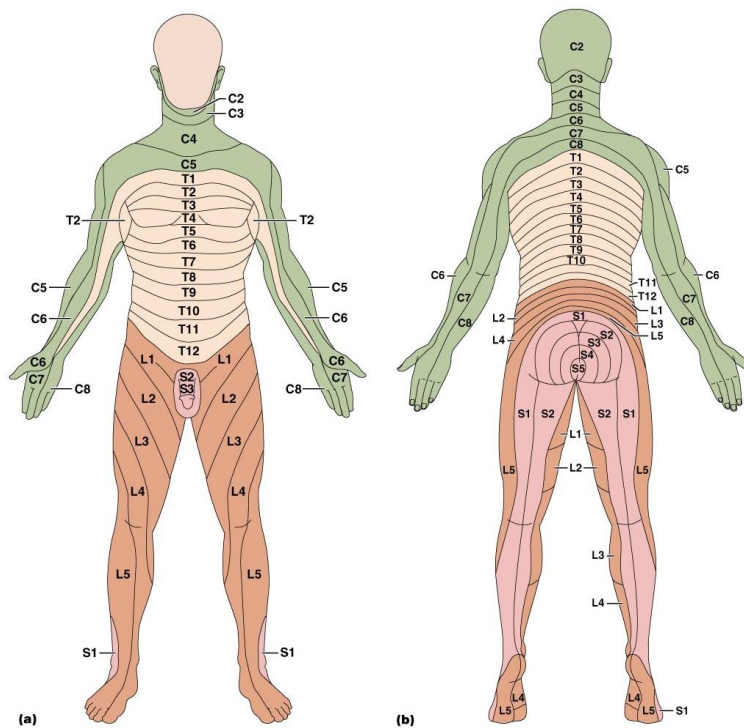


## **PART 2: Spinal Cord**

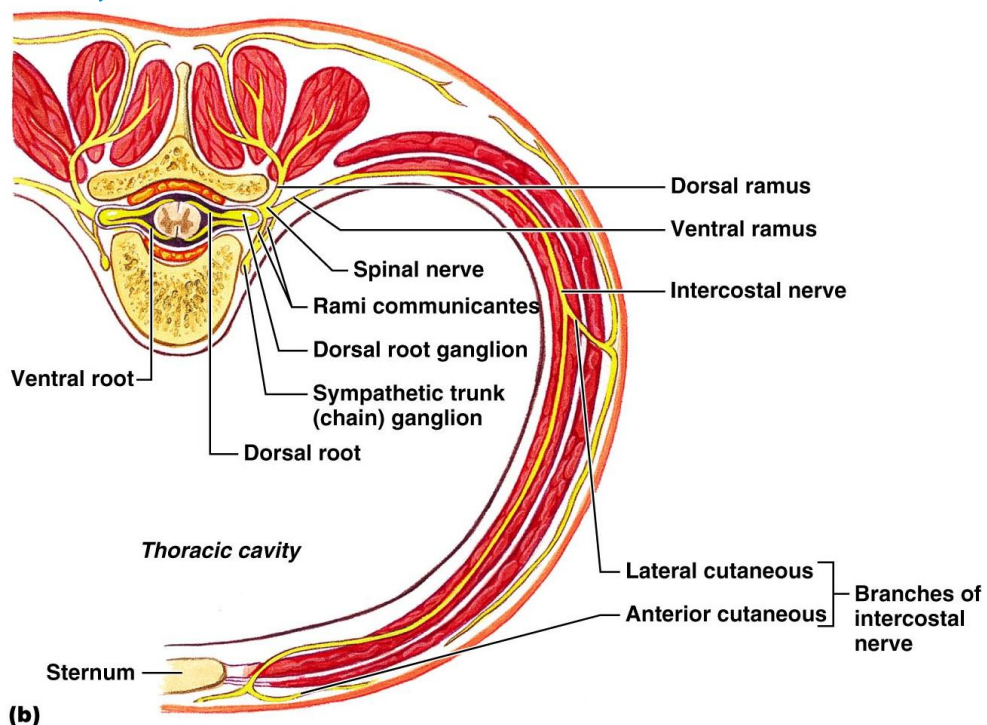
### **Danil Hammoudi.MD**

- The spinal cord is the connection center for the reflexes as well as the afferent (sensory) and efferent (motor) pathways for most of the body below the head and neck.
- The spinal cord begins at the brainstem and ends at about the second lumbar vertebra. The sensory, motor, and interneurons discussed previously are found in specific parts of the spinal cord and nearby structures. Sensory neurons have their cell bodies in the **spinal (dorsal root) ganglion**.
- Their axons travel through the **dorsal root** into the gray matter of the cord.
- Within the **gray matter** are interneurons with which the sensory neurons may connect.
- Also located in the gray matter are the motor neurons whose axons travel out of the cord through the **ventral root**.
- The **white matter** surrounds the gray matter.
- It contains the spinal tracts which ascend and descend the spinal cord.
- Surrounding both the spinal cord and the brain are the **meninges**, a three layered covering of connective tissue.
- The **dura mater** is the tough outer layer.
- Beneath the dura is the **arachnoid** which is like a spider web in consistency.
- The arachnoid has abundant space within and beneath it (the **subarachnoid space**) which contains cerebrospinal fluid, as does the space beneath the dura mater (**subdural space**).
- This cerebrospinal fluid supplies buoyancy for the spinal cord and brain to help provide shock absorption.
- The **pia mater** is a very thin layer which adheres tightly to the surface of the brain and spinal cord. It follows all contours and fissures (sulci) of the brain and cord.
- At 31 places along the spinal cord the dorsal and ventral roots come together to form **spinal nerves**.
- Spinal nerves contain both sensory and motor fibers, as do most nerves.
- Spinal nerves are given numbers which indicate the portion of the vertebral column in which they arise.
- There are 8 cervical (C1-C8), 12 thoracics (T1-T12), 5 lumbar (L1-L5), 5 sacral (S1-S5), and 1 coccygeal nerve.
- Nerve C1 arises between the cranium and atlas (1<sup>st</sup> cervical vertebra) and C8 arises between the 7<sup>th</sup> cervical and 1<sup>st</sup> thoracic vertebra. All the others arise below the respective vertebra or former vertebra in the case of the sacrum. Since the actual cord ends at the second lumbar vertebra, the later roots arise close together on the cord and travel downward to exit at the appropriate point.
- These nerve roots are called the **cauda equina** because of their resemblance to a *horses tail*.
- The **dermatomes** are somatic or musculoskeletal areas served by fibers from specific spinal nerves. .

# Dermatomes



## Spinal Nerve Innervation: Back, Anterolateral Thorax, and Abdominal Wall



- **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.
- So pain in the heart is often interpreted as pain in the left arm or shoulder, pain in the diaphragm is interpreted as along the left clavicle and neck, and the "stitch in your side" you sometimes feel when running is pain in the liver as its vessels vasoconstrict.

### **Spinal Nerves**

- Thirty-one pairs of mixed nerves arise from the spinal cord and supply all parts of the body except the head
- They are named according to their point of issue
  - 8 cervical (C<sub>1</sub>-C<sub>8</sub>)
  - 12 thoracic (T<sub>1</sub>-T<sub>12</sub>)
  - 5 Lumbar (L<sub>1</sub>-L<sub>5</sub>)
  - 5 Sacral (S<sub>1</sub>-S<sub>5</sub>)
  - 1 Coccygeal (C<sub>0</sub>)

### **Spinal Nerves: Roots**

- Each spinal nerve connects to the spinal cord via two medial roots
- Each root forms a series of rootlets that attach to the spinal cord
- Ventral roots arise from the anterior horn and contain motor (efferent) fibers
- Dorsal roots arise from sensory neurons in the dorsal root ganglion and contain sensory (afferent) fibers

### **Spinal Nerves: Rami**

- The short spinal nerves branch into three or four mixed, distal rami
  - Small dorsal ramus
  - Larger ventral ramus
  - Tiny meningeal branch
  - Rami communicantes at the base of the ventral rami in the thoracic region

### **Nerve Plexuses**

- All ventral rami except T<sub>2</sub>-T<sub>12</sub> form interlacing nerve networks called plexuses
- Plexuses are found in the cervical, brachial, lumbar, and sacral regions
- Each resulting branch of a plexus contains fibers from several spinal nerves
- Fibers travel to the periphery via several different routes
- Each muscle receives a nerve supply from more than one spinal nerve
- Damage to one spinal segment cannot completely paralyze a muscle

### **Spinal Nerve Innervation: Back, Anterolateral Thorax, and Abdominal Wall**

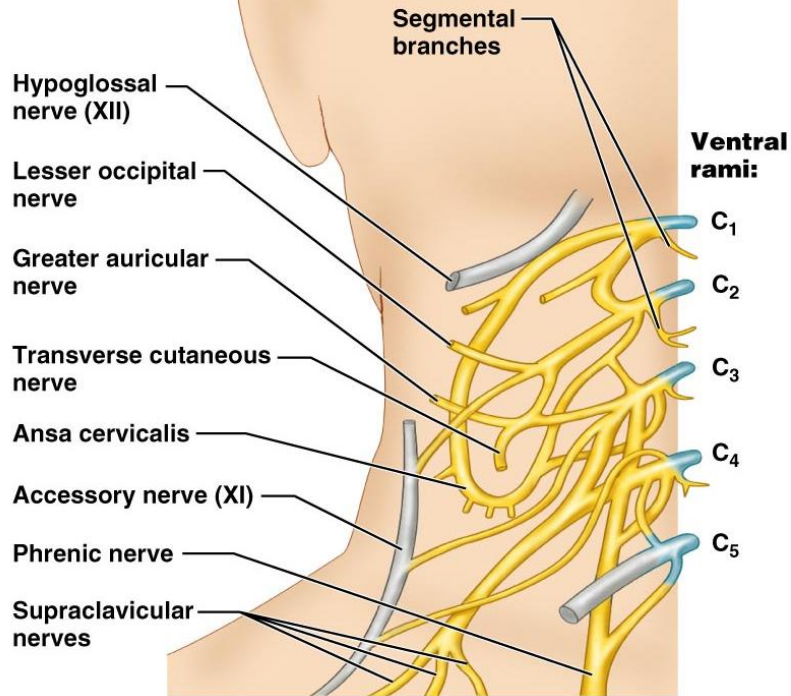
- The back is innervated by dorsal rami via several branches
- The thorax is innervated by ventral rami T<sub>1</sub>-T<sub>12</sub> as intercostal nerves
- Intercostal nerves supply muscles of the ribs, anterolateral thorax, and abdominal wall

### **Cervical Plexus**

- The cervical plexus is formed by ventral rami of C<sub>1</sub>-C<sub>4</sub>
- Most branches are cutaneous nerves of the neck, ear, back of head, and shoulders
- The most important nerve of this plexus is the phrenic nerve
- The phrenic nerve is the major motor and sensory nerve of the diaphragm

**Key:**

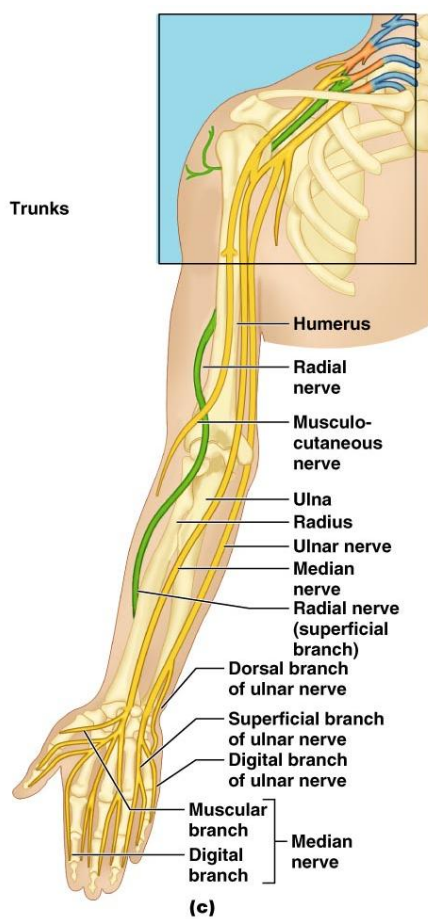
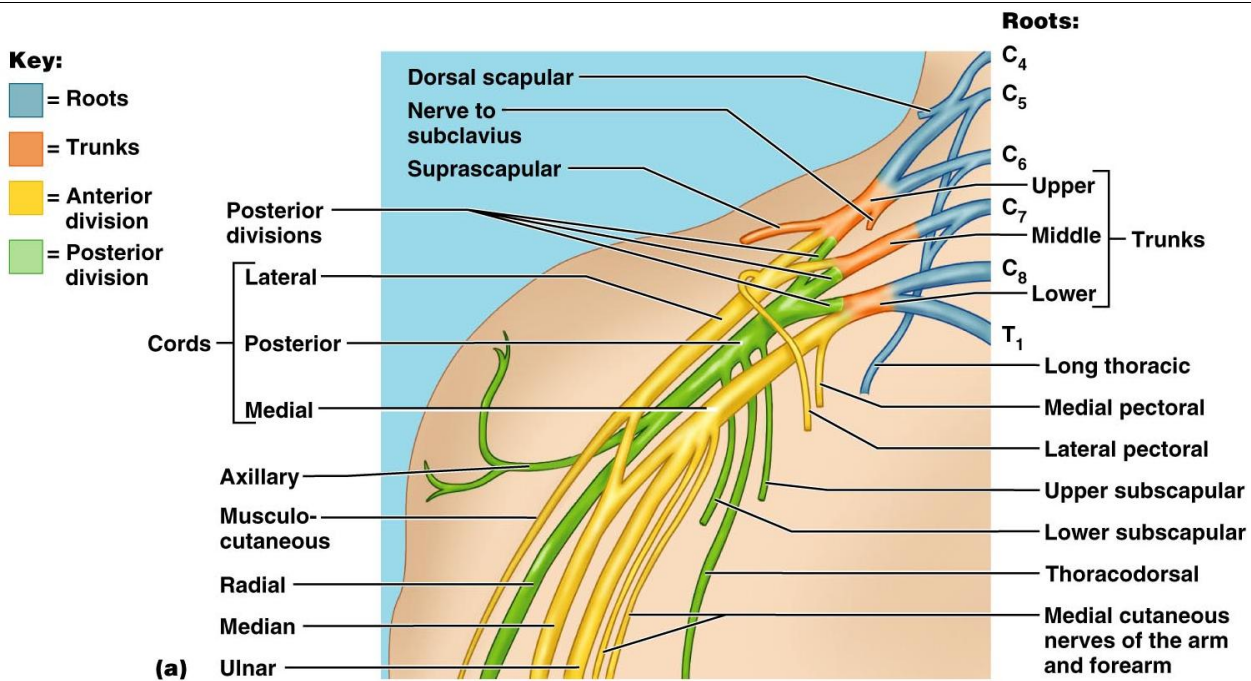
■ = Ventral  
rami

**Brachial Plexus**

- Formed by C<sub>5</sub>-C<sub>8</sub> and T<sub>1</sub> (C<sub>4</sub> and T<sub>2</sub> may also contribute to this plexus)
- It gives rise to the nerves that innervate the upper limb
- There are four major branches of this plexus
  - Roots – five ventral rami (C<sub>5</sub>-T<sub>1</sub>)
  - Trunks – upper, middle, and lower, which form divisions
  - Divisions – anterior and posterior serve the front and back of the limb
  - Cords – lateral, medial, and posterior fiber bundles

**Brachial Plexus: Nerves**

- Axillary – innervates the deltoid and teres minor
- Musculocutaneous – sends fibers to the biceps brachii and brachialis
- Median – branches to most of the flexor muscles of arm
- Ulnar – supplies the flexor carpi ulnaris and part of the flexor digitorum profundus
- Radial – innervates essentially all extensor muscles



(b)

Major terminal branches (peripheral nerves)	Cords	Divisions	Trunks	Roots (ventral rami)
Musculocutaneous	Lateral	Anterior	Upper	C <sub>5</sub>
Median	Lateral	Posterior	Upper	C <sub>6</sub>
Ulnar	Medial	Anterior	Middle	C <sub>7</sub>
Radial	Medial	Posterior	Middle	C <sub>8</sub>
Axillary	Posterior	Anterior	Lower	T <sub>1</sub>
	Posterior	Posterior	Lower	T <sub>1</sub>

### Lumbar Plexus

- Arises from L<sub>1</sub>-L<sub>4</sub> and innervates the thigh, abdominal wall, and psoas muscle
- The major nerves are the femoral and the obturator

### Sacral Plexus

- Arises from L<sub>4</sub>-S<sub>4</sub> and serves the buttock, lower limb, pelvic structures, and the perineum



- The major nerve is the sciatic, the longest and thickest nerve of the body
- The sciatic is actually composed of two nerves: the tibial and the common fibular (peroneal) nerves

#### **Dermatomes**

- A dermatome is the area of skin innervated by the cutaneous branches of a single spinal nerve
- All spinal nerves except C<sub>1</sub> participate in dermatomes

#### **Spinal nerves join together in plexuses.**

A **plexus** is an interconnection of fibers which form new combinations as the "named" or **peripheral nerves**.

There are four voluntary plexuses (there are some autonomic plexuses which will be mentioned later): they are the **cervical plexus**, the **brachial plexus**, the **lumbar plexus**, and the **sacral plexus**. Each plexus gives rise to new combinations of fibers as the **peripheral nerves**.

The nerves and plexuses you need to know are:

**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.

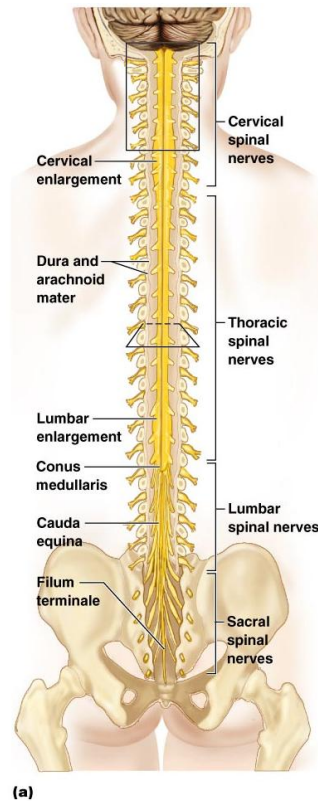
**nerve** - a group of fibers (axons) *outside* the CNS. The spinal nerves contain the fibers of the sensory and motor neurons. A nerve does not contain cell bodies. They are located in the ganglion (sensory) or in the gray matter (motor).

**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.

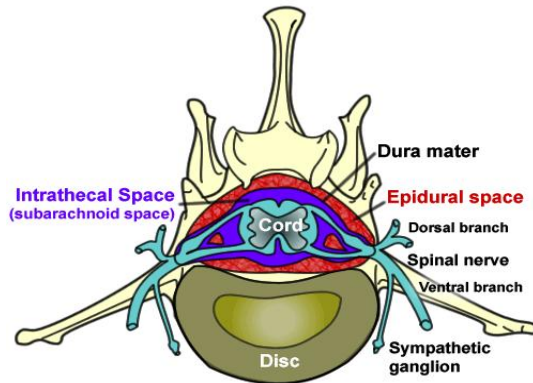
**gray matter** - an area of unmyelinated neurons where cell bodies and synapses occur. In the spinal cord the synapses between sensory and motor and interneurons occurs in the gray matter. The cell bodies of the interneurons and motor neurons also are found in the gray matter.

**white matter** - an area of myelinated fiber tracts. Myelination in the CNS differs from that in nerves.



- CNS tissue is enclosed within the vertebral column from the foramen magnum to L<sub>1</sub>
- Provides two-way communication to and from the brain
- Protected by bone, meninges, and CSF
- Epidural space – space between the vertebrae and the dural sheath (dura mater) filled with fat and a network of veins
- 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

## SPINAL CORD ANATOMY



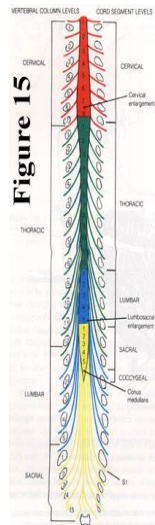
There are 31 spinal cord segments:

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

There are two regions where the spinal cord enlarges:

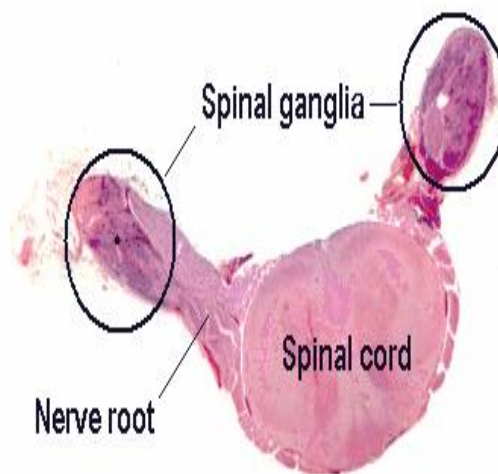
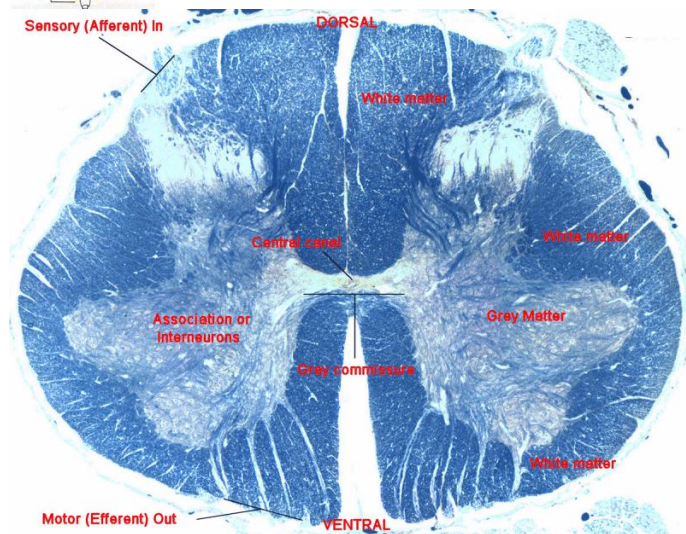
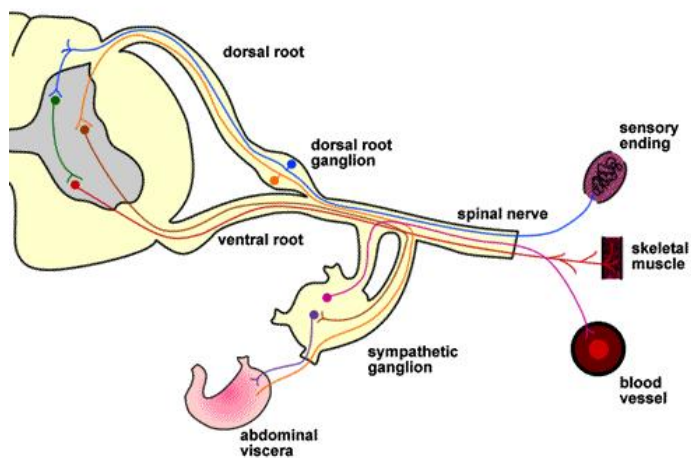
- **Cervical enlargement** - corresponds roughly to the brachial plexus nerves, which innervate the upper limb. It includes spinal cord segments from about C4 to T1. The vertebral levels of the enlargement are roughly the same (C4 to T1).
- **Lumbosacral enlargement** - corresponds to the lumbosacral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

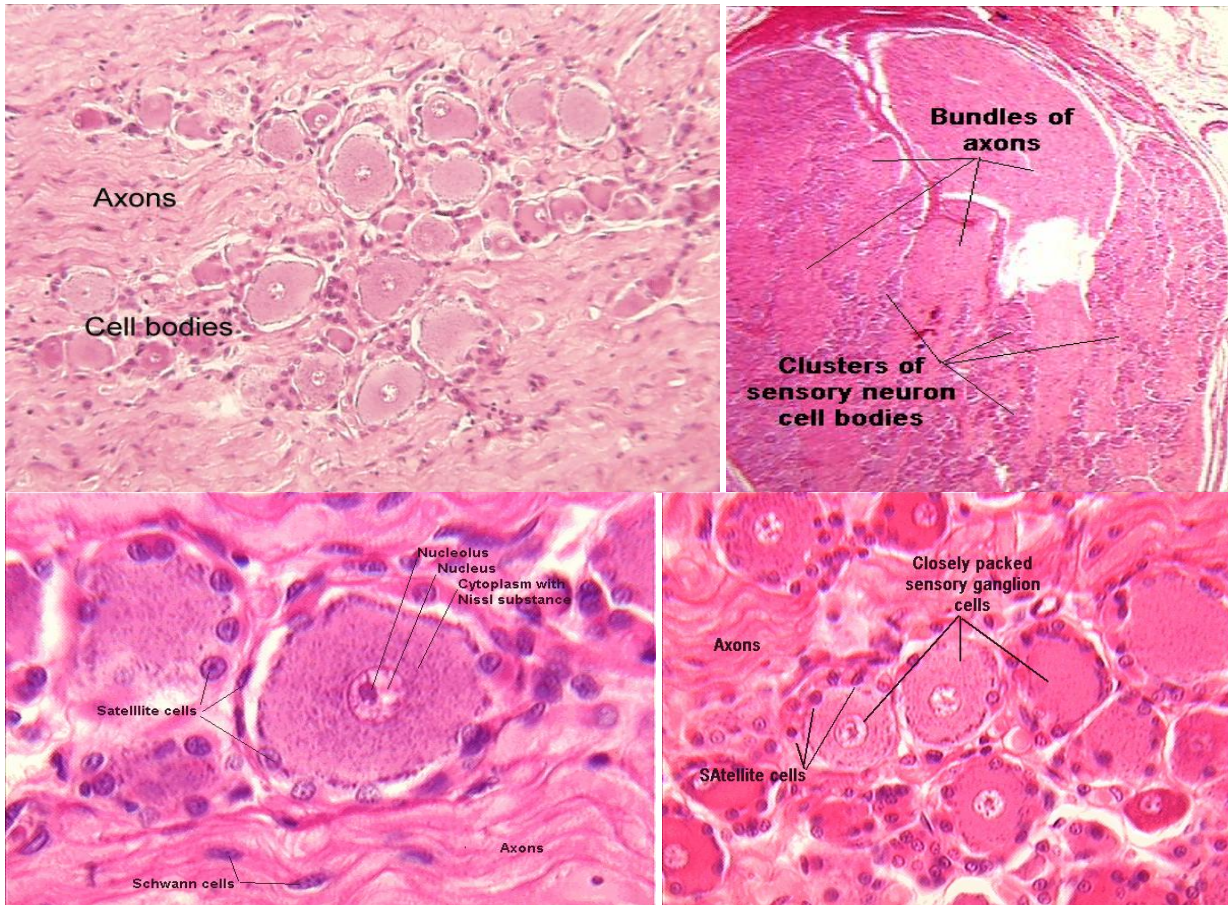




**Figure 15**

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





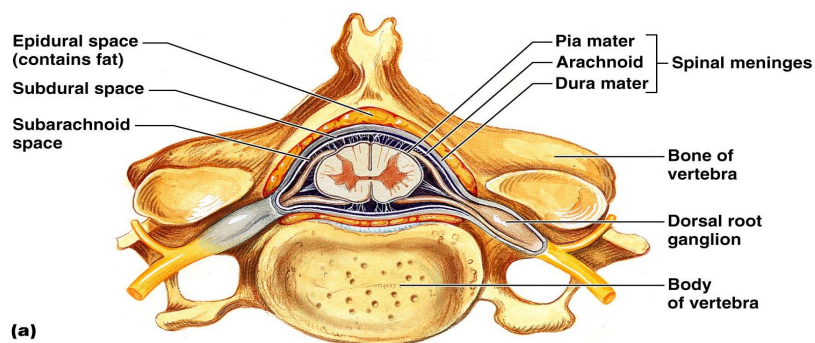
- Spinal nerves – 31 pairs attach to the cord by paired roots
- Cervical and lumbar enlargements – sites where nerves serving the upper and lower limbs emerge
- Cauda equina – collection of nerve roots at the inferior end of the vertebral canal

### Cross-Sectional Anatomy of the Spinal Cord

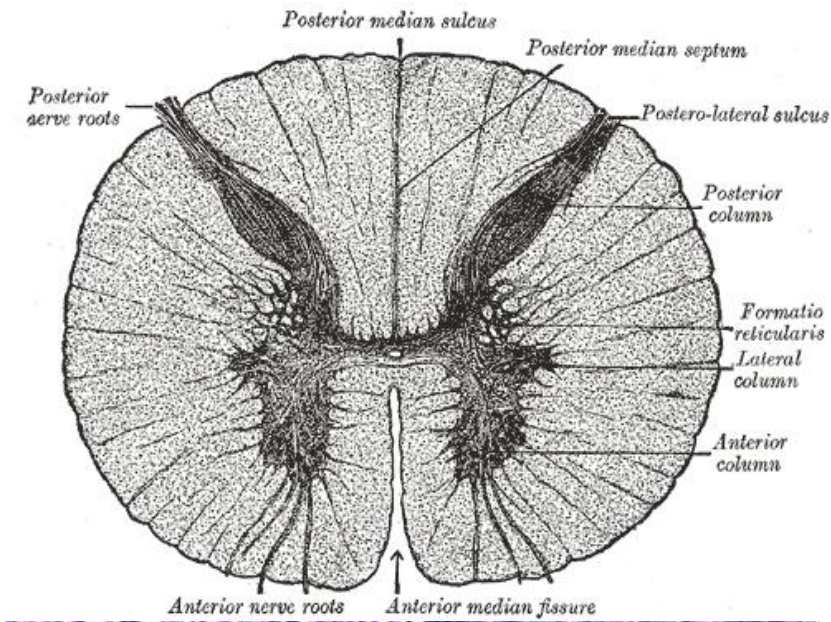
- Anterior median fissure – separates anterior funiculi
- Posterior median sulcus – divides posterior funiculi

### Cross-Sectional Anatomy of the Spinal Cord

- Anterior median fissure – separates anterior funiculi
- Posterior median sulcus – divides posterior funiculi



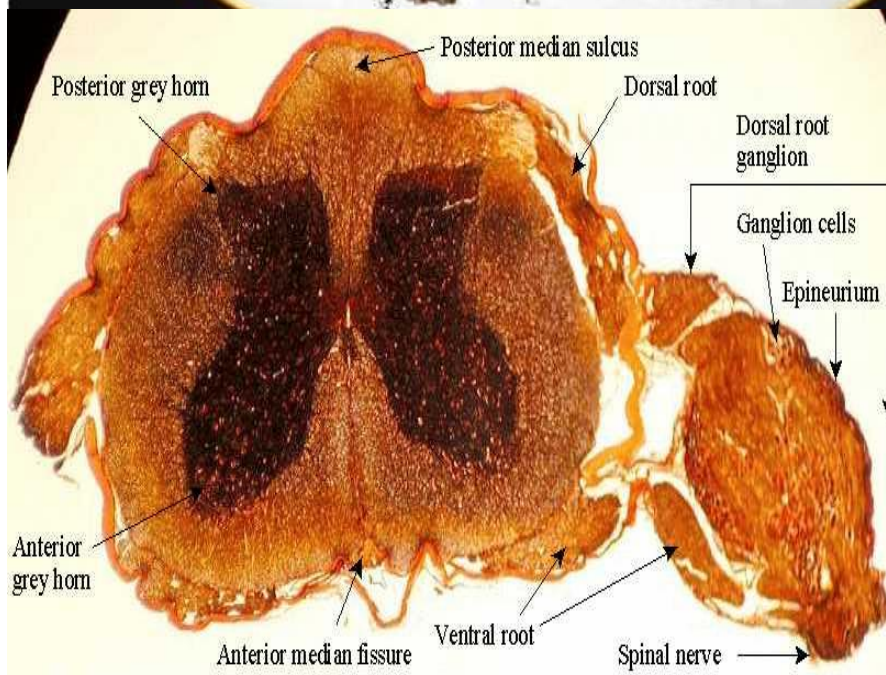
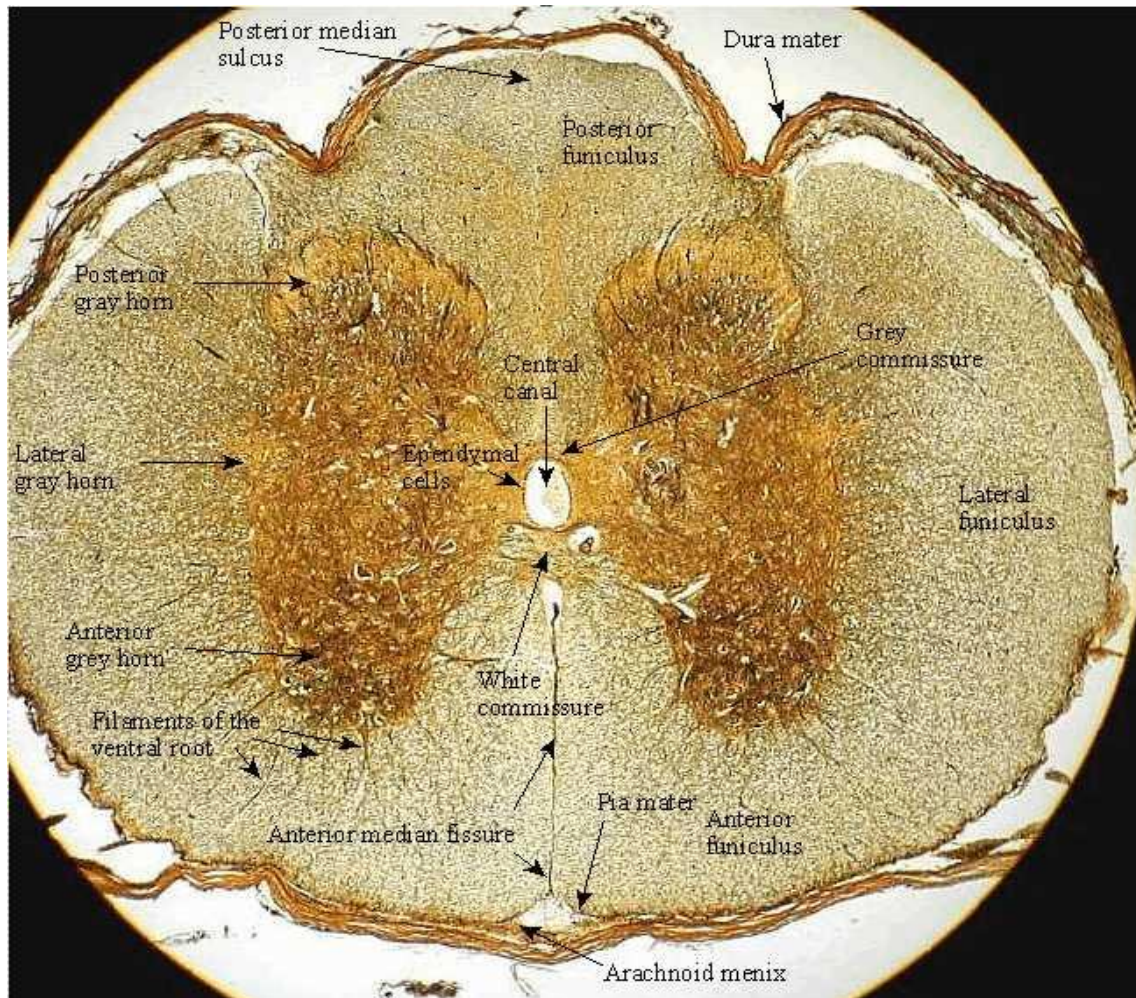




### Central Canal

Within the spinal cord is the central canal that contains cerebrospinal fluid (CSF). Note the ependymal cells (simple cuboidal with cilia) that line the lumen.



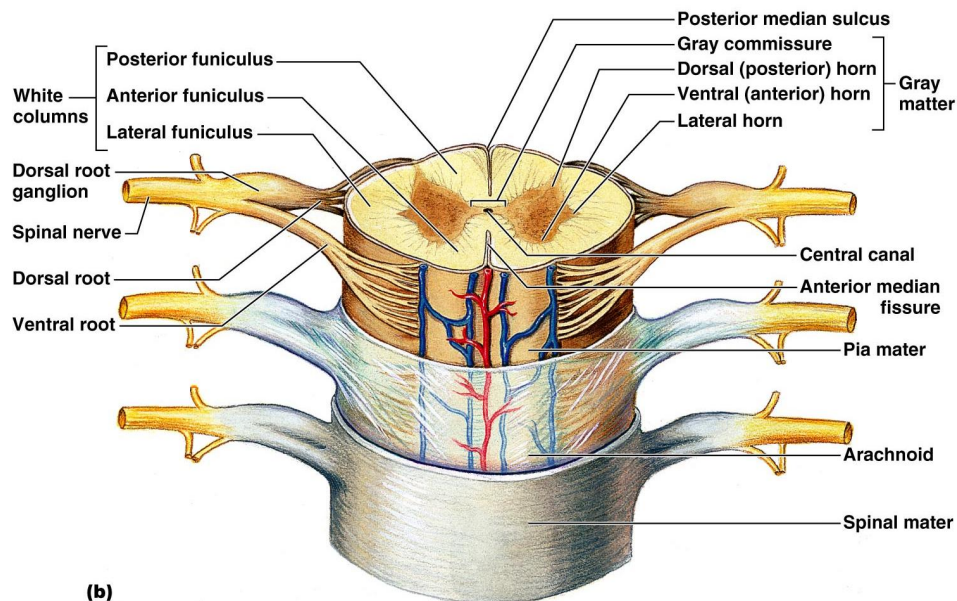


### Gray Matter and Spinal Roots

- Gray matter consists of soma, unmyelinated processes, and neuroglia
- Gray commissure – connects masses of gray matter; encloses central canal
- Posterior (dorsal) horns – interneurons
- Anterior (ventral) horns – interneurons and somatic motor neurons

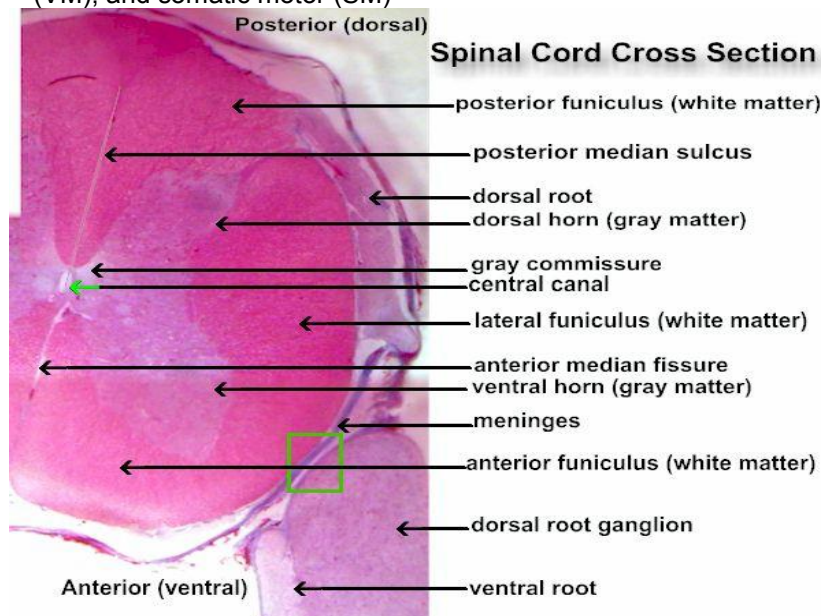


- Lateral horns – contain sympathetic nerve fibers



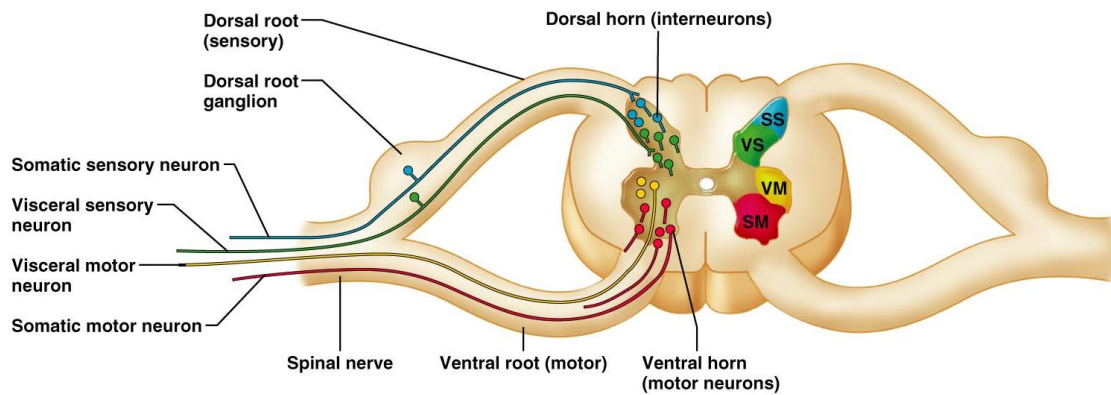
### Gray Matter: Organization

- Dorsal half – sensory roots and ganglia
- Ventral half – motor roots
- Dorsal and ventral roots fuse laterally to form spinal nerves
- Four zones are evident within the gray matter – somatic sensory (SS), visceral sensory (VS), visceral motor (VM), and somatic motor (SM)



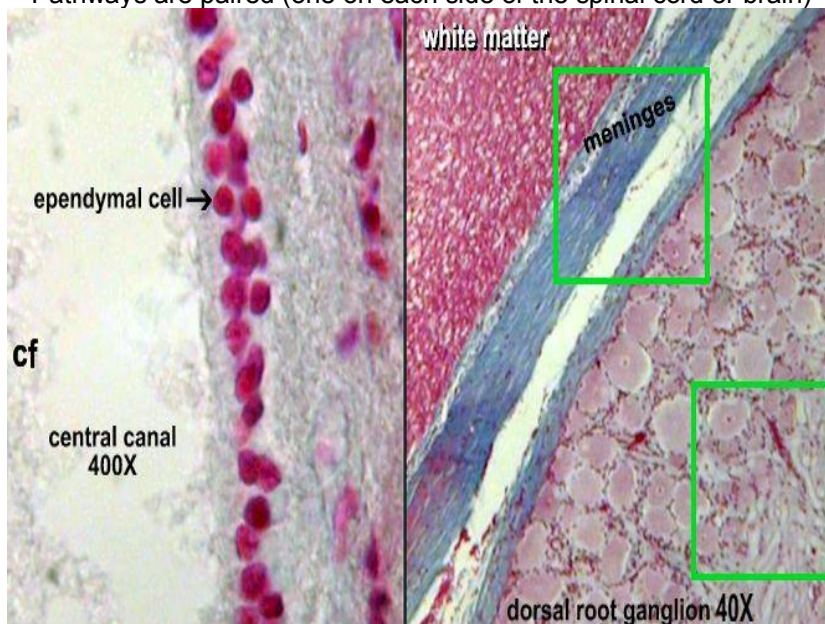
### White Matter in the Spinal Cord

- Fibers run in three directions – ascending, descending, and transversely
- Divided into three funiculi (columns) – posterior, lateral, and anterior
- Each funiculus contains several fiber tracks
  - Fiber tract names reveal their origin and destination
  - Fiber tracts are composed of axons with similar functions



### White Matter: Pathway Generalizations

- Pathways decussate
- Most consist of two or three neurons
- Most exhibit somatotopy (precise spatial relationships)
- Pathways are paired (one on each side of the spinal cord or brain)

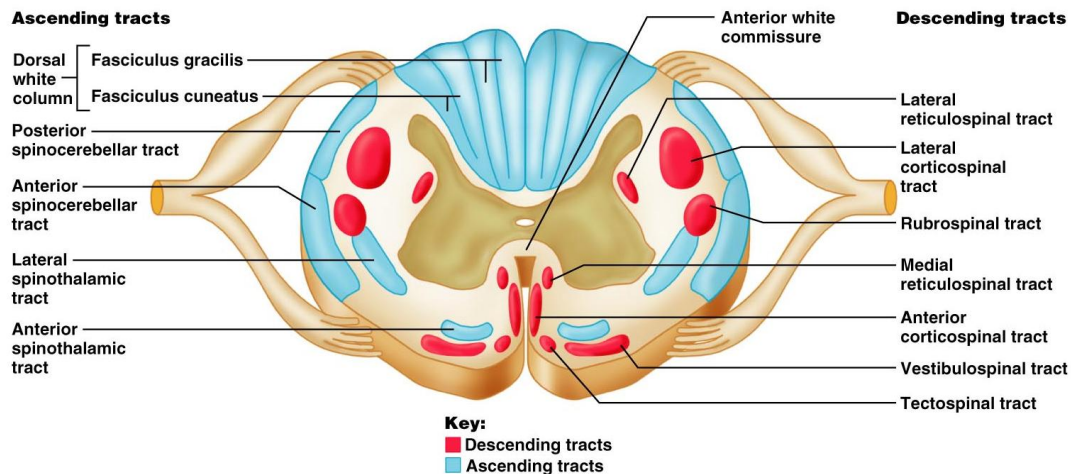


### Main Ascending Pathways

- The central processes of first-order neurons branch diffusely as they enter the spinal cord and medulla
- Some branches take part in spinal cord reflexes
- Others synapse with second-order neurons in the cord and medullary nuclei
- Fibers from touch and pressure receptors form collateral synapses with interneurons in the dorsal horns



# White Matter: Pathway Generalizations



## Three Ascending Pathways

- The nonspecific and specific ascending pathways send impulses to the sensory cortex
  - These pathways are responsible for discriminative touch and conscious proprioception
- The spinocerebellar tracts send impulses to the cerebellum and do not contribute to sensory perception

## Nonspecific Ascending Pathway

- Nonspecific pathway for pain, temperature, and crude touch within the lateral spinothalamic tract

## Specific and Posterior Spinocerebellar Tracts

- Specific ascending pathways within the fasciculus gracilis and fasciculus cuneatus tracts, and their continuation in the medial lemniscal tracts
- The posterior spinocerebellar tract

## Descending (Motor) Pathways

- Descending tracts deliver efferent impulses from the brain to the spinal cord, and are divided into two groups
  - Direct pathways equivalent to the pyramidal tracts
  - Indirect pathways, essentially all others
- Motor pathways involve two neurons (upper and lower)

## The Direct (Pyramidal) System

- Direct pathways originate with the pyramidal neurons in the precentral gyri
- Impulses are sent through the corticospinal tracts and synapse in the anterior horn
- Stimulation of anterior horn neurons activates skeletal muscles
- Parts of the direct pathway, called corticobulbar tracts, innervate cranial nerve nuclei
- The direct pathway regulates fast and fine (skilled) movements

## Indirect (Extrapyramidal) System

- Includes the brain stem, motor nuclei, and all motor pathways not part of the pyramidal system
- This system includes the rubrospinal, vestibulospinal, reticulospinal, and tectospinal tracts

## Indirect (Extrapyramidal) System

- These motor pathways are complex and multisynaptic, and regulate:
  - Axial muscles that maintain balance and posture

- Muscles controlling coarse movements of the proximal portions of limbs
- Head, neck, and eye movement

### **Extrapyramidal (Multineuronal) Pathways**

- Reticulospinal tracts – maintain balance
- Rubrospinal tracts – control flexor muscles
- Superior colliculi and tectospinal tracts mediate head movements

### **Spinal Cord Trauma: Paralysis**

- Paralysis – loss of motor function
- Flaccid paralysis – severe damage to the ventral root or anterior horn cells
  - Lower motor neurons are damaged and impulses do not reach muscles
  - There is no voluntary or involuntary control of muscles
- Spastic paralysis – only upper motor neurons of the primary motor cortex are damaged
  - Spinal neurons remain intact and muscles are stimulated irregularly
  - There is no voluntary control of muscles

### **Spinal Cord Trauma: Transection**

- Cross sectioning of the spinal cord at any level results in total motor and sensory loss in regions inferior to the cut
- Paraplegia – transection between T<sub>1</sub> and L<sub>1</sub>
- Quadriplegia – transection in the cervical region

### **Poliomyelitis**

- Destruction of the anterior horn motor neurons by the poliovirus

- Early symptoms – fever, headache, muscle pain and weakness, and loss of somatic reflexes
- Vaccines are available and can prevent infection

### **Amyotrophic Lateral Sclerosis (ALS)**

- Lou Gehrig's disease – neuromuscular condition involving destruction of anterior horn motor neurons and fibers of the pyramidal tract
- Symptoms – loss of the ability to speak, swallow, and breathe
- Death occurs within five years
- Linked to malfunctioning genes for glutamate transporter and/or superoxide dismutase

### **Developmental Aspects of the CNS**

- CNS is established during the first month of development
- Gender-specific areas appear in response to testosterone (or lack thereof)
- Maternal exposure to radiation, drugs (e.g., alcohol and opiates), or infection can harm the fetus' developing CNS
- Smoking decreases oxygen in the blood, which can lead to neuron death and fetal brain damage
- The hypothalamus is one of the last areas of the CNS to develop
- Visual cortex develops slowly over the first 11 weeks
- Growth and maturation of the nervous system occurs throughout childhood and reflects progressive myelination
- Age brings some cognitive declines, but these are not significant in healthy individuals until they reach their 80s
- Excessive use of alcohol causes signs of senility unrelated to the aging process

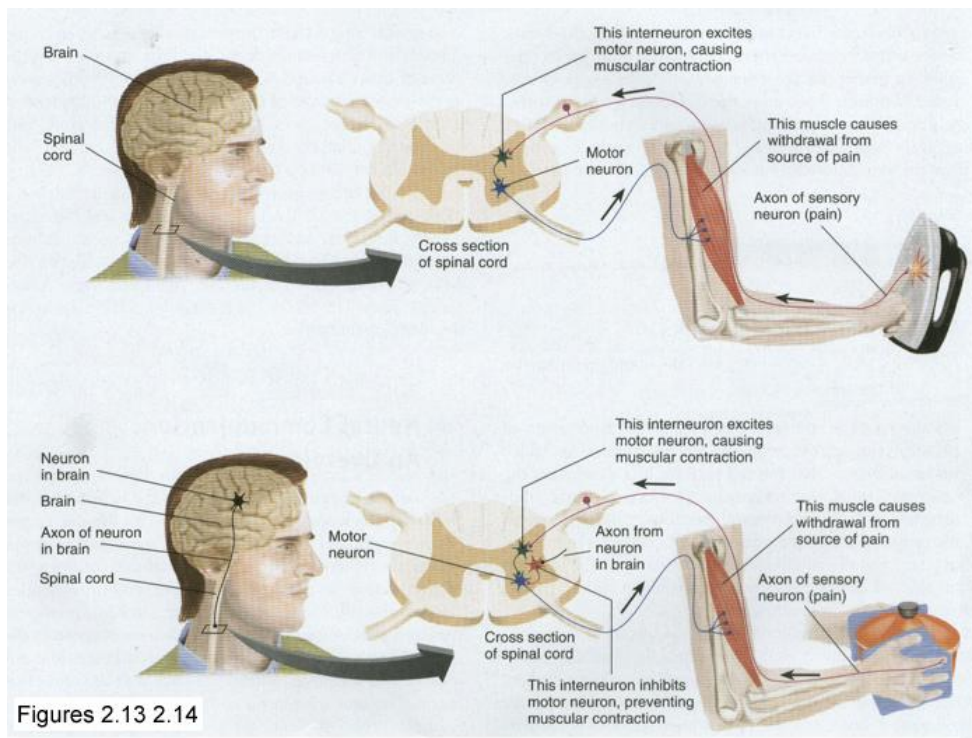
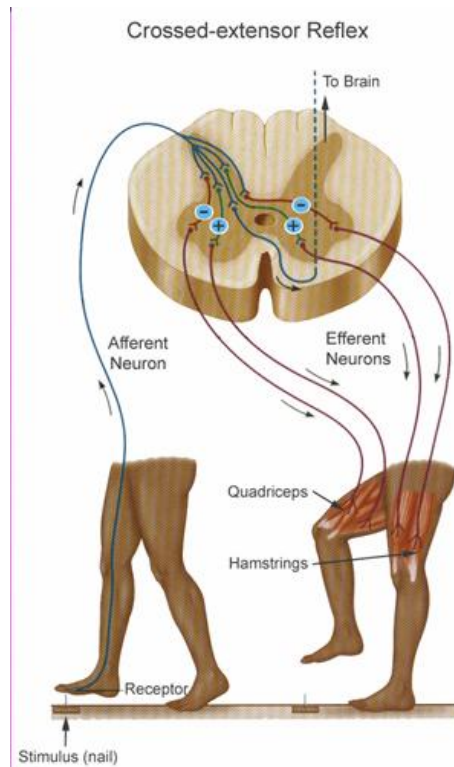
## **REFLEXES**

Sneezing and Blinking are two examples of Reflexes.

1. . A Reflex produces a rapid **MOTOR RESPONSE** to a **STIMULUS** because the Sensory Neuron Synapses **DIRECTLY** with a **MOTOR NEURON** in the Spinal Cord.
2. **REFLEXES** are very fast, and **Most Reflexes Never Reach the Brain.**
3. Blinking to protect your eyes from danger is a reflex.
4. 31 **PAIRS** of spinal nerves originate in the spinal cord and branch out to both sides of the body. Carrying messages to and from the spinal cord.
5. Sensory Neurons carry impulses from **RECEPTORS** to the spinal cord.
6. Motor Neurons carry impulses from the spinal cord to the **EFFECTORS.**
7. Within the spinal cord, motor and sensory neurons are connected by **INTERNEURONS.**

A reflex is a direct connection between stimulus and response, which does not require conscious thought. There are voluntary and involuntary reflexes. It is the voluntary reflexes we are considering here. As discussed earlier, a reflex involves at least 2 or 3 neurons. The reflex shown in this figure is called a **3-neuron reflex** because it requires three types of neurons: a **sensory**, an **interneuron**, and a **motor** neuron. It is also called a **withdrawal reflex** because it is commonly involved in withdrawing from painful stimuli. Withdrawing from painful stimuli does not require thought. But the interneuron does send a fiber through the spinothalamic tract to the brain where the pain is perceived. This occurs at virtually the same instant you are withdrawing from the

stimulus. For example, let's say you accidentally touch a hot stove. Instantly you withdraw your hand from the stove, at the same time you are feeling the pain.



Figures 2.13 2.14

### **Classification of Reflexes**

Reflexes may be classified in 4 ways: by early development, the type of motor response, the complexity of the neural circuit, and the site of information processing:

1. How the reflex was developed:

- Innate reflexes are the basic neural reflexes a person is born with.
- Acquired reflexes are rapid, automatic, learned motor patterns.

2. The nature of the resulting motor response:

- Somatic reflexes provide involuntary control of the nervous system.

- a. superficial reflexes of the skin or mucous membranes
- b. stretch reflexes (deep tendon reflexes) such as the patellar reflex

- Visceral reflexes (autonomic reflexes) control systems other than the muscular system.

3. The complexity of the neural circuit involved:

- In a monosynaptic reflex, a sensory neuron synapses directly onto a motor neuron.
- A polysynaptic reflex has at least 1 interneuron between the sensory neuron and the motor neuron.

4. The site of information processing:

- In spinal reflexes, processing occurs in the spinal cord.
- In cranial reflexes, processing occurs in the brain.
- Spinal reflexes increase in complexity from monosynaptic reflexes to polysynaptic reflexes to intersegmental reflex arcs (reflexes in which many segments interact to produce a highly variable motor response).

### ***Monosynaptic Reflexes,***

- Monosynaptic reflexes have the least delay between sensory input and motor output. The best known monosynaptic reflex is the stretch reflex (e.g. the patellar reflex) which is completed within 20-40 msec.
- The receptors in stretch reflexes are called muscle spindles. Muscle spindles are bundles of small, specialized intrafusal muscle fibers (innervated by sensory and motor neurons) surrounded by extrafusal muscle fibers (which maintain tone and contract the muscle).
- The central sensory region of the intrafusal fibers is wound with dendrites of sensory neurons. The axon of a sensory neuron enters the CNS in a dorsal root and synapses onto motor neurons (gamma motor neurons) in the anterior gray horn of the spinal cord. Completing the reflex arc, axons of the motor neurons (gamma efferents) synapse back onto the intrafusal fibers.
- Many stretch reflexes are postural reflexes (reflexes that maintain normal upright posture). A stretched muscle responds by contracting, automatically maintaining balance.
- Gamma efferents are also important in voluntary muscle contractions, allowing the CNS to adjust the sensitivity of muscle spindles.

#### **The Stretch Reflex:**

The stretch reflex in its simplest form involves only 2 neurons, and is therefore sometimes called a **2-neuron reflex**. The two neurons are a **sensory** and a **motor** neuron. The sensory neuron is stimulated by **stretch (extension) of a muscle**. Stretch of a muscle normally happens when its antagonist contracts, or artificially when its tendon is stretched, as in the **knee jerk reflex**. Muscles contain receptors called muscle spindles.) These receptors respond to the muscles's stretch. They send stimuli back to the spinal cord through a sensory neuron which connects directly to a motor neuron serving the same muscle. This causes the muscle to contract, reversing the stretch. The stretch reflex is important in helping to coordinate normal movements in which antagonistic muscles are contracted and relaxed in sequence, and in keeping the muscle from overstretching.

Since at the time of the muscle stretch its antagonist was contracting, in order to avoid damage it must be inhibited or tuned off in the reflex. So an additional connection through an interneuron sends an inhibitory pathway to the antagonist of the stretched muscle - this is called **reciprocal inhibition**.

### **The Deep Tendon Reflex:**

Tendon receptors respond to the **contraction** of a muscle. Their function, like that of stretch reflexes, is the coordination of muscles and body movements. The deep tendon reflex involves sensory neurons, interneurons, and motor neurons. The response reverses the original stimulus therefore causing relaxation of the muscle stimulated. In order to facilitate that the reflex sends excitatory stimuli to the antagonists causing them to contract - **reciprocal activation**.

### **The Crossed Extensor Reflex -**

The crossed extensor reflex is just a withdrawal reflex on one side with the addition of inhibitory pathways needed to maintain balance and coordination. For example, you step on a nail with your right foot as you are walking along. This will initiate a withdrawal of your right leg. Since your quadriceps muscles, the extensors, were contracting to place your foot forward, they will now be inhibited and the flexors, the hamstrings will now be excited on your right leg. But in order to maintain your balance and not fall down your left leg, which was flexing, will now be extended to plant your left foot (e.g. crossed extensor). So on the left leg the flexor muscles which were contracting will be inhibited, and the extensor muscles will be excited. The textbook illustration uses the arms. Study it to see how the same process works there, even though it isn't necessary to maintain balance.

### **Effectors:**

- **Skeletal muscles** ==→ **somatic reflex**
- **Gland, smooth muscle, cardiac muscles** ==→ **autonomic reflex**

### **Polysynaptic Reflexes,**

- Polysynaptic reflexes are more complicated than monosynaptic reflexes. Their interneurons can control more than one muscle group, and can produce either EPSPs (excitatory) or IPSPs (inhibitory).

#### **1. The Tendon Reflex**

The tendon reflex generally prevents skeletal muscles from developing enough tension to tear or break the tendon. The sensory receptors for this reflex are different from muscle spindles or proprioceptors, but have not been specifically identified.

#### **2. Withdrawal Reflexes**

Withdrawal reflexes move a body part away from a stimulus such as pain or pressure.

For example: The flexor reflex pulls your hand away from a hot stove. For this to work automatically, the stretch reflex that normally tenses the antagonistic (extensor) muscle must be inhibited by interneurons in the spinal cord (reciprocal inhibition). The strength and extent of a withdrawal response depends on the intensity and location of the stimulus.

#### **3. Crossed Extensor Reflexes**

- Stretch, tendon and withdrawal reflexes are ipsilateral reflex arcs, occurring on the same side of the body as the stimulus. A crossed extensor reflex occurs on the side opposite the stimulus (contralateral reflex arc).

The crossed extensor reflex occurs simultaneously and in coordination with a flexor reflex. *E.g.* when the flexor reflex causes one leg to pull up, the crossed extensor reflex straightens the other leg to receive the body's weight, using reverberating circuits to maintain the response.

- All polysynaptic reflexes share 5 general characteristics:

1. They involve pools of neurons.
2. They are intersegmental in distribution.
3. They involve reciprocal inhibition.
4. They have reverberating circuits which prolong the reflexive motor response.



5. Several reflexes may cooperate to produce a coordinated, controlled response.

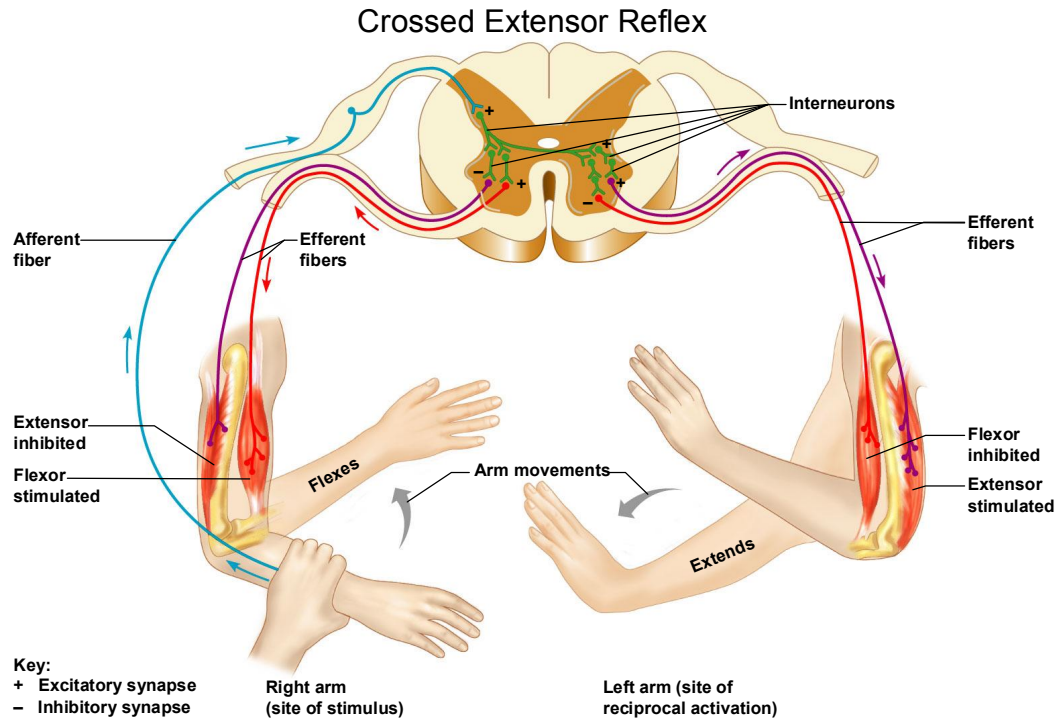


Figure 13.19

### Integration and Control of Spinal Reflexes,

- Although reflex behaviors occur automatically, processing centers in the brain can facilitate or inhibit reflex motor patterns based in the spinal cord.

- Automatic reflexes can be activated as needed by the brain, using relatively few nerve impulses to control complex motor functions. A simple mental command can trigger complex motions such as walking, running or jumping without much conscious effort. The higher centers of the brain modulate or build on lower, reflexive motor patterns.

#### Key

- 1• Reflexes are rapid, automatic responses to stimuli that “buy time” for the planning and execution of more complex responses that are often consciously directed.

- The fastest reflexes are somatic motor reflexes that (1) involve myelinated axons,

- (2) involve only one segment of the spinal cord or one nucleus of the brain, and

- (3) are monosynaptic.

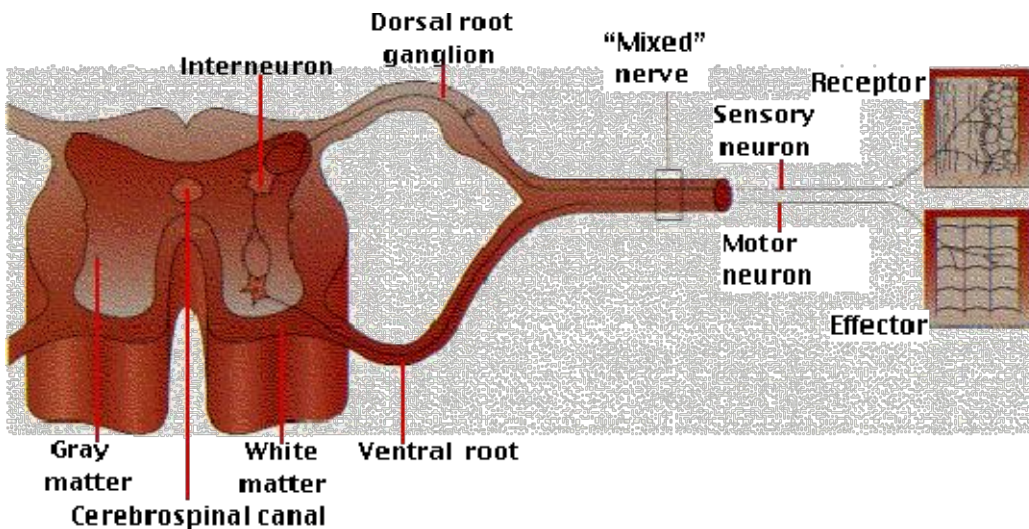
### Reinforcement and Inhibition.

- By stimulating excitatory or inhibitory neurons within the brain stem or spinal cord, higher centers can adjust the sensitivity of reflexes by creating EPSPs or IPSPs at the motor neurons involved in reflex responses.

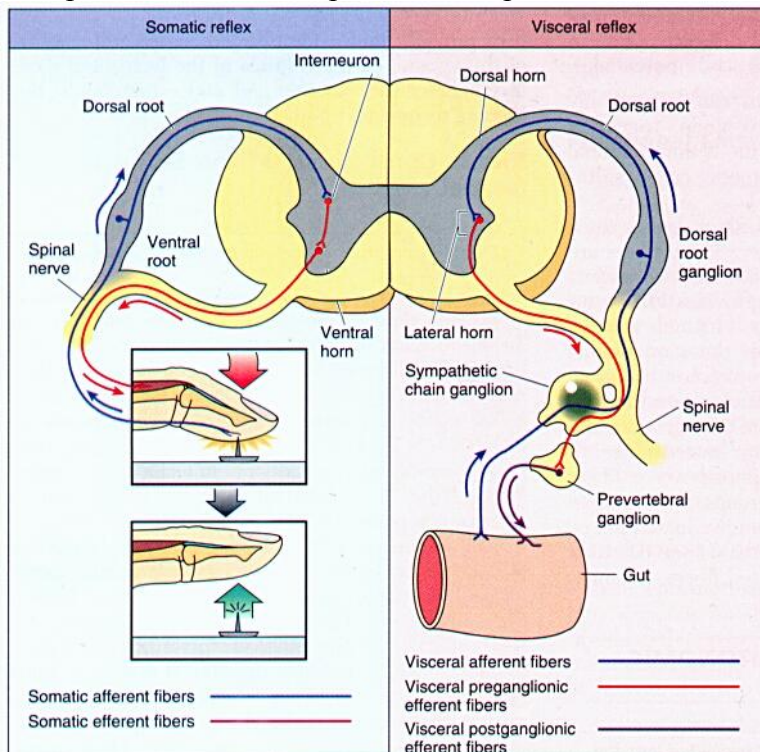
Facilitated postsynaptic neurons enhance or reinforce spinal reflexes, usually making them too strong to suppress consciously.

- Other nerves can suppress or inhibit spinal reflexes. A healthy adult will respond to a stimulus on the sole of the foot by curling the toes (the plantar reflex or negative Babinski reflex). The opposite response (fanning the toes or the Babinski sign), while normal in infants, may indicate CNS damage in adults.

•



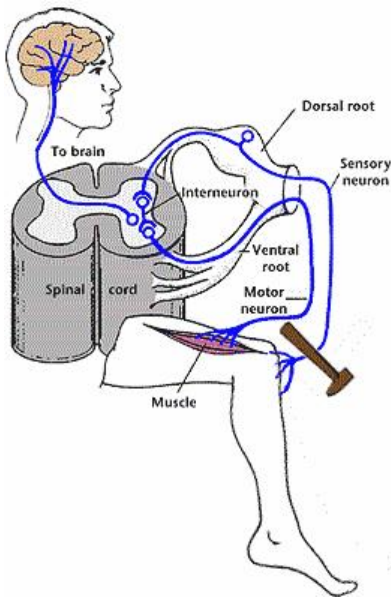
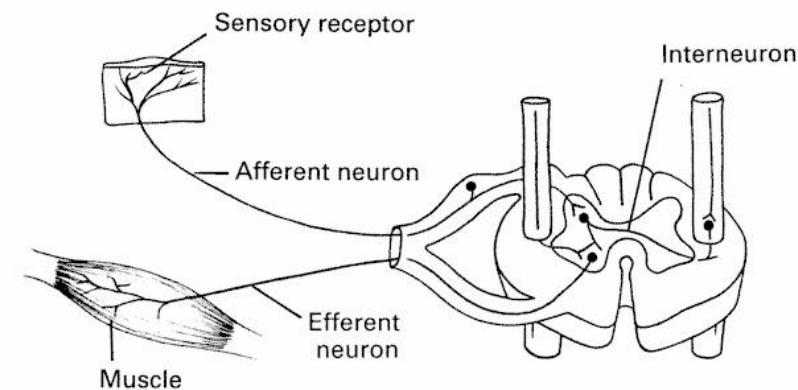
- The spinal cord extends from the skull (foramen magnum) to the first lumbar vertebra. Like the brain, the spinal cord consists of gray matter and white matter.
- The gray matter (cell bodies & synapses) of the cord is located centrally & is surrounded by white matter (myelinated axons).
- The white matter of the spinal cord consists of ascending and descending fiber tracts, with the ascending tracts transmitting sensory information (from receptors in the skin, skeletal muscles, tendons, joints, & various visceral receptors) and the descending tracts transmitting motor information (to skeletal muscles, smooth muscle, cardiac muscle, & glands).
- The spinal cord is also responsible for spinal reflexes



**Reflex-** rapid (and unconscious) response to changes in the internal or external environment needed to maintain homeostasis

**Reflex arc** - the neural pathway over which impulses travel during a reflex. The components of a reflex arc include:

- 1 - receptor - responds to the stimulus
- 2 - afferent pathway (sensory neuron) - transmits impulse into the spinal cord
- 3 - Central Nervous System - the spinal cord processes information
- 4 - efferent pathway (motor neuron) - transmits impulse out of spinal cord
- 5- effector - a muscle or gland that receives the impulse from the motor neuron & carries out the desired response



In the knee jerk reflex, the lower leg swings forward quickly when an area just below the knee is tapped. In order for this reflex to occur, a message travels through a sensory neuron to the spinal cord, where an interneuron carries it to a motor neuron, which sends the information to the leg muscle and causes the movement.

## Reflexes

- A reflex is a rapid, predictable motor response to a stimulus
- Reflexes may:
  - Be inborn (intrinsic) or learned (acquired)
  - Involve only peripheral nerves and the spinal cord
  - Involve higher brain centers as well

### Reflexes

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### Reflex Arc

- There are five components of a reflex arc
  - Receptor – site of stimulus
  - Sensory neuron – transmits the afferent impulse to the CNS
  - Integration center – either monosynaptic or polysynaptic region within the CNS
  - Motor neuron – conducts efferent impulses from the integration center to an effector
  - Effector – muscle fiber or gland that responds to the efferent impulse

### Stretch and Deep Tendon Reflexes

- For skeletal muscles to perform normally:
  - The Golgi tendon organs (proprioceptors) must constantly inform the brain as to the state of the muscle
  - Stretch reflexes initiated by muscle spindles must maintain healthy muscle tone

### Muscle Spindles

- Are composed of 3-10 intrafusal muscle fibers that lack myofilaments in their central regions, are noncontractile, and serve as receptive surfaces
- Muscle spindles are wrapped with two types of afferent endings: primary sensory endings of type Ia fibers and secondary sensory endings of type II fibers
- These regions are innervated by gamma ( $\gamma$ ) efferent fibers
- Note: contractile muscle fibers are extrafusal fibers and are innervated by alpha ( $\alpha$ ) efferent fibers

### Operation of the Muscle Spindles

- Stretching the muscles activates the muscle spindle
  - There is an increased rate of action potential in Ia fibers
- Contracting the muscle reduces tension on the muscle spindle
  - There is a decreased rate of action potential on Ia fibers

### Stretch Reflex

- Stretching the muscle activates the muscle spindle
- Excited  $\gamma$  motor neurons of the spindle cause the stretched muscle to contract
- Afferent impulses from the spindle result in inhibition of the antagonist
- Example: patellar reflex
  - Tapping the patellar tendon stretches the quadriceps and starts the reflex action
  - The quadriceps contract and the antagonistic hamstrings relax

### Golgi Tendon Reflex

- The opposite of the stretch reflex
- Contracting the muscle activates the Golgi tendon organs
- Afferent Golgi tendon neurons are stimulated, neurons inhibit the contracting muscle, and the antagonistic muscle is activated
- As a result, the contracting muscle relaxes and the antagonist contracts

#### **Flexor and Crossed Extensor Reflexes**

- The flexor reflex is initiated by a painful stimulus (actual or perceived) that causes automatic withdrawal of the threatened body part
- The crossed extensor reflex has two parts
  - The stimulated side is withdrawn
  - The contralateral side is extended

#### **Superficial Reflexes**

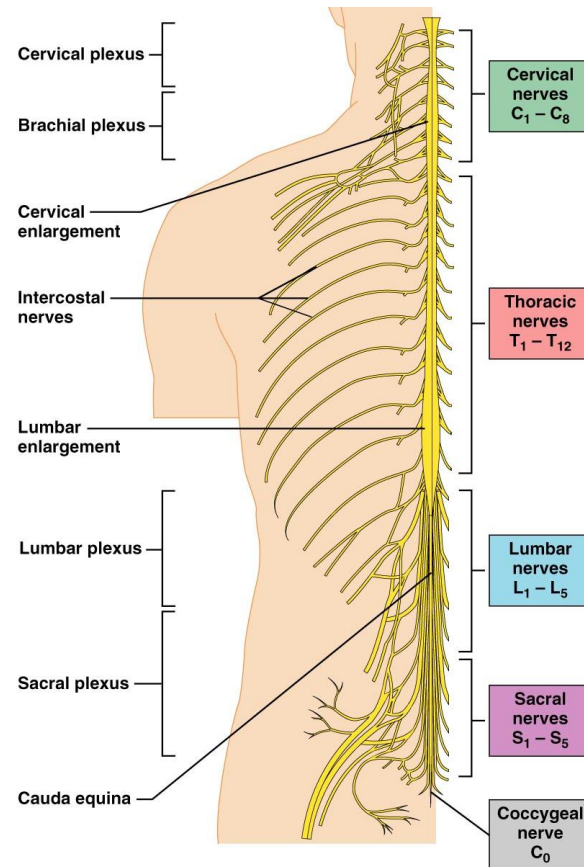
- Initiated by gentle cutaneous stimulation
- Example:
  - Plantar reflex is initiated by stimulating the lateral aspect of the sole of the foot
  - The response is downward flexion of the toes
  - Indirectly tests for proper corticospinal tract functioning
  - Babinski's sign: abnormal plantar reflex indicating corticospinal damage where the great toe dorsiflexes and the smaller toes fan laterally

### **Spinal Nerves:**

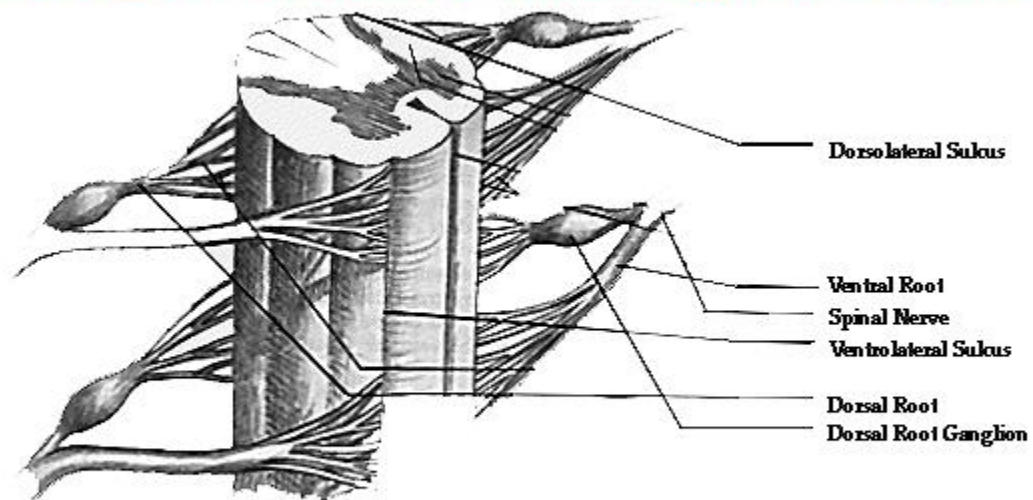
#### **Spinal Nerves**

- Thirty-one pairs of mixed nerves arise from the spinal cord and supply all parts of the body except the head
- They are named according to their point of issue
  - 8 cervical (C<sub>1</sub>-C<sub>8</sub>)
  - 12 thoracic (T<sub>1</sub>-T<sub>12</sub>)
  - 5 Lumbar (L<sub>1</sub>-L<sub>5</sub>)
  - 5 Sacral (S<sub>1</sub>-S<sub>5</sub>)
  - 1 Coccygeal (C<sub>0</sub>)





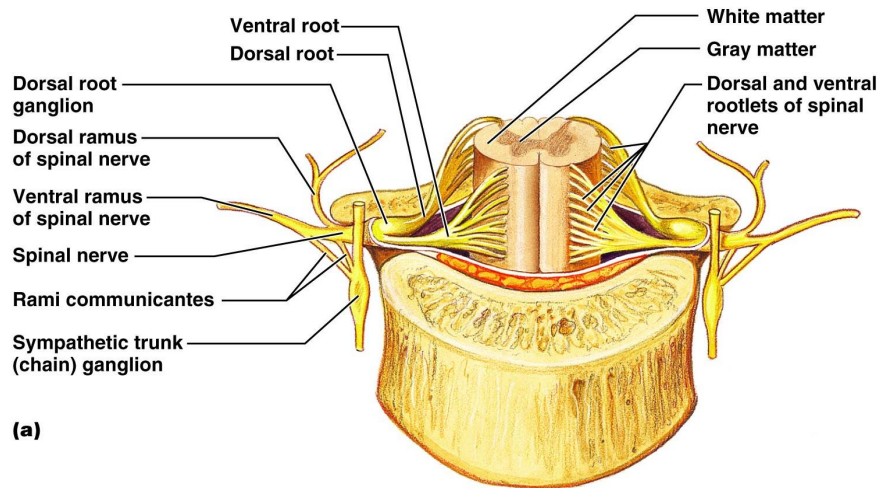
**FIGURE 7. Ventral view of the spinal cord showing the spinal nerve roots**



Source: <http://nanonline.org/nandistance/nanneuro/modules/cranial/cranial.html>



## Spinal Nerves: Roots

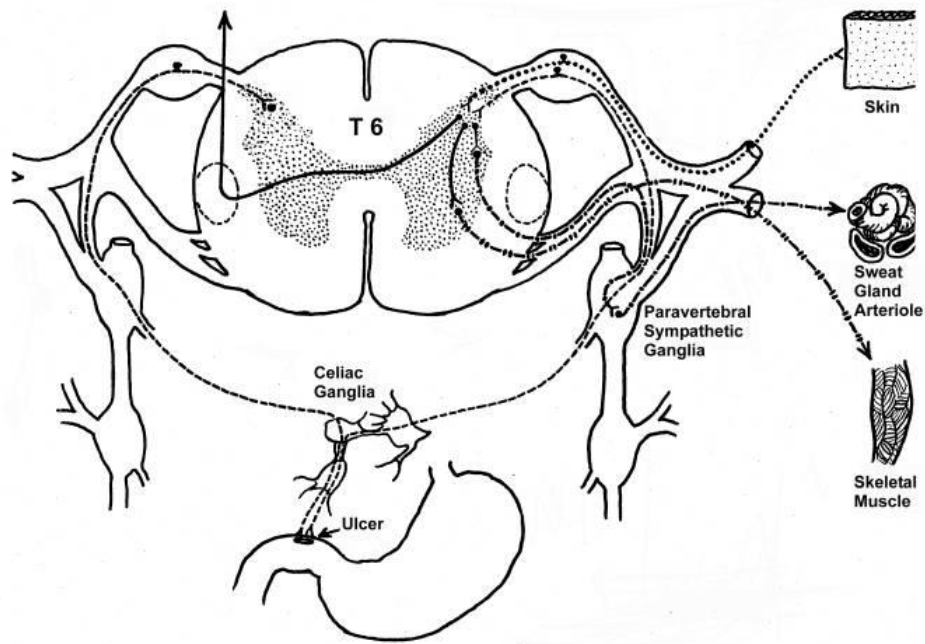


There are 31 pair of spinal nerves & each has a dorsal root and a ventral root. The dorsal root is sensory (all neurons conduct impulses into the spinal cord) while the ventral root is motor (all neurons conduct impulses out of the spinal cord). The dorsal root has a ganglion that contains the cell bodies of the sensory neurons that pass through the dorsal root. Each spinal nerve includes numerous sensory, or afferent, & motor, or efferent, neurons. Some of these neurons are classified as somatic, and these neurons conduct impulses to or from 'somatic' structures (skin, skeletal muscles, tendons, & joints). Other neurons are 'visceral', and these conduct impulses to or from 'visceral' structures (smooth muscle, cardiac muscle, and glands). Thus, all neurons in spinal nerves (& the peripheral nervous system) can be placed in one of four categories:

- Somatic afferent
- Somatic efferent
- Visceral afferent
- Visceral efferent

**Somatic afferent neurons** are sensory neurons that conduct impulses initiated in receptors in the skin, skeletal muscles, tendons, & joints. Receptors in the skin are responsible for sensing such things as touch, temperature, pressure, & pain and are called exteroceptors. Receptors in the skeletal muscles, tendons, & joints provide information about body position & movement and are called proprioceptors. Somatic afferent neurons are unipolar neurons that enter the spinal cord through the dorsal root & their cell bodies are located in the dorsal root ganglia.

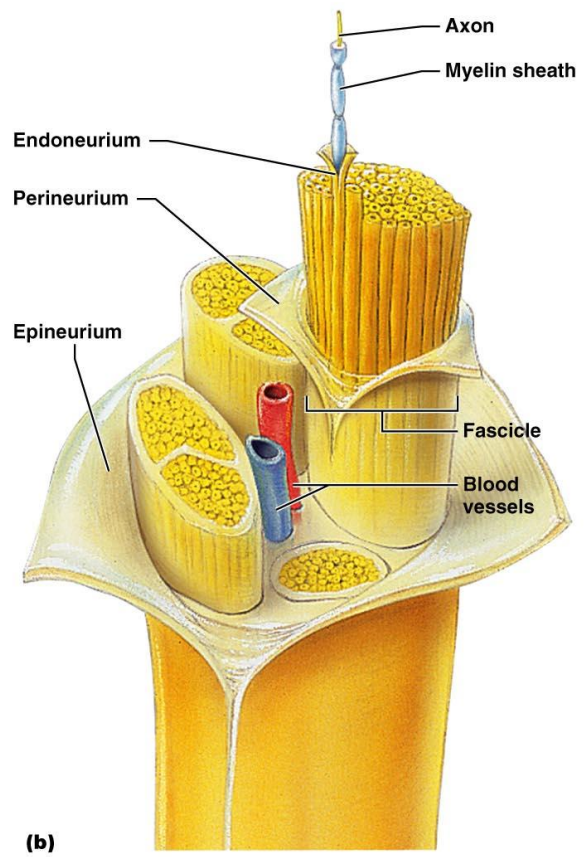
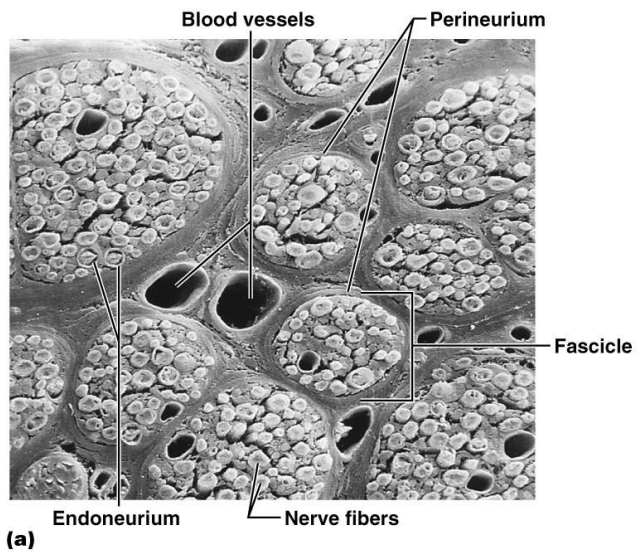
**Somatic efferent neurons** are motor neurons that conduct impulses from the spinal cord to skeletal muscles. These neurons are multipolar neurons, with cell bodies located in the gray matter of the spinal cord. Somatic efferent neurons leave the spinal cord through the ventral root of spinal nerves.

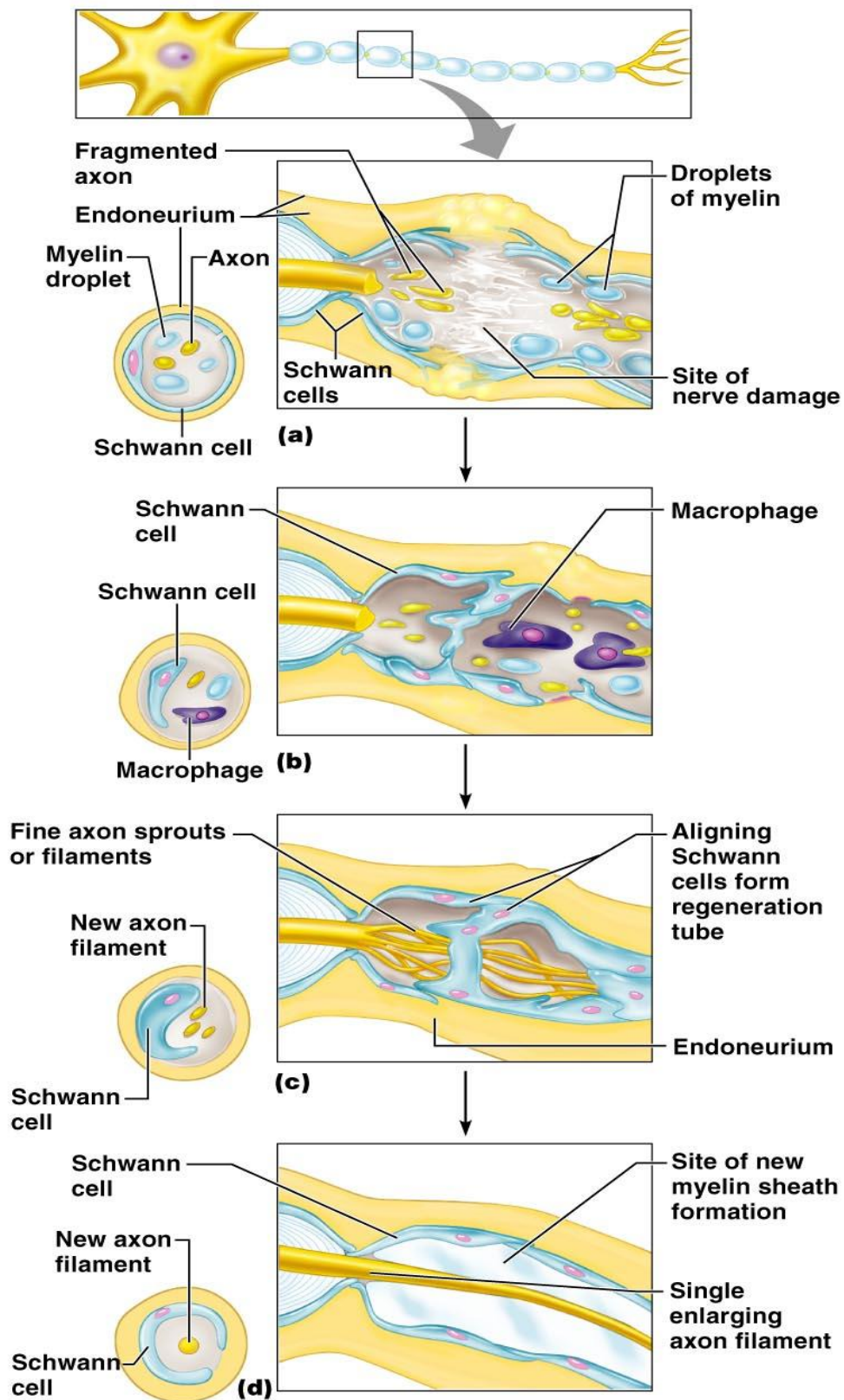


**Visceral afferent neurons** are sensory neurons that conduct impulses initiated in receptors in smooth muscle & cardiac muscle. These neurons are collectively referred to as enteroceptors or viscerceptors. Visceral afferent neurons are unipolar neurons that enter the spinal cord through the dorsal root & their cell bodies are located in the dorsal root ganglia.

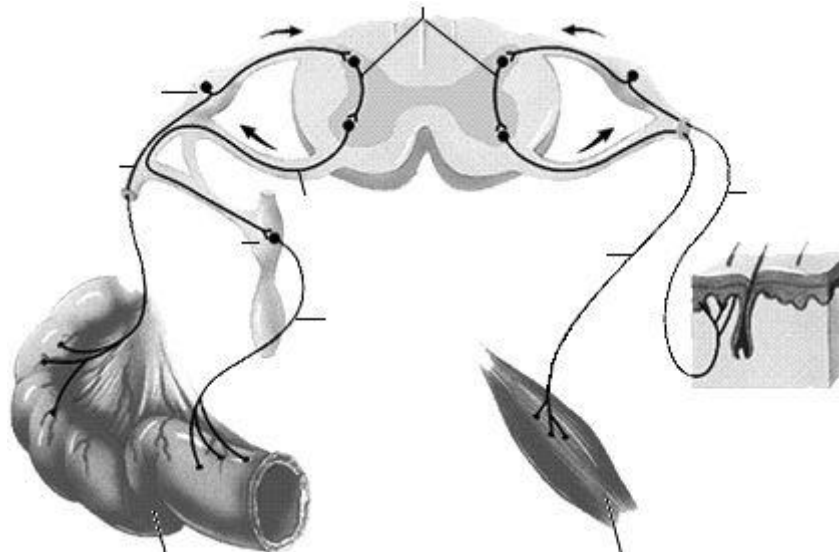
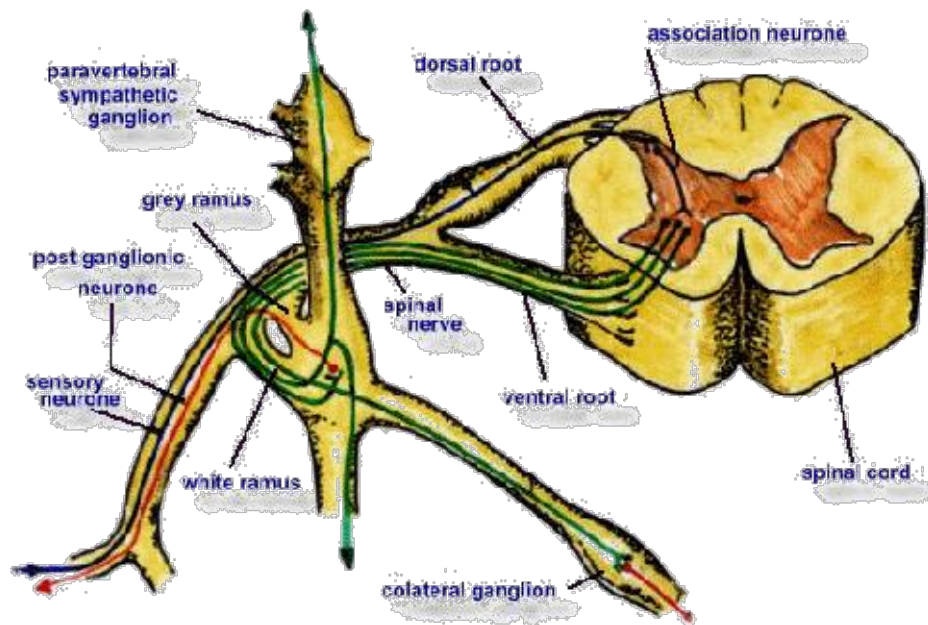
**Visceral efferent neurons** are motor neurons that conduct impulses to smooth muscle, cardiac muscle, & glands. These neurons make up the **Autonomic Nervous System**. Some visceral efferent neurons begin in the brain; others in the spinal cord. Because we're focusing on spinal nerves right now, we'll focus on those that begin in the spinal cord. It always takes two visceral efferent neurons to conduct an impulse from the spinal cord (or brain, in some cases) to a muscle or gland:

- **Visceral efferent 1** (also called the preganglionic neuron) is a multipolar neuron that begins in the gray matter of the spinal cord, which is where its cell body is located. This neuron leaves the cord through the ventral root of a spinal nerve, leaves the spinal nerve via a structure called the white ramus, then ends in an autonomic ganglion (either sympathetic or parasympathetic). In the ganglion, the visceral efferent 1 neuron synapses with a visceral efferent 2 neuron.
- **Visceral efferent 2** (also called the postganglionic neuron) is also a multipolar neuron and it begins in the sympathetic ganglion (which is where its cell body is located). Visceral efferent 2 neurons may exit the ganglion through the gray ramus, then proceed to some visceral structure (smooth muscle, cardiac muscle, or gland).









The 4 types of peripheral neurons: somatic afferent (top right), somatic efferent (bottom right), visceral afferent (top left), and visceral efferent (bottom left).

## The Peripheral Nervous System (PNS)

### Innervation of Joints

- Hilton's law: any nerve serving a muscle that produces movement at a joint also innervates the joint itself and the skin over the joint

### Motor Endings

- PNS elements that activate effectors by releasing neurotransmitters at:

- Neuromuscular junctions
- Varicosities at smooth muscle and glands

### **Innervation of Skeletal Muscle**

- Takes place at a neuromuscular junction
- Acetylcholine is the neurotransmitter that diffuses across the synaptic cleft
- ACh binds to receptors resulting in:
  - Movement of  $\text{Na}^+$  and  $\text{K}^+$  across the membrane
  - Depolarization of the interior of the muscle cell
  - An end-plate potential that triggers an action potential

### **Innervation of Visceral Muscle and Glands**

- Autonomic motor endings and visceral effectors are simpler than somatic junctions
- Branches form *synapses en passant* via varicosities
- Acetylcholine and norepinephrine are used as neurotransmitters
- Visceral responses are slower than somatic responses

### **Levels of Motor Control**

- The three levels of motor control are
  - Segmental level
  - Projection level
  - Precommand level

### **Hierarchy of Motor Control**

#### **Segmental Level**

- The segmental level is the lowest level of motor hierarchy
- It consists of segmental circuits of the spinal cord
- Its circuits control locomotion and specific, oft-repeated motor activity
- These circuits are called central pattern generators (CPGs)

#### **Projection Level**

- The projection level consists of:
  - Cortical motor areas that produce the direct (pyramidal) system
  - Brain stem motor areas that oversee the indirect (multineuronal) system
- Helps control reflex and fixed-pattern activity and houses command neurons that modify the segmental apparatus

#### **Precommand Level**

- Cerebellar and basal nuclei systems that:
  - Regulate motor activity
  - Precisely start or stop movements
  - Coordinate movements with posture
  - Block unwanted movements
  - Monitor muscle tone

### **Developmental Aspects of the PNS**

- Spinal nerves branch from the developing spinal cord and neural crest cells
  - Supply motor and sensory function to developing muscles
- Cranial nerves innervate muscles of the head

### **Developmental Aspects of the PNS**

- Distribution and growth of spinal nerves correlate with the segmented body plan
- Sensory receptors atrophy with age and muscle tone lessens
- Peripheral nerves remain viable throughout life unless subjected to trauma