Functions of the Spinal Cord

• Conduction
  - bundles of fibers passing information up and down spinal cord, connecting different levels of the trunk with each other and with the brain

• Locomotion
  - walking involves repetitive, coordinated actions of several muscle groups
  - local neural circuits (central pattern generators) are pools of neurons providing control of flexors and extensors that cause alternating movements of the lower limbs

• Reflexes
  - involuntary, stereotyped responses to stimuli // e.g. withdrawal of hand from pain
  - involves spinal cord and peripheral nerves (i.e. brain finds out about the event after the event has already occurred)
Overview of the spinal cord structure and function.

- Gray commissure
- Posterior horn
- Posterior root (sensory)
- Posterior root ganglion
- Spinal nerve
- Somatic sensory (skin)
- Visceral sensory (blood vessel)
- Visceral motor (smooth muscle)
- Somatic motor (skeletal muscle)
Surface Anatomy

- **Spinal cord** – cylinder of nervous tissue that starts at the brainstem at the foramen magnum of the skull
  - passes through the **vertebral foramin**
  - inferior margin **ends at L1** or a little beyond
  - averages 1.8 cm thick and 45 cm long
  - occupies the **upper two-thirds of the vertebral canal**
External structure of the spinal cord.
Surface Anatomy

- Spinal cord gives rise to 31 pair of **spinal nerves**
  
  first pair passes between the skull and C1

  all other pass through intervertebral foramina

- Note: a segment in the spinal cord refers to part of the spinal cord which is supplied by each **pair of spinal nerves**
The Spinal Nerve and Vertebrae

Anterior median fissure
Spinal gray matter
Spinal white matter
Pia mater
Nerve roots
Arachnoid mater
Dura mater
Spinal nerves
Posterior median sulcus
Thoracic vertebrae
Vertebral cavity

(b) Section of spinal cord and associated structures, posterior view
Spinal Nerve and Vertebrae

- Spinous process of vertebra
- Fat in epidural space
- Subarachnoid space
- Spinal cord
- Denticulate ligament
- Posterior root ganglion
- Spinal nerve
- Vertebral body

Meninges:
- Dura mater (dural sheath)
- Arachnoid mater
- Pia mater

(a) Spinal cord and vertebra (cervical)
Connective Tissue Surrounding Spinal Nerve

- **Transverse plane**
- **Spinal nerve**
  - **EPINEURRIUM** around entire nerve
  - **PERINEURRIUM** around each fascicle
  - **ENDONEURRIUM** around
- **Blood vessels**
- **Fascicle**
- **Myelin sheath**
- **Axon**
(b) Transverse section of several nerve fascicles
Surface Anatomy

- Longitudinal grooves on anterior and posterior surface of spinal cord
  
  • anterior median fissure
  
  • posterior median sulcus

- Spinal cord divided into the cervical, thoracic, lumbar, and sacral regions

- Two areas of the cord are thicker than elsewhere
  
  • cervical enlargement – nerves to upper limb
  
  • lumbar enlargement – nerves to pelvic region and lower limbs
(b) Transverse section of lumbar spinal cord

- Posterior median sulcus
- Posterior white column
- Posterior gray horn
- Lateral white column
- Gray commissure
- Lateral gray horn
- Central canal
- Anterior gray horn
- Anterior white column
- Anterior median fissure

View

Transverse plane

Courtesy Michael Ross, University of Florida
Surface Anatomy

medullary cone (conus medullaris) – cord tapers to a point inferior to lumbar enlargement

cauda equina – bundle of nerve roots that occupy the vertebral canal from L2 to S5

terminal filum – extension of pia matter from medullary cone which anchors spinal cord to inferiorly to coccyx
The Meninges of the Spinal Cord

• Three fibrous connective tissue membranes that enclose the brain and spinal cord
  – separate soft tissue of central nervous system from bones of cranium and vertebral canal
  – from superficial to deep
    • dura mater
    • arachnoid mater
    • pia mater
The Spinal Cord's Connective Tissue Cover

(a) Spinal meninges and spinal cord, anterior view
Dura Mater

Forms loose fitting sleeve around spinal cord // dura mater around brain is fused to periosteum

Dura mater is tough, collagenous membrane with an epidural space between dura mater and periosteum. This space is filled with adipocytes.

An epidural anesthesia is often injected into the epidural space during childbirth.

(b) Spinal meninges and spinal cord, transverse section
(a) Anterior view and transverse section through spinal cord
Arachnoid Mater

- **arachnoid membrane** - layer of simple squamous epithelium lining dura mater and a loose mesh of collagenous and elastic fibers spanning the gap between the arachnoid membrane and the pia mater

- **subarachnoid space** – gap between arachnoid membrane and the pia mater

  - filled with **cerebrospinal fluid (CSF)**

  - **lumbar cistern** – subarachnoid space inferior to medullary cone that contains **cauda equina and CSF**
Meninges of Vertebra and Spinal Cord

- Spinous process of vertebra
- Fat in epidural space
- Subarachnoid space
- Spinal cord
- Denticulate ligament
- Posterior root ganglion
- Spinal nerve
- Vertebral body

Meninges:
- Dura mater (dural sheath)
- Arachnoid mater
- Pia mater

(a) Spinal cord and vertebra (cervical)
Grey matter

White matter

Dura mater
Arachnoid mater
Pia mater

Posterior

Epidural space
Subdural space
Subarachnoid space
Denticulate ligament

Body of vertebra

Grey matter

White matter

Anterior

(b) Spinal meninges and spinal cord, transverse section
Pia Mater

- delicate, translucent membrane that follows the contours of the spinal cord

- terminal filum – fibrous strand of pia mater that extends beyond the medullary cone within the lumbar cistern

- coccygeal ligament – formed from fusion of terminal filum and dura mater // anchors the cord and meninges to vertebra Co1

- denticulate ligaments – pia mater extends through the arachnoid mater to the dura mater // anchors spinal cord to limit side to side movement
(a) Anterior view and transverse section through spinal cord
(b) Transverse section of the spinal cord within a cervical vertebra
Grey Matter and White Matter of Spinal Cord

- central area of **gray matter** shaped like a butterfly and surrounded by **white matter in 3 columns** // white areas = tracts

- **gray matter** - neuron cell bodies with little myelin // site of information processing – synaptic integration // grey matter = horns

- **white matter** – abundantly myelinated axons // carry signals from one part of the CNS to another
Spinal Cord Horns
Posterior, Anterior, and Lateral

(b) Transverse section of lumbar spinal cord

Courtesy Michael Ross,
University of Florida

Posterior median sulcus
Posterior white column
Posterior gray horn
Lateral white column
Gray commissure
Lateral gray horn
Central canal
Anterior gray horn
Anterior white column
Anterior median fissure
Spinal Cord Horns

Posterior, Anterior, and Lateral

(a) Transverse section of lumbar spinal cord

Nerve impulses to skeletal muscles

Nerve impulses to cardiac muscle, smooth muscle, and glands
Functions of the Spinal Cord Horns

- **Posterior grey horns**: cell bodies and axons of interneurons + incoming sensory neurons form dorsal root ganglion

- **Anterior grey horns**: somatic motor nuclei to skeletal muscles

- **Lateral grey horns**: only in thoracic and upper lumbar / contain autonomic motor nuclei / regulate smooth muscle – cardiac muscle - glands
- pair of posterior (dorsal) horns // posterior (dorsal) root of spinal nerve carries only sensory fibers

- pair of thicker anterior (ventral) horns // anterior (ventral) root of spinal nerve carries only motor fibers
The Function of Commisure and Lateral Horn

- **gray commissure** connects right and left sides // punctured by a central canal lined with ependymal cells and filled with CSF

- **lateral horn** = visible from T2 through L1 // contains neurons of sympathetic nervous system
White Matter in the Spinal Cord

- White matter surrounds the gray matter in spinal cord
- White matter is bundles of axons that course up and down the cord (i.e. arranged in fasicles)
- Provide pathway of communication between CNS and PNS target tissues
(a) Ascending tracts (sensory)

<table>
<thead>
<tr>
<th>ASCENDING TRACT</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior columns—fasciculus gracilis</td>
<td>Carry somatosensory information including fine touch, vibration, and proprioception from the lower limbs</td>
</tr>
<tr>
<td>Posterior columns—fasciculus cuneatus</td>
<td>Carry somatosensory information including fine touch, vibration, and proprioception from the trunk, neck, and upper limbs</td>
</tr>
<tr>
<td>Spinocerebellar tracts</td>
<td>Carry proprioceptive information to the cerebellum</td>
</tr>
<tr>
<td>Anterolateral system—spinothalamic tracts</td>
<td>Carry information about pain, temperature, and certain types of touch</td>
</tr>
</tbody>
</table>

(b) Descending tracts (motor)

<table>
<thead>
<tr>
<th>DESCENDING TRACT</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corticospinal tracts</td>
<td>Carry motor information from the motor areas of the cerebral cortex</td>
</tr>
</tbody>
</table>
| Reticulospinal tracts | Carry motor information from the brainstem  
                               Important for the maintenance of posture and proper orientation of the limbs during movement |
| Tectospinal tract  | Carries motor information from the superior colliculus of the brainstem  
                               Important for reflexive movement of the head and eyes |
| Vestibulospinal tract | Carries motor information from vestibular nuclei in the brainstem  
                               Important for the maintenance of posture and balance |
White Matter in the Spinal Cord

- **columns** or funiculi – three pair of these white matter bundles
  - Posterior columns (dorsal)
  - Lateral columns
  - Anterior columns (ventral)

- **tracts or fasciculi** – subdivisions of each column

![Diagram of White Matter in the Spinal Cord]
• **ascending tracts** – carry sensory information up the spinal cord

• **descending tracts** – carry motor information down the spinal cord // all nerve fibers in a given tract have a similar origin, destination, and function

• **decussation** – as the fibers pass up or down the brainstem and spinal cord they cross over from the left to the right side and vise versa
Spinal Tracts

- **contralateral** – when the origin and destination of a tract are on opposite sides of the body

- **ipsilateral** – when the origin and destination of a tract are on the same side of the body // does not decussate
Ascending Tracts

- ascending tracts carry sensory signals **up the spinal cord** // sensory to the brain

- sensory signals **travel across three neurons** from origin in receptors to the destination in the sensory areas of the brain // typical pattern
  - first order neurons – detect stimulus and transmit signal to spinal cord or brainstem
  - second order neurons – continues to the thalamus at the upper end of the brainstem
  - third order neurons – carries the signal the rest of the way to the sensory region of the cerebral cortex
Major Ascending Tracts

- cuneate fasciculus (above T6)
- gracile fasciculus (below T6)
- spinothalamic tract
- spinoreticular tract
- spinocerebellar tracts - posterior and anterior
Cuneate Fasciculus

- originate at the level of T6 and above // upper limb and chest
- joins gracile fasciculus at T6
- occupies lateral portion of the posterior column // forces gracile fasciculus medially
- these are somatosensory (somesthetic) which are conscious signals
- carries signals for vibration, visceral pain, deep and discriminative touch, and proprioception from lower limbs and lower trunk
- fibers end in the cuneate nucleus on the ipsilateral side of the medulla oblongata
- proprioception = non-visual sense of the position and movements of the body / conscious
Gracile Fasciculus

- carries signals from midthoracic and lower parts of the body
- below T6, it composes the entire posterior column // at T6 joins cuneate fasciculus
- consists of first-order nerve fibers that travel up the ipsilateral side of the spinal cord
- terminates at the gracile nucleus of the medulla oblongata
- carries signals for vibration, visceral pain, deep and discriminative touch, and proprioception from lower limbs and lower trunk
- proprioception – non-visual sense of the position and movements of the body / conscious
• **medial lemniscus** // formed from the second-order neurons of gracile and cuneate systems that decussate in the medulla

  – tracts of these nerve fibers lead the rest of the way to the thalamus

  – third-order neurons go from thalamus to cerebral cortex

  – carry signals to contralateral cerebral hemisphere
Spinothalamic Pathway

- one of the smaller tracts of the anterolateral system passes up the anterior and lateral columns of the spinal cord
- carry signals for pain, pressure, temperature, light touch, tickle, and itch
- first-order neurons end in posterior horn of spinal cord
- synapse with second-order neurons which decussate to other side of spinal cord and form the ascending spinothalamic tract that goes to the thalamus
- third-order neurons continue from there to cerebral cortex
- sends signals to the contralateral cerebral hemisphere
- these are also conscious signals
Spinoreticular Tract

- travel up the anterolateral system
- carries pain signals resulting from tissue injury
- first-order neurons enter posterior horn and immediately synapse with second-order neurons
- decussate to opposite anterolateral system
  - ascends the cord // end in reticular formation – loosely organized core of gray matter in the medulla and pons
- third-order neurons continue from the pons to the thalamus
- fourth-order neurons complete the path to the cerebral cortex (Note: exception to the rule!)
Spinocerebellar Tracts

- travel through lateral column
- carry **proprioceptive signals** from limbs and trunk to the cerebellum
- **first-order** neurons originate in the muscles and tendons // end in posterior horn of the spinal cord
- second-order nerves ascend spinocerebellar tracts and end in cerebellum
  - fibers of the posterior tract travel up the ipsilateral side of the spinal cord
  - fibers of the anterior tract cross over and travel up the contralateral side // cross back in the brainstem to enter the ipsilateral side of the cerebellum
- provide cerebellum with feedback needed to coordinate muscle actions // **subconscious knowledge** of muscle's actual performance
Descending Tracts

• Carry motor signals down the brainstem and spinal cord // direct and indirect motor pathways (pyramidal and extrapyramidal)

• Involves two neurons

  – upper motor neuron // originate in cerebral cortex or brainstem // terminates on a lower motor neuron

  – lower motor neuron // originate in brainstem or spinal cord // the upper motor neuron synapse on LMN that leads the rest of the way to the muscle or other target organ
Descending Tracts

- Carry motor signals down the brainstem and spinal cord // direct and indirect motor pathways (pyramidal and extrapyramidal)

- Direct pathways (consist of upper and lower motor neurons)
  - **Corticospinal** = upper motor neuron / synapse with anterior horn neurons = lower motor neuron
  - **Corticobulbar** = upper motor neuron / synapse with cranial nerves = lower motor neuron / innervate skeletal muscles in head and neck

- Indirect pathways
  - Involved in the involuntary responses to skeletal muscles / visual, equilibrium, posture
  - Tectospinal / vestibulospinal / rubriospinal / reticularspinal tracts
Descending Direct Pathways

Pathways = Axon Tracts

- UMN / Precentral Gyrus of Cerebrum
- Corticospinal Tract / UMN
- LMN / Anterior Horn of Spinal Cord
- Corticobulbar Tract / UMN
- LMN // Cranial Nerves of Brain Stem

Somatic Skeletal muscles of head and neck

Somatic skeletal muscles below head and neck

“common pathway”
• from cerebral cortex for **precise, finely coordinated limb movements**

• **pyramids** – ridges on anterior surface of the medulla oblongata formed from fibers of this system

• **decussate in lower medulla**
• lateral corticospinal tract on contralateral side of spinal cord

• anterior (ventral) corticospinal tract on ipsilateral side of spinal cord

• two neuron pathway
  – upper motor neuron in cerebral cortex
  – lower motor neuron in spinal cord
Descending Indirect Pathways

Pathways = Axon Tracts

UMN // Nuclei in medulla oblongata
1. tectospinal tract
2. vestibulospinal tract
3. rubriospinal tract
4. reticularospinal tract

LMN / Anterior Horn of Spinal Cord

LMN / Cranial Nerves

common pathway

Skeletal Muscles of head and neck

Somatic Skeletal Muscles
Indirect Motor Tracts

- **tectospinal tract** – begins in midbrain region (tectum)
  - crosses to contralateral side of midbrain
  - reflex turning of head in response to sights and sounds

- lateral and medial **reticulospinal tract**
  - originate in the reticular formation of brainstem
  - controls muscles of upper and lower limbs especially those for posture and balance
  - contain descending analgesic pathways reduce the transmission of pain signals to brain
Indirect Motor Tracts

- **Lateral** and **medial** vestibulospinal tract
  - begins in brainstem **vestibular nuclei**
  - receives impulses from vestibular organs of balance from inner ear
  - controls extensor muscles of limbs for balance control
  - The tripping response!
Damage to Spinal Cord

- accidents damage the spinal cord of thousands of people every year
  - paraplegia - paralysis of lower limbs
  - quadriplegia – paralysis of all four limbs
  - hemiplegia – paralysis of one side of the body only
  - respiratory paralysis - loss of sensation or motor control
  - disorders of bladder, bowel and sexual function

- damage to spinal cord also occur from strokes or other brain injuries
Spina Bifida

• spina bifida – **congenital defect** in which one or more vertebrae fail to form a complete vertebral arch for enclosure of the spinal cord
  
  – in 1 baby out of 1000
  – common in lumbosacral region
  – spina bifida occulta and spina bifida cystica

• **folic acid** (a B vitamin) as part of a healthy diet for all women of childbearing age reduces risk

  – defect occurs during the first four weeks of development, so folic acid supplementation must begin 3 months before conception
Bi-Directional Pathways of Action Potentials Between the PNS, Spinal Cord, and Brain
Note: the short process extending from the soma of the dorsal root ganglion is called a protoplasmic process by some authors. They refer to the entire portion distal to the protoplasmic process as the dendrite and the portion proximal to the protoplasmic process as the axon. Here is the key idea about unipolar neurons. The soma is not used to create a local potential between the dendrites and the axon.