Chapter 13

The Spinal Cord, Spinal Nerves, and Spinal Reflexes

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

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

13-2 Spinal Cord

- Gross Anatomy of the Spinal Cord
  - About 18 inches (45 cm) long
  - 1/2 inch (14 mm) wide
  - Ends between vertebrae L_1 and L_2
  - Bilateral symmetry
    - Grooves divide the spinal cord into left and right
      - **Posterior median sulcus** – on posterior side
      - **Anterior median fissure** – deeper groove on anterior side

13-2 Spinal Cord

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

13-2 Spinal Cord

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

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13-2 Spinal Cord

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

13-2 Spinal Cord

- Roots
  - Two branches of spinal nerves
    1. **Ventral root**
       - Contains axons of motor neurons
    2. **Dorsal root**
       - Contains axons of sensory neurons
  - **Dorsal root ganglia**
    - Contain cell bodies of sensory neurons

13-2 Spinal Cord

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

13-2 Spinal Cord

- The **Spinal Meninges**
  - Specialized membranes isolate spinal cord from surroundings
  - Functions of the spinal meninges include:
    - Protecting spinal cord
    - Carrying blood supply
    - Continuous with **cranial meninges**
  - **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

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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 **Dura Mater**
    - 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

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13-2 Spinal Cord

- The **Pia Mater**
  - Is the innermost meningeal layer
  - Is a mesh of collagen and elastic fibers
  - Is bound to underlying neural tissue

13-2 Spinal Cord

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

13-3 Gray Matter and White Matter

- Sectional Anatomy of the Spinal Cord
  - **White matter**
    - Is superficial
    - Contains myelinated and unmyelinated axons
  - **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
  - 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
  - **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
  - The cell bodies of neurons form functional groups called **nuclei**
    - **Sensory nuclei**
      - Dorsal (posterior)
      - Connect to peripheral receptors
    - **Motor nuclei**

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- Ventral (anterior)
- Connect to peripheral effectors

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

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- 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
  - Each spinal cord segment:
    - Is connected to a pair of spinal nerves
  - 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
  - Interconnecting branches of spinal nerves
  - Surrounded by connective tissue sheaths

13-4 Spinal Nerves and Plexuses

- Peripheral Distribution of Spinal Nerves
  - 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
  - Motor nerves

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        - 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

- Peripheral Distribution of Spinal Nerves
    - 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**

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2. **Brachial plexus**
3. **Lumbar plexus**
4. **Sacral plexus**

13-4 Spinal Nerves and Plexuses

- The **Cervical Plexus**
  - Includes ventral rami of spinal nerves C_1–C_5
  - 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 C_5–T_1
  - 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 T_{12}–L_4
  - 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 L_4–S_4
  - Major nerves

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        - **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

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

13-6 Reflexes

- *Neural Reflexes*
  - Rapid, automatic responses to specific stimuli
  - Basic building blocks of neural function
  - One neural reflex produces one motor response
  - **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
  - ***Step 1: Arrival of stimulus, activation of receptor***
    - Physical or chemical changes
  - ***Step 2: Activation of sensory neuron***
    - Graded depolarization
  - ***Step 3: Information processing by postsynaptic cell***
    - Triggered by neurotransmitters
  - ***Step 4: Activation of motor neuron***
    - Action potential
  - ***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
  - **Innate reflexes**
    - Basic neural reflexes
    - Formed before birth
  - **Acquired reflexes**

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        - Rapid, automatic
        - Learned motor patterns

13-6 Reflexes

- Motor Response
    - 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
    - **Monosynaptic reflex**
        - Sensory neuron synapses directly onto motor neuron
    - **Polysynaptic reflex**
        - At least one interneuron between sensory neuron and motor neuron

13-6 Reflexes

- Sites of Information Processing
    - **Spinal reflexes**
        - Occur in spinal cord
    - **Cranial reflexes**
        - Occur in brain

13-7 Spinal Reflexes

- Spinal Reflexes
    - 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
    - A **stretch reflex**
    - Have least delay between sensory input and motor output
        - For example, stretch reflex (such as **patellar reflex**)

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- Completed in 20–40 msec
- Receptor is muscle spindle

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

13-7 Spinal Reflexes

- 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

13-7 Spinal Reflexes

- **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

13-7 Spinal Reflexes

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

13-7 Spinal Reflexes

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

13-7 Spinal Reflexes

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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

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

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

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

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

13-7 Spinal Reflexes

- Five General Characteristics of Polysynaptic Reflexes
  1. *Involve pools of interneurons*
  2. *Are intersegmental in distribution*
  3. *Involve reciprocal inhibition*

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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

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