Anatomy of the Spinal Cord

- Cylinder of nerve tissue within the vertebral canal.
  - Vertebral column grows faster than the spinal cord so in an adult the spinal cord only extends to L1.
- 31 pairs of spinal nerves arise from cervical, thoracic, lumbar, sacral and coccygeal regions of the cord.
- Cauda Equina (resemble a horse’s tail) is the highly branched part of the spinal cord from L2 to S5 which is composed of nerve roots.
Gross Anatomy of Lower Spinal Cord

- Spinal cord
- Cauda equina
- Sciatic nerve
Gross Anatomy of the Lower Spinal Cord

1. Spinal Cord
2. Dura Mater reflected open
3. Medulary Cone
4. Cauda Equina
Meninges of the Spinal Cord and Brain are similar

Dura Mater
- outermost membrane of tough collagen fibers
- epidural space between the dura mater and the vertebral canal is filled with fat and blood vessels
  - epidural anesthesia is delivered into the epidural space

Arachnoid (Mater)
- middle layer composed of a simple squamous epithelium and a loose mesh of connective tissue fibers (like a spider web)
- Subarachnoid space is filled with Cerebrospinal Fluid (CSF)
  - spinal anesthesia is delivered into the subarachnoid space

Pia Mater
- delicate membrane attached to surface of spinal cord
Spinal Meninges

- Periosteum on bone
- Spinal cord
- Denticulate ligament
- Dorsal root ganglion
- Spinal nerve
- Vertebral body
- Fat in epidural space
- Subarachnoid space
- Meninges:
  - Dura mater (dural sheath)
  - Arachnoid mater
  - Pia mater
Meninges of the Spinal Cord
Spina Bifida

- Congenital defect in 1 baby out of 1000
- Failure of vertebral arch to form over spinal cord
- CSF pressure stretches meninges
- Mothers can reduce risk by taking sufficient folic acid during pregnancy
Anatomy of the Spinal Cord

- Gray matter = mostly neuron cell bodies
- White matter = myelinated axons
Anatomy of a Spinal Nerve

- 31 pairs of spinal nerves
  - 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal
A nerve is a bundle of nerve fibers (axons) covered with 3 layers of Connective Tissue:

- **Epineurium** covers nerves and conducts blood vessels along nerves.
- **Perineurium** surrounds a fascicle (bundle) of axons and conducts blood vessels into the nerve.
- **Endoneurium** is the basal lamina and loose connective tissue fibers around the Schwann cells. Blood vessels do not penetrate through the endoneurium.
Ganglia in the PNS are clusters of neuron somas (cell bodies) in a nerve.

Example: Dorsal Root Ganglion is the location of the sensory neuron somas.
Branches of the Spinal Nerves

- **Proximal Branches**
  - *dorsal root* (sensory input to spinal cord)
  - *ventral root* (motor output of spinal cord)

- **Distal Branches**
  - *dorsal ramus* serves dorsal body muscle and skin
  - *ventral ramus* serves ventral body and limb muscles and skin
  - *meningeal branch* serves meninges, vertebrae and ligaments
Cutaneous Innervation and Dermatomes

• Each spinal nerve receives sensory input from a specific area of skin called a dermatome.
Pain

- Pain is discomfort caused by tissue injury or noxious stimulation.
- Pain is a valuable sense because it helps us learn how to avoid serious injury.
  - Neuropathy is the loss of the sense of pain.
  - Diseases including diabetes mellitus and leprosy can cause neuropathy.
Nociceptors

- Nociceptors are specialized sensory nerve fibers that sense pain.
- Nociceptors are abundant in skin, mucous membranes, organs, meninges, but NOT the brain.
- Fast Pain is transmitted through myelinated fibers and produces instantaneous sharp, localized, stabbing pain.
- Slow Pain follows fast pain and is transmitted through unmyelinated fibers and produces longer-lasting, dull, diffuse feeling of pain.
- Somatic Pain comes from the skin, muscles and joints.
- Visceral Pain comes from internal organs.
- Bradykinin released by injured tissues is the most potent pain stimulus known, and triggers a cascade of reactions that promote healing.
- Serotonin, prostaglandins, histamine, $K^+$, and ATP also stimulate nociceptors.
Shingles

• Skin eruptions along the path of a spinal nerve (dermatome) caused by the chicken pox virus (Varicella zoster) that lives in the dorsal root ganglia for life.

• Periodic flair-ups can occur along the path of an infected nerve.

• Flair-ups are more common after age 50 or if the person’s immune system is compromised.

• Treated with aspirin and cortisone creams to relieve pain and inflammation.
In 1998, at age 38, Mary Ellen Nelsen had a shingles outbreak. Antiviral drugs cleared up the painful shingles rash on her face and scalp, but a ferocious itch took its place. “It was relentless,” Nilsen says. Over a 13 month period, Nilsen scratched, despite her best efforts not to, and despite her horror at the growing lesions she saw in the mirror. At the time, Nilsen says, she had no idea that the damage she was doing to herself was more than skin deep, but she ended up in a Boston emergency room with brain tissue protruding through a hole she scratched through her skull which resulted in frontal-lobe brain damage. The virus damaged sensory nerves in a way that induced itch, but left her unable to feel pain from the scratching-induced wounds.

Gray Matter in the Spinal Cord is divided into Horns

- Dorsal horns lead to the dorsal roots of spinal nerves
  - dorsal root is totally composed of sensory fibers
  - dorsal root ganglion contains the somas of unipolar sensory neurons
- Ventral horns lead to the ventral roots of spinal nerves
  - ventral root is totally composed of motor fibers
- Gray Commissure forms a bridge of gray matter between the horns
- Central canal filled with CSF and is continuous with the 4th ventricle of the brain
White Matter in the Spinal Cord is divided into Tracts

- Ascending Tracts carry signals up to brain.
- Descending tracts carry signals down spinal cord.
- Tracts can be Contralateral (origin and destination are on opposite sides) or Ipsilateral (origin and destination are on the same side).
Somatic Reflexes

- Somatic Reflexes are quick, involuntary, stereotyped reactions of glands or muscle in response to sensory stimulation.
- Automatic responses to sensory input that occur without our intent or often even our awareness occur through a Somatic Reflex Arc:
  1) stimulation of somatic receptors
  2) afferent fibers carry signal to dorsal horn of spinal cord
  3) interneurons integrate the information in spinal cord
  4) efferent fibers carry impulses to skeletal muscles
  5) skeletal muscles respond
- Examples: Flexor Withdrawal Reflex and Crossed Extensor Reflex
Flexor Withdrawal Reflex

- Flexor Withdrawal Reflex quickly withdraws foot from pain.
- Neural circuitry in spinal cord controls sequence and duration of muscle contractions without the brain.
Crossed Extensor Reflex

1. Stepping on glass stimulates pain receptors in right foot
2. Contralateral extensor contracts
3. Contralateral motor neurons to extensor excited
4. and maintains balance
The Stretch (Myotatic) Reflex

- When a muscle is stretched quickly, it contracts to help maintain equilibrium and posture.
  - example: when your head starts to tip forward as you fall asleep, the muscles are stretched and respond by quickly contracting to raise the head and correct the posture.
  - the reflex maintains posture by balancing tension in extensors and flexors at particular joints (neck, knees, hips, spine, etc.).

- Stretch is sensed by modified muscle cells called Muscle Spindles that are innervated by special sensory neurons called primary afferent neurons.

- Special motor neurons called alpha-motor neurons quickly respond to contract the stretched muscle.

- Reciprocal inhibition prevents flexors and extensors from working against each other.
The patellar tendon (knee jerk) reflex illustrates a monosynaptic stretch reflex and reciprocal inhibition of the antagonistic muscle.

**Stimulus:** Tap to tendon stretches muscle.

**Receptor:** Muscle spindle stretches and fires.

**Afferent path:** Action potential travels through sensory neuron.

**Integrating center:** Sensory neuron synapses in spinal cord.

**Efferent path 1:** Somatic motor neuron

**Effector 1:** Quadriceps muscle

**Response:** Quadriceps contracts, swinging lower leg forward.

**Efferent path 2:** Interneuron inhibiting somatic motor neuron

**Effector 2:** Hamstring muscle

**Response:** Hamstring stays relaxed, allowing extension of leg (reciprocal inhibition).
END
Muscle Spindle

- Muscle spindle senses the length of skeletal muscles.
- The spindles are modified skeletal muscle cells that are wrapped with special sensory fibers that synapse with interneurons in the spinal cord that quickly activate motor neurons to compensate for the stretch and inhibit antagonistic muscles.
Muscle Spindle

Connective tissue sheath
Extrafusal fibers

Intramuscular fibers
Nuclear chain fibers
Nuclear bag fiber

Sensory nerve endings
Flower-spray endings
Annulospiral endings

Motor neurons
Gamma
Alpha

Motor end plates
Muscle Spindle

- Efferent
- Afferent
- Flower spray ending
- Annulospiral endings
- Nuclear chain fiber
- Nuclear bag fiber
- Capsule
- Motor end plate
Ascending Pathway Example: The Dorsal Column

• Sensations of deep touch, visceral pain, vibration are relayed from First Order to Second Order to Third Order Neurons.

• Third Order Neurons in thalamus carry signal to cerebral cortex where it is perceived.
Precise, coordinated limb movements are initiated in the motor cortex of the brain and relayed to the spinal cord.

Two neuron pathway starts with an upper motor neuron in cerebral cortex that makes a synapse with a lower motor neuron in the spinal cord that carries the signal to a muscle.

Descending Pathway Example: The Corticospinal Tract

- Upper motor neurons
- Lower motor neurons
The Patellar Tendon Reflex Arc

1. Extensor muscle stretched
2. Muscle spindle stimulated
3. Primary afferent neuron excited
4. Primary afferent neuron stimulates α motor neuron to extensor muscle
5. α motor neuron stimulates extensor muscle to contract
6. Primary afferent neuron stimulates inhibitory interneuron
7. Interneuron inhibits α motor neuron to flexor muscle
8. Flexor muscle (antagonist) relaxes
Golgi Tendon Reflex

- Golgi Tendon Organs are Proprioceptors in tendons.
- Excessive tension on the tendon inhibits the motor neuron to that muscle and muscle contraction is decreased.
The Spinal Cord

- Conducts information between brain and body.
- Extends through vertebral canal from foramen magnum to L1.
- Each pair of spinal nerves receives sensory information and sends out motor signals to muscles and glands.
- Spinal cord is part of the Central Nervous System while the spinal nerves are part of the Peripheral Nervous System.
Functions of the Spinal Cord

• Conduction
  – bundles of nerve fibers pass information up and down spinal cord.

• Locomotion
  – coordinates actions of several muscle groups
  – central pattern generators are pools of neurons that provide control of flexors and extensors as in walking.

• Reflexes
  – involuntary, stereotyped responses to stimuli (remove hand from hot stove) involves brain, spinal cord and peripheral nerves.
Spinothalamic Pathway

- Pain, pressure, temperature, light touch, tickle & itch
- Decussation of the second order neuron occurs in spinal cord
Spinocerebellar Pathway

- Proprioceptive signals in limbs and trunk travel up to the cerebellum
- Second order nerves ascend in lateral column
Descending Motor Tracts

• Tectospinal tract
  – reflex movements of head

• Reticulospinal tract
  – controls limb movements important to maintain posture

• Vestibulospinal tract
  – postural muscle activity in response to inner ear signals
Spinal Cord Trauma

• 10-12,000 people/year are paralyzed
• 55% occur in traffic accidents
• This damage poses risk of respiratory failure
• Early symptoms are called spinal shock
• Tissue damage at time of injury is followed by post-traumatic infarction
Nerve Plexuses

- Ventral rami branch & anastomose repeatedly to form 5 nerve plexuses
  - cervical in the neck, C1 to C5
    - supplies neck and phrenic nerve to the diaphragm
  - brachial in the armpit, C5 to T1
    - supplies upper limb and some of shoulder & neck
  - lumbar in the low back, L1 to L4
    - supplies abdominal wall, anterior thigh & genitalia
  - sacral in the pelvis, L4, L5 & S1 to S4
    - supplies remainder of butt & lower limb
  - coccygeal, S4, S5 and C0
Structure of a Nerve Plexus

- Notice the branching and merging of nerves in this example of a plexus
The Cervical Plexus

- Segmental branch
- Hypoglossal nerve (XII)
- Lesser occipital nerve
- Great auricular nerve
- Transverse cervical nerve
- Anterior root
- Posterior root
- Ansa cervicalis
- Supraclavicular nerve
- Branch to brachial plexus
- Phrenic nerve
The Brachial Plexus

- Roots
- Trunks
- Anterior divisions
- Posterior divisions

- Clavicle
- Lateral cord
- Posterior cord
- Medial cord
- Axillary nerve
- Scapula
- Musculocutaneous nerve
- Median nerve
- Humerus
- Radial nerve
- Ulna
- Median nerve
- Ulnar nerve
- Radial nerve
- Radius
- Superficial branch of ulnar nerve
- Digital branch of median nerve
- Digital branch of ulnar nerve

Nerves:
- Dorsal scapular nerve
- Long thoracic nerve
- Suprascapular nerve
- Subclavian nerve
- Posterior cord
- Axillary nerve
- Subscapular nerve
- Thoracodorsal nerve
- Radial nerve
- Lateral cord
- Musculocutaneous nerve
- Medial and lateral pectoral nerves
- Median nerve
- Ulnar nerve
- Medial cutaneous antebrachial nerve
- Medial brachial cutaneous nerve
Dissection of the Brachial Plexus
The Lumbar Plexus

Roots
Anterior divisions
Posterior divisions

From lumbar plexus
From sacral plexus

Os coxae
Sacrum
Femoral nerve
Pudendal nerve
Sciatic nerve
Femur
Tibial nerve
Common fibular nerve
Superficial fibular nerve
Deep fibular nerve
Fibula
Tibia
Tibial nerve
Medial plantar nerve
Lateral plantar nerve

Anterior view

Posterior view

Iliohypogastric nerve
Iliinguinal nerve
Genitofemoral nerve
Lateral femoral cutaneous nerve
Femoral nerve
Saphenous nerve
Obturator nerve
Lumbosacral trunk
The Sacral and Coccygeal Plexuses

- Lumbosacral trunk
- Superior gluteal nerve
- Inferior gluteal nerve
- Common fibular nerve
- Tibial nerve
- Posterior cutaneous femoral nerve
- Internal pudendal nerve
- Sciatic nerve

Roots
Anterior divisions
Posterior divisions
Poliomyelitis and ALS

- Diseases causing destruction of motor neurons and skeletal muscle atrophy
- Poliomyelitis caused by poliovirus spread by fecally contaminated water
  - weakness progresses to paralysis and respiratory arrest
- Amyotrophic lateral sclerosis
  - sclerosis of spinal cord due to astrocyte failure to reabsorb glutamate neurotransmitter
  - paralysis and muscle atrophy
• White matter is divided into columns which are bundles of myelinated axons that carry signals up and down the spinal cord.
• Each column is filled with tracts named for fibers with a similar origin, destination and function.
Anatomy of Ganglia in the PNS

- Ganglia in the PNS are clusters of neuron somas (cell bodies) in a nerve.
- Example: Dorsal Root Ganglion is the location of the sensory neuron somas.