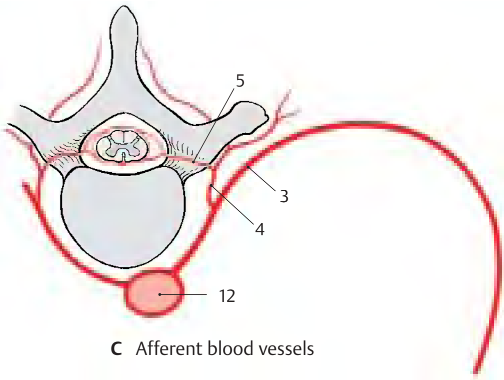
Areas of blood supply (E). The anterior spinal artery supplies the anterior horns, the bases of the posterior horns, and the largest part of the anterior lateral funiculi (**E9**). The posterior funiculi and the remaining parts of the posterior horns are supplied by the **posterior spinal arteries** (**E10**). The marginal zone of the anterior lateral funiculus is supplied by the plexus of the vasocorona (**E11**).

The **spinal veins** (**B**) form a network in which one *anterior spinal vein* and two *posterior spinal veins* stand out. The efferent veins run along the spinal roots and open into the *epidural venous plexus* (see vol. 2). The spinal veins lack valves prior to their penetration through the dura.

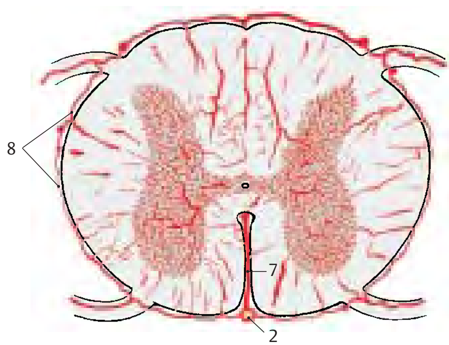
C12 Aorta.



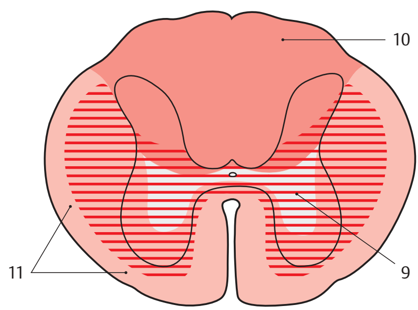
Arteries and veins of the spinal cord



C Afferent blood vessels



D Vascularization of the spinal cord



E Areas supplied by the spinal cord arteries (according to *Gillilan*)

Spinal Ganglion and Posterior Root (A – H)

The posterior spinal root contains a spindle-shaped bulge, the **spinal ganglion** (**A**), an accumulation of cell bodies of sensory neurons; their bifurcated processes send one branch to the periphery and the other branch to the spinal cord (p. 70, A7). They lie as cell clusters or as cell rows between the bundles of nerve fibers.

Development of the ganglia (C). The cells originate from the lateral zone of the **neural plate** (**C1**); however, they do not participate in the formation of the neural tube but remain at both sides as the **neural crest** (**C2**). Hence, the spinal ganglia can be regarded as gray matter of the spinal cord that became translocated to the periphery. Other derivatives of the neural crest are the cells of the autonomic ganglia, the paraganglia, and the adrenal medulla.

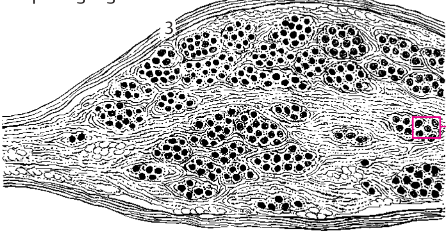
From the capsule (**A3**) of the spinal ganglion, which merges into the perineurium of the spinal nerve, connective tissue extends to the interior and forms a sheath around each neuron (*endoganglionic connective tissue*) (**B4**). The innermost sheath, however, is formed by ectodermal *satellite cells* (**BE5**) and is surrounded by a basal membrane comparable to that around the Schwann cells of the peripheral nerve. The large nerve cells (**B6, E**) with their myelinated process conglomerated into a *glomerulus* represent only one-third of the ganglion. They transmit impulses of *epicritic sensibility* (p. 322). The remainder consists of medium-sized and small ganglion cells with poorly myelinated or unmyelinated nerve fibers which are thought to conduct pain signals and sensations from the intestine. There are also some multipolar nerve cells.

Development of the ganglion cells (D). The spinal ganglion cells are initially *bipolar cells*. During development, however, the two processes fuse to form a single trunk which then bifurcates in a T-shaped manner. The cells are therefore called *pseudounipolar nerve cells*.

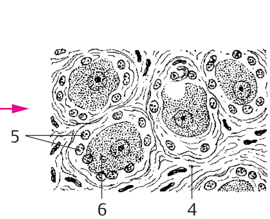
The posterior root is thicker than the anterior root. It contains fibers of various calibers, two-thirds of them being poorly myelinated or unmyelinated fibers. The thin poorly myelinated and unmyelinated fibers, which transmit impulses of the *protopathic sensibility* (p. 324), enter through the lateral part of the root into the spinal cord (**F7**). The thick myelinated fibers transmit impulses of the *epicritic sensibility* and enter through the median part of the root into the spinal cord (**F8**).

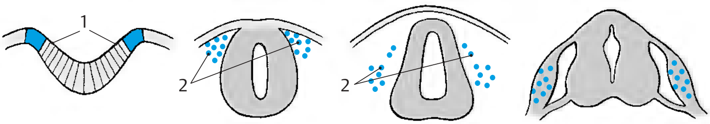
At the entrance into the spinal cord, there is a narrow zone where the myelin sheaths are very thin so that the fibers appear unmyelinated. This zone is regarded as the *boundary between the central and the peripheral nervous systems* (**Redlich – Obersteiner zone**) (**G**). In the electron-microscopic image (**H**), however, this boundary does not exactly coincide with the Redlich – Obersteiner zone. For each axon, the boundary is marked by the last node of Ranvier prior to the entrance into the spinal cord. Up to this point, the peripheral myelin sheath is surrounded by a *basal membrane* (blue in **H**). The next internode no longer has a basal membrane. For unmyelinated fibers, the boundary is also marked by the basal membrane of the enveloping Schwann cell. Thus, the basal membranes around the spinal cord form a boundary that is only penetrated by the axons.

A Spinal ganglion

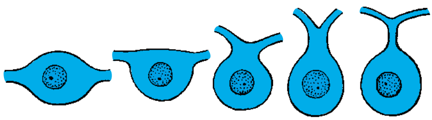


B Detail of **A**

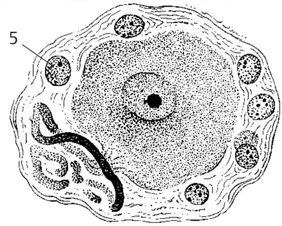




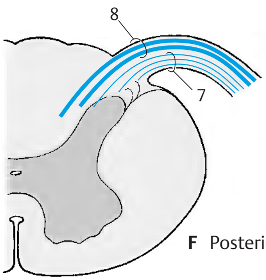
C Development of the spinal ganglion



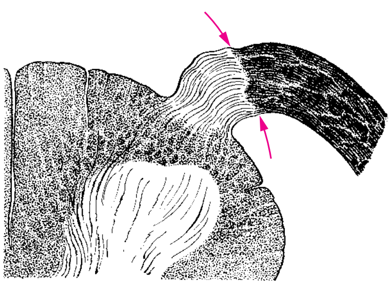
D Development of the pseudounipolar ganglion cell



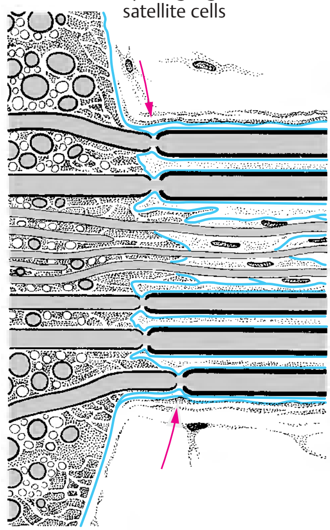
E Spinal ganglion cell and satellite cells



F Posterior root



G Redlich – Obersteiner zone



H Posterior root, electron-micro scopic diagram (according to *Andres*)

Spinal Meninges (A – E)

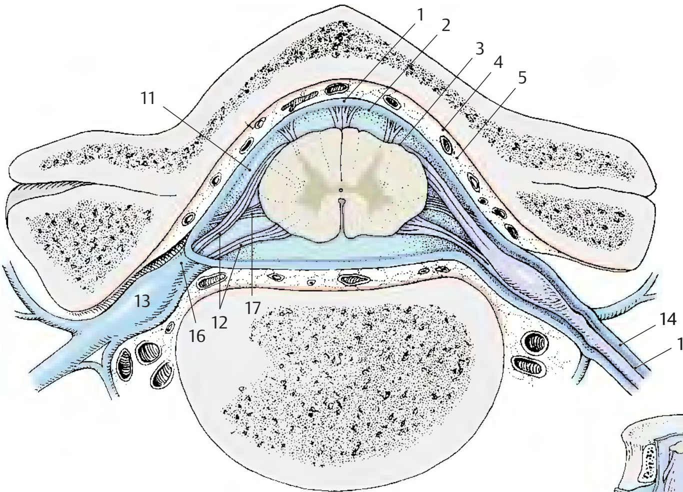
The spinal cord in the vertebral canal is surrounded by the following connective tissue membranes: the *tough spinal meninx* (*pachymeninx*), or **spinal dura mater** (**A1**), and the *soft spinal meninx* (*leptomeninx*) consisting of the **spinal arachnoidea** (**A2**) and the **spinal pia mater** (**A3**).

The spinal dura mater forms the outermost sheath which is separated from the periosteum-like lining of the vertebral canal, the **endorhachis** (**A4**), by the **epidural space** (**A5**). The space is filled with adipose tissue and contains an extensive venous plexus, the *internal vertebral venous plexus* (see vol. 2). The dura mater forms caudally the *dural sac* (**B6**), enveloping the *cauda equina* (**B7**), and finally extends together with the terminal filament as a thin cord up to the periosteum of the coccyx (*dural terminal filament*) (**B8**). Only at the oral end at the *foramen magnum* (occipital bone) is the dural sac attached to bone. The epidural space forms a resilient cushion for the dural sac, which moves together with the vertebral column and the head. Bending the head pulls the dural sac upward, causing mechanical stress on the spinal cord; when bending the head forward, roots and blood vessels are stretched (**D9**), when bending the head backward, they are compressed (**D10**).

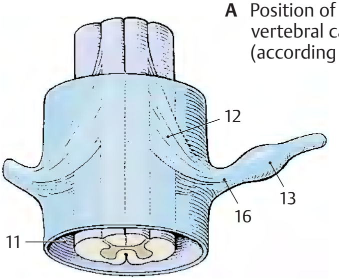
The **arachnoidea** borders closely onto the inner surface of the dura mater. It forms the boundary of the **subarachnoidal space** (**AC11**), which is filled with *cerebrospinal fluid* (CSF). Between the inner surface of the dura and the arachnoidea lies a capillary cleft, the *subdural space*, which widens into a real space only under pathological conditions (subdural bleeding). Dura and arachnoidea accompany the spinal roots (**AC12**), pass with them through the intervertebral foramina, and also envelope the spinal ganglia (**AC13**). The funnel-like root sleeves contain CSF in their proximal portions. The dura then turns into the *epineurium* (**A14**), and the arachnoidea into the *perineurium* (**A15**) of the spinal nerves. The part of the root leaving the vertebral canal, the *radicular nerve* (**A16**), runs obliquely downward in the cervical and lumbosacral regions and obliquely upward in the midthoracic region (**C**).

The **spinal pia mater** borders directly onto the marginal glial layer of the spinal cord. This represents the boundary between mesodermal envelopes and ectodermal nerve tissue. The pia mater contains numerous small blood vessels that penetrate from the surface into the spinal cord. A connective tissue plate, the **denticulate ligament** (**A17**), extends on both sides of the spinal cord from the pia to the dura and is attached to the latter by individual pointed processes. The ligament extends from the cervical spinal cord to the midlumbar spinal cord, thus keeping the spinal cord, which floats in the CSF, in position.

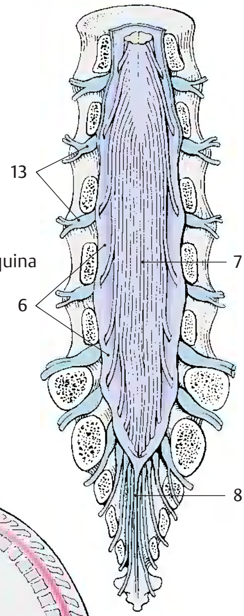
Clinical Note: Under sterile conditions, cerebrospinal fluid may be safely withdrawn for examination from the lower segment of the dural sac that contains only the fibers of the cauda equina. For this purpose, with the patient bending over, a needle is deeply inserted between the processes of the second to fifth lumbar vertebrae until CSF begins to drop (*lumbar puncture*) (**E**).



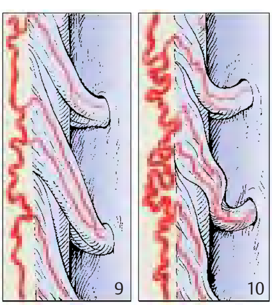
A Position of the spinal cord in the vertebral canal, cross section (according to *Rauber-Kopsch*)



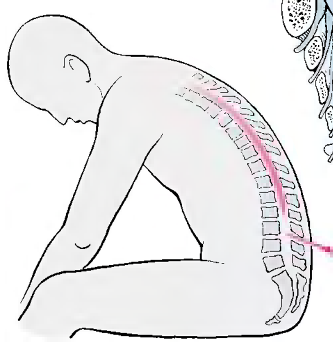
C Dorsal view of root, radicular nerve, and spinal ganglion



B Cauda equina



D Cervical spinal cord with neck flexed and extended (according to *Breig*)



E Lumbar puncture

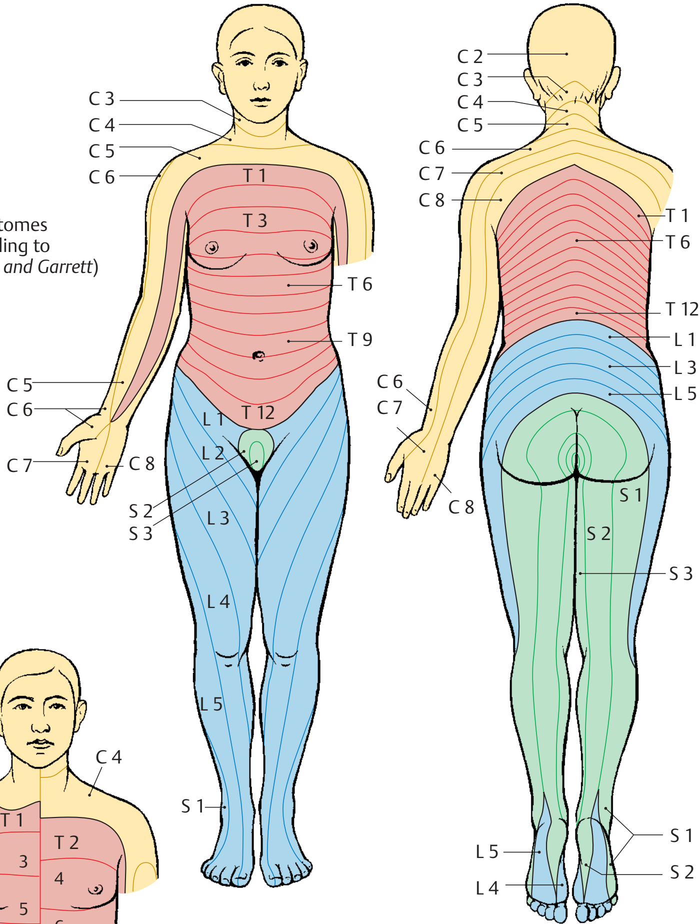
Segmental Innervation (A – C)

The vertebrate body, with the exception of the head, is originally subdivided into *segments* or *metameres*. The vertebrae, ribs, and intercostal muscles can be regarded as remnants of such a segmentation in humans. Metamerism concerns only tissues of the mesoderm (**myotomes**, **sclerotomes**) but not derivatives of the ectoderm. Thus, there are no spinal cord segments, only the levels at which the individual spinal roots enter and emerge. However, the spinal fibers join to form the spinal nerves as they emerge through the metameric intervertebral foramina, thus creating an *apparent secondary segmentation*. The sensory fibers of the spinal nerves supply stripe-shaped zones of the skin, called **dermatomes** in analogy to myotomes and sclerotomes. This, too, is a secondary segmentation and reflects the innervation of each dermatome by a single posterior root (segmental innervation).

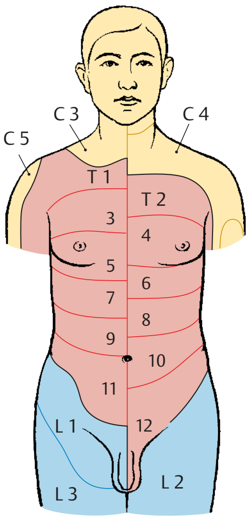
Clinical Note: The dermatomes play an important role in the *diagnosis and localization of spinal cord injuries*. Loss of sensibility in certain dermatomes indicates a specific level of injury in the spinal cord. Simplified reference points are the line through the nipples, regarded as the boundary between T4 and T5, and the groin, regarded as the boundary between L1 and L2. The first cervical spinal nerve has no sensory representation on the body surface, for the spinal ganglion of its posterior root is absent or rudimentary.

There are slightly different segmental boundaries for various modalities, such as touch and pain, and for sweating and piloerection. The diagram (**A**) was designed according to the *decrease in sensibility* (**hypoesthesia**) resulting from disk prolapse; it shows how the dermatomes extending around the trunk become elongated in the limbs. They may even lose their continuity with the midline (C7, L5). They become translocated to the distal limb areas during embryonic development when the limbs are budding (**C**).

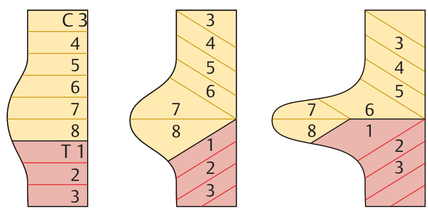
The dermatomes overlap like roof tiles, as illustrated by the shift in boundaries that have been determined according to the expanded areas in case of *posterior root pain* (hypersensitivity to pain, **hyperalgesia**) (**B**). The loss of a single posterior root cannot be demonstrated for touch sensation, since the corresponding dermatome is also supplied by the neighboring posterior roots. The dermatomes for pain and temperature sensation are narrower, and the loss of a posterior root can still be demonstrated when these modalities are tested.



A Dermatomes (according to *Keegan and Garrett*)



B Overlap of dermatomes (according to *Förster*)



C Development of dermatomes in the upper limb (according to *Bolk*)

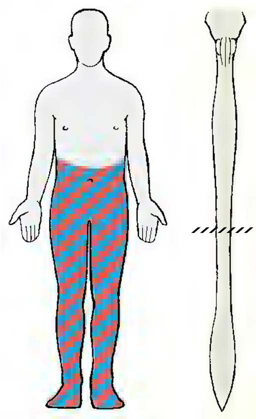
Spinal Cord Syndromes (A – C)

The anatomy of the spinal cord causes very specific patterns of functional deficiencies after injury; depending on the site of lesion, different pathways and therefore different functions are lost.

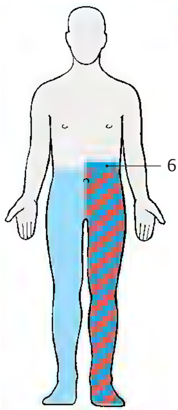
Complete transection (**A**) cuts off all descending motor pathways, causing *complete paralysis* below the injured level. At the same time, it interrupts all ascending pathways, causing a complete *loss of all sensations*. If the lesion is above the sacral spinal cord, it results in the loss of voluntary control over urination and defecation. If the lesion lies above the lumbar enlargement, both lower limbs are paralyzed (**paraplegia**), and if it lies above the cervical enlargement, both upper limbs are also paralyzed (**tetraplegia**).

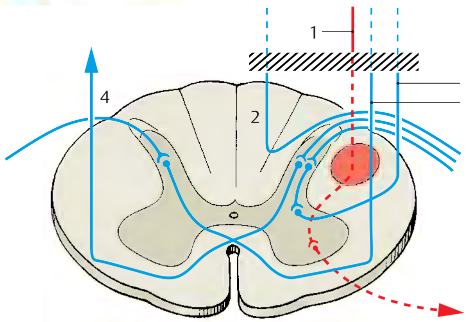
Hemisection of the spinal cord (**B**) results in the **Brown – Séquard's syndrome**. For example, hemisection on the left interrupts the lateral and anterior corticospinal tracts (**B1**) and results in left-sided *paralysis*. Transection of the vasomotor pathway causes ipsilateral vasomotor paralysis. Transection of the posterior funiculi (**B2**) and the cerebellar lateral funiculi (**B3**) leads to severely *impaired deep sensibility* (posture sensation). On the same side as the lesion, there is also **hyperesthesia** (touch is perceived as pain). This is thought to be caused by a loss of epicritic sensibility (posterior funiculi) with retention of the protopathic sensibility (crossing pathways of the anterior corticospinal tract ascend contralaterally) (**B4**). Finally, there is *dissociated anesthesia* on the intact right side from the lesion downward; while touch sensation is hardly impaired, pain and temperature sensations are lost (ipsilateral interruption of the crossing pathway of the anterior corticospinal tract) (**B5**). The anesthetic zone (**B6**) above the transection on the affected side is attributed to destruction of the posterior root entrance zone at the level of the spinal cord lesion.

Central injury (**C**) to the gray substance of the spinal cord also causes *dissociated anesthesia* at the corresponding levels. The epicritic sensibility transmitted via the ipsilateral posterior funiculi (**C2**) is retained. However, pain and temperature sensations are lost (**analgesia** and **thermoanesthesia**), because their fibers, which cross through the white commissure, are interrupted (**C5**).

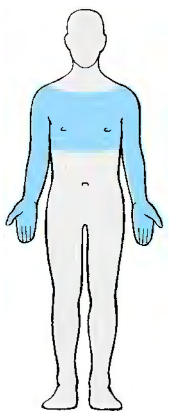


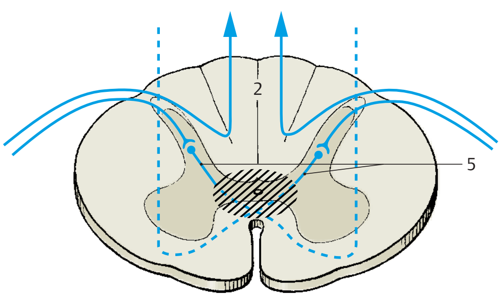
A Complete transection of the spinal cord





B Brown – Séquard’s syndrome in hemisection of the spinal cord





C Dissociated anesthesia in case of injury to the central spinal cord

Peripheral Nerves

The **peripheral nerves** may contain four different types of fibers:

- **Somatomotor** (efferent) fibers (**A1**) for striated muscles
- **Somatosensory** (afferent) fibers (**A2**) for skin sensibility
- **Visceromotor** fibers (**A3**) for smooth muscles
- **Viscerosensory** fibers (**A4**) for inner organs

The spinal nerves usually contain several types of fibers; they are *mixed nerves*.

The different fibers have the following pathways. The *somatomotor fibers* pass from the anterior horn cells (**A5**) through the anterior root (**A6**); the *somatosensory* and *viscerosensory fibers* originate from the nerve cells of the spinal ganglia (**A7**); and the *visceromotor fibers* of the lateral horn cells (**A8**) pass mostly through the anterior root. Anterior and posterior roots (**A9**) join to form the spinal nerve (**A10**), which contains all types of fibers. This short nerve trunk then divides into four branches:

- The *meningeal branch* (**A11**), a recurrent sensory branch extending to the spinal meninges
- The *posterior branch* (**A12**)
- The *anterior branch* (**A13**)
- The *communicating branch* (**A14**)

The **posterior branch** supplies motor fibers to the deep (autochthonous) muscles of the back and sensory fibers to the skin areas on both sides of the vertebral column (p. 84). The **anterior branch** supplies motor fibers to the muscles of the anterior and lateral walls of the trunk and to the muscles of the limbs; it also supplies sensory fibers to the corresponding skin areas. The **communicating branch** connects with the sympathetic chain ganglion (**A15**) (autonomic nervous system, p. 292). It usually forms two independent communicating branches, the *white communicating branch* (**A16**) (myelinated) and the *gray communicating branch* (**A17**) (unmyelinated). The visceromotor fibers pass via the white branch to the sympathetic chain ganglion, where they are relayed to neurons, the axons of which partly reenter the spinal nerve as *postganglionic fibers* (p. 297 **A5**) via the gray branch.

Nerve Plexusus (B)

At the level of the limbs, the *anterior branches* of the spinal nerves form networks (**plexusus**) in which fibers are exchanged. The resulting nerve trunks, which then extend to the periphery, possess a newly organized supply of fibers derived from different spinal nerves.

Cervical plexus (p. 72). The *plexus of the neck* is formed by the anterior branch of the first four spinal nerves. The following nerves originate here: the lesser occipital nerve (**B18**), the greater auricular nerve (**B19**), the transverse nerve of the neck (**B20**), the supraclavicular nerves (**B21**), the phrenic nerve (**B22**), and also the roots of the deep cervical ansa (**B23**).

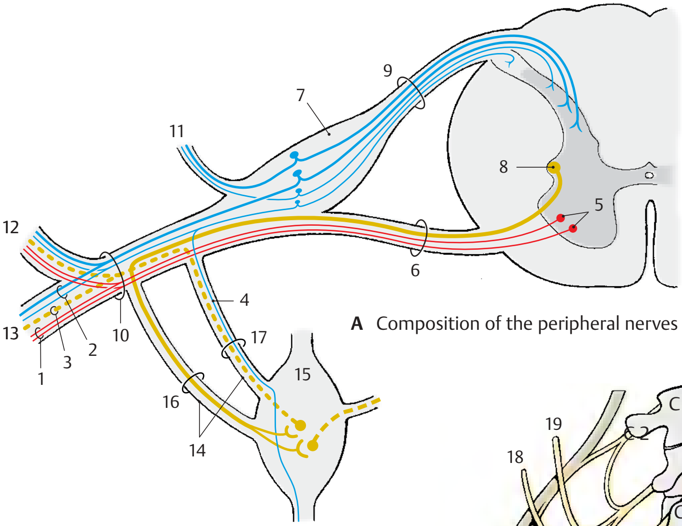
Brachial plexus (p. 74). The *plexus of the arm* is formed by the anterior branches of spinal nerves C5 to C8 and by a part of the T1 nerve. We distinguish between a section lying above the clavicle, the **supraclavicular part**, and a section lying below the clavicle, the **infraclavicular part**. The anterior branches pass through the scalene gap into the posterior cervical triangle, where they form *three primary trunks* above the clavicle:

- The **superior trunk** (**B24**) (C5, C6)
- The **medial trunk** (**B25**) (C7)
- The **inferior trunk** (**B26**) (C8, T1)

The nerves that originate here form the supraclavicular part (p. 74). Below the clavicle, *three secondary cords* form; they are named according to their position relative to the axillary artery (**B27**):

- The **lateral cord** (**B28**) (p. 74) (from the anterior branches of the superior and medial trunks)
- The **medial cord** (**B29**) (p. 78) (from the anterior branch of the inferior trunk)
- The **posterior cord** (**B30**) (p. 80) (from the dorsal branches of the three trunks)

The lateral cord gives rise to the *musculocutaneous nerve* (**B31**). The remaining fibers together with fibers of the medial cord form



A Composition of the peripheral nerves

B Cervical plexus and brachial plexus (preparation by Professor *Platzer*)

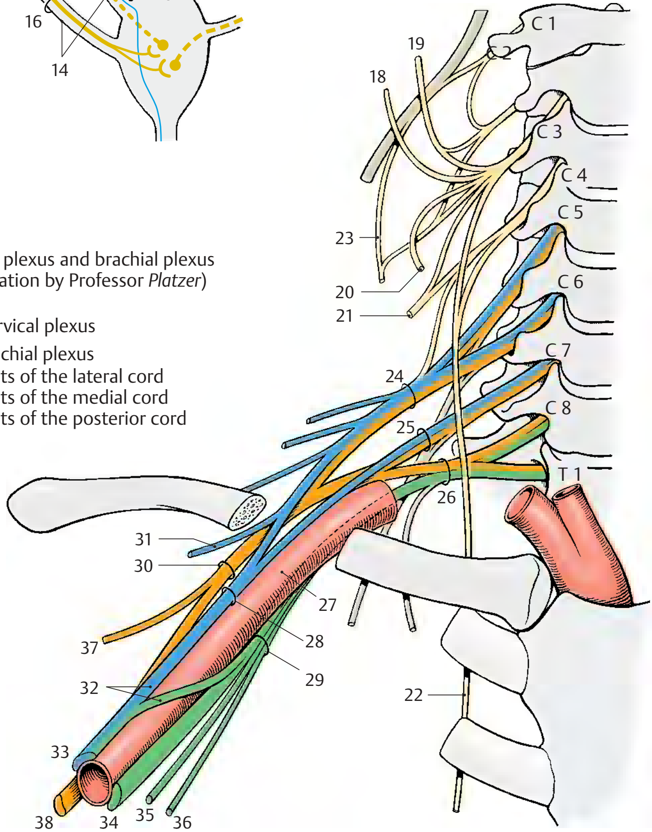
Cervical plexus

Brachial plexus

Parts of the lateral cord

Parts of the medial cord

Parts of the posterior cord



the **median loop** (**B32**) (p. 76, AC1) and unite to form the *median nerve* (**B33**). The medial cord gives rise to the *ulnar nerve* (**B34**), the *medial cutaneous nerve of the forearm* (**B35**), and the *medial cutaneous nerve of the arm* (**B36**). The posterior cord gives off the *axillary nerve* (**B37**) and continues as the *radial nerve* (**B38**).

Cervical Plexus (C1 – C4) **(A – D)**

Innervation of the muscles (A). Short nerves run from the **anterior branches** directly to the deep neck muscles, namely, the anterior (**A1**) and lateral (**A2**) rectus capitis muscles, the long muscle of the head, and the long muscle of the neck (**A3**). From the anterior branch of C4, nerves run to the upper part of the anterior scalene muscle (**A4**) and to the medial scalene muscle (**A5**).

The anterior branches of C1 – C3 form the deep cervical ansa (**C6**): fibers from C1 and C2 temporarily appose the hypoglossal nerve (**AC7**) and then leave it as the **superior root** (anterior) (**AC8**); the fibers for the thyrohyoid muscle (**A9**) and the geniohyoid muscle then continue with the hypoglossal nerve. The superior root combines with the **inferior root** (posterior) (**AC10**) (C2, C3) to form the cervical ansa, from where branches run to supply the infrahyoid muscles, namely, the omohyoid muscle (**A11**), the sternothyroid muscle (**A12**), and sternohyoid muscle (**A13**).

Innervation of the skin (B, C). The sensory nerves of the plexus pass behind the sternocleidomastoid muscle through the fascia, where they form the **punctum nervosum** (**B14**). From here they spread over head, neck, and shoulder; the **lesser occipital nerve** (**BC15**) (C2, C3) extends to the occiput, the **greater auricular nerve** (**BC16**) (C3) into the area surrounding the ear (auricula, mastoid process, region of the mandibular angle). The **transverse nerve of the neck** (**BC17**) (C3) supplies the upper neck region up to the chin, while the **supraclavicular nerves** (**BC18**) (C3, C4) supply the subclavicular fossa and the shoulder region.

Area innervated by the phrenic nerve (C, D). The **phrenic nerve** (**CD19**) (C3, C4) contains fibers of the fourth, and often also of the third, spinal nerve. It crosses the anterior scalene muscle and enters into the superior thoracic aperture in front of the subclavian artery. It extends through the mediastinum to the diaphragm and, on its way, gives off fine branches for sensory supply to the pericardium, the **pericardiac branches** (**D20**). At the surface of the diaphragm, it branches and supplies all muscles of the diaphragm (**D21**). Fine branches provide the sensory fibers for the membranes bordering on the diaphragm, that is, cranially the pleura and caudally the peritoneum of the diaphragm and the peritoneal covering of the upper intestinal organs.

Clinical Note: Injury to the cervical spinal cord or its roots at the C3 – C5 levels results in paralysis of the diaphragm and in reduced respiration. In case of paralysis of the thoracic muscles, on the other hand, respiration can still be maintained by the cervical spinal cord via the phrenic nerve.

Posterior Branches (C1 – C8)

The *dorsal branches of the cervical nerves*, or **posterior branches**, supply motor fibers to neck muscles belonging to the autochthonous muscles of the back and sensory fibers to the skin of the neck.

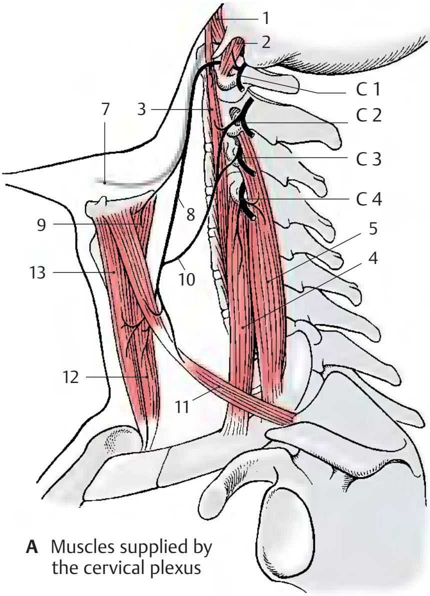
The posterior branch of the first cervical nerve is exclusively motor and runs as *suboccipital nerve* to the small muscles in the region of occiput, atlas, and axis.

The *greater occipital nerve* runs from the second cervical nerve to the occiput and supplies its skin up to the vertex (p. 84 **D4**).

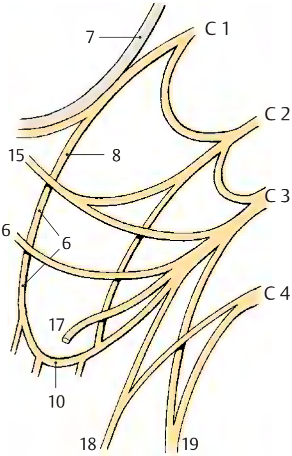
The posterior branch of the third cervical spinal nerve, the *third occipital nerve*, supplies sensory fibers to the neck region.

The remaining posterior branches of the cervical spinal nerves supply sensory fibers to the skin area bordering caudally and motor fibers to the autochthonous back muscles of this region.

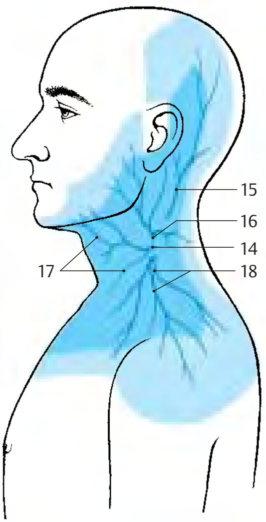
Innervation of the skin (B). Autonomic zone (dark blue) and maximum zone (light blue).



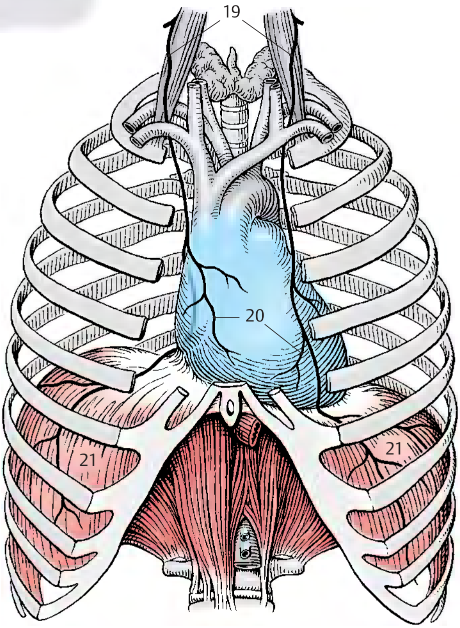
A Muscles supplied by the cervical plexus



C Cervical plexus



B Skin area supplied by the cervical plexus (according to *Lanz-Wachsmuth*)



D Area supplied by the phrenic nerve

Brachial Plexus (C5 – T1)

Peripheral sensory innervation. The innervation of the skin by peripheral nerves originating from the plexus differs from the segmental innervation (p. 66). The regions supplied by individual nerves overlap at their margins. The region innervated by a single nerve is called the *autonomic zone* (dark blue), and the total area supplied by the nerve including the area cosupplied by adjacent nerves is called the *maximum zone* (light blue).

Clinical Note: Interruption of a nerve causes complete insensibility (*anesthesia*) in the autonomic zone but only a decreased sensibility (*hypoesthesia*) in the maximum zones.

Supraclavicular Part (A – C)

The supraclavicular part gives rise to motor nerves that innervate the *muscles of the shoulder girdle.*

The following nerves run to the *posterior and lateral surfaces of the thorax*: the **dorsal scapular nerve** (**A1**) (C5) to the scapular muscle (**C2**) and to the lesser (**C3**) and greater (**C4**) rhomboid muscles; the **long thoracic nerve** (**A5**) (C5 – C7), the branches of which terminate at the lateral thoracic wall in the peaks of the anterior serratus muscle (**B6**); and the **thoracodorsal nerve** (**A7**) (C7, C8), which supplies the latissimus dorsi muscle (**C8**). The muscles of the shoulder blade are innervated at the posterior surface of the shoulder blade (supraspinous muscle [**C9**] and infraspinous muscle [**C10**]) by the **suprascapular nerve** (**A11**) (C5, C6), and at the anterior surface by the **subscapular nerve** (**A12**) (C5 – C7), which extend to the subscapular muscle and the greater teres muscle (**C13**).

The following nerves reach the *anterior surface of the thorax*: the **subclavius nerve** (**A14**) (C4 – C6) (to the subclavius muscle [**B15**), the **lateral pectoral nerve** (**A16**) (C5 – C7) and the **medial pectoral nerve** (**A17**) (C7 – T1), which supply the greater (**B18**) and lesser (**B19**) pectoral muscles.

Clinical Note: Injury to the supraclavicular part leads to paralysis of the muscles of the shoulder girdle and makes it impossible to raise the arm. This type of *upper brachial plexus paralysis* (*Erb's palsy*) may be caused by dislocation of the shoulder joint during birth, or through improper positioning of the arm during anesthesia. Injury to the infraclavicular part of the brachial plexus results in *lower brachial plexus paralysis* (*Klumpke 's palsy*), which predominantly involves the small muscles of the hand and possibly also the flexor muscles of the forearm.

Infraclavicular Part (D – F)

Three main trunks of the anterior branches, the *superior*, *middle*, and *inferior trunks of the brachial plexus*, give rise to three cords, the *lateral*, *middle*, and *posterior fascicles*; they are named according to their position relative to the axillary artery.

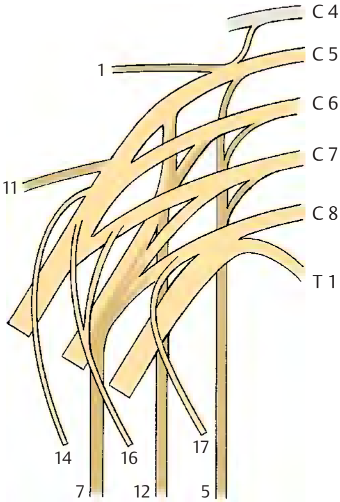
Lateral Fascicle

The lateral fascicle gives rise to the *musculocutaneous nerve* and the *median nerve.*

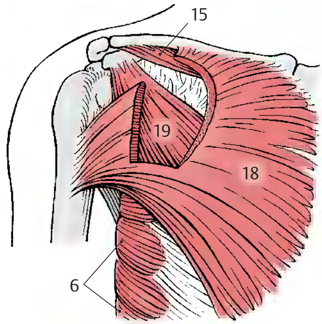
Musculocutaneous nerve (C5 – C7) **(D – F).** The nerve passes through the coracobrachial muscle and runs between the biceps muscle and the brachial muscle down to the elbow. It gives off branches (**E20**) to the flexor muscles of the upper arm, namely, to the coracobrachial muscle (**D21**), to the short head (**D22**) and long head (**D23**) of the biceps muscle of the arm, and to the brachial muscle (**D24**).

The sensory fibers of the nerves come to the surface through the fascia at the elbow and supply the skin in the lateral region of the forearm as **lateral cutaneous nerve of the forearm** (**D – F25**). Injury to this nerve causes loss of sensibility in a small zone of the elbow; diminished sensibility extends to the middle of the forearm.

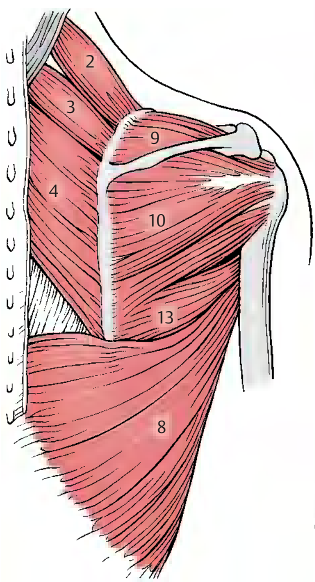
Innervation of the skin (F). Autonomic zone (dark blue) and maximum zone (light blue).



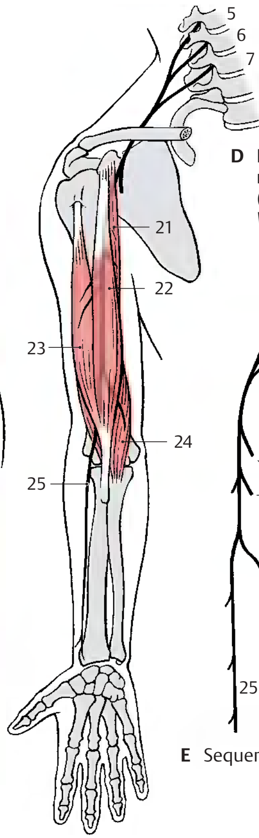
A Supraclavicular part of the brachial plexus



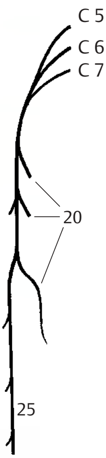
B Muscles supplied by the supra-clavicular part, frontal view



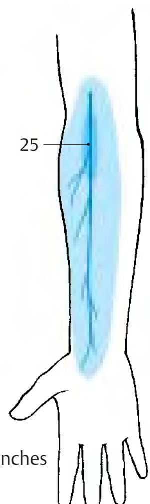
C Muscles supplied by the supra-clavicular part, dorsal view



D Muscles supplied by the musculocutaneous nerve (according to *Lanz-Wachsmuth*)



E Sequence of branches



F Innervation of skin

Infraclavicular Part (continued)

Lateral Fascicle (continued) (A – D)

Median nerve (C6 – T1). Parts of the lateral and medial fascicles form the **median loop** (**AC1**) at the anterior surface of the axillary artery and join to form the *median nerve*.

The nerve extends in the medial bicipital sulcus along the surface of the brachial artery to the elbow, where it passes between the two heads of the round pronator muscle to the forearm. It runs between the superficial flexor muscle of the fingers and the deep flexor muscle of the fingers to the wrist. Prior to its passage through the *carpal tunnel*, it lies superficially between the tendons of the radial flexor muscle of the wrist and the long palmar muscle. In the carpal tunnel, it ramifies into its terminal branches.

The **muscular branches** (**C2**) of the nerve supply the *pronator muscles* and most of the *flexor muscles of the forearm*, namely, the round pronator muscle (**A3**), the radial flexor muscle of the wrist (**A4**), the long palmar muscle (**A5**), and the superficial flexor muscle of the fingers with radial head (**A6**) and humeroulnar head (**A7**). In the elbow, the **anterior interosseous nerve of the forearm** (**AC8**) branches off and runs along the interosseous membrane to the quadrate pronator muscle (**A9**). It gives off branches to the long flexor muscle of the thumb (**A10**) and to the radial part of the deep flexor muscle of the fingers.

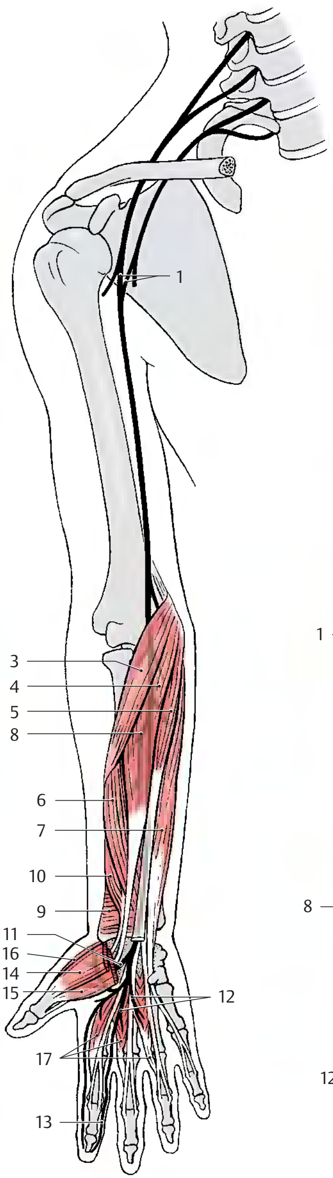
In the lower third of the forearm, the sensory **palmar branch of the median nerve** (**A – C11**) branches off to the skin of the ball of the thumb (thenar eminence), to the radial side of the wrist, and to the palm.

After passing through the carpal tunnel, the median nerve divides into three branches: the **common palmar digital nerves I – III** (**A – C12**), each of which bifurcates at the level of the metacarpophalangeal joints into two **proper palmar digital nerves** (**A – C13**). From the *first common palmar digital nerve*, a branch extends to the thenar eminence (short abductor muscle of thumb [**A14**], superficial head of the short flexor muscle of thumb [**A15**], and opposing muscle of thumb [**A16**]). The *common palmar digital nerves* supply the lumbrical muscles I – III (**A17**). They run to the interdigits and bifurcate in such a way that each pair of *proper palmar digital nerves* provides sensory fibers to the lateral aspects of an interdigit. Thus, the first pair of nerves supplies the ulnar side of the thumb and the radial side of the index finger, the second pair supplies the ulnar side of the index finger and the radial side of the middle finger, and the third pair supplies the ulnar side of the middle finger and the radial side of the ring finger. The area innervated by the proper palmar digital nerves on the posterior side includes the end phalanx of the thumb as well as the distal and middle phalanges of the fingers (**B**).

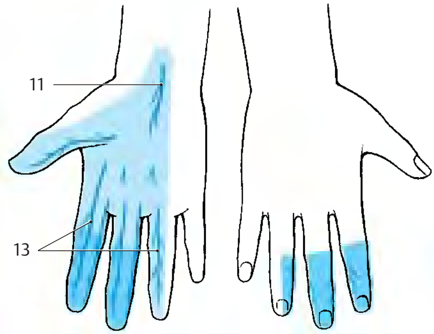
The median nerve gives off branches to the periosteum, elbow joint, radiocarpal joint, and mediocarpal joint. At the level of the wrist, there is normally an anastomosis with the ulnar nerve.

Clinical Note: After injury to the nerve, pronation of the forearm is no longer possible and flexion is severely restricted. As to the hand, the thumb, index finger and middle finger can no longer be flexed at the end and middle phalanges, resulting in a characteristic feature of median paralysis, the so-called **hand of oath** (**D**). On passing the carpal tunnel, the nerve can be injured by pressure in older persons (*carpal tunnel syndrome*).

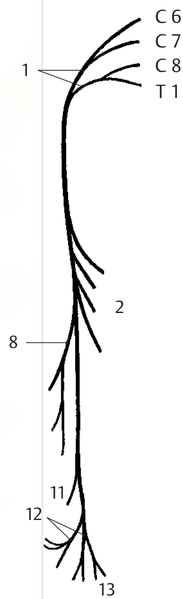
Innervation of the skin (B). Autonomic zone (dark blue) and maximum zone (light blue).



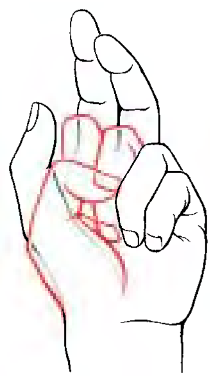
A Muscles supplied by the median nerve (according to *Lanz-Wachsmuth*)



B Skin supplied by the median nerve



C Sequence of branches



D Paralysis of the median nerve (according to *Lanz-Wachsmuth*)

Infraclavicular Part (continued)

Medial Fascicle (A–D)

Ulnar nerve (C8–T1). Initially, the ulnar nerve runs in the *upper arm* in the medial bicipital sulcus without giving off any branches.

On the ulnar side of the upper arm, the nerve runs down behind the medial intermuscular septum, being covered by the medial head of the triceps muscle. It crosses the elbow joint on the extensor side in a bony groove, the sulcus for the ulnar nerve, at the medial epicondyle of the humerus. Here, the nerve can be palpated, and the pressure causes an electrifying pain radiating into the ulnar side of the hand. The nerve then passes between the two heads of the ulnar flexor muscle of the wrist to the flexor side of the forearm and runs beneath this muscle down to the wrist. It does not pass through the carpal tunnel but extends over the flexor retinaculum to the palm of the hand, where it divides into a *superficial branch* and a *deep branch*.

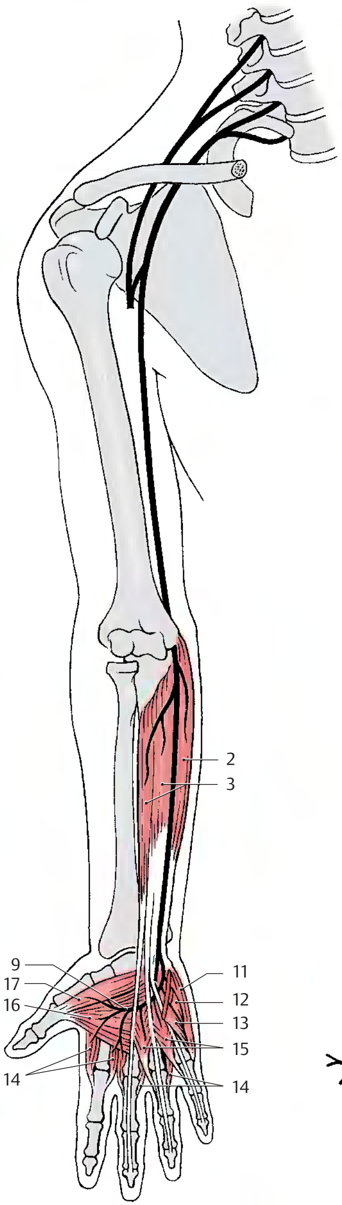
In the *forearm*, the nerve gives off branches (**C1**) to the ulnar flexor muscle of the wrist (**A2**) and to the ulnar half of the deep flexor muscle of the fingers (**A3**). A sensory branch, the **dorsal branch of the ulnar nerve** (**BC4**), branches off in the middle of the forearm and runs to the ulnar side of the back of the hand where it supplies the skin. As for the rest of the back of the hand, its area of innervation overlaps with that of the radial nerve. Another sensory branch, the **palmar branch of the ulnar nerve** (**BC5**), branches off in the distal third of the forearm. It extends to the palm and supplies the skin of the hypothenar eminence.

The **superficial branch** runs as **common palmar digital nerve IV** (**BC6**) toward the interdigital space between ring finger and little finger and divides into the **proper palmar digital nerves** (**BC7**), which supply sensory fibers to the volar aspects of the little finger and the ulnar side of the ring finger and reach to the distal phalanges on the extensor side of both fingers. There is a connection to a branch of the median nerve, called the communicating branch of the median nerve with the ulnar nerve (**C8**).

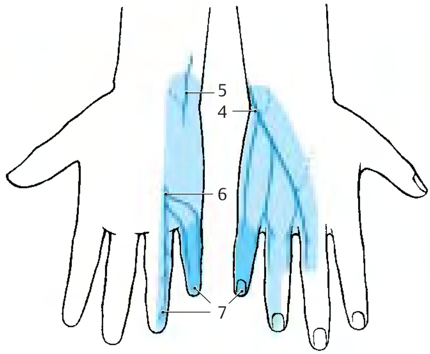
The **deep branch** (**AC9**) sinks into the depth of the palm and curves toward the thenar eminence. It gives off branches for all muscles of the hypothenar eminence (**C10**) (abductor muscle of fifth finger [**A11**], short flexor muscle of fifth finger [**A12**], opposing muscle of fifth finger [**A13**]), for all dorsal and palmar interosseous muscles (**A14**), for the lumbrical muscles III and IV (**A15**), and finally, at the thenar eminence, for the abductor muscle of thumb (**A16**) and the deep head of the short flexor muscle of thumb (**A17**).

Clinical Note: Injury to the ulnar nerve causes the formation of a so-called **clawhand** (**D**), where the fingers are extended in the metacarpophalangeal joints but flexed in the proximal and distal interphalangeal joints. This characteristic posture of the fingers is caused by paralysis of the interosseous muscles and lumbrical muscles, which flex the phalanges in the metacarpophalangeal joints but extend them in the proximal and distal interphalangeal joints. Failure of the flexor muscles causes the fingers to remain in this posture due to the now predominant extensor muscles. Since the little finger and the adductors of the thumb are paralyzed, thumb and little finger can no longer touch each other.

Innervation of the skin (B). Autonomic zone (dark blue) and maximum zone (light blue).

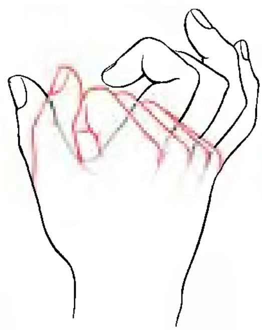


A Muscles supplied by the ulnar nerve (according to *Lanz-Wachsmuth*)



B Skin supplied by the ulnar nerve (according to *Lanz-Wachsmuth*)

C Sequence of branches



D Paralysis of the ulnar nerve (according to *Lanz-Wachsmuth*)

Infraclavicular Part (continued)

Medial Fascicle (continued) (A – C)

In addition to the ulnar nerve, the medial fascicle gives rise to the *medial cutaneous nerve of the arm* and the *medial cutaneous nerve of the forearm*; both are exclusively sensory nerves supplying the skin on the median side of the arm.

Medial cutaneous nerve of the arm (C8 – T1) **(A, B).** The nerve approaches the anterior surface of the upper arm below the axillary fossa. Here it ramifies and supplies the skin of the medial aspect between axilla and elbow joint. It reaches to the flexor side with its anterior branches and to the extensor side of the upper arm with its posterior branches. Frequently, there are anastomoses to the intercostobrachial nerve.

Medial cutaneous nerve of the forearm (C8 – T1) **(A, C).** The nerve runs below the fascia on the ulnar side of the forearm and passes in the lower third through the fascia with two branches, the **anterior branch** (**AC1**) and the **ulnar branch** (**AC2**). The anterior branch supplies the medial flexor side of the forearm almost up to the midline, and the ulnar branch supplies the upper region of the medial extensor side almost up to the midline. The area innervated by the medial cutaneous nerve of the forearm extends slightly to the upper arm and to the hand.

Posterior Fascicle (D, F)

The posterior fascicle gives rise to the *axillary nerve* and the *radial nerve*.

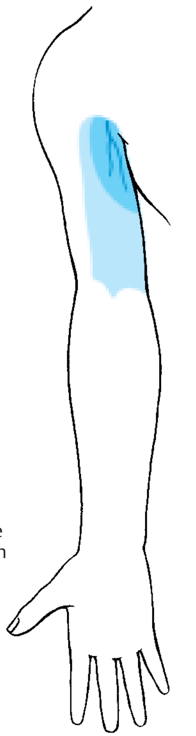
Axillary nerve (C5 – C6)**.** This runs deep inside the axilla and across the capsule of the shoulder joint around the surgical neck on the back of the humerus. It passes through the lateral axillary gap and extends beneath the deltoid muscle to the anterior margin of the latter.

Before the nerve trunk passes through the lateral axillary gap, it gives off a motor branch (**DF3**) to the lesser teres muscle (**D4**), which also passes through the lateral axillary gap. At the same level, the *superior lateral cutaneous nerve of the arm* (**D – F5**) branches off and reaches the skin at the posterior margin of the deltoid muscle, where it supplies the skin of the lateral aspects of shoulder and upper arm. From the nerve trunk extending beneath the deltoid muscle to the front, numerous branches (**D6**) to the deltoid muscle (**D7**) branch off and supply its various parts.

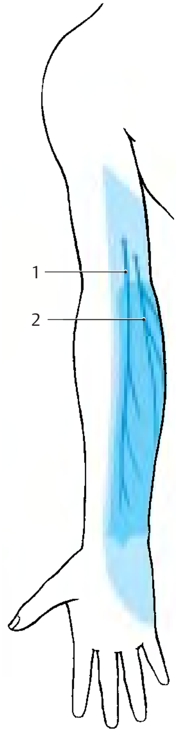
Clinical Note: As a result of its location on the capsule of the shoulder joint, the nerve can be injured by dislocation of the humerus or by humeral neck fracture. This causes anesthesia in the skin area over the deltoid muscle.

Innervation of the skin (B, C, E). Autonomic zone (dark blue) and maximum zone (light blue).

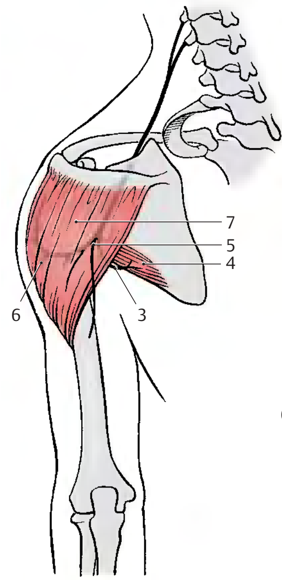
A Sequence of branches of the medial cutaneous nerve of the arm and of the medial cutaneous nerve of the forearm



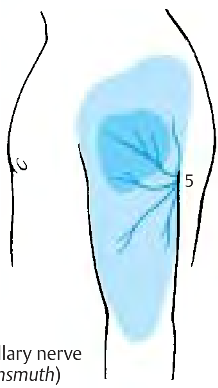
B Skin supplied by the medial cutaneous nerve of the arm (according to *Lanz-Wachsmuth*)



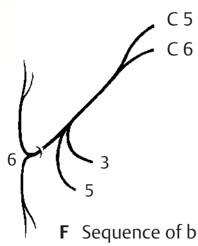
C Skin supplied by the medial cutaneous nerve of the forearm (according to *Lanz-Wachsmuth*)



D Muscles supplied by the axillary nerve



E Skin supplied by the axillary nerve (according to *Lanz-Wachsmuth*)



F Sequence of branches

Infraclavicular Part (continued)

Posterior Fascicle (continued) (A – D)

Radial nerve (C5 – C8) **(A – C).** The main nerve of the posterior cord supplies the *extensor muscles of upper arm and forearm.*

The nerve trunk extends from the axilla into the proximal third of the medial bicipital sulcus and then spirals around the dorsal surface of the humerus, to which it is directly apposed in the *sulcus of the radial nerve*. In the distal third of the upper arm, it passes to the flexor side between brachial muscle and brachioradial muscle. In the sulcus of the radial nerve, the nerve can easily be injured by pressure or by bone fractures because of its proximity to the bone. The nerve crosses the elbow joint on the flexor side and divides at the level of the head of radius into two terminal branches, the *superficial branch* and the *deep branch*. The superficial branch continues in the forearm on the medial surface of the brachioradial muscle and then runs in the lower third between brachioradial muscle and radius to the extensor side in order to reach the back of the hand. The deep branch obliquely penetrates the supinator muscle, gives off numerous muscular branches, and extends as the thin *posterior interosseous nerve of the forearm* to the wrist.

For the upper arm, the radial nerve gives off the **posterior cutaneous nerve of the arm** (**A** – **C1**), which supplies a skin area on the extensor side of the upper arm with sensory fibers, and the **inferior lateral cutaneous nerve of the arm** (**A** – **C2**). In the middle third of the upper arm, it gives off *muscular branches* (**AC3**) for the long head, the lateral head, and the medial head of the triceps muscle (**A4**). The branch for the medial head gives off also the branch for the anconeus muscle (**A5**).

The *posterior cutaneous nerve of the forearm* (**A** – **C6**) branches off in the region of the upper arm; it supplies a strip of skin on the radial extensor side of the forearm. At the level of the lateral epicondyle, *muscular branches* (**C7**) extend to the brachioradial muscle (**A8**) and to the long radial extensor muscle of the wrist (**A9**). The nerve trunk then ramifies into its two major branches in the forearm.

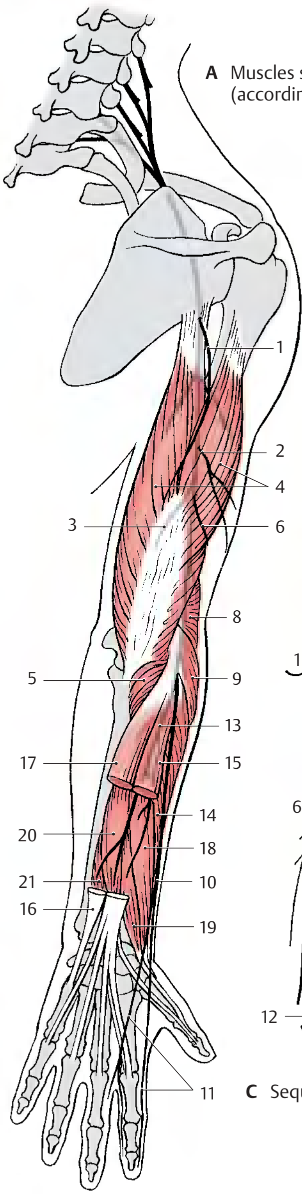
At the back of the hand, the **superficial branch** (**A** – **C10**) gives off the **dorsal digital nerves** (**A** – **C11**); they supply sensory fibers to the radial back of the hand, the extensor side of the thumb, the proximal phalanges of index and middle fingers, and the radial half of the extensor side of the ring finger. The ulnar communicating branch of the radial nerve connects with the ulnar nerve (**C12**).

The **deep branch** (**AC13**) gives off *muscular branches* to the short radial extensor muscle of the wrist (**A14**) and to the supinator muscle, while passing through the supinator muscle. Thereafter, it gives off motor branches to the hand extensor muscles, namely, to the common extensor muscle of the fingers (**A15**), the extensor muscle of the little finger (**A16**), the ulnar extensor muscle of the wrist (**A17**), the long abductor muscle of the thumb (**A18**), and the short extensor muscle of the thumb (**A19**). Finally, the terminal branch of the deep branch, the **posterior interosseous nerve**, gives off branches to the long extensor muscle of the thumb (**A20**) and to the extensor muscle of the index finger (**A21**).

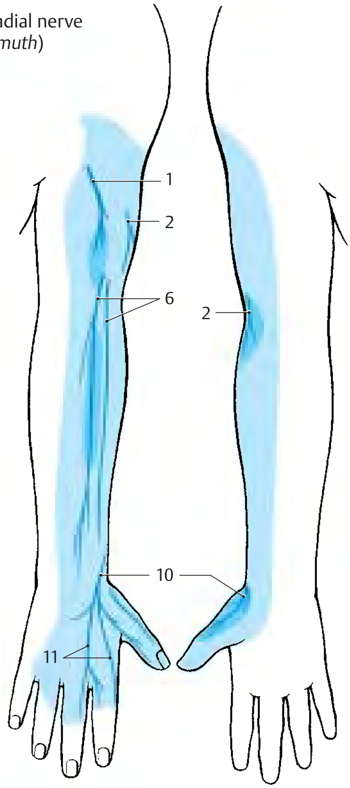
The nerve sends sensory branches to the shoulder joint and wrist.

Clinical Note: Injury to the main nerve trunk in the area of the upper arm results in paralysis of the extensor muscles. This mainly affects the hand, leading to the so-called **wristdrop** (**D**) characteristic for radial paralysis: extension is possible neither in the wrist nor in the fingers, thus making the hand drop down limply.

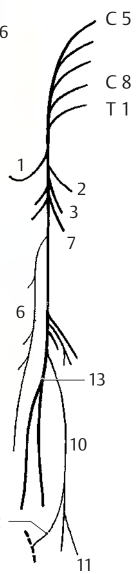
Innervation of the skin (B). Autonomic zone (dark blue) and maximum zone (light blue).



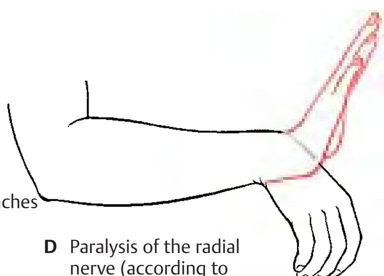
A Muscles supplied by the radial nerve (according to *Lanz-Wachsmuth*)



B Skin supplied by the radial nerve (according to *Lanz-Wachsmuth*)



C Sequence of branches



D Paralysis of the radial nerve (according to *Lanz-Wachsmuth*)

Nerves of the Trunk

In the trunk region, the original metamerism of the body can still be recognized through the arrangement of the ribs and their intercostal muscles. The thoracic nerves, too, fit in well with this segmental organization.

Each of the *twelve thoracic spinal nerves* divides into a **posterior branch** (**A1**) and an **anterior branch** (**A2**).

Posterior Branches (A, D)

Each posterior branch divides into a *medial* and a *lateral branch*. Both supply motor fibers to the deep autochthonous back muscles. Sensory innervation of the back comes mainly from the lateral branches of the posterior branches (**AD3**). The area supplied by the posterior branches of cervical spinal nerves expands widely and includes the occiput (**greater occipital nerve**) (**D4**). In the lumbar region, sensory innervation of the back comes from the posterior branches of the lumbar spinal nerves L1 – L3 and the sacral spinal nerves S1 – S3 (**superior cluneal nerves** [**D5**] and **medial cluneal nerves** [**D6**]).

Anterior Branches (A – D)

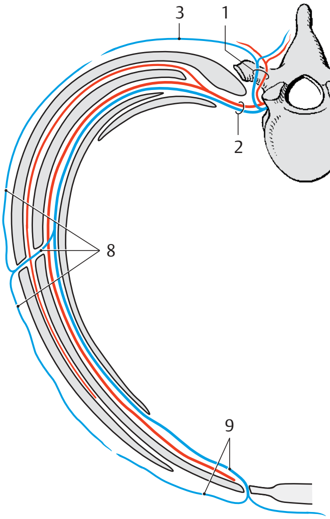
The anterior branches of the spinal thoracic nerves run as **intercostal nerves** between the ribs, initially on the inner surface of the thorax and later within the internal intercostal muscles. We distinguish between an upper group and a lower group of intercostal nerves.

The **nerves of the upper group** (T1 – T6) run up to the sternum and supply the intercostal muscles (**C7**), the superior and inferior posterior serrate muscles, and the transverse thoracic muscle. They give off sensory branches to the skin of the thorax, namely, the **lateral cutaneous branches** (**AD8**) at the anterior margin of the anterior serrate muscle, which further divide into anterior and posterior branches, and the **anterior cutaneous branches** (**AD9**) close to the sternum, which also divide into anterior and posterior branches. The lateral and medial cutaneous branches of anterior branches 4 – 6, which extend to the area of the mammary gland, are referred to as *lateral and medial mammary branches*.

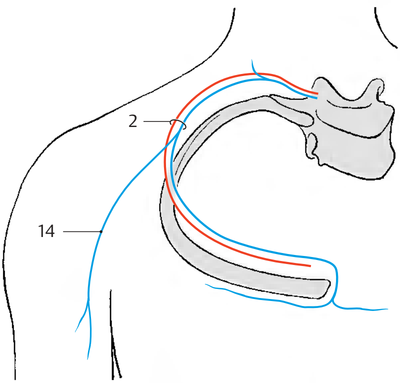
The **nerves of the lower group** (T7 – T12), the intercostal segments of which no longer end at the sternum, extend across the costal cartilages up to the white line. They take an increasingly oblique downward path and supply the muscles of the abdominal wall (abdominal transverse muscle [**C10**], external [**C11**] and internal [**C12**] abdominal oblique muscles, rectus abdominis muscle [**C13**] and pyramidal muscle).

Special features. Intercostal nerve 1 participates in forming the brachial plexus and sends only a thin branch to the intercostal space. Intercostal nerve 2 (and often 3 as well) gives off its *lateral cutaneous branch* to the upper arm (**intercostobrachial nerve**) (**B14**), where it connects with the *medial cutaneous nerve of the arm*. The last intercostal nerve running beneath the twelfth rib is referred to as the **subcostal nerve;** it runs obliquely downward across the iliac crest.

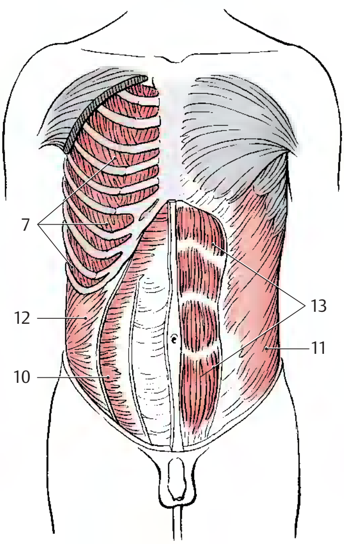
The inguinal region and hip region receive their sensory innervation from the uppermost branches of the lumbar plexus, namely, from the **iliohypogastric nerve** (**D15**) (lateral branch and anterior branch), from the **ilioinguinal nerve** (**D16**), and from the **genitofemoral nerve** (genital branch [**D17**, femoral branch [**D18**]).



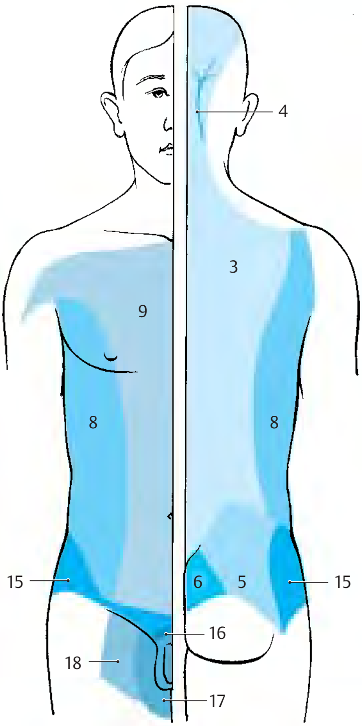
A Course of a thoracic nerve



B Intercostobrachial nerve



C Muscles supplied by the intercostal nerves



D Innervation of the skin of the trunk

Lumbosacral Plexus (A)

The lumbosacral plexus is formed by the *anterior branches* of the lumbar and sacral spinal nerves. Its branches provide sensory and motor innervation to the lower limb. The branches of L1 – L3 and part of L4 form the **lumbar plexus**, the roots of which lie within the psoas muscle. The **obturator nerve** (**A1**) and the **femoral nerve** (**A2**) originate from here, in addition to several short muscular branches. The remainder of the fourth lumbar nerve and the L5 nerve join to form the **lumbosacral trunk** (**A3**), which then unites in the small pelvis with sacral branches 1 – 3 to form the **sacral plexus**. The sacral branches emerge from the anterior sacral foramina of the sacrum and form together with the lumbosacral trunk the sacral plexus; the main nerves originating from here are the **sciatic nerve** (**A4**) (**common peroneal nerve** [**A5**] and **tibial nerve** [**A6**]).

Lumbar Plexus

The lumbar plexus gives off direct short *muscular branches* to the hip muscles, namely, to the greater and lesser psoas muscles (L1 – L5), the lumbar quadrate muscle (T12 – L3), and the lumbar intercostal muscles. The upper nerves of the plexus are still roughly organized in the same way as the intercostal nerves. Together with the *subcostal nerve* (**A7**), they represent transitional nerves between the intercostal nerves and the lumbar nerves.

Iliohypogastric Nerve (T12, L1)

The *iliohypogastric nerve* (**A8**) initially runs on the inside of the lumbar quadrate muscle along the dorsal aspect of the kidney and then between the abdominal transverse muscle and the internal oblique muscle of the abdomen. It participates in the innervation of the broad abdominal muscles. It gives off two main branches, namely, the lateral cutaneous branch which supplies the lateral hip region, and the anterior cutaneous branch which penetrates the aponeurosis of the external oblique muscle of the abdomen cranially to the outer inguinal ring and supplies the skin of this region as well as the pubic region (p. 84, D15; p. 96, C16).

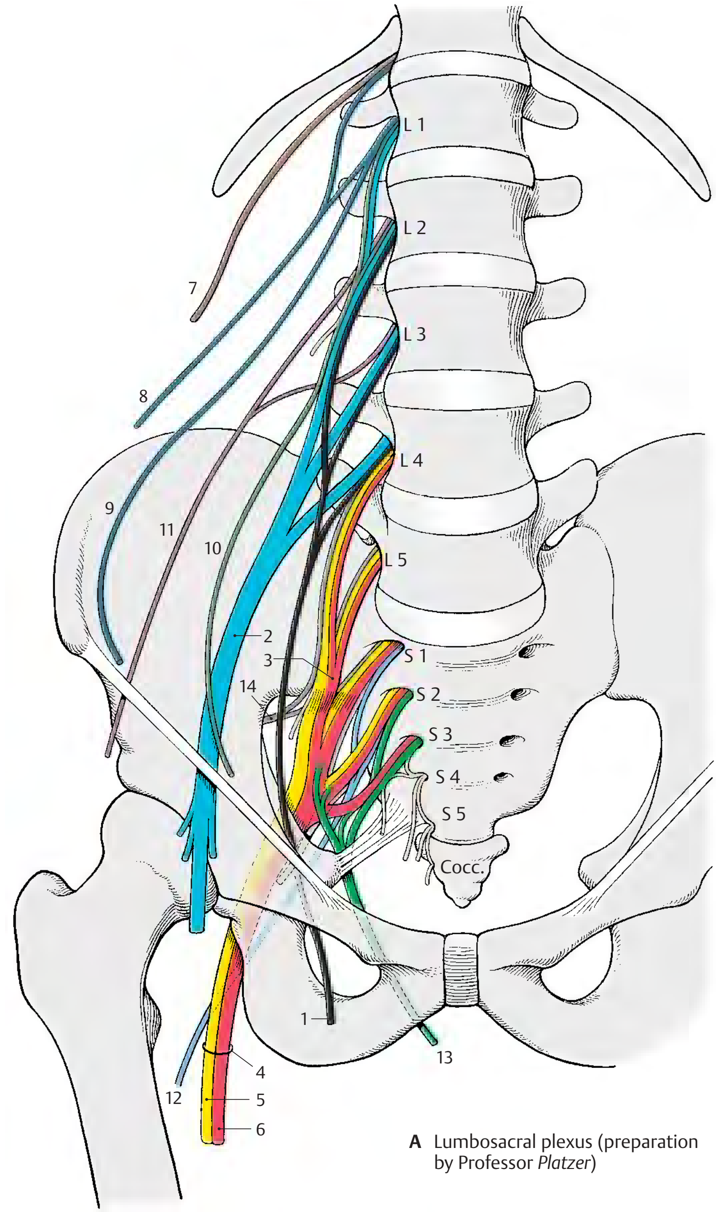
Ilioinguinal Nerve (L1)

The *ilioinguinal nerve* (**A9**) runs along the inguinal ligament and inguinal canal with the spermatic cord up to the scrotum, or with the round ligament of the uterus up to the greater lips in the female, respectively. It participates in the innervation of the broad abdominal muscles and supplies sensory fibers to the skin of the mons pubis and the upper part of the scrotum, or labia majora, respectively (p. 84, D16).

Genitofemoral Nerve (L1, L2)

The *genitofemoral nerve* (**A10**) divides already in, or on, the psoas muscle into two branches, the **genital branch** and the **femoral branch**. The *genital branch* runs in the abdominal wall along the inguinal ligament through the inguinal canal and reaches the scrotum with the spermatic cord or, in the female, the labia majora with the round ligament of the uterus. It innervates the cremaster muscle and supplies sensory fibers to the skin of the scrotum, or the labia majora, respectively, and the adjacent skin area of the thigh (p. 84, D17; p. 96, C15). The *femoral branch* continues to below the inguinal ligament and becomes subcutaneous in the saphenous hiatus. It supplies the skin of the thigh lateral to the region of the genital branch (p. 84, D18).

A11 Lateral cutaneous nerve of femur (p. 88, A).
A12 Posterior cutaneous nerve of femur (p. 90, D).
A13 Pudendal nerve (p. 96, AB1).
A14 Superior gluteal nerve (p. 90, E).



A Lumbosacral plexus (preparation by Professor *Platzer*)

Lumbar Plexus (continued)

Lateral Cutaneous Nerve of Thigh (L2 – L3) (A)

The nerve runs over the iliac muscle to below the superior anterior iliac spine. It then extends underneath the inguinal ligament through the lateral part of the muscular lacuna to the outer aspect of the thigh and passes through the fascia lata to the skin. The nerve is exclusively sensory and supplies the skin of the lateral aspect of the thigh down to the level of the knee.

Femoral Nerve (L1 – L4) (B – D)

The nerve runs along the margin of the greater psoas muscle up to the inguinal ligament and underneath it through the muscular lacuna to the front of the thigh. The nerve trunk divides below the inguinal ligament into several branches, namely, a mostly sensory group, the **anterior cutaneous branches** (**B – D1**), a lateral and medial group of motor branches for the extensor muscles of the thigh, and the *saphenous nerve* (**B – D2**). The saphenous nerve extends to the adductor canal and enters into it. It penetrates the vastoadductor membrane and runs along the medial side of the knee joint and the lower leg together with the great saphenous vein down to the medial ankle.

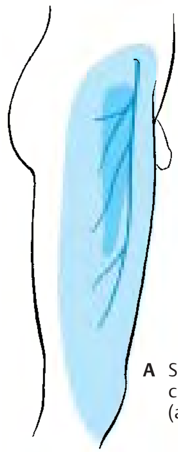
In the small pelvis, the femoral nerve gives off fine branches (**D3**) to the greater psoas muscle (**B4**) and to the iliac muscle (**B5**). Below the inguinal ligament, a branch (**D6**) extends to the pectineal muscle (**B7**). The *anterior cutaneous branches* (**B – D1**) originate slightly more distally, with the strongest one continuing along the middle of the thigh down to the knee. They supply sensory fibers to the skin of the anterior and medial aspects of the thigh.

The lateral group of branches (**D8**) consists of **muscular branches** for the sartorius muscle (**B9**), the rectus femoris muscle (**B10**), the lateral vastus muscle (**B11**), and the intermediate vastus muscle (**B12**). The muscular branch (**D13**) for the medial vastus muscle (**B14**) runs along the medial margin of the sartorius muscle. The muscular branches always ramify into several branches for the proximal and distal portions of the muscles. The muscular branches also give off fine sensory branches to the capsule of the knee joint and the periosteum of the tibia. Fibers from the branch for the medial vastus muscle extend to the femoral artery and femoral vein.

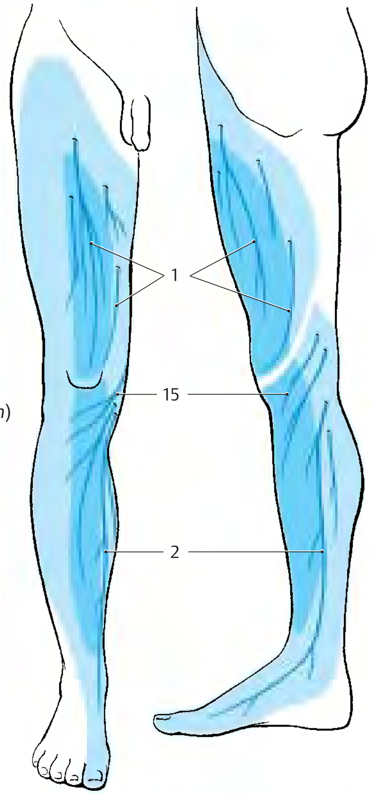
The **saphenous nerve** (**CD2**) is exclusively sensory. Below the knee joint, it gives off the *infrapatellar branch* (**B – D15**) which supplies the skin below the patella. The remaining branches, the *medial crural cutaneous branches*, supply the skin of the anterior and medial aspects of the lower leg. The supplied area extends on the anterior side over the edge of the tibia and may reach to the great toe along the medial aspect of the foot.

Clinical Note: Injury to the femoral nerve makes it impossible to extend the leg in the knee joint. Flexion in the hip joint is reduced, and the patellar tendon reflex is absent.

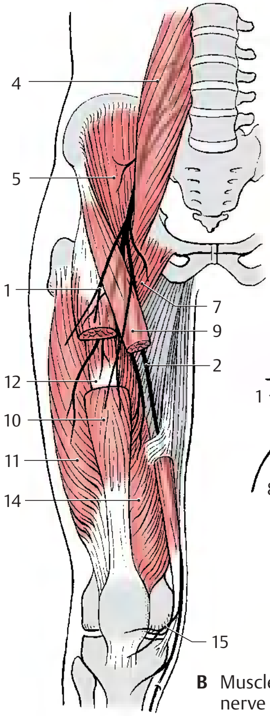
Innervation of the skin (A, C). Autonomic zone (dark blue) and maximum zone (light blue).



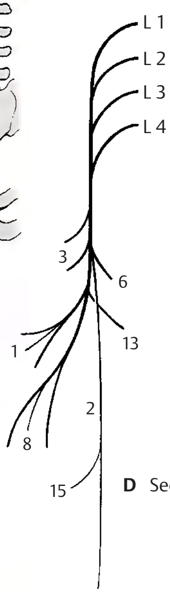
A Skin supplied by the lateral cutaneous nerve of thigh (according to *Lanz-Wachsmuth*)



C Skin supplied by the femoral nerve (according to *Lanz-Wachsmuth*)



B Muscles supplied by the femoral nerve (according to *Lanz-Wachsmuth*)



D Sequence of branches

Lumbar Plexus (continued) (A – C)

Obturator Nerve (L2 – L4)

The nerve provides motor innervation to the **adductor muscles** of the thigh. Medial to the greater psoas muscle, it extends along the lateral wall of the small pelvis down to the obturator canal through which it passes to reach the thigh. It gives off a muscular branch to the external obturator muscle (**AB1**) and then divides into a superficial branch and a deep branch. The **superficial branch** (**AB2**) runs between the long adductor muscle (**A3**) and short adductor muscle (**A4**) and innervates both. The nerve also gives off branches to the pectineal muscle and the gracilis muscle (**A5**) and finally terminates in a *cutaneous branch* (**A – C6**) to the distal region of the medial aspect of the thigh. The **deep branch** (**AB7**) runs along the external obturator muscle and then down to the great adductor muscle (**A8**).

Clinical Note: Paralysis of the obturator nerve (for example, as a result of pelvic fracture) causes loss of adductor muscle function. This restricts standing and walking, and the affected leg can no longer be crossed over the other leg.

Sacral Plexus (D – F)

The *lumbosacral trunk* (parts of L4 and L5) and the anterior branches of S1 – S3 join on the anterior surface of the piriform muscle to form the sacral plexus. Direct branches extend from the plexus to the muscles of the pelvic region, namely, to the piriform muscle, the gemellus muscles (**F9**), the internal obturator muscle, and the quadrate muscle of thigh (**F10**).

Superior Gluteus Nerve (L4 – S1) (E)

The nerve extends across the upper margin of the piriform muscle in dorsal direction through the suprapiriform foramen to the gluteus medius (**E11**) and minimus (**E12**) muscles and supplies both with motor fibers. The nerve continues between the two muscles to the tensor muscle of the fascia lata (**E13**).

Clinical Note: Paralysis of the nerve weakens abduction of the leg. Standing on the affected leg and lifting the healthy leg makes the pelvis of the other side drop (*Trendelenburg's symptom*).

Inferior Gluteus Nerve (L5 – S2) (F)

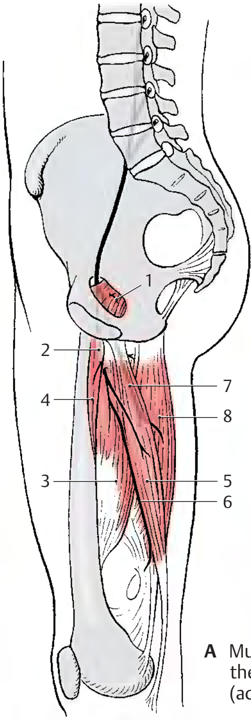
The nerve leaves the pelvis through the infrapiriform foramen and gives off several branches to the gluteus maximus muscle (**F14**).

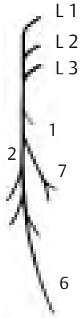
Clinical Note: Paralysis of the nerve weakens extension of the hip joint (for example, when standing up or climbing stairs).

Posterior Cutaneous Nerve of Thigh (S1 – S3) (D)

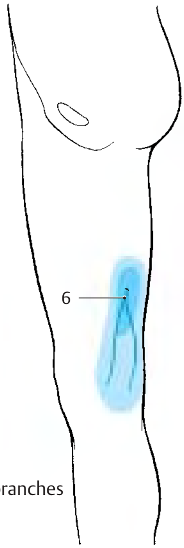
The nerve leaves the pelvis together with sciatic nerve and inferior gluteus nerve through the infrapiriform foramen and reaches below the gluteus maximus muscle to the posterior aspect of the thigh. Located directly beneath the fascia lata, it extends along the middle of the thigh into the popliteal fossa. This exclusively sensory nerve gives off branches to the lower part of the buttock, the **inferior cluneal nerves**, and to the perineal region, the **perineal branches**. It provides sensory innervation to the posterior aspect of the thigh from the lower buttock region into the popliteal fossa and reaches to the proximal aspect of the lower leg.

Innervation of the skin (C, D). Autonomic zone (dark blue) and maximum zone (light blue).



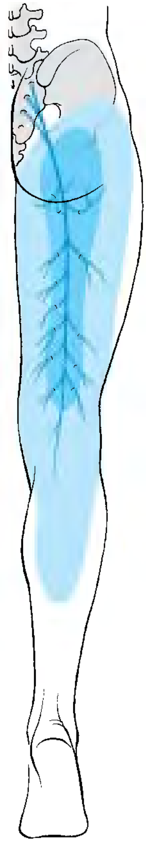


B Sequence of branches

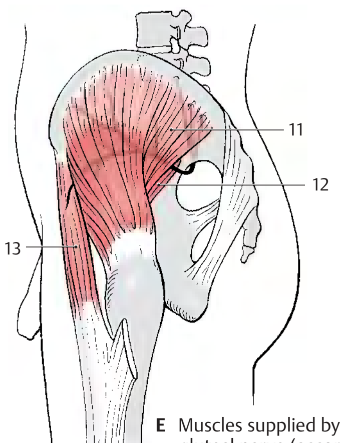


C Skin supplied by the obturator nerve (according to *Lanz-Wachsmuth*)

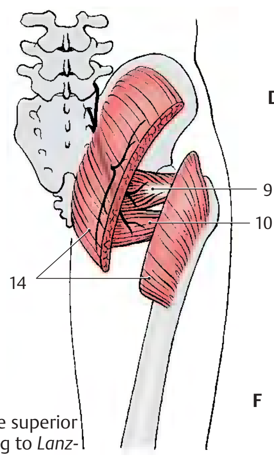
A Muscles supplied by the obturator nerve (according to *Lanz-Wachsmuth*)



D Skin supplied by the posterior cutaneous nerve of thigh (according to *Lanz-Wachsmuth*)



E Muscles supplied by the superior gluteal nerve (according to *Lanz-Wachsmuth*)



F Muscles supplied by the inferior gluteal nerve (according to *Lanz-Wachsmuth*)

Sacral Plexus (continued)

Sciatic Nerve (L4 – S3) **(A – C)**

The nerve has two components, the **common peroneal nerve** (*common fibular nerve*) and the **tibial nerve**; they appear as a uniform nerve trunk (**AC1**) because they are surrounded by a common connective-tissue sheath in the small pelvis and in the thigh. The sciatic nerve leaves the pelvis through the infrapiriform foramen and extends beneath the gluteus maximus muscle and biceps muscle along the posterior aspects of the internal obturator muscle, the quadrate muscle of femur, and the great adductor muscle in the direction of the knee joint. Peroneal nerve and tibial nerve separate above the knee joint. In the pelvis within the connective tissue sheath, the peroneal nerve is on the top and the tibial nerve below. In the thigh, the peroneal nerve lies laterally and the tibial nerve medially. However, both may run completely separately, in which case only the tibial nerve passes through the infrapiriform foramen, while the peroneal nerve penetrates the piriform muscle.

Common peroneal nerve (common fibular nerve) (L4 – S2). In the thigh, the peroneal part **(AC2)** of the sciatic nerve gives off a muscular branch to the short head of the biceps muscle of the thigh (**A3**).

After division of the sciatic nerve, the common peroneal nerve extends along the biceps muscle at the lateral edge of the popliteal fossa to the head of the fibula. It then winds around the neck of the fibula to the anterior aspect of the lower leg and enters into the long peroneal (fibular) muscle. The common peroneal nerve divides within this muscle into the *superficial peroneal nerve* (**AC4**) and the *deep peroneal nerve* (**AC5**). The superficial peroneal nerve is predominantly sensory and runs between the long peroneal muscle and the fibula to the back of the foot. The deep peroneal nerve is predominantly a motor nerve; it turns toward the front to the extensor muscles of the lower leg and extends on the lateral surface of the anterior tibial muscle to the back of the foot.

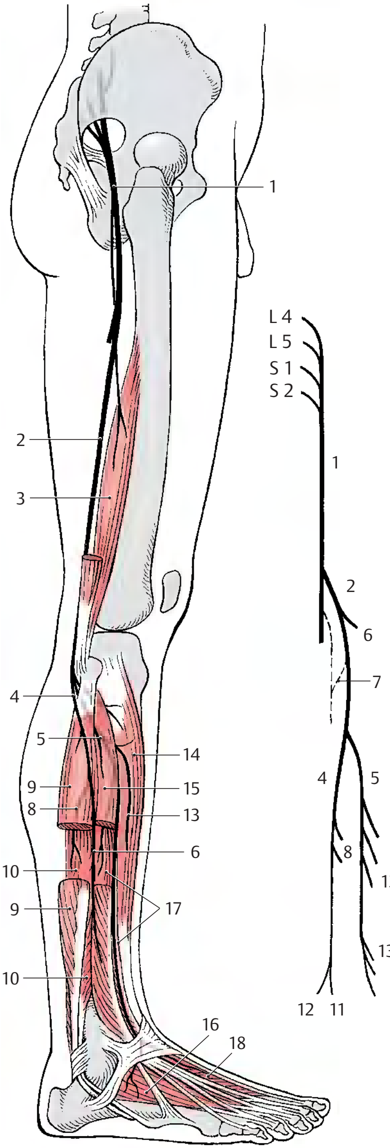
At the lateral margin of the popliteal fossa, the common peroneal nerve gives off two main branches for the skin, the **lateral sural cutaneous nerve** (**A – C6**), which supplies the skin at the lateral aspect of the lower leg, and the **fibular communicating branch** (**C7**), which joins the *medial sural cutaneous nerve* to form the *sural nerve*.

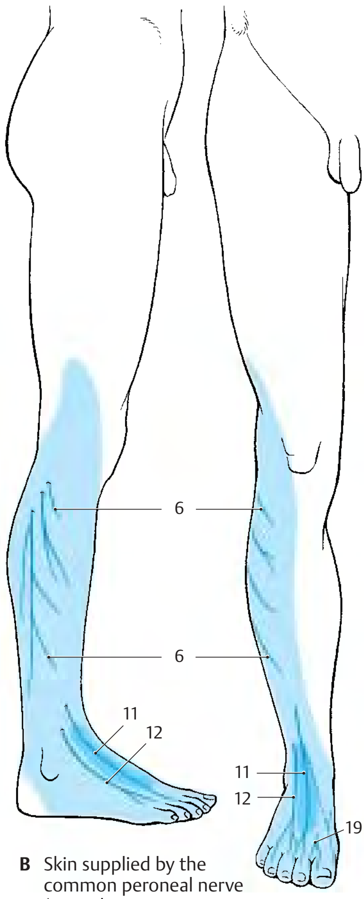
The **superficial peroneal nerve** gives off *muscular branches* (**AC8**) to the long (**A9**) and short (**A10**) peroneal muscles. The rest of the nerve is exclusively sensory; it ramifies into terminal branches, the **medial dorsal cutaneous nerve** (**BC11**) and the **intermediate dorsal cutaneous nerve** (**BC12**), which supply the skin of the back of the foot except for the interdigital space between great toe and second toe.

The **deep peroneal nerve** gives off several muscular branches (**AC13**) to the extensor muscles of the lower leg and the foot, namely, to the anterior tibial muscle (**A14**), the long (**A15**) and short (**A16**) extensor muscles of toes, and the long (**A17**) and short (**A18**) extensor muscles of the great toe. The terminal branch is sensory and supplies the apposing skin surfaces of the interdigital space between great toe and second toe (**B19**).

Clinical Note: Injury to the nerve affects the extensor muscles of the foot. The foot can no longer be lifted in the ankle joint. When walking, the foot hangs down and the toes drag along the floor. The leg must be lifted higher than normal, resulting in the so-called *steppage gait*.

Innervation of the skin (B). Autonomic zone (dark blue) and maximum zone (light blue).





B Skin supplied by the common peroneal nerve (according to *Lanz-Wachsmuth*)

C Sequence of branches

A Muscles supplied by the common peroneal nerve (according to *Lanz-Wachsmuth*)

Sacral Plexus (continued)

Sciatic Nerve (continued) (A–D)

Tibial nerve (L4–S3). Several *motor branches* (**AC1**) originate from the tibial portion of the sciatic nerve, namely, those for the proximal and distal parts of the semitendinous muscle (**A2**), for the long head of the biceps muscle (**A3**), and a branch dividing further for the semimembraneous muscle (**A4**) and the medial part of the great adductor muscle (**A5**).

After the division of the sciatic nerve, the tibial nerve descends vertically through the middle of the popliteal fossa and underneath the gastrocnemius muscle. It then lies under the tendinous arch of the soleus muscle and, further distal, between the long flexor muscle of the great toe and the long flexor muscle of toes. It extends between the tendons of both muscles to the back of the medial ankle and winds around it. Below the ankle, it divides into two terminal branches, the *medial plantar nerve* and the *lateral plantar nerve*.

The **medial sural cutaneous nerve** (**C6**) branches off in the popliteal fossa; it descends between the two heads of the gastrocnemius muscle and joins the communicating branch of the peroneal nerve to form the **sural nerve** (**BC7**). The latter extends laterally from the Achilles tendon behind the lateral ankle and around it to the lateral aspect of the foot. It gives off the **lateral calcaneal branches** (**BC8**) to the skin of the lateral side of the heel and the **lateral dorsal cutaneous nerve** (**BC9**) to the lateral aspect of the foot.

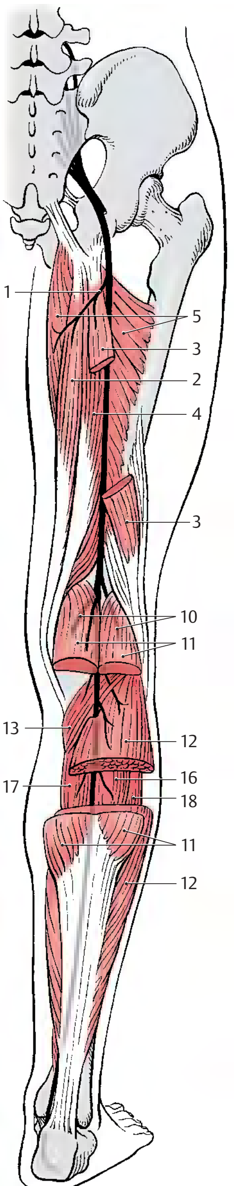
Also in the popliteal fossa, *motor branches* (**AC10**) go off to the flexor muscles of the lower leg, namely, to the two heads of the gastrocnemius muscle (**A11**), to the soleus muscle (**A12**), to the plantar muscle and the popliteal muscle (**A13**). The *popliteal branch* gives rise to the *interosseous nerve of the leg* (**C14**), which runs along the dorsal surface of the interosseous membrane and provides sensory innervation to the periosteum of the tibia, the upper ankle joint, and the tibiofibular joint. The tibial nerve gives off *muscular branches* (**C15**) to the posterior tibial muscle (**A16**), the long flexor muscle of toes (**A17**), and the long flexor muscle of the great toe (**A18**). Before the nerve trunk ramifies into terminal branches, it sends off the **medial calcaneal branches** (**B19**) to the medial skin area of the heel.

The medial of the two terminal branches, the **medial plantar nerve** (**CD20**), innervates the abductor muscle of the great toe (**D21**), the short flexor muscle of toes (**D22**), and the short flexor muscle of the great toe (**D23**). Finally, it divides into the three **common plantar digital nerves** (**BC24**), which supply lumbrical muscles 1 and 2 (**D25**) and divide further into the proper plantar digital nerves (**BC26**) for the skin of the interdigital spaces from the great toe up to the fourth toe.

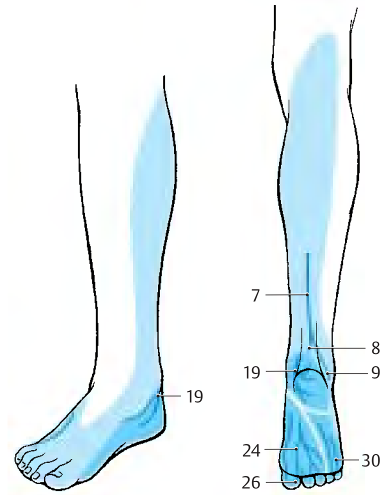
The second terminal branch, **lateral plantar nerve** (**CD27**), divides into a **superficial branch** (**C28**) with the *common plantar digital nerves* (**C29**) and *proper plantar digital nerves* (**BC30**) for the skin of the little toe area and into a **deep branch** (**CD31**) with the *muscular branches* for the interosseous muscles (**D32**), the adductor muscle of great toe (**D33**) and the three lateral lumbrical muscles. **D34**, short flexor muscle of the little toe.

Clinical Note: Injury of the tibial nerve leads to paralysis of the flexor muscles of toes and foot. The foot can no longer be moved in plantar direction: tiptoeing becomes impossible.

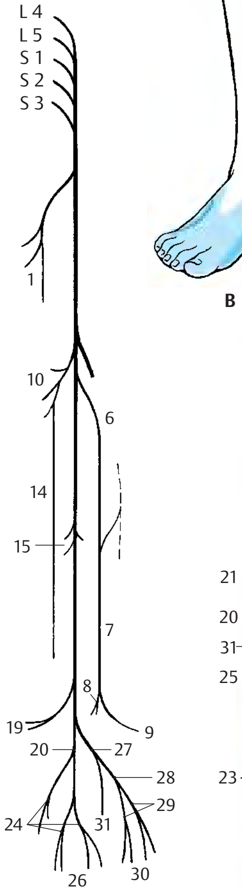
Innervation of the skin (B). Autonomic zone (dark blue) and maximum zone (light blue).



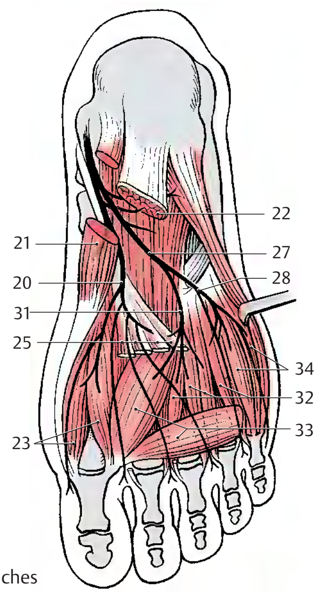
A Muscles supplied by the tibial nerve (according to *Lanz-Wachsmuth*)



B Skin supplied by the tibial nerve (according to *Lanz-Wachsmuth*)



C Sequence of branches



D Foot muscles supplied by the tibial nerve (according to *Lanz-Wachsmuth*)

Sacral Plexus (continued)

Pudendal Nerve (S2 – S4) (A, B)

The pudendal nerve (**AB1**) leaves the pelvis through the infrapiriform foramen (**AB2**), extends dorsally around the sciatic spine (**AB3**) and passes through the lesser sciatic foramen (**AB4**) into the ischioanal fossa. It then runs along the lateral wall of the fossa within the *pudendal canal* (*Alcock's canal*) to below the symphysis, sending its terminal branch to the dorsal side of the penis or clitoris, respectively.

Numerous branches are given off in the pudendal canal; the **inferior rectal nerves** (**A – C5**), which may also originate directly from the second to fourth sacral nerves, penetrate through the wall of the canal to the perineum and supply motor fibers to the external sphincter muscle of anus (**AB6**) and sensory fibers to the skin around the anus as well as the lower two-thirds of the anal canal.

The **perineal nerves** (**AB7**) subdivide into deep and superficial branches. The deep branches participate in the innervation of the external sphincter muscle of the anus. More superficially, they supply the bulbocavernous muscle, the ischiocavernous muscle, and the superficial transverse perineal muscle. The superficial branches supply sensory fibers to the posterior part of the scrotum (posterior scrotal nerves) (**AC8**) in males and to the labia majora (posterior labial nerves) (**BC9**) in females. They also supply the mucosa of the urethra and the bulb of penis in males, and the external urethral opening and the vestibule of vagina in females.

The terminal branch, the **dorsal nerve of the penis** (**A10**) or **dorsal nerve of the clitoris** (**B11**), respectively, sends motor branches to the deep transverse perineal muscle, the deep sphincter muscle, and the sphincter muscle of urethra (**B12**). After passing through the urogenital diaphragm (**AB13**), it gives off a branch to the cavernous body of the penis in males, and to the cavernous body of the clitoris in females. In males, the nerve runs along the dorsum of the penis and gives off sensory branches to the skin of the penis and the glans. In females, it supplies sensory fibers to the clitoris including the glans.

Muscular Branches (S3, S4)

The levator ani muscle and the coccygeal muscle are supplied directly by nerve branches from the sacral plexus.

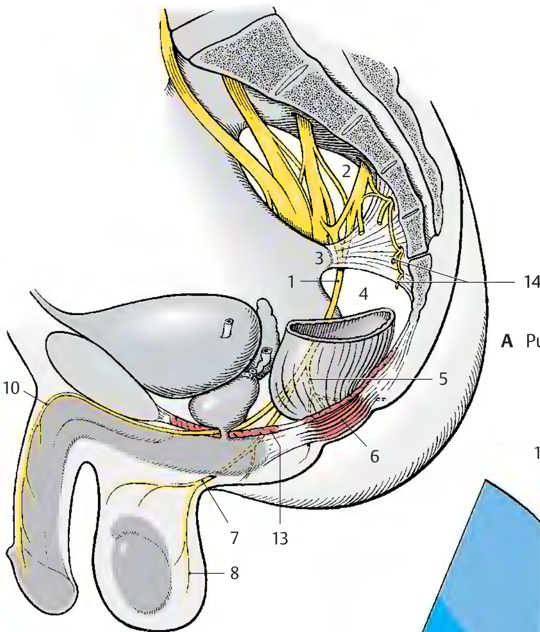
Coccygeal Plexus (S4 – Co) (A – C)

The anterior branches of the fourth and fifth sacral nerves form a fine plexus on the coccygeal muscle, the coccygeal plexus (**AB14**). The **anococcygeal nerves** originate from here; they supply sensory fibers to the skin over the coccyx and between coccyx and anus (**C14**).

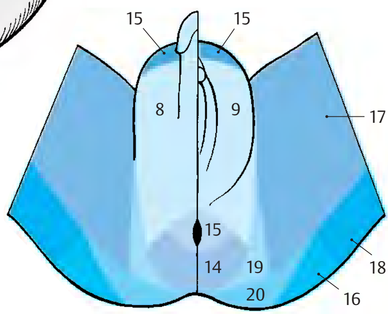
Sensory Innervation of Pelvis and Perineum (C)

In addition to the sacral and coccygeal nerves, the following nerves participate: the *ilioinguinal nerve* and the *genitofemoral nerve* (**C15**), the *iliohypogastric nerve* (**C16**), the *obturator nerve* (**C17**), the *posterior cutaneous nerve of the thigh* (**C18**), the *inferior cluneal nerves* (**C19**), and the *medial cluneal nerves* (**C20**).

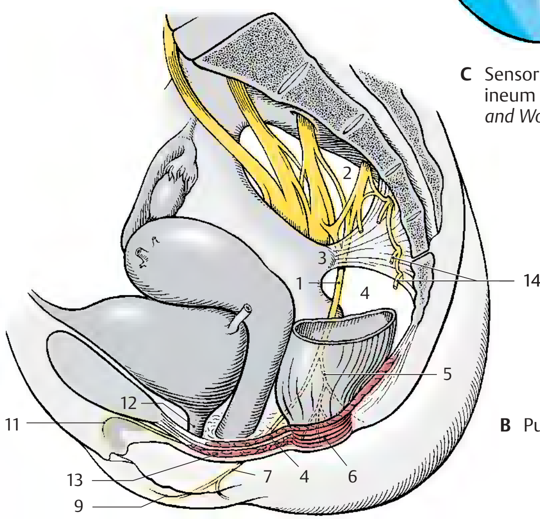
External openings of genitals, bladder, and rectum are border areas between involuntary smooth intestinal muscles and voluntary striated muscles. Accordingly, autonomic and somatomotor fibers are here intertwined. The pudendal nerve contains, apart from sensory, somatomotor, and sympathetic fibers, also parasympathetic fibers from the sacral spinal cord. Sympathetic fibers also originate as pelvic splanchnic nerves from the second to fourth sacral nerves.



A Pudendal nerve in the male



C Sensory innervation of the perineum (according to *Haymaker and Woodhall*)



B Pudendal nerve in the female