SPINAL CORD ANATOMY AND FUNCTION

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[Diagram of spinal cord anatomy with labeled parts such as dorsal funiculi, dorsal root, dorsal horn, lateral funiculus, lateral horn, ventral horn, ventral root, ventral funiculi, central canal]
<table>
<thead>
<tr>
<th>Spinal Level</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-C3</td>
<td>Neck Muscles</td>
</tr>
<tr>
<td>C4</td>
<td>Diaphragm</td>
</tr>
<tr>
<td>C5</td>
<td>Deltoid (shoulder)</td>
</tr>
<tr>
<td>C6</td>
<td>Wrist</td>
</tr>
<tr>
<td>C7</td>
<td>Triceps</td>
</tr>
<tr>
<td>C7-C8</td>
<td>Fingers</td>
</tr>
<tr>
<td>T1</td>
<td>Hand</td>
</tr>
<tr>
<td>T2-T12</td>
<td>Intercostals (Trunk)</td>
</tr>
<tr>
<td>T7-L1</td>
<td>Abdominals</td>
</tr>
<tr>
<td>T11-L2</td>
<td>Ejaculation</td>
</tr>
<tr>
<td>L2</td>
<td>Hips</td>
</tr>
<tr>
<td>L3</td>
<td>Quadriceps</td>
</tr>
<tr>
<td>L4-L5</td>
<td>Hamstrings - Knee</td>
</tr>
<tr>
<td>L4-S1</td>
<td>Foot</td>
</tr>
<tr>
<td>S2</td>
<td>Penile erection</td>
</tr>
<tr>
<td>S2-S3</td>
<td>Bowel and bladder</td>
</tr>
</tbody>
</table>
Figure 12.30

Lumbar Tap

- T12
- L5

- Ligamentum flavum
- Lumbar puncture needle
- Supraspinous ligament
- Filum terminale

- Vertebral disc
- Dura mater and arachnoid
- Cauda equina in subarachnoid space

S1
There are 31 spinal cord segments:

- 8 cervical segments
- 12 thoracic segments
- 5 lumbar segments
- 5 sacral segments
- 1 coccygeal segment

There are two regions where the spinal cord enlarges:

- **Cervical enlargement** - corresponds roughly to the brachial plexus nerves, which innervate the upper limb. It includes spinal cord segments from about C4 to T1. The vertebral levels of the enlargement are roughly the same (C4 to T1).

- **Lumbosacral enlargement** - corresponds to the lumbosacral plexus nerves, which innervate the lower limb. It comprises the spinal cord segments from L2 to S3, and is found about the vertebral levels of T9 to T12.
The Spinal Cord and Spinal Nerves

Cervical enlargement
Dura and arachnoid mater
Lumbar enlargement
Conus medullaris
Cauda equina
Filum terminale
Anchors the cord to the sacrum.

The meningeal sack below the end of the spinal cord at L2 can be used to withdraw cerebrospinal fluid (a lumbar tap) without risking damage to the cord.

The cauda equina (horses tail in Latin)

Nerve roots descend to the appropriate location beneath the vertebra or in the sacrum. The ganglion occurs just outside the vertebral column.
Spinal Cord

- Conus medullaris – terminal portion of the spinal cord
- Filum terminale – fibrous extension of the pia mater; anchors the spinal cord to the coccyx
- Denticulate ligaments – delicate shelves of pia mater; attach the spinal cord to the vertebrae
The dermatomes are somatic or musculocutaneous areas served by fibers from specific spinal nerves.

Referred pain is caused when the sensory fibers from an internal organ enter the spinal cord in the same root as fibers from a dermatome. The brain is poor at interpreting visceral pain and instead interprets it as pain from the somatic area of the dermatome.
Cervical Plexus - the **phrenic nerve** travels through the thorax to innervate the diaphragm.

**Brachial Plexus**

- **Axillary nerve** - innervates the deltoid muscle and shoulder, along with the posterior aspect of the upper arm.
- **Musculocutaneous nerve** - innervates anterior skin of upper arm and elbow flexors.
- **Radial nerve** - innervates dorsal aspect of the arm and extensors of the elbow, wrist, and fingers, abduction of thumb.
- **Median nerve** - innervates the middle elbow, wrist and finger flexors, adducts the thumb.
- **Ulnar nerve** - innervates the medial aspect wrist and finger flexors.

**Lumbar Plexus**

- **Genitofemoral** - to the **external** genitalia
- **Obturator** - to the adductor muscles
- **Femoral** - innervates the skin and muscles of upper thigh, including the quadriceps.

**Sacral Plexus**

- **Gluteal nerves (superior and inferior)** - superior innervates the gluteus medius and minimus, inferior innervates the gluteus maximus.
- **Sciatic nerve** - the body's largest nerve, consisting of two major branches, the **tibial** and **common peroneal**. Together they innervate most all of leg including the flexors of the knee, part of adductor magnus, muscles for plantar flexion, dorsiflexion, and other movements of the foot and toes.
- **ganglion** - a collection of cell bodies located outside the Central Nervous System. The spinal ganglia or dorsal root ganglia contain the cell bodies of sensory neurons entering the cord at that region.

- **nerve** - a group of fibers (axons) outside the CNS. The spinal nerves contain the fibers of the sensory and motor neurons. A nerve does not contain cell bodies. They are located in the ganglion (sensory) or in the gray matter (motor).

- **tract** - a group of fibers inside the CNS. The spinal tracts carry information up or down the spinal cord, to or from the brain. Tracts within the brain carry information from one place to another within the brain. Tracts are always part of white matter.

- **gray matter** - an area of unmyelinated neurons where cell bodies and synapses occur. In the spinal cord the synapses between sensory and motor and interneurons occurs in the gray matter. The cell bodies of the interneurons and motor neurons also are found in the gray matter.

- **white matter** - an area of myelinated fiber tracts. Myelination in the CNS differs from that in nerves.
The spinal cord proper begins at the level of the foramen magnum of the skull and ends at the level of the L1–L2 intervertebral joint.
Substantia grisea
1. Cornu anterius
2. Cornu posterius
3. Commissura grisea

Substantia alba
4. Funiculus anterior
5. Funiculus lateralis
6. Funiculus posterior
7. Commissura alba anterior
8. Fissura mediana anterior
9. Sulcus medianus posterior
10. Canalis centralis
11. Radix anterior
12. Radix posterior
13. Ganglion sensorium nervi spinalis
Myelinated fibers
Spinal Cord - Neuron Relationships

- Sensory cell bodies
- Dorsal root
- Ganglion
- Sensory fibers
- Interneuron
- Motor fibers
- Ventral root
- Motor cell bodies
- Dorsal sulcus (fissure)
- White matter
- Gray matter
- Central canal - contains cerebrospinal fluid
a pia mater   b subarachnoid space   c dura mater   d myelinated axon  
e unipolar neuron of the dorsal root ganglion surrounded by satellite cells (neuroglia).
a. Pia mater
b. Subarachnoid space filled with cerebral spinal fluid, wastes, and various cells.
c. Fibrocyte mixed in the blue collagen fibers of the dura mater.
d. Nucleus & nucleolus of unipolar neuron

e. Nucleus of one of many tiny satellite cells surrounding the large unipolar neuron.
f. Myelinated axon

g. Node of Ranvier

h. Nucleus of white Schwann cell
a Synaptic bulbs over the motor end plate - neuromuscular junction
b Neuron axon terminal - black fibers
The central canal is the cerebrospinal fluid-filled space that runs longitudinally through the length of the entire spinal cord. The central canal is contiguous with the ventricular system of the brain.
PNS in the Nervous System

Figure 13.1
### Levels of Injury and Extent of Paralysis

- **C4** injury (quadriplegia)
- **C6** injury (quadriplegia)
- **T6** injury (paraplegia)
- **L1** injury (paraplegia)

### Cervical (neck)

- **C1 to C5**: Paralysis of muscles used for breathing and of all arm and leg muscles; usually fatal.
- **C5 to C6**: Legs paralyzed; slight ability to flex arms.
- **C6 to C7**: Paralysis of legs and part of wrists and hands; shoulder movement and elbow bending relatively preserved.
- **C8 to T1**: Legs and trunk paralyzed; eyelids droop; loss of sweating on the forehead (Horner's syndrome); arms relatively normal; hands paralyzed.

### Thoracic (upper back)

- **T2 to T4**: Legs and trunk paralyzed; loss of feeling below the nipples.
- **T5 to T8**: Legs and lower trunk paralyzed; loss of feeling below the rib cage.
- **T9 to T11**: Legs paralyzed; loss of feeling below the umbilicus.
- **T12 to L1**: Paralysis and loss of feeling below the groin.

### Lumbar (lower back)

- **L2 to L5**: Different patterns of leg weakness and numbness.
- **S1 to S2**: Different patterns of leg weakness and numbness.
- **S3 to S5**: Loss of bladder and bowel control; numbness in the perineum.

### Sacral

*Loss of bladder and bowel control can occur with severe injury anywhere along the spinal column.*
Scheuermann kyphosis
In some rare cases, the bones of the back (vertebrae) do not grow correctly. In Scheuermann kyphosis, the front part of the vertebrae does not grow as well as the back part.
Structure of a Nerve

- **Nerve** – cordlike organ of the PNS consisting of peripheral axons enclosed by connective tissue

- **Connective tissue coverings include:**
  - **Endoneurium** – loose connective tissue that surrounds axons
  - **Perineurium** – coarse connective tissue that bundles fibers into fascicles
  - **Epineurium** – tough fibrous sheath around a nerve
Peripheral Nerve (cross section)
Structure of a Nerve

A nerve is a group of axons (nerve fibers) outside the CNS. These fibers are bundled together with connective layers. Many of the fibers are myelinated, which means they have a covering made from successive wrappings of Schwann cells.

M = the myelin sheath, composed of wrappings of a Schwann cell. The outer membrane or layer of the myelin sheath is called the neurilemma.
Classification of Nerves

- Sensory and motor divisions
  - Sensory (afferent) – carry impulse to the CNS
  - Motor (efferent) – carry impulses from CNS
  - Mixed – sensory and motor fibers carry impulses to and from CNS; most common type of nerve
Peripheral Nerves

- Mixed nerves – carry somatic and autonomic (visceral) impulses
- The four types of mixed nerves are:
  - Somatic afferent and somatic efferent
  - Visceral afferent and visceral efferent
- Peripheral nerves originate from the brain or spinal column
Regeneration of Nerve Fibers

- Damage to nerve tissue is serious because mature neurons are amitotic.
- If the soma of a damaged nerve remains intact, damage can be repaired.
- Regeneration involves coordinated activity among:
  - Macrophages – remove debris
  - Schwann cells – form regeneration tube and secrete growth factors
  - Axons – regenerate damaged part
Regeneration of Nerve Fibers

Figure 13.4

(a) Fragmented axon, Endoneurium, Myelin droplet, Axon, Schwann cells, Site of nerve damage

(b) Schwann cell, Macrophage
Regeneration of Nerve Fibers

Figure 13.4

- Fine axon sprouts or filaments
- New axon filament
- Schwann cell
- Aligning Schwann cells form regeneration tube
- Endoneurium
- Schwann cell
- New axon filament
- Schwann cell
- Site of new myelin sheath formation
- Single enlarging axon filament

(c)
(d)
Twelve pairs of cranial nerves arise from the brain.

They have sensory, motor, or both sensory and motor functions.

Each nerve is identified by a number (I through XII) and a name.

Four cranial nerves carry parasympathetic fibers that serve muscles and glands.
Peripheral Nervous System

- 31 spinal nerves
  - We’ve already discussed their structure
- 12 cranial nerves
  - How do they differ from spinal nerves?
  - We need to learn their:
    - Names
    - Locations
    - Functions
Cranial Nerves

I  Olfactory
II  Optic
III  Oculomotor
IV  Trochlear
V  Trigeminal
VI  Abducens
VII  Facial
VIII  Vestibulocochlear
IX  Glossopharyngeal
X  Vagus
XI  Accessory
XII  Hypoglossal
Cranial Nerves

Filaments of olfactory nerve (I)
Olfactory bulb
Olfactory tract
Optic nerve (II)
Optic chiasma
Optic tract
Oculomotor nerve (III)
Trochlear nerve (IV)
Trigeminal nerve (V)
Abducens nerve (VI)
Cerebellum
Medulla
Frontal lobe
Temporal lobe
Infundibulum
Facial nerve (VII)
Vestibulocochlear nerve (VIII)
Glosso-pharyngeal nerve (IX)
Vagus nerve (X)
Accessory nerve (XI)
Hypoglossal nerve (XII)
### Summary of Function of Cranial Nerves

<table>
<thead>
<tr>
<th>Cranial nerves I – VI</th>
<th>Sensory function</th>
<th>Motor function</th>
<th>PS* fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Olfactory</td>
<td>Yes (smell)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>II Optic</td>
<td>Yes (vision)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>III Oculomotor</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>IV Trochlear</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>V Trigeminal</td>
<td>Yes (general sensation)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>VI Abducens</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cranial nerves VII – XII</th>
<th>Sensory function</th>
<th>Motor function</th>
<th>PS* fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>VII Facial</td>
<td>Yes (taste)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>VIII Vestibulocochlear</td>
<td>Yes (hearing and balance)</td>
<td>Some</td>
<td>No</td>
</tr>
<tr>
<td>IX Glossopharyngeal</td>
<td>Yes (taste)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>X Vagus</td>
<td>Yes (taste)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>XI Accessory</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>XII Hypoglossal</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

(b) *PS = parasympathetic
12 Cranial Nerves

- How do you remember which nerve is which number?
  - Here is a G-rated mnemonic device:
    - *Old Opie occasionally tries trigonometry and feels very gloomy, vague, and hypoactive.*
  - There are also several R-rated ones
- Some cranial nerves are sensory, some motor, and some are both (mixed)?
  - Some say marry money but my brother says big butts matter more.
Cranial Nerve I: Olfactory

- Arises from the olfactory epithelium
- Passes through the cribriform plate of the ethmoid bone
- Fibers run through the olfactory bulb and terminate in the primary olfactory cortex
- Functions solely by carrying afferent impulses for the sense of smell
Cranial Nerve I: Olfactory

Frontal lobe of cerebral hemisphere
Olfactory bulb
Olfactory tract
Cribriform plate of ethmoid bone
Filaments of olfactory nerve (I)
Nasal mucosa
- How many noses do you have?
- Sensory, motor, or mixed?
- Run from the nasal mucosa to the olfactory bulb.
- Extend thru the cribriform plate.
- Lesion to these nerves or cribriform plate fracture may yield anosmia – loss of smell.
Cranial Nerve II: Optic

Figure II from Table 13.2
How many eyes do you have?

Sensory, motor, or mixed?

Begin at the retina, run to the optic chiasm, cross over, continue as the optic tract and synapse in the thalamus.

Optic nerve damage yields blindness in the eye served by the nerve. Optic tract damage yields partial visual loss.

Visual defects = anopsias
Cranial Nerve III: Oculomotor

- Fibers extend from the ventral midbrain, pass through the superior orbital fissure, and go to the extrinsic eye muscles
- Functions in raising the eyelid, directing the eyeball, constricting the iris, and controlling lens shape
- Parasympathetic cell bodies are in the ciliary ganglia
Cranial Nerve III: Oculomotor

Figure III from Table 13.2

- Medial rectus muscle
- Superior rectus muscle
- Levator palpebrae muscle
- Inferior oblique muscle
- Ciliary ganglion
- Inferior rectus muscle
- Superior orbital fissure
- Parasympathetic motor fibers
- Oculomotor nerve (III)
- Pons
- Midbrain
“Eye mover”
- Sensory, motor, or mixed?
- Originate at the ventral midbrain.
- Synapse on:
  - Extraocular muscles
    - Inferior oblique; Inferior, medial, and superior rectus
  - Iris constrictor muscle
  - Ciliary muscle
- Disorders can result in eye paralysis, diplopia or ptosis.
Cranial Nerve IV: Trochlear

- Fibers emerge from the dorsal midbrain and enter the orbits via the superior orbital fissures; innervate the superior oblique muscle
- Primarily a motor nerve that directs the eyeball
- Controls the superior oblique muscle which depresses the eye via pulling on the superior oblique tendon which loops over a ligamentous pulley known as the trochlea.
- Originates on the dorsal midbrain and synapses on the superior oblique
- Sensory, motor, or mixed?
- Trauma can result in double vision. Why?
Cranial Nerve V: Trigeminal

- Three divisions: ophthalmic ($V_1$), maxillary ($V_2$), and mandibular ($V_3$)
- Fibers run from the face to the pons via the superior orbital fissure ($V_1$), the foramen rotundum ($V_2$), and the foramen ovale ($V_3$)
- Conveys sensory impulses from various areas of the face ($V_1$) and ($V_2$), and supplies motor fibers ($V_3$) for mastication
Cranial Nerve V: Trigeminal

Figure V from Table 13.2
CN5
Trigeminal Nerves

- Sensory, motor, or mixed?
- Biggest cranial nerve
- Originates in the pons and eventually splits into 3 divisions:
  - Ophthalmic (V1), Maxillary (V2), & Mandibular (V3).
- Sensory info (touch, temp., and pain) from face.
- Motor info to muscles of mastication
- Damage?
Trigeminal Nerve

ophthalmic (V1 sensory)

maxillary (V2 sensory)

mandibular (V3 sensory and motor)
The spinal trigeminal nucleus represents pain/temperature sensation from the face. Pain/temperature fibers from peripheral nociceptors are carried in cranial nerves V, VII, IX and X. On entering the brainstem, sensory fibers are grouped together and sent to the spinal trigeminal nucleus. This bundle of incoming fibers can be identified in cross sections of the pons and medulla as the spinal tract of the trigeminal nucleus, which parallels the spinal trigeminal nucleus itself. The spinal tract of V is analogous to, and continuous with, Lissauer’s tract in the spinal cord.
Cranial Nerve VI: Abducens

- Fibers leave the inferior pons and enter the orbit via the superior orbital fissure
- Primarily a motor nerve innervating the lateral rectus muscle

Figure VI from Table 13.2
- Sensory, motor, or mixed?
- Runs between inferior pons and lateral rectus.
Cranial Nerve VII: Facial

- Fibers leave the pons, travel through the internal acoustic meatus, and emerge through the stylomastoid foramen to the lateral aspect of the face
- Mixed nerve with five major branches
- Motor functions include facial expression, and the transmittal of autonomic impulses to lacrimal and salivary glands
- Sensory function is taste from the anterior two-thirds of the tongue
The facial nerve has four components with distinct functions:

<table>
<thead>
<tr>
<th>Component Type</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Branchial motor (special visceral efferent)</td>
<td>Supplies the muscles of facial expression; posterior belly of digastric muscle; stylohyoid, and stapedius.</td>
</tr>
<tr>
<td>Visceral motor (general visceral efferent)</td>
<td>Parasympathetic innervation of the lacrimal, submandibular, and sublingual glands, as well as mucous membranes of nasopharynx, hard and soft palate.</td>
</tr>
<tr>
<td>Special sensory (special afferent)</td>
<td>Taste sensation from the anterior 2/3 of tongue; hard and soft palates.</td>
</tr>
<tr>
<td>General sensory (general somatic afferent)</td>
<td>General sensation from the skin of the concha of the auricle and from a small area behind the ear.</td>
</tr>
</tbody>
</table>
Branches of facial nerve in the face

- Temporal
- Zygomatic
- Buccal
- Mandibular
- Cervical

Facial nerve
Facial muscles
Cranial Nerve VII: Facial

(a) Parasympathetic efferents and sensory afferents

(b) Motor branches to muscles of facial expression and scalp muscles
Facial Nerves

- Sensory, motor, or mixed?
- Originates at the pons
- Convey motor impulses to facial skeletal muscles – except for chewing muscles.
- Convey parasympathetic motor impulses to tear, nasal, and some salivary glands.
- Convey sensory info from taste buds on anterior 2/3 of the tongue.
- Facial nerve damage may yield Bell’s palsy, total ipsilateral hemifacial paralysis
(a) Parasympathetic efferents and sensory afferents

(b) Motor branches to muscles of facial expression and scalp muscles
CN8
Auditory/Vestibulocochlear Nerves

- Sensory, motor, or mixed?
- Originates at the pons
- 2 divisions:
  - Cochlear
    - Afferent fibers from cochlea in the inner ear
    - HEARING
  - Vestibular
    - Afferent fibers from equilibrium receptors in inner ear
    - BALANCE
- Functional impairment?
CN9
Glossopharyngeal Nerves

- Sensory, motor, or mixed?
- Fibers run emerge from medulla and run to the throat.
- Motor Functions:
  - Motor fibers to some swallowing muscles
  - Parasympathetic fibers to some salivary glands
- Sensory Functions:
  - Taste, touch, heat from pharynx and posterior tongue.
  - Info from chemoreceptors on the level of $O_2$ and $CO_2$ in the blood.
    Info from baroreceptors on BP.
    Chemoreceptors and baroreceptors are located in the carotid sinus - a dilation in the internal carotid artery.
Vagus Nerves

- Sensory, motor, or mixed?
- Only cranial nerves to extend beyond head and neck.
  - Fibers emerge from medulla, leave the skull, and course downwards into the thorax and abdomen.
- Motor Functions:
  - Parasympathetic efferents to the heart, lungs, and abdominal organs.
- Sensory Functions:
  - Input from thoracic and abdominal viscera; from baro- and chemoreceptors in the carotid sinus; from taste buds in posterior tongue and pharynx.
Sensory, motor, or mixed?
- Formed by the union of a cranial root and a spinal root.
  - CR arises from medulla while SR arises from superior spinal cord. SR passes thru the FM and joins with CR to form the accessory nerve. They then leave the skull via the jugular foramen.
  - Cranial division then joins vagus and innervates larynx, pharynx, and soft palate.
  - Spinal division innervates sternocleidomastoids and trapezius.
Hypoglossal Nerves

- Sensory, motor, or mixed?
- Arise from the medulla and exit the skull via the hypoglossal canal and innervate the tongue.
- Innervate the intrinsic & extrinsic muscles of the tongue.
  - Swallowing, speech, food manipulation.
- Damage?
Peripheral Nervous System

- Now that we’ve looked at spinal and cranial nerves, we can examine the divisions of the PNS.
- The PNS is broken down into a sensory and a motor division.
- We’ll concentrate on the motor division which contains the somatic nervous system and the autonomic nervous system.