Chapter 13
The Nervous System

Neural Tissue

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Introduction

• Nervous System Characteristics
  • Controls and adjust the activity of the body
  • Provides swift but brief responses
An Overview of the Nervous System

• The nervous system includes:
  • **Central Nervous System (CNS)**
    • Associated with the brain and the spinal cord
  • **Peripheral Nervous System (PNS)**
    • Associated with the tissue outside the CNS
An Overview of the Nervous System

- **Central Nervous System (CNS)**
  - Responsible for integrating, processing, and coordinating sensory input
  - Responsible for integrating, processing, and coordinating motor output
  - It is the seat of intelligence, memory, learning, and emotion
An Overview of the Nervous System

• Peripheral Nervous System (PNS)
  • Provides sensory information to the CNS and carries motor commands away from the CNS
  • Can be divided into:
    • Afferent division
      • Brings sensory information to the CNS
    • Efferent division
      • Carries motor commands to muscles and glands
Figure 13.1 The Nervous System

CENTRAL NERVOUS SYSTEM
- Brain
- Spinal cord

PERIPHERAL NERVOUS SYSTEM
- Peripheral nerves
An Overview of the Nervous System

• The Peripheral Nervous System (PNS) can be subdivided into:
  • **Afferent**: Brings sensory information toward the CNS
    • Can be further subdivided into **somatic** and **visceral**
  • **Efferent**: Carries motor commands away from the CNS
    • Can be further subdivided into **somatic nerves** and **autonomic nerves**
An Overview of the Nervous System

• The Peripheral Nervous System (PNS) can be further subdivided into:
  • **Afferent:**
    • Can be further subdivided into **somatic** and **visceral**
  • **Efferent:**
    • Can be further subdivided into **somatic nerves** and **autonomic nerves**
      • Can be further subdivided into sympathetic and parasympathetic nerves
An Overview of the Nervous System

• The Peripheral Nervous System (PNS)
  • Afferent
    • **Somatic** portion: monitors skeletal muscles and joints
    • **Visceral** portion: monitors smooth muscles, cardiac muscle, and other internal organs
  • Efferent
    • **Somatic nerves**: control skeletal muscle contraction
    • **Autonomic nerves**: control internal organ activities
An Overview of the Nervous System

• The Peripheral Nervous System (PNS)
  • **Parasympathetic nerves**
    • Cause pupil constriction, decrease heart rate, and tense the urinary bladder (for example)
  • **Sympathetic nerves**
    • Cause pupil dilation, increase heart rate, and relax urinary bladder (for example)
Figure 13.2 A Functional Overview of the Nervous System

**CENTRAL NERVOUS SYSTEM**
(brain and spinal cord)

- Sensory information within afferent division
- Information processing
- Motor commands within efferent division

**PERIPHERAL NERVOUS SYSTEM**

- Somatic nervous system
- Autonomic nervous system
  - Parasympathetic division
  - Sympathetic division

**RECEPTORS**

- Special sensory receptors: provide sensations of smell, taste, vision, balance, and hearing
- Visceral sensory receptors: monitor internal organs, including those of the cardiovascular, respiratory, digestive, urinary, and reproductive systems
- Somatic sensory receptors: monitor skeletal muscles, joints, skin surface; provide position sense and touch, pressure, pain, and temperature sensations

**EFFECTORS**

- Skeletal muscle
  - Smooth muscle
  - Cardiac muscle
  - Glands

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Cellular Organization in Neural Tissue

• Neural tissue consists of two cell types:
  • Neurons
    • Nerve cells that are responsible for the transfer and processing of information in the nervous system
    • Consist of a soma, axon, and dendrites
  • Neuroglia
    • Supporting cells
    • Protect the neuron
Figure 13.4 A Review of Neuron Structure

**Dendrites**
- Stimulated by environmental changes or the activities of other cells

**Cell body**
- Contains the nucleus, mitochondria, ribosomes, and other organelles and inclusions

**Axon**
- Conducts nerve impulse (action potential) toward synaptic terminals

**Terminal boutons**
- Affect another neuron or effector organ (muscle or gland)

- Mitochondrion
- Nucleus
- Nucleolus
- Nissl bodies (clusters of RER and free ribosomes)
- Dendritic spines
Cellular Organization in Neural Tissue

- Functions of Neuroglia
  - Provide the framework for the neural tissue
  - Maintain the intercellular environment
  - Act as phagocytes
  - Have the ability to reproduce
Neuroglia

• Neuroglia Cells of the CNS
  • Astrocytes
  • Oligodendrocytes
  • Microglia
  • Ependymal cells

• Neuroglia Cells of the PNS
  • Satellite cells
  • Schwann cells
Neuroglia

**Peripheral Nervous System**
- **Satellite cells**: Surround neuron cell bodies in ganglia; regulate $O_2$, $CO_2$, nutrient, and neurotransmitter levels around neurons in ganglia.
- **Schwann cells**: Surround all axons in PNS; responsible for myelination of peripheral axons; participate in repair process after injury.

**Central Nervous System**
- **Oligodendrocytes**: Myelinate CNS axons; provide structural framework.
- **Astrocytes**: Maintain blood-brain barrier; provide structural support; regulate ion, nutrient, and dissolved-gas concentrations; absorb and recycle neurotransmitters; form scar tissue after injury.
- **Microglia**: Remove cell debris, wastes, and pathogens by phagocytosis.
- **Ependymal cells**: Line ventricles (brain) and central canal (spinal cord); assist in producing, circulating, and monitoring cerebrospinal fluid.
Neuroglia

• Neuroglia of the CNS
  • Astrocytes
    • Have a large number of cytoplasmic processes
    • Control the chemical content of the interstitial environment
    • Maintain the blood–brain barrier
    • Isolate the neurons from general circulation

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Neuroglia

• Neuroglia of the CNS
  • Oligodendrocytes
    • Cytoplasmic extensions contact the somas or axons
    • Cytoplasmic extensions tie axons together in a sheath of myelin
  • Microglia
    • Phagocytic cells
    • Protect the neuron by removing waste and debris
Neuroglia of the CNS

- Ependymal cells
  - Line the ventricles of the brain
  - Line the central canal of the spinal cord
  - Monitor the CSF (cerebrospinal fluid) composition
  - Some ependymal cells secrete CSF
Figure 13.6 Histology of Neural Tissue in the CNS

- **Gray matter**
  - Neurons
  - Internode
  - Myelinated axons
  - Myelin (cut)

- **White matter**
  - Oligodendrocyte
  - Axon
  - Axolemma
  - Myelin sheath gap
  - Unmyelinated axon
  - Basal lamina
  - Capillary
  - CENTRAL CANAL
  - Microglial cell
  - Ependymal cells
  - Astrocyte

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a Light micrograph showing the ependymal lining of the central canal
Neuroglia

• Neuroglia of the PNS
  • **Satellite cells**
    • Regulate the exchange of material between the cell body and the environment
  • **Schwann cells**
    • Also called *neurolemmocytes*
    • Form a myelin sheath
Figure 13.8 Satellite Cells and Peripheral Neurons

- Nerve cell body
- Nucleus
- Satellite cells
- Connective tissue

Peripheral ganglion

LM × 25
Because each Schwann cell can myelinate only about 1 mm of an axon, it takes many Schwann cells to myelinate an entire axon. The narrow open region between two adjacent Schwann cells is called a node. The internodes are the areas myelinated by individual Schwann cells.

In this cross section of a myelinated axon, the myelin sheath appears as concentric dense lines around the axon.
Neurons

• Neuron Structure
  • Neurons consist of:
    • Axons
    • Soma (cell body)
    • Dendrites
    • Terminal aborizations
    • Terminal boutons
    • Axon hillock
    • Axoplasm
Figure 13.10a Anatomy of a Representative Neuron

- Dendritic spines
- Dendrite
- Nucleolus
- Nucleus
- Golgi apparatus
- Chromatophilic substance
- Neurofilament
- Mitochondrion
- Axon hillock
- Initial segment of axon
- Nerve cell body
- Axon (may be myelinated)
- Terminal boutons
- Postsynaptic cell

Multipolar neuron.
Neurons

• Details of Neuron Structure
  • Soma consists of:
    • Nucleus
    • Nucleolus
    • Ribosomes (clusters are called \textit{chromatophilic substance}—create gray matter)
    • Mitochondria
    • Golgi apparatus
    • Lack centrosomes—cannot reproduce
Figure 13.10a Anatomy of a Representative Neuron

- Dendritic spines
- Dendrite
- Nucleolus
- Nucleus
- Chromatophilic substance
- Golgi apparatus
- Neurofilament
- Mitochondrion
- Axon hillock
- Initial segment of axon
- Nerve cell body
- Axon (may be myelinated)
- Terminal boutons
- Postsynaptic cell

Multipolar neuron.
Neurons

• Details of Neuron Structure
  • Axon (nerve fiber) consists of:
    • Axon hillock area
    • Axoplasm
    • Axon vesicles
      • Contain neurotransmitters
Neurons

• Neuron Classification
  • Can be classified based on structure or function
    • Structural classification
      • Based on the number of processes extending from the cell body
    • Functional classification
      • Sensory
      • Motor
      • Interneuron (involved with both sensory and motor)
Neurons

• Structural Classification of Neurons
  • **Anaxonic**
    • Has many processes but cannot differentiate between axons and dendrites
    • Found only in the CNS
  • **Bipolar**
    • The cell body is between the dendrite and axon
    • Axons are not myelinated
Neurons

• Structural Classification of Neurons
  • **Pseudounipolar**
    • The cell body is off to one side of the axon
  • **Multipolar**
    • Typically has a single axon and multiple dendrites
    • Most common type in the CNS
A neuron may innervate (1) other neurons, (2) skeletal muscle fibers, or (3) gland cells. Synapses are shown in boxes for each example. A single neuron would not innervate all three.
Neurons

• Functional Classification of Neurons
  • Sensory (afferent division)
    • Almost all are pseudounipolar neurons
    • Sends information from the PNS to the CNS
    • There are:
      • Somatic sensory and visceral sensory
  • Motor (afferent division)
    • Sends information from the CNS to the periphery
    • Consists of:
      • Somatic nerves and autonomic nerves
Neurons

• Functional Classification of Neurons
  • Interneurons
    • Located entirely in the CNS
    • Situated between the motor and sensory neurons
    • Analyze sensory input and coordinate motor outputs
    • Can be **excitatory** or **inhibitory**
Neurons

There are three major types of receptors associated with sensory neurons:

- **Exteroceptors**
  - Provide information about the external environment such as:
    - Touch, temperature, pressure, sight, smell, and hearing

- **Proprioceptors**
  - Monitor position and movement of the body

- **Interoceptors**
  - Monitor internal organ activity
Figure 13.12 A Functional Classification of Neurons

**Receptors**
- Interoceptors
- Exteroceptors
- Proprioceptors

**Peripheral Nervous System**
- Afferent fibers
- Sensory neurons in peripheral ganglia
- Efferent fibers

**Effectors**
- Skeletal muscles
  - Skeletal muscle fibers
- Visceral effectors
  - Smooth muscles
  - Glands
  - Cardiac muscle
  - Adipose tissue

**Central Nervous System**
- Somatic motor neurons
- Visceral motor neurons
- Interneurons

Visceral motor neurons in CNS and postganglionic fibers to visceral motor neurons in peripheral motor ganglia.

Somatic (sensory & motor) fibers and visceral (sensory & motor) fibers.

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Neural Regeneration

• Neural Regeneration
  • Steps involved in the limited ability to repair
    • Schwann cells grow into the cut area
    • Axon sends buds into network of Schwann cells
    • Axons begin to grow into the Schwann cells
Figure 13.13 Nerve Regeneration

1. Fragmentation of axon and myelin occurs in distal stump.
   - Axon
   - Myelin
   - Proximal stump
   - Distal stump

2. Schwann cells form cord, grow into cut, and unite stumps. Macrophages engulf degenerating axon and myelin.
   - Schwann cell
   - Macrophage

3. Axon sends buds into network of Schwann cells and then starts growing along cord of Schwann cells.

4. Axon continues to grow into distal stump and is enfolded by Schwann cells.
The Nerve Impulse

• A nerve impulse is the **action potential** of a nerve

• The action potential is due to the **exchange of ions** across the membrane

• The ability to conduct the impulse is known as **excitability**
The Nerve Impulse

- A **stimulus** is anything that causes an action potential to occur.
- The stimulus has to overcome the **threshold level** of that particular neuron.
- The threshold level is the amount of stimuli required to create the action potential.
- Once an impulse starts, it is propagated along the length of the axon.
The Nerve Impulse

• The “speed” of the impulse depends on:
  • Presence of a myelin sheath
    • Fast impulse
  • Lack of a myelin sheath
    • Slow impulse
  • Myelinated axons with a large diameter
    • Fast impulse
    • Up to 140 m/sec
  • Unmyelinated axons with a small diameter
    • Slow impulse
    • Less than 1 m/sec
Synaptic Communication

• Vesicular Synapses

• A synapse is the junction between:
  • Axodendritic
    • The axon of one neuron and the dendrite of another neuron
  • Axosomic
    • The axon of one neuron and the soma of another neuron
  • A xoaxonic
    • The axon of one neuron and the axon of another neuron
Synaptic Communication

• Vesicular Synapses

• A synapse is the junction between:
  • Neuromuscular
    • The axon of a neuron and a muscle
  • Neuroglandular
    • The axon of a neuron and a gland
A neuron may innervate (1) other neurons, (2) skeletal muscle fibers, or (3) gland cells. Synapses are shown in boxes for each example. A single neuron would not innervate all three.
Synaptic Communication

• At a synaptic terminal, a nerve impulse triggers events at a synapse that transfers information across the synapse

• This transfer process is accomplished by:
  • **Vesicular synapses** (chemical synapses)
    • Involve a neurotransmitter
  • **Nonvesicular synapses**
    • Involve the flow of ions
Synaptic Communication

• Vesicular Synapse Events
  • Impulses are conveyed in one direction only
  • Sequence of events:
    • An action potential arrives at the presynaptic membrane
    • This triggers the release of a neurotransmitter from the axon vesicles
    • The neurotransmitter diffuses across the synapse
    • The neurotransmitter binds to the postsynaptic membrane
    • This binding action causes a change in the permeability of the postsynaptic membrane
    • This change in permeability results in an action potential of the next neuron
Diagrammatic view of a vesicular synapse between two neurons.
Synaptic Communication

• Nonvesicular Synapse Events
  • Impulses can be conveyed in any direction
  • Sequence of events:
    • The presynaptic membrane of one neuron is tightly bound to the postsynaptic membrane of another neuron
    • This binding permits the passage of ions from one neuron to the next
Neuron Organization and Processing

• Neurons can be organized into smaller organized groups called **neuronal pools**
• The neuronal pools are identified by their neural circuitry such as:
  • Divergence
  • Convergence
  • Serial processing
  • Parallel processing
  • Reverberation
Neuron Organization and Processing

• **Divergence**
  - The spread of information from one neuron to several neurons
  - Permits broad distribution of a specific input
  - Information enters the CNS and then spreads to the brain and spinal cord at the same time

• **Convergence**
  - Information going from several neurons to a single neuron
  - Movements of the diaphragm muscle are involuntary, but yet at times we can move the diaphragm muscle voluntarily
Divergence; a mechanism for spreading stimulation to multiple neurons or neuronal pools in the CNS
Convergence; a mechanism providing input to a single neuron from multiple sources.
Neuron Organization and Processing

- **Serial Processing**
  - Information going from one neuron to the next in a sequence
  - Information going to one part of the brain, then to another part, and then to another part, etc.

- **Parallel Processing**
  - Several neurons are processing the information at the same time
  - If you step on a nail, you typically move your foot, shout “ouch,” and dance a bit, all at the same time
Serial processing; neurons or pools work in a sequential manner
Parallel processing; individual neurons or neuronal pools process information simultaneously.
Neuron Organization and Processing

• Reverberation
  • Collateral axons extend back toward the origin of the impulse to cause an enhancement or a continuation of the impulse
Reverberation; a feedback mechanism that may be excitatory or inhibitory
Anatomical Organization of the Nervous System

- Organization in the CNS
  - Gray matter organization
    - Neural cortex
    - Gray matter on the surface of the brain
    - Nuclei
      - Neuron cell bodies in the interior of the CNS
  - White matter organization
    - Bundles of CNS axons that form ascending and descending columns

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Figure 13.16 Anatomical Organization of the Nervous System

**PERIPHERAL NERVOUS SYSTEM**

**GRAY MATTER**
- Ganglia: Collections of neuron cell bodies in the PNS

**WHITE MATTER**
- Nerves: Bundles of axons in the PNS

**CENTRAL NERVOUS SYSTEM**

**GRAY MATTER ORGANIZATION**
- Neural Cortex: Gray matter on the surface of the brain
- Nuclei: Collections of neuron cell bodies in the interior of the CNS

**WHITE MATTER ORGANIZATION**
- Tracts: Bundles of CNS axons that share a common origin and destination
- Columns: Several tracts that form an anatomically distinct mass

**TRACTS**
- Centers and pathways that connect the brain with other organs and systems in the body
  - Ascending (sensory) tracts
  - Descending (motor) tracts

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Anatomical Organization of the Nervous System

• Organization in the PNS
  • Gray matter
    • Ganglia are collections of neuron cell bodies in the PNS
  • White matter
    • Bundles of axons in the PNS
Figure 13.16 Anatomical Organization of the Nervous System

PERIPHERAL NERVOUS SYSTEM

GRAY MATTER

Ganglia
Collections of neuron cell bodies in the PNS

WHITE MATTER

Nerves
Bundles of axons in the PNS

CENTRAL NERVOUS SYSTEM

GRAY MATTER ORGANIZATION

Neural Cortex
Gray matter on the surface of the brain

Nuclei
Collections of neuron cell bodies in the interior of the CNS

Centers
Collections of neuron cell bodies in the CNS; each center has specific processing functions. Higher centers are the most complex centers in the brain

WHITE MATTER ORGANIZATION

Tracts
Bundles of CNS axons that share a common origin and destination

Columns
Several tracts that form an anatomically distinct mass

TRACTS

Centers and pathways that connect the brain with other organs and systems in the body

- Ascending (sensory) tracts
- Descending (motor) tracts