While the brain and the spinal cord make up the Central Nervous System (CNS), the Peripheral Nervous System (PNS) is comprised mainly of nerve fibers and ganglion cells. The two systems cannot be clearly distinguished from one another as they are functionally closely interlinked. The PNS conducts information from the CNS, via numerous nerve fibers, to the effector organs and vice versa. The cranial and spinal nerves belong to the PNS. In this article, we address the spinal nerves and the nerve plexuses that supply the extremities, namely the cervical and brachial plexus.
Spinal Nerves
Organisation and structure of the spinal nerves

From the spinal cord segments, the **ventral root** (*radix anterior*; efferent fibers) and **dorsal root** (*radix posterior*; afferent fibers) emerge and join in the **intervertebral foramen** to form the **spinal nerve**. Therefore, the spinal nerve contains both motor and sensory fibers. Altogether, 31 or 32 **spinal nerve pairs** leave the vertebral canal **caudally** from the respective vertebral body:

- **Neck**: 8 cervical nerve pairs (C1–C8)
- **Thorax**: 12 thoracic nerve pairs (T1–T12)
- **Loins**: 5 lumbar nerve pairs (L1–L5)
- **Sacrum**: 5 sacral nerve pairs (S1–S5)
- **Coccyx**: 1–2 coccygeal nerve pairs

**Exception**: Because there are only 8 cervical vertebrae, the nerve pairs exit **cranially** from the vertebrae.

Shortly after passing through the intervertebral foramen, the spinal nerve gives off a thin **meningeal branch** that runs back into the spinal canal and provides sensory innervation to the spinal meninges. Next, the spinal nerve divides into **anterior** and **posterior rami**.

While the posterior ramus divides into **medial and lateral branches**, which supply the skin of the back and the autochthonous back muscles, the anterior ramus innervates the **ventrolateral** body wall structures and the limbs and contributes to the **formation of plexuses**.

Furthermore, there is a connection to the sympathetic trunk via the 2 **rami communicantes**: the white ramus communicans appears white because of the **myelinated** fibers that lead to the sympathetic trunk, while the gray ramus communicans carries **unmyelinated** fibers from the sympathetic trunk to the spinal nerve, which cause the gray coloring.
Segmental vs. peripheral innervation

Each spinal cord segment supplies, with its spinal nerves, a certain part of the body (segmental or radicular innervation). In the thoracic wall, for example, intercostal nerves provide the motor and sensory innervation.

At the sensory level, the segmental innervation creates dermatomes: areas of the skin that can be assigned to the respective spinal cord segments. Only the C1 segment does not possess a dermatome because it consists of only motor fibers. In the thoracic area, the dermatomes lie in regular strips, one above the other.

**Note**: T10 corresponds approximately to the level of the navel; the boundary between T4 and T5 corresponds to the mamilla.

In the cervical, lumbar, and sacral regions; however, the anterior rami exchange fibers and intermix, thus forming the following nerve plexuses:

- Cervical plexus
- Brachial plexus
- Lumbar plexus
- Sacral plexus

Peripheral nerves emerge from the plexuses which each run to a supply area. Their last branches consist mostly of sensory skin nerves (peripheral innervation). The nerve fibers end in a segmental arrangement, so that the limb skin can also be divided into dermatomes.

**Note**: Segmental and peripheral innervations are not identical.
Knowledge of segmental and peripheral innervation is important for clinical practice because it can help to localize the damage in cases of sensory loss: if a dermatome is affected, damage is located at the level of the nerve root; if the sensory loss occurs in a peripheral area of the skin, the corresponding peripheral nerve will be damaged.

This is, for example, why shingles (herpes zoster) causes painful skin blistering in the corresponding dermatomes because the pathogenic virus (varicella) attacks dorsal root ganglions.
Autonomous zones and segment-indicating muscles of peripheral nerves

The innervation areas of neighboring peripheral nerves overlap at the edges, leading to a double innervation. There are skin areas, however, which are innervated by one peripheral nerve alone. These are known as autonomous zones.

<table>
<thead>
<tr>
<th>Examples of Autonomous Zones</th>
<th>Nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small finger</td>
<td>Ulnar nerve</td>
</tr>
<tr>
<td>First interdigital space</td>
<td>Deep peroneal nerve</td>
</tr>
<tr>
<td>Foot sole/heel</td>
<td>Tibial nerve</td>
</tr>
</tbody>
</table>

Examples of Autonomous Zones

The same applies to motor innervation: the innervation areas of neighboring spinal cord segments overlap so that the muscles receive information from several nerves. Muscles that are exclusively innervated by one spinal cord segment are called segment-indicating muscles.

<table>
<thead>
<tr>
<th>Segment-Indicating Muscle</th>
<th>Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoid muscle</td>
<td>C5</td>
</tr>
<tr>
<td>Biceps brachii muscle</td>
<td>(C5 –) C6</td>
</tr>
<tr>
<td>Triceps brachii muscle</td>
<td>C7</td>
</tr>
<tr>
<td>Interosseous muscles</td>
<td>C8</td>
</tr>
<tr>
<td>Quadriceps femoris muscle</td>
<td>(L3 –) L4</td>
</tr>
<tr>
<td>Tibialis muscle</td>
<td>L4</td>
</tr>
<tr>
<td>Extensor hallucis longus muscle</td>
<td>L5</td>
</tr>
<tr>
<td>Triceps surae muscle</td>
<td>S1 (~ S2)</td>
</tr>
</tbody>
</table>

Thus, it is possible to directly trace back the sensory loss in an autonomous zone or the malfunction of a segment-indicating muscle to the respective damaged nerve or spinal cord segment.
Cervical Plexus

The interjoining of nerves in the neck (cervical plexus) is formed by the anterior rami of the spinal nerves of segments C1–C4 and is located on the side of the transverse processes of the cervical spine between the prevertebral muscles (scaleneus and levator scapulae) and below the sternocleidomastoid muscle.

Sensory nerves of the cervical plexus

At the posterior edge of the sternocleidomastoid, the sensory branches of the cervical plexus emerge from the middle 3rd and come up to the surface (nerve point of the neck or Erb’s point) and innervate the head and neck region. The nerves are also known as cutaneous nerves and include:

- **Lesser occipital nerve** (C2, C3): lateral, the lower part of the back of the head (occiput) i.e., posterosuperior to the auricle.
- **Great auricular nerve** (C2, C3): bottom of the ear and back of the pinna (auricle)
- **Transverse cervical nerve** (C2, C3): lateral and ventral neck; anastomosis with the cervical branch of the facial nerve, thereby forming the ansa cervicalis
- **Supraclavicular nerves** (C3, C4): shoulder and upper chest area

Note: Because of the joint outlet of sensory nerves at Erb’s point, anesthesia of the entire skin surface of the neck and nape of the corresponding side can be administered here.
Motor Nerves of the Cervical Plexus

They are nerves that supply various muscles. They include:

- The ansa cervicalis which gives motor innervation branches to the infrayoid muscles. It lies between the levator scapulae and scalene muscles. The ansa cervicalis arises from C1–C3 and results from the anastomosis of a superior root (C1, C2) with an inferior root (C2, C3). The superior root is temporarily attached to the hypoglossal nerve (cranial nerve [CN] XII). The geniohyoid and thyrohyoid are supplied by the C1 part, while the rest supply the sternothyroid and omohyoid muscles.
- The cervical plexus also gives off smaller branches, which are attached to the accessory nerve (CN XI) and supply the trapezius and sternocleidomastoid.
- Segmental branches also innervate the anterior and middle scalene muscles.

Phrenic nerve

The phrenic nerve emerges from the C3-C5 cervical nerve pairs. It extends along the anterior scalene muscle between the subclavian artery and vein into the mediastinum, where it runs between the pleura and pericardium. It is the only nerve that provides motor innervation to the diaphragm and is therefore essential for breathing.

A unilateral phrenic nerve palsy can lead to an elevated hemidiaphragm on the affected side. The phrenic nerve also provides sensory innervation to the diaphragm, pleura, pericardium, and peritoneum.

Note: Three, Four, Five, Keep the Diaphragm Alive!
Formation of trunks and cords of the brachial plexus

The spinal nerves of segments **C5-T1** and, in parts, also of segments C4 and T2 are involved in the formation of the **brachial plexus**. They pass through a gap between the anterior and middle scalene muscles (**scalenum gap**) in a distal direction. They form the **supraclavicular part** of the plexus by joining together above the clavicle as 3 **primary strands** that run alongside the **subclavian artery** in a caudolateral direction:

- **Upper trunk**: C5 and C6
- **Middle trunk**: C7
- **Lower trunk**: C8 and T1

Dorsal to the **clavicle**, they divide into 3 anterior strands (**anterior divisions**) and 3 posterior strands (**posterior divisions**). After entering the **axilla** below the clavicle, the primary strands join again as secondary strands (the **cords** [fasciculi]) and form the **infraclavicular part** of the plexus:

- **Lateral cord**: Upper trunk and middle trunk (C5-C7)
- **Posterior cord**: Upper, middle, and lower trunk (C5-T1)
- **Medial cord**: Lower trunk (C8-T1)
Supraclavicular part of the brachial plexus

From the supraclavicular part of the brachial plexus, the nerves exit either via the trunks or directly from the spinal nerves to innervate the shoulder girdle muscles:

- **Dorsal scapular nerve** (C4–C5): levator scapulae muscle and rhomboid major and minor muscles
- **Suprascapular nerve** (C4-C6): supraspinatus muscle and infraspinatus muscle
- **Subclavian nerve** (C5–C6): subclavius muscle
- **Subclavian nerve** (C5–C6): supraspinatus and infraspinatus

Infraclavicular part of the brachial plexus

The infraclavicular part consists of short nerve branches, which run at the level of the fasciculi towards the shoulder and long nerves, which represent the terminal branches of the secondary strands and run to the arm. The following 3 motor and 2 sensory nerves belong to the short branches:

- **Thoracodorsal nerve** (C6–C8): latissimus dorsi
- **Subscapular nerves** (C5–C6): subscapularis, teres major
- **Medial pectoral nerve** (C8-T1) and **lateral pectoral nerve** (C5–C7): pectoralis major and minor
- **Medial cutaneous nerve of the arm** (T1): upper arm skin
- **Medial cutaneous nerve of the forearm** (C8-T1): forearm skin
The cords give off long nerves to the arm including:

**Musculocutaneous nerve (C5-C7)**
The **musculocutaneous nerve** branches off from the lateral cord and pierces the **coracobrachialis**, and runs between the **brachialis** and **biceps brachii** to the forearm, where it ends as the **lateral cutaneous nerve of the forearm** that supplies sensory innervation to the lateral side of the forearm. The 3 flexor muscles it passes receive motor innervation from it.

**Axillary nerve (C5-C6)**

The **axillary nerve** exits the **posterior cord** dorsally and runs with the **posterior humeral circumflex artery** through the **lateral axillary space** to the rear of the **humerus**. There, it runs along the **surgical neck**. It provides motor innervation to the **deltoid** and **teres minor**. It ends as the **superior lateral cutaneous nerve**, a sensory nerve that innervates the skin on top of the deltoid.

**Note:** Humeral fractures frequently occur at the surgical neck, which is why the axillary nerve is particularly vulnerable due to its proximity to this breaking point.

![Image: "Surgical neck fracture of humerus" by Jojo. License: CC BY-SA 3.0](image)

**Radial nerve (C5 - T1)**
The radial nerve runs as a continuation of the posterior cord in a distal direction. Already in the proximal upper arm area, it gives off sensory branches (posterior cutaneous and inferior lateral cutaneous nerves of the arm) that supply the skin and a motor branch for innervation of the triceps.

The radial nerve courses through the groove for the radial nerve (also called a spiral groove) in a spiraling fashion alongside the deep artery of the arm passing behind the humerus. It then pierces through the lateral intermuscular septum, and finally it runs between the brachial and brachioradialis muscles, which receive motor innervation from it towards the elbow.

Here, it divides into 2 branches. The purely sensory superficial branch runs together with the radial artery along the brachioradialis muscle and towards the back of the hand, which it supplies, as well as the radial 2½ fingers.

The deep branch supplies and pierces the supinator muscle, and ends as the
**posterior interosseous nerve of the forearm** at the wrist, and innervates all of the extensors of the forearm and hand (see table).

<table>
<thead>
<tr>
<th>Location/Nerve</th>
<th>Sensory Innervation</th>
<th>Motor Innervation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before radial tunnel</td>
<td>Lateral upper arm, lower half</td>
<td>Triceps brachii</td>
</tr>
<tr>
<td>Within radial tunnel</td>
<td>Dorsal side of the upper arm and forearm</td>
<td></td>
</tr>
<tr>
<td>After radial tunnel</td>
<td>-</td>
<td>Brachioradialis; extensor carpi radialis longus; extensor carpi radialis brevis</td>
</tr>
<tr>
<td>Deep branch</td>
<td>-</td>
<td>Supinator; extensor digitorum; extensor digit minimi; extensor carpi ulnaris; extensor pollicis longus; extensor pollicis brevis; extensor indicis; abductor pollicis longus</td>
</tr>
<tr>
<td>Superficial branch</td>
<td>Dorsal palm (lateral ¾) Radial 2 ½ fingers</td>
<td>-</td>
</tr>
</tbody>
</table>

**Note:** In case of a fracture in the area of the humeral shaft, a lesion of the radial nerve may occur leading to a **wrist drop** (radial neuropathy). Because the extensors are not functioning properly, the hand and finger joints can no longer be stretched.

**Median nerve (C6-T1)**

A branch of the medial cord (the medial root) unites with a branch of the lateral cord (the lateral root) before the axillary artery, to form the median nerve. It primarily innervates the flexor muscles of the forearm, as well as the pronators (see table).

It runs anterior to the **brachial artery** along the upper arm in the **medial bicipital groove** towards the elbow. Here, it pierces **pronator teres**, which it innervates, runs along the underarm and gives off the **anterior interosseous nerve of the forearm** before it passes between **flexor digitorum superficialis** and **flexor digitorum profundus** towards the wrist.

There, it passes through the **carpal tunnel**, which is formed by the **flexor retinaculum of the hand** (ligamentum carpi transversum), and divides on the palm into terminal branches to provide motor innervation to the **thenar muscles** and sensory innervation...
to the inner side of the radial 3½ fingers (**common** and **proper palmar digital nerves**).

![Image: “Branches of median nerve” by Anatomist90. License: CC BY-SA 3.0](image)

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<th>Location/Nerve</th>
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<th>Motor Innervation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forearm, before passing the carpal tunnel</td>
<td>Thenar eminence (palmar branches of the median nerve); palm (radial ⅔)</td>
<td>Flexor carpi radialis; palmaris longus; flexor digitorum superficialis; flexor digitorum profundus muscle (radial part); flexor pollicis longus; pronator teres; pronator quadratus</td>
</tr>
<tr>
<td>Hand, after passing the carpal tunnel</td>
<td>Radial 3½ fingers (palmar); parts of fingers 2–4 (dorsal); autonomous zone: distal fingers 2 and 3</td>
<td>Abductor pollicis brevis; flexor pollicis brevis; opponens pollicis; lumbrical muscles I and II</td>
</tr>
</tbody>
</table>

**Note:** A lesion of the median nerve proximal to its passage through the carpal tunnel, results in the characteristic appearance of the hand called simian hand or **ape hand** where the patient cannot bend the thumb, index, or middle fingers. Flexion is still possible in the 2 ulnar fingers (innervation of flexor digitorum profundus by the median and ulnar nerves).

**Median nerve and carpal tunnel syndrome**

The median nerve supplies all the intrinsic muscles of the hand; thus, it has a long course from the brachial plexus all the way through the flexor retinaculum where entrapment and a mononeuropathy could ensue. The disorder is known as carpal tunnel syndrome (CTS); however, other syndromes have been reported, such as the pronator teres or anterior interosseous nerve syndrome.
CTS is characterized by paresthesias of the finger, typically nocturnal (*brachialgia paraesthesia nocturna*). When it progresses, symptoms may radiate to the entire hand and even arm, and occur also during the day. Further symptoms include painful sensitivity to pressure above the *flexor retinaculum*, sensory loss of the radial 3½ fingers, and *atrophy* of the thenar muscles.

Causes can be diverse, including mechanical *compression* of the median nerve,
tendovaginitis, or polyarthritis. Also, diabetes mellitus or pregnancy predisposes to CTS due to the additional connective tissue. Furthermore, a tumor that compresses the median nerve can cause CTS.

A clinical sign is that patients can no longer hold a bottle because the abductor pollicis brevis is weakened. Other indications include Tinel's sign, in which a tap on the flexor retinaculum triggers an electrifying pain in the hand, and the Phalen sign, in which the hand is held in volar flexion for 30 seconds, which causes dysesthesia.

CTS is initially treated with a forearm splint, which is worn during the night and immobilizes the wrist. For decompression of the nerve, the transverse carpal ligament is surgically split.
The ulnar nerve continues directly from the medial cord. It runs behind the brachial artery through the medial bicipital groove. Because it is relatively exposed in this area and lies directly on top of the bone, this part of the elbow is particularly sensitive to pain (“funny bone”). In the area of the upper arm, the ulnar nerve courses to the arm’s extensor side by piercing the medial intermuscular septum.

At the elbow, it runs underneath the medial epicondyle in the groove of the ulnar nerve. Together with the ulnar vessels, the nerve passes between the 2 heads of the flexor carpi ulnaris to the wrist. Here, it courses, unlike the median nerve, above the flexor retinaculum in Guyon’s canal to the inner side of the hand where it divides into its terminal branches: the superficial and deep branches.

<table>
<thead>
<tr>
<th>Location/Nerve</th>
<th>Sensory Innervation</th>
<th>Motor Innervation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forearm</td>
<td>Ulnar side of the dorsal and palmar hand; fingers 4 and 5 (dorsal; dorsal branch)</td>
<td>Flexor carpi ulnaris; flexor digitorum profundus (ulnar part)</td>
</tr>
<tr>
<td>Hand: deep branch – motor; superficial branch – sensory</td>
<td>Fingers 4 and 5 (palmar); Autonomous zone: distal small finger</td>
<td>Palmaris brevis; abductor digiti minimi; flexor digiti minimi; opponens digiti minimi; lumbricals III and IV; palmar and dorsal interossei; adductor pollicis; flexor pollicis brevis</td>
</tr>
</tbody>
</table>

Note: Injury to the ulnar nerve, in its groove, leads to a claw hand: When active finger flexors are innervated by the median nerve, it causes the malfunction of the lumbrical and interosseous muscles. Moreover, hypothenar and interosseous atrophy can be observed.

Hint: To remember the characteristic effects that nerve injuries have on the hand, use the ‘Dr. Cuma’ mnemonic: wrist Drop – Radial nerve, Claw hand – Ulnar nerve, Median nerve – Ape hand.

For an overview of the sensory innervation of the upper limbs, see the following illustration:
Gray and White Matter

The formation of the spinal nerve from the dorsal and ventral roots
MRI: White matter structure

High resolution data acquired on 3 Tesla magnet and post-processed using automated tracking procedure. Voxels within fiber bundles are color-coded according to their FA values (i.e., blue, low anisotropy; and red, high anisotropy.) by Kubicki M., McCarley R.W., Westin C-F., Park H-J., Maier S.E., Kikinis R., Jolesz F.A., Shenton M.E. A review of diffusion tensor imaging studies in schizophrenia. J Psychiatr Res. 2007 Jan-Feb;41(1-2):15-30. PMID: 16023676. PMCID: PMC2768134. License: CC BY-SA 3.0

Continuation

Read the second part of this article about the spinal cord and peripheral nervous system, which addresses the lumbosacral plexus.

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