Chapter 13
The Spinal Cord, Spinal Nerves, and Spinal Reflexes

An Introduction to the Spinal Cord, Spinal Nerves, and Spinal Reflexes

• Spinal Reflexes
  o Rapid, automatic nerve responses triggered by specific stimuli
  o Controlled by spinal cord alone, not the brain

13-2 Spinal Cord
• Gross Anatomy of the Spinal Cord
  o About 18 inches (45 cm) long
  o 1/2 inch (14 mm) wide
  o Ends between vertebrae L₁ and L₂
  o Bilateral symmetry
    ▪ Grooves divide the spinal cord into left and right
      o Posterior median sulcus – on posterior side
      o Anterior median fissure – deeper groove on anterior side

13-2 Spinal Cord
• Enlargements of the Spinal Cord
  o Caused by:
    ▪ Amount of gray matter in segment
    ▪ Involvement with sensory and motor nerves of limbs
  o Cervical enlargement
    ▪ Nerves of shoulders and upper limbs
  o Lumbar enlargement
    ▪ Nerves of pelvis and lower limbs

13-2 Spinal Cord
• Gross Anatomy of the Spinal Cord
  o The distal end
    ▪ Conus medullaris
      o Thin, conical spinal cord below lumbar enlargement
    ▪ Filum terminale
      o Thin thread of fibrous tissue at end of conus medullaris
      o Attaches to coccygeal ligament
    ▪ Cauda equina
      o Nerve roots extending below conus medullaris

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13-2 Spinal Cord
• 31 Spinal Cord Segments
  o Based on vertebrae where spinal nerves originate
  o Positions of spinal segment and vertebrae change with age
    ▪ Cervical nerves
      o Named for inferior vertebra
    ▪ All other nerves
      o Named for superior vertebra

13-2 Spinal Cord
• Roots
  o Two branches of spinal nerves
    1. Ventral root
      o Contains axons of motor neurons
    2. Dorsal root
      o Contains axons of sensory neurons
  o Dorsal root ganglia
    ▪ Contain cell bodies of sensory neurons

13-2 Spinal Cord
• The Spinal Nerve
  o Each side of spine
    ▪ Dorsal and ventral roots join
    ▪ To form a spinal nerve
  o Mixed Nerves
    ▪ Carry both afferent (sensory) and efferent (motor) fibers

13-2 Spinal Cord
• The Spinal Meninges
  o Specialized membranes isolate spinal cord from surroundings
  o Functions of the spinal meninges include:
    ▪ Protecting spinal cord
    ▪ Carrying blood supply
    ▪ Continuous with cranial meninges
  o Meningitis
    ▪ Viral or bacterial infection of meninges

13-2 Spinal Cord
• The Three Meningeal Layers
  1. Dura mater
    ▪ Outer layer of spinal cord
  2. Arachnoid mater
    ▪ Middle meningeal layer
3. **Pia mater**
   - Inner meningeal layer

### 13-2 Spinal Cord

**The Dura Mater**
- Tough and fibrous
- Cranially
  - Fuses with periosteum of occipital bone
  - Is continuous with cranial dura mater
- Caudally
  - Tapers to dense cord of collagen fibers
  - Joins filum terminale in **coccygeal ligament**

### 13-2 Spinal Cord

**The Epidural Space**
- Between spinal dura mater and walls of vertebral canal
- Contains loose connective and adipose tissue
- Anesthetic injection site

### 13-2 Spinal Cord

**The Arachnoid Mater**
- Middle meningeal layer
- Arachnoid membrane
  - Simple squamous epithelia
  - Covers arachnoid mater

### 13-2 Spinal Cord

**The Interlayer Spaces of Arachnoid Mater**
- **Subdural space**
  - Between arachnoid mater and dura mater
- **Subarachnoid space**
  - Between arachnoid mater and pia mater
  - Contains collagen/elastin fiber network (arachnoid trabeculae)
  - Filled with **cerebrospinal fluid (CSF)**

### 13-2 Spinal Cord

**The Interlayer Spaces of Arachnoid Mater**
- **Cerebrospinal Fluid (CSF)**
  - Carries dissolved gases, nutrients, and wastes
  - **Lumbar puncture** or **spinal tap** withdraws CSF
13-2 Spinal Cord
• The Pia Mater
  o Is the innermost meningeal layer
  o Is a mesh of collagen and elastic fibers
  o Is bound to underlying neural tissue

13-2 Spinal Cord
• Structures of the Spinal Cord
  o Paired denticulate ligaments
    ▪ Extend from pia mater to dura mater
    ▪ Stabilize side-to-side movement
  o Blood vessels
    ▪ Along surface of spinal pia mater
    ▪ Within subarachnoid space

13-3 Gray Matter and White Matter
• Sectional Anatomy of the Spinal Cord
  o White matter
    ▪ Is superficial
    ▪ Contains myelinated and unmyelinated axons
  o Gray matter
    ▪ Surrounds the central canal of spinal cord
    ▪ Contains neuron cell bodies, neuroglia, unmyelinated axons
    ▪ Has projections (gray horns)

13-3 Gray Matter and White Matter
• Organization of Gray Matter
  o The gray horns
    ▪ Posterior gray horns contain somatic and visceral sensory nuclei
    ▪ Anterior gray horns contain somatic motor nuclei
    ▪ Lateral gray horns are in thoracic and lumbar segments; contain visceral motor nuclei
  o Gray commissures
    ▪ Axons that cross from one side of cord to the other before reaching gray matter

13-3 Gray Matter and White Matter
• Organization of Gray Matter
  o The cell bodies of neurons form functional groups called nuclei
    ▪ Sensory nuclei
      o Dorsal (posterior)
      o Connect to peripheral receptors
    ▪ Motor nuclei

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13-3 Gray Matter and White Matter

• Control and Location
  - Sensory or motor nucleus location within the gray matter determines which body part it controls

13-3 Gray Matter and White Matter

• Organization of White Matter
  - Posterior white columns lie between posterior gray horns and posterior median sulcus
  - Anterior white columns lie between anterior gray horns and anterior median fissure
    - Anterior white commissure is area where axons cross from one side of spinal cord to the other
  - Lateral white columns located on each side of spinal cord between anterior and posterior columns

13-3 Gray Matter and White Matter

• Organization of White Matter
  - Tracts or fasciculi
    - In white columns
    - Bundles of axons
    - Relay same information in same direction
  - Ascending tracts
    - Carry information to brain
  - Descending tracts
    - Carry motor commands to spinal cord

13-3 Gray Matter and White Matter

• Spinal Cord Summary
  - Spinal cord has a narrow central canal
    - Surrounded by gray matter
    - Containing sensory and motor nuclei
      - Sensory nuclei are dorsal
      - Motor nuclei are ventral

13-3 Gray Matter and White Matter

• Spinal Cord Summary
  - Gray matter
    - Is covered by a thick layer of white matter
White matter
- Consists of ascending and descending axons
- Organized in columns
- Contains axon bundles with specific functions

Spinal cord is so highly organized:
- It is possible to predict results of injuries to specific areas

13-4 Spinal Nerves and Plexuses
• Anatomy of Spinal Nerves
  o Each spinal cord segment:
    ▪ Is connected to a pair of spinal nerves
  o Each spinal nerve:
    ▪ Is surrounded by three connective tissue layers
    ▪ That support structures and contain blood vessels

13-4 Spinal Nerves and Plexuses
• Three Connective Tissue Layers of Spinal Nerves
  1. Epineurium
     ▪ Outer layer
     ▪ Dense network of collagen fibers
  2. Perineurium
     ▪ Middle layer
     ▪ Divides nerve into fascicles (axon bundles)
  3. Endoneurium
     ▪ Inner layer
     ▪ Surrounds individual axons

13-4 Spinal Nerves and Plexuses
• Peripheral Nerves
  o Interconnecting branches of spinal nerves
  o Surrounded by connective tissue sheaths

13-4 Spinal Nerves and Plexuses
• Peripheral Distribution of Spinal Nerves
  o Spinal nerves
    ▪ Form lateral to intervertebral foramen
    ▪ Where dorsal and ventral roots unite
    ▪ Then branch and form pathways to destination

13-4 Spinal Nerves and Plexuses
• Peripheral Distribution of Spinal Nerves
  o Motor nerves
- The first branch
  - White ramus
    - Carries visceral motor fibers to sympathetic ganglion of autonomic nervous system
  - Gray ramus
    - Unmyelinated nerves
    - Return from sympathetic ganglion to rejoin spinal nerve

13-4 Spinal Nerves and Plexuses
- Peripheral Distribution of Spinal Nerves
  - Motor nerves
    - Dorsal and ventral rami
      - Dorsal ramus
        - Contains somatic and visceral motor fibers
        - Innervates the back
      - Ventral ramus
        - Larger branch
        - Innervates ventrolateral structures and limbs

13-4 Spinal Nerves and Plexuses
- Sensory nerves
  - In addition to motor impulses:
    - Dorsal, ventral, and white rami also carry sensory information
  - Dermatomes
    - Bilateral region of skin
    - Monitored by specific pair of spinal nerves

13-4 Spinal Nerves and Plexuses
- Peripheral Neuropathy
  - Regional loss of sensory or motor function
  - Due to trauma or compression

13-4 Spinal Nerves and Plexuses
- Nerve Plexuses
  - Complex, interwoven networks of nerve fibers
  - Formed from blended fibers of ventral rami of adjacent spinal nerves
  - Control skeletal muscles of the neck and limbs

13-4 Spinal Nerves and Plexuses
- The Four Major Plexuses of Ventral Rami
  1. Cervical plexus
2. Brachial plexus
3. Lumbar plexus
4. Sacral plexus

13-4 Spinal Nerves and Plexuses
- The Cervical Plexus
  - Includes ventral rami of spinal nerves C₁–C₅
  - Innervates neck, thoracic cavity, diaphragmatic muscles
  - Major nerve
    - Phrenic nerve (controls diaphragm)

13-4 Spinal Nerves and Plexuses
- The Brachial Plexus
  - Includes ventral rami of spinal nerves C₅–T₁
  - Innervates pectoral girdle and upper limbs
  - Nerves that form brachial plexus originate from:
    - Superior, middle, and inferior trunks
    - Large bundles of axons from several spinal nerves
    - Lateral, medial, and posterior cords
    - Smaller branches that originate at trunks

13-4 Spinal Nerves and Plexuses
- The Brachial Plexus
  - Major nerves
    - Musculocutaneous nerve (lateral cord)
    - Median nerve (lateral and medial cords)
    - Ulnar nerve (medial cord)
    - Axillary nerve (posterior cord)
    - Radial nerve (posterior cord)

13-4 Spinal Nerves and Plexuses
- The Lumbar Plexus
  - Includes ventral rami of spinal nerves T₁₂–L₄
  - Major nerves
    - Genitofemoral nerve
    - Lateral femoral cutaneous nerve
    - Femoral nerve

13-4 Spinal Nerves and Plexuses
- The Sacral Plexus
  - Includes ventral rami of spinal nerves L₄–S₄
  - Major nerves
- Pudendal nerve
- Sciatic nerve
  - Two branches of the sciatic nerve
    1. Fibular nerve
    2. Tibial nerve

13-5 Neuronal Pools
- Functional Organization of Neurons
  - Sensory neurons
    - About 10 million
    - Deliver information to CNS
  - Motor neurons
    - About 1/2 million
    - Deliver commands to peripheral effectors
  - Interneurons
    - About 20 billion
    - Interpret, plan, and coordinate signals in and out

13-5 Neuronal Pools
- Neuronal Pools
  - Functional groups of interconnected neurons (interneurons)
  - Each with limited input sources and output destinations
  - May stimulate or depress parts of brain or spinal cord

13-5 Neuronal Pools
- Five Patterns of Neural Circuits in Neuronal Pools
  1. Divergence
    - Spreads stimulation to many neurons or neuronal pools in CNS
  2. Convergence
    - Brings input from many sources to single neuron
  3. Serial processing
    - Moves information in single line

13-5 Neuronal Pools
- Five Patterns of Neural Circuits in Neuronal Pools
  4. Parallel processing
    - Moves same information along several paths simultaneously
  5. Reverberation
    - Positive feedback mechanism
    - Functions until inhibited

13-6 Reflexes
• **Reflexes**
  o Automatic responses coordinated within spinal cord
  o Through interconnected sensory neurons, motor neurons, and interneurons
  o Produce simple and complex reflexes

13-6 Reflexes
• **Neural Reflexes**
  o Rapid, automatic responses to specific stimuli
  o Basic building blocks of neural function
  o One neural reflex produces one motor response
    o **Reflex arc**
      ▪ The wiring of a single reflex
      ▪ Beginning at receptor
      ▪ Ending at peripheral effector
      ▪ Generally opposes original stimulus (negative feedback)

13-6 Reflexes
• Five Steps in a Neural Reflex
  o **Step 1: Arrival of stimulus, activation of receptor**
    ▪ Physical or chemical changes
  o **Step 2: Activation of sensory neuron**
    ▪ Graded depolarization
  o **Step 3: Information processing by postsynaptic cell**
    ▪ Triggered by neurotransmitters
  o **Step 4: Activation of motor neuron**
    ▪ Action potential
  o **Step 5: Response of peripheral effector**
    ▪ Triggered by neurotransmitters

13-6 Reflexes
• Four Classifications of Reflexes
  1. By early development
  2. By type of motor response
  3. By complexity of neural circuit
  4. By site of information processing

13-6 Reflexes
• Development of Reflexes
  o **Innate reflexes**
    ▪ Basic neural reflexes
    ▪ Formed before birth
  o **Acquired reflexes**
13-6 Reflexes
• Motor Response
  o Nature of resulting motor response
    ▪ Somatic reflexes
      ▪ Involuntary control of nervous system
        ▪ Superficial reflexes of skin, mucous membranes
        ▪ Stretch or deep tendon reflexes (e.g., patellar, or “knee-jerk,” reflex)
    ▪ Visceral reflexes (autonomic reflexes)
      ▪ Control systems other than muscular system

13-6 Reflexes
• Complexity of Neural Circuit
  o Monosynaptic reflex
    ▪ Sensory neuron synapses directly onto motor neuron
  o Polysynaptic reflex
    ▪ At least one interneuron between sensory neuron and motor neuron

13-6 Reflexes
• Sites of Information Processing
  o Spinal reflexes
    ▪ Occur in spinal cord
  o Cranial reflexes
    ▪ Occur in brain

13-7 Spinal Reflexes
• Spinal Reflexes
  o Range in increasing order of complexity
    ▪ Monosynaptic reflexes
    ▪ Polysynaptic reflexes
    ▪ Intersegmental reflex arcs
      ▪ Many segments interact
      ▪ Produce highly variable motor response

13-7 Spinal Reflexes
• Monosynaptic Reflexes
  o A stretch reflex
    ▪ Have least delay between sensory input and motor output
      ▪ For example, stretch reflex (such as patellar reflex)
13-7 Spinal Reflexes

- **Muscle Spindles**
  - The receptors in stretch reflexes
  - Bundles of small, specialized *intrafusal muscle fibers*
    - Innervated by sensory and motor neurons
  - Surrounded by *extrafusal muscle fibers*
    - Which maintain tone and contract muscle

- **The Sensory Region**
  - Central region of intrafusal fibers
  - Wound with dendrites of sensory neurons
  - Sensory neuron axon enters CNS in dorsal root
    - Synapses onto motor neurons (gamma motor neurons)
    - In anterior gray horn of spinal cord

- **Gamma Efferents**
  - Axons of the motor neurons
  - Complete reflex arc
    - Synapse back onto intrafusal fibers
  - Important in voluntary muscle contractions
    - Allow CNS to adjust sensitivity of muscle spindles

- **Postural Reflexes**
  - Stretch reflexes
  - Maintain normal upright posture
  - Stretched muscle responds by contracting
    - Automatically maintains balance

- **Polysynaptic Reflexes**
  - More complicated than monosynaptic reflexes
  - Interneurons control more than one muscle group
  - Produce either EPSPs or IPSPs

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• The **Tendon Reflex**
  - Prevents skeletal muscles from:
    - Developing too much tension
    - Tearing or breaking tendons
  - Sensory receptors unlike muscle spindles or proprioceptors

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**13-7 Spinal Reflexes**

**Withdrawal Reflexes**

- Move body part away from stimulus (pain or pressure)
  - For example, **flexor reflex**
    - Pulls hand away from hot stove
  - Strength and extent of response
    - Depend on intensity and location of stimulus

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**13-7 Spinal Reflexes**

**Reciprocal Inhibition**

- For flexor reflex to work
  - The stretch reflex of antagonistic (extensor) muscle must be inhibited (reciprocal inhibition) by interneurons in spinal cord

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**13-7 Spinal Reflexes**

**Reflex Arcs**

- **Ipsilateral reflex arcs**
  - Occur on same side of body as stimulus
  - Stretch, tendon, and withdrawal reflexes

- **Crossed extensor reflexes**
  - Involve a **contralateral reflex arc**
  - Occur on side opposite stimulus

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**13-7 Spinal Reflexes**

**Crossed Extensor Reflexes**

- Occur simultaneously, coordinated with flexor reflex
  - For example, flexor reflex causes leg to pull up
    - Crossed extensor reflex straightens other leg
    - To receive body weight
    - Maintained by reverberating circuits

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**13-7 Spinal Reflexes**

**Five General Characteristics of Polysynaptic Reflexes**

1. **Involve pools of interneurons**
2. **Are intersegmental in distribution**
3. **Involve reciprocal inhibition**
4. *Have reverberating circuits*
   - Which prolong reflexive motor response
5. *Several reflexes cooperate*
   - To produce coordinated, controlled response

### 13-8 The Brain Can Alter Spinal Reflexes

- **Integration and Control of Spinal Reflexes**
  - Reflex behaviors are automatic
    - But processing centers in brain can facilitate or inhibit reflex motor patterns based in spinal cord

### 13-8 The Brain Can Alter Spinal Reflexes

- **Voluntary Movements and Reflex Motor Patterns**
  - Higher centers of brain incorporate lower, reflexive motor patterns
  - Automatic reflexes
    - Can be activated by brain as needed
    - Use few nerve impulses to control complex motor functions
    - Walking, running, jumping

### 13-8 The Brain Can Alter Spinal Reflexes

- **Reinforcement** of Spinal Reflexes
  - Higher centers reinforce spinal reflexes
    - By stimulating excitatory neurons in brain stem or spinal cord
    - Creating EPSPs at reflex motor neurons
    - Facilitating postsynaptic neurons

### 13-8 The Brain Can Alter Spinal Reflexes

- **Inhibition of Spinal Reflexes**
  - Higher centers inhibit spinal reflexes by:
    - Stimulating inhibitory neurons
    - Creating IPSPs at reflex motor neurons
    - Suppressing postsynaptic neurons

### 13-8 The Brain Can Alter Spinal Reflexes

- **The Babinski Reflexes**
  - Normal in infants
  - May indicate CNS damage in adults