NERVOUS SYSTEM PHYSIOLOGY

Course Outline

- Introduction to the nervous system
- General organization of the nervous system
- Neuronal physiology
- Central nervous system
- Peripheral nervous system
- Autonomic nervous system

1. Introduction to the Nervous System

The nervous system is a highly complex system that controls all functions of the organism. It ensures the reception, integration, and transmission of information from both the environment and the body itself.

It is composed of **nerve centers** and **nerve pathways**. It can be considered as a network of nerve cells through which signals travel. These nerve cells are organized into **receptor elements** and **effector elements**.

1.1 Main Functions of the Nervous System

The nervous system is a specialized unit that controls, regulates, and coordinates all body functions by ensuring three essential functions:

- **Sensory function**
  Allows detection and reception of stimuli from the environment and the body, transformation of these stimuli into nerve signals, and conduction of these signals to the integration center.
- **Integrative function**
  Enables analysis and interpretation of incoming sensory information and determination of the appropriate response.
- **Motor function**
  Provides an appropriate response to effector organs.

2. General Organization of the Nervous System

Based on anatomical and physiological considerations, the nervous system can be divided into:

- ➢ **Central Nervous System (CNS):** Integrative Part, also called the **neuraxis**, it consists of:

- **The spinal cord**, located in the vertebral canal
- **The brain**, located in the cranial cavity, including: Brainstem, Cerebellum, Cerebrum

It is the **center of regulation and integration** of the nervous system. It manages interactions with the external environment, analyzes and interprets sensory information, sorts and compares it, and generates appropriate motor responses.

- **Peripheral Nervous System (PNS):** Receptive and Effector Part. It is composed of:

- **Cranial nerves** emerging from the brainstem
- **Spinal nerves** emerging from the spinal cord
- **Ganglia**

These nerves act as communication pathways linking the entire body to the CNS. It includes two functional subdivisions:

- **Somatic nervous system**
  A subdivision of the efferent pathway of the PNS under voluntary control, responsible for the innervation of skeletal (striated) muscles.
- **Autonomic nervous system**
  A subdivision of the efferent pathway of the PNS not under voluntary control, regulating visceral organs, blood vessels, and glands.

3. Neuronal Physiology

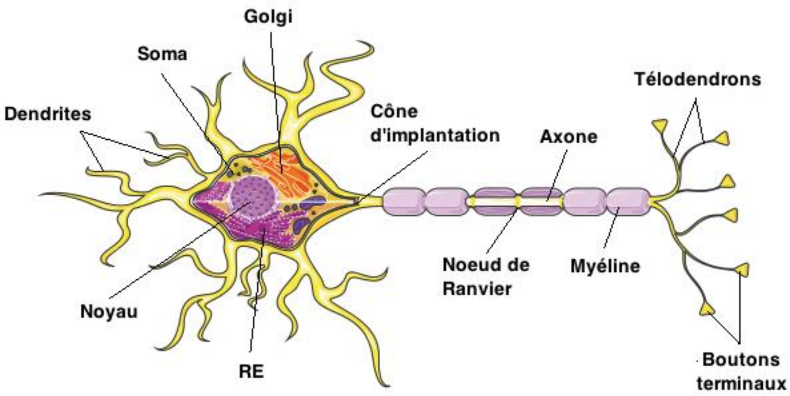
Nervous tissue is mainly composed of two types of cells: **neurons** and **glial cells**.

3.1 The Neuron

The neuron is the structural and functional unit of the nervous system. It is a highly differentiated cell specialized in the conduction of nerve impulses. A neuron consists of a **cell body** from which two types of processes arise:

- **Dendrites**
- **Axon**

These form nerve fibers that may or may not be surrounded by a protective sheath called the **myelin sheath** (a whitish fatty substance). It is estimated that the human nervous system contains about **100 billion neurons**.



3.1.1 Types of Neurons

➤ Structural Classification

- **Multipolar neurons**: several processes (found in the brain)
- **Bipolar neurons**: one cell body, one dendrite, and one axon (retina and inner ear)
- **Unipolar neurons**: dendrite and axon are continuous with each other (spinal cord)

➤ Functional Classification

- **Sensory neurons**: conduct nerve impulses toward the CNS
  - **Somatic sensory neurons**: carry impulses from receptors in the skin, bones, muscles, and joints
  - **Visceral sensory neurons**: carry impulses from the internal organs
- **Motor neurons**: conduct impulses from the CNS
  - **Somatic motor neurons**: innervate skeletal muscles
  - **Visceral motor neurons**: innervate cardiac muscle, smooth muscles, and glands
- **Interneurons (association neurons)**: transmit impulses from sensory neurons to motor neurons

3.2 Glial Cells

Glial cells form a tissue closely associated with neurons. They are support and protective cells of the central nervous system. They perform functions similar to connective tissue (support, exchange, and nutrition). In the Central Nervous System (CNS), four types of glial cells are distinguished:

- **Astrocytes**
  Play a nutritional role and have many processes extending in all directions. They send extensions toward blood vessels to facilitate exchanges.
- **Oligodendrocytes**
  Found in the CNS, they produce myelin and exhibit rhythmic activity.
- **Microglial cells**
  These are the macrophages of nervous tissue; they remove cellular debris and move as needed to sites requiring cleanup.
- **Ependymal cells**
  Epithelial cells that line the brain ventricles and the central canal of the spinal cord.

In the Peripheral Nervous System (PNS), two types of glial cells are found:

- **Schwann cells (neurolemmocytes)**
- **Satellite cells**

3.3 Nerves

Nerves are composed of axons from both **motor neurons** and **sensory neurons**. Some nerves contain only sensory fibers.

Spinal nerves contain approximately **600,000 nerve fibers**. The cell body is located within and/or near the central nervous system.

3.4 Physiological Properties of Neurons

- **Excitability**: the ability to respond to a stimulus and convert it into a nerve signal
- **Conductivity**: the ability to propagate and transmit this nerve impulse to other neurons, muscles, or glands

3.5 Transmission of the Nerve Impulse

As in all cells of the body, the neuron membrane is **polarized**, with a positive charge outside and a negative charge inside.

This polarization is due to a **concentration gradient of sodium and potassium ions** across the plasma membrane. At rest, this gradient is maintained by the **Na^+-K^+-ATPase pump**, creating a **resting potential of -70 mV**.

Temporary changes in membrane permeability to certain ions allow exchanges between the two sides of the membrane, leading to **depolarization**.

If this depolarization is strong enough to propagate along the axon, it is called an **action potential**, which is a wave of depolarization that travels along the neuron.

This propagated depolarization is referred to as the **nerve impulse**.

3.6 Action Potential

The action potential is a property of excitable cells characterized by a **rapid depolarization followed by repolarization** of the membrane. It consists of four phases:

• Depolarization (rising phase)

Following stimulation, **voltage-gated sodium channels** open rapidly, leading to an inward Na^+ current.

The membrane potential approaches the sodium equilibrium potential (**+65 mV**) but does not reach it.

• Repolarization

Sodium channels close, and **voltage-gated potassium channels** open, resulting in an outward K^+ current.

The membrane potential returns toward its resting value.

• **Hyperpolarization**

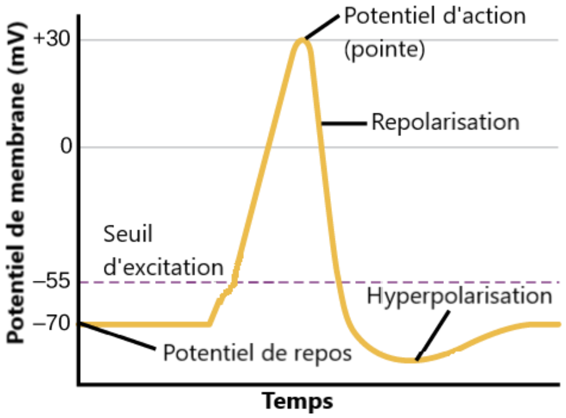
Potassium conductance remains elevated for a short time, causing the membrane to become more negative than the resting potential (**about -75 mV**).

• **Resting Potential**

The **Na^+-K^+-ATPase pump** restores ionic balance by pumping Na^+ out of the cell and K^+ into the cell.

The action potential propagates along the axon by activating adjacent voltage-gated channels, allowing the depolarization wave to move along the neuron.

This depolarization constitutes the **physical basis of the nerve impulse**.



3.7 Laws of the Action Potential

- **Threshold**: the minimum (liminal) level of stimulation below which no action potential can be generated.
- **All-or-none law**: once the threshold is reached, the response is complete and maximal, regardless of the intensity of the stimulus.
- **Summation**:
    - **Temporal summation**: a subthreshold (infraliminal) stimulus can produce a response if it occurs immediately after another subthreshold stimulus
    - **Spatial summation**: two subthreshold stimuli applied simultaneously and close to each other can produce a response

3.8 Refractory Periods

- **Absolute refractory period**
  The period during which no new action potential can be initiated, regardless of stimulus intensity. It corresponds to the time when sodium channels are closed and overlaps almost entirely with the action potential.
- **Relative refractory period**
  Begins at the end of the absolute refractory period and continues until the membrane potential returns to its resting level. During this time, action potentials can occur but require a stronger-than-normal stimulus.

Note: These refractory periods explain the direction of nerve impulse propagation, as the depolarization cannot travel backward because the membrane is temporarily non-excitable in the region already activated.

3.9 Propagation of the Nerve Impulse

- **Continuous conduction**
  In unmyelinated fibers, depolarization is gradual. Each sodium channel reached by the action potential opens and contributes to impulse propagation.
- **Saltatory conduction**
  In myelinated fibers, the impulse propagates by generating action potentials at each **node of Ranvier** (jumping from node to node). This makes conduction much faster.

3.10 Neuromuscular and Synaptic Transmission

Transmission of the nerve impulse from one neuron to another, or to an effector cell (muscle, gland, viscera), occurs at specialized structures called **synapses**.

A synapse is the contact between:

- The axon terminal of a neuron
- The “active” region of the target cell

In neurons, the active region is located on the soma and dendrites. There are two types of synapses:

- **Electrical synapse**
  Involves direct connection via gap junctions, allowing direct passage of the nerve impulse from one neuron to another. This type does not exist in mammals.
- **Chemical synapse**
  Composed of three elements:
  - Presynaptic membrane (rich in vesicles containing neurotransmitters)
  - Synaptic cleft (space between the two membranes)
  - Postsynaptic membrane (contains neurotransmitter receptors)

Chemical synapses are **unidirectional** and **fatigable**, meaning repeated stimulation leads to a gradual decrease in the postsynaptic response.

3.11 Functioning of a Chemical Synapse

Arrival of the action potential at the axon terminal opens **voltage-gated calcium channels**. Calcium ions enter the presynaptic neuron, triggering **exocytosis** of neurotransmitter-containing vesicles into the synaptic cleft. Thus, calcium channels convert the **electrical signal into a chemical signal**. The neurotransmitter diffuses across the synaptic cleft and binds to receptors on the postsynaptic membrane, altering its permeability to ions and its membrane potential.

- **Inhibitory neurotransmitters**
  Open Cl^- channels → Cl^- enters the cell → hyperpolarization
- **Excitatory neurotransmitters**
  Open Na^+ channels → Na^+ enters the cell → depolarization → action potential → cellular response (muscle contraction, hormone secretion, etc.)

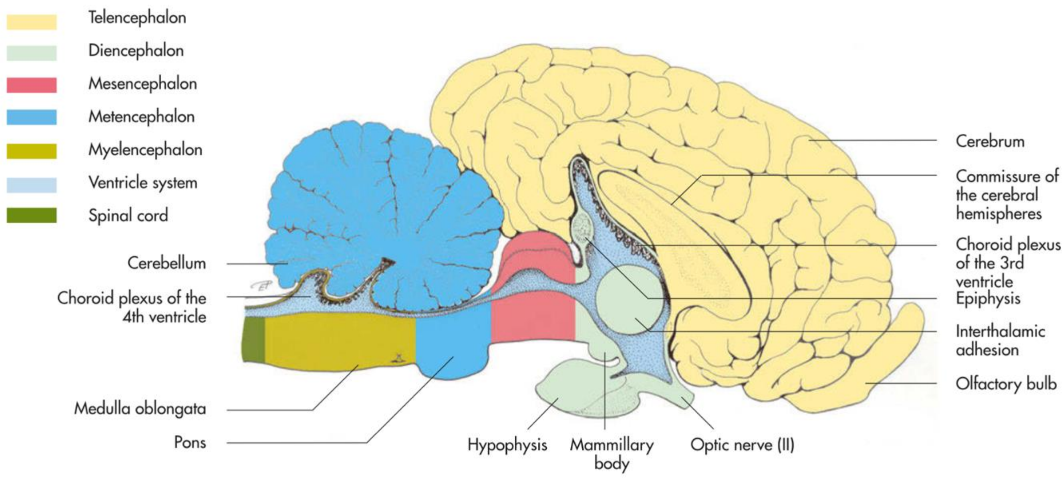
Finally, the neurotransmitter is either **degraded or reabsorbed (reuptake)**.

4. Central Nervous System

4.1. Brain

The brain is located in the cranial cavity and is separated from it by the meninges. It consists of three main parts:

- **Cerebrum** (anterior part), composed of two cerebral hemispheres (right and left)
- **Cerebellum** (posterior part)
- **Brainstem**, composed of:
    - Medulla oblongata
    - Pons
    - Midbrain
    - Diencephalon



Let us study the different brain structures one by one:

• Telencephalon

The brain, also called the **telencephalon**, consists of two cerebral hemispheres (right and left) connected by the **corpus callosum**.

Each hemisphere has numerous folds, the deepest and most constant of which are called **sulci or fissures**. These divide the cerebral cortex into four lobes with distinct functions:

- **Frontal lobe**: voluntary control of skeletal muscles, personality, intellectual processes, verbal communication
- **Parietal lobe**: skin and muscle sensations, language comprehension and formulation
- **Temporal lobe**: interpretation of auditory sensations, auditory and visual memory
- **Occipital lobe**: conscious vision, integration of movement with visual stimuli, interpretation of visual information based on past experiences

• Diencephalon

It includes:

- **Thalamus**: a paired structure located just below the lateral ventricles. It acts as a major relay center for sensory information to the cerebral cortex (except for olfaction).
- **Hypothalamus**: involved in many regulatory functions of the body, including:
    - Cardiovascular regulation
    - Body temperature regulation
    - Water and electrolyte balance
    - Gastrointestinal activity
    - Hunger, thirst, energy expenditure
    - Sleep–wake cycle
    - Sexual responses and emotions
    - Endocrine control via stimulation of the pituitary gland
- **Epithalamus (pineal gland)**: secretes melatonin, a hormone regulating circadian rhythms and involved in the onset of puberty
- **Neurohypophysis (posterior pituitary)**: secretes two neurohormones, **ADH** and **oxytocin**

  (The adenohypophysis is not part of the CNS)

• Mesencephalon (Midbrain)

The mesencephalon is a short segment of the brainstem located between the diencephalon and the pons.

It includes:

- Two **rostral colliculi** (visual processing)
- Two **caudal colliculi** (auditory processing)

• Metencephalon

The metencephalon includes:

- **Pons**: composed of nerve fibers that relay impulses between different regions of the brain. Several cranial nerves originate here. It contains:
  - The **apneustic center**
  - The **pneumotaxic center**
  (both involved in regulating breathing rate)
- **Cerebellum**: composed of two hemispheres
  - Responsible for balance, posture, and motor coordination
  - Regulates involuntary contraction of skeletal muscles in response to proprioceptive inputs
  - Has an exclusively motor function

• Myelencephalon (Medulla Oblongata)

The **medulla oblongata** is connected to the spinal cord and forms the most caudal part of the brainstem. It consists mainly of white matter tracts connecting the spinal cord to the brain.

It contains three major autonomic centers:

- **Cardiac center**: controls heart rate via inhibitory and stimulatory fibers
- **Vasomotor center**: regulates contraction of arteriolar smooth muscle
- **Respiratory centers**: control breathing rate and depth

4.2 Functional Lateralization of the Cerebral Hemispheres

Although both hemispheres are involved in most activities, there is a **functional specialization (lateralization)** between them.

Each hemisphere has specific abilities, and one may dominate depending on the task.

- In **90% of people**, the **left hemisphere is dominant**, controlling:
  - Language
  - Logical and mathematical abilities
- The **right hemisphere** is involved in:
  - Spatial and visual abilities
  - Intuition
  - Emotions
  - Artistic and musical appreciation

(Most individuals with left-hemisphere dominance are right-handed.)

- In the remaining **10%**, dominance may be reversed or equal.
  - Right-dominant individuals are often left-handed
  - Some individuals have bilateral cortical functions and may be ambidextrous

4.3 Cortical Areas

A **cortical area** is a region of the cerebral cortex (gray matter) with a specific function.

According to the map established by the German anatomist **Brodmann**, the cellular organization of the cortex varies across regions, defining functionally distinct areas numbered from 1 to 52. These areas are responsible for mental functions such as:

- Speech
- Memory
- Reasoning
- Emotion
- Consciousness
- Sensory interpretation
- Communication
- Voluntary movement

4.3.1 Motor Areas

Located in the posterior part of the frontal lobes:

- **Primary motor area (somatic motor cortex):** Located in the **precentral gyrus.** Controls voluntary skeletal muscle movements. Motor control is **contralateral** (left hemisphere → right body, and vice versa). The **motor homunculus** represents body regions according to their motor control importance
- **Motor speech area (Broca's area)**
  Controls muscles involved in speech (tongue, throat, lips). Present in both hemispheres but usually dominant in the left.

4.3.2 Sensory Areas

Located in the parietal, temporal, and occipital lobes:

- **Primary somesthetic (somatosensory) area**
  Perceives touch, temperature, and pain. Allows localization of stimuli (spatial discrimination). Also organized contralaterally. The **sensory homunculus** represents sensory body regions
- **Posterior parietal area**
  An associative tactile area that analyzes sensory information (size, texture perception)
- **Visual areas**
  - Primary visual area: receives visual input from the retina
  - Associative visual area: interprets visual information based on past experiences
- **Auditory areas**
  - Primary auditory area: perceives sound pitch, intensity, and rhythm
  - Associative auditory area: interprets sounds (speech, music, noise)

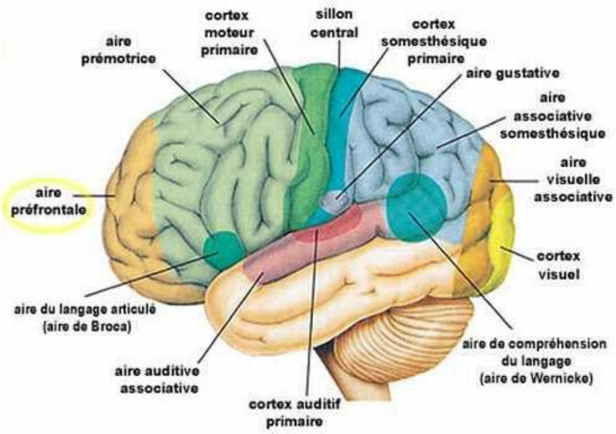
4.3.3 Association Areas

These areas integrate and process sensory information to generate motor responses.

They are generally located near their corresponding primary areas.

- **Prefrontal cortex**

  Located in the anterior frontal lobe. Plays key roles in:
    - Intelligence and learning
    - Personality
    - Abstract thinking
    - Judgment and reasoning
    - Anticipation and perseverance
    - Emotional regulation (via connection with the limbic system)



4.2 Spinal Cord

The **spinal cord** is a long cylindrical structure of nervous tissue located within the vertebral canal, which it does not completely fill. It is continuous with the brainstem and gives rise to **spinal nerves** on each side through two rows of roots:

- **Dorsal roots** (sensory)
- **Ventral roots** (motor)

It extends from the **foramen magnum** to the **lumbar or sacral region**. It is whitish, firm, and slightly elastic.

In a **cross-section** of the spinal cord, a narrow central canal called the **central canal (ependymal canal)** can be observed. It is filled with **cerebrospinal fluid (CSF)** and surrounded by **gray matter** arranged in a butterfly shape, itself completely enclosed by **white matter**.
The spinal cord has two main functions:

- **A communication pathway** between the brain and all organs connected to spinal nerves
  It receives information from peripheral receptors (pain, limb position, etc.) and transmits it to the brain for integration. It also receives motor commands from the brain and sends them to effectors (muscles).
- **A reflex integration center**
  It integrates certain simple reflexes without involving the brain.

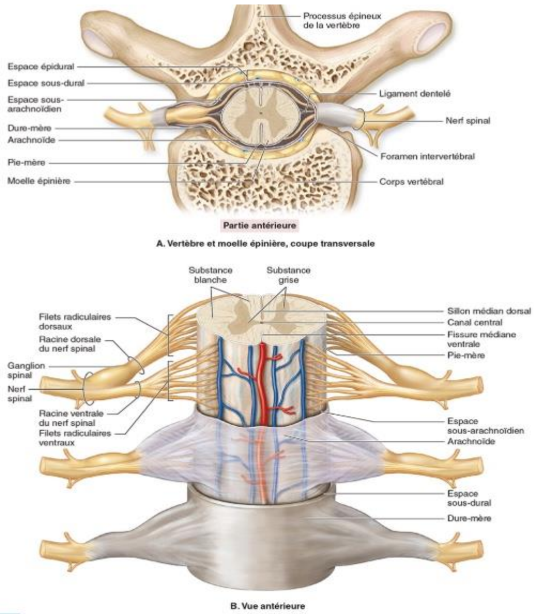


FIGURE 14.2
Méninges spinales et structure de la moelle épinière ›
A. La coupe transversale de la moelle épinière illustre le lien qui unit les feuillets méningés et les points de repère superficiels de la moelle épinière et de la colonne vertébrale. **B.** Cette vue antérieure présente la moelle épinière et les méninges.

4.2.1 Spinal Reflexes

A **reflex** is an unconscious, involuntary, and stereotyped motor response to a stimulus.

It allows the organism to adapt rapidly, although it lacks precision and fine control.

The physiological characteristics of this response are based on a fundamental structure called the **reflex arc**.

4.2.2 Organization of the Reflex Arc

The reflex arc is the anatomical basis required for any reflex activity. The simplest reflex arc includes:

- **Afferent pathway**

  Composed of a **sensory receptor** (muscular or cutaneous) stimulated by a stimulus. The receptor sends information through **afferent sensory fibers** to the spinal cord.
- **Reflex center**

  Located in the spinal cord, where synaptic connections (simple or complex) occur between afferent and efferent pathways.
- **Efferent pathway**

  Composed of **alpha motor neurons** that innervate the effector muscle (flexor or extensor).

4.2.3 Classification of Reflexes

Reflexes are generally classified into:

4.2.3.1 Phasic Reflexes

These are **monosynaptic tendon reflexes**.

They consist of a brief, sudden contraction in response to a rapid stretch of a tendon.

Example: the **patellar reflex (knee-jerk reflex)**.

4.2.3.2 Myotatic Reflexes

A **myotatic reflex** is a reflex contraction of a muscle in response to its own stretching, aimed at maintaining a constant muscle length. It is a **proprioceptive monosynaptic reflex**, present in all muscles, especially **extensor muscles** (e.g., quadriceps, gastrocnemius), which are involved in posture against gravity. Thus, the myotatic reflex plays a **postural role**. When an extensor muscle is stretched following tendon stimulation:

- The **muscle spindle** detects the stretch
- The signal is transmitted via a **sensory neuron** to the spinal cord through the dorsal root

At the spinal cord level:

- The sensory neuron forms a synapse with a **motor neuron** that stimulates the same extensor muscle → causing its **reflex contraction**

- Simultaneously, it synapses with an **interneuron**, which connects to an **inhibitory motor neuron** innervating the antagonist (flexor muscle) → causing its **relaxation**

Note

Phasic reflexes and stretch (myotatic) reflexes differ in the nature of the stimulus and their function.

- **Phasic reflexes** are rapid responses that occur in reaction to a sudden stimulus.
- **Myotatic reflexes** are responses to muscle stretching, aimed at maintaining posture and muscle tone.

4.2.3.3 Flexion Reflexes

Flexion reflexes are **protective or withdrawal responses** involving flexor muscles in response to usually painful (nociceptive) stimuli, typically from the skin. They result in an **ipsilateral flexion movement**. These are **polysynaptic reflexes**, involving several spinal interneurons.

Monosynaptic and polysynaptic reflexes differ by the number of synapses involved in the reflex pathway:

- **Monosynaptic reflexes**
  Involve a single synapse between a sensory neuron and a motor neuron (e.g., the **patellar reflex**). These reflexes are generally **very fast**, as only one synaptic connection is involved.
- **Polysynaptic reflexes**
  Involve multiple synapses and several neurons within the reflex circuit. They may include interneurons, allowing more complex integration of information (e.g., the **flexion reflex**). These reflexes are generally **slower** due to the greater number of synapses.

4.3 Protection of the Central Nervous System

Let us now examine the different protective mechanisms of the CNS.

4.3.1 Meninges

The **central nervous system** (brain and spinal cord) is completely covered by three protective layers of connective tissue called the **meninges**. From outermost to innermost:

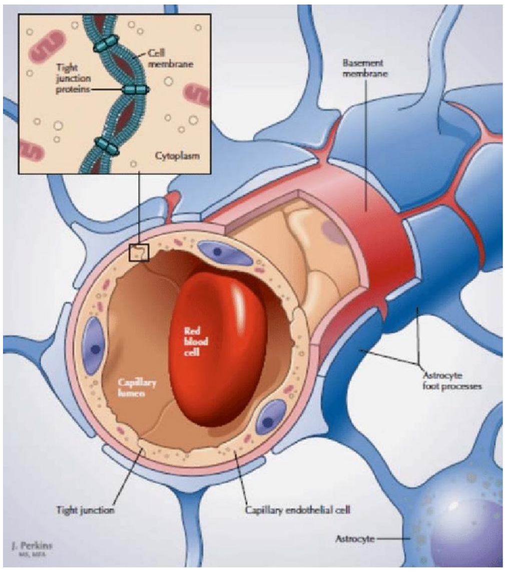
- **Dura mater:** A thick, tough connective tissue layer adherent to the skull, but separated from the vertebral canal by the **epidural space**
- **Arachnoid mater:** A loose, avascular connective tissue network. Its outer surface is separated from the dura mater by the **subdural space**
- **Pia mater:** A delicate layer composed of glial cells

Between the arachnoid and pia mater lies the **subarachnoid space**, which contains **cerebrospinal fluid (CSF)**.

4.3.2 Blood–Brain Barrier (BBB)

The separation between the blood and the brain is ensured by both **endothelial cells** and **glial cells**. Cerebral capillaries are of the **continuous type**, unlike the fenestrated capillaries found in other organs. **Tight junctions** between endothelial cells make the passage of substances from blood plasma to the brain's extracellular fluid highly selective.

- Substances that cross easily:
    - Lipid-soluble compounds
    - Water (H_2O)
    - Oxygen (O_2)
    - Carbon dioxide (CO_2)
    - Glucose
- Substances that cross slowly or are restricted:
    - Inorganic ions (slow passage)
    - Large proteins
    - Lipids (some)
    - Certain toxins and Most antibiotics



4.3.3 Cerebrospinal Fluid (CSF)

Cerebrospinal fluid is a clear, transparent, and colorless liquid. It is continuously produced by active transport of substances from blood plasma by the **choroid plexuses** and flows into the **subarachnoid space** through openings at the level of the fourth ventricle. It bathes the central nervous system and fills the subarachnoid space, the cerebral ventricles, the central canal (ependymal canal). It plays a very important role in:

- **Mechanical protection** by cushioning shocks
- **Removal of metabolic waste** from nervous tissue

It is reabsorbed into the bloodstream at the level of the **arachnoid villi**.

5. Peripheral Nervous System

The **peripheral nervous system (PNS)** consists of all nervous structures located outside the central nervous system. Nerves form its most characteristic and extensive component, connecting the CNS to all parts of the body. According to their function, two types of nerves are distinguished:

- **Cranial nerves**
- **Spinal nerves**

5.1 Cranial Nerves

Cranial nerves originate from the brain and, except for the olfactory nerves, are attached to the brainstem. They are arranged symmetrically in pairs, with **12 pairs** in total. They are classified into three groups:

- **Sensory nerves**
- **Motor nerves**
- **Mixed nerves**

5.2 Spinal Nerves

Formerly called **spinal (rachidian) nerves**, they arise in symmetrical pairs from the spinal cord. Like vertebrae, they are classified into:

- Cervical spinal nerves
- Thoracic spinal nerves
- Lumbar spinal nerves
- Sacral spinal nerves
- Coccygeal spinal nerves

Each spinal nerve originates from two roots:

- A **dorsal (sensory) root**, containing a ganglion
- A **ventral (motor) root**

From a functional perspective, the PNS includes two pathways:

- **Sensory (afferent) pathway**
  Composed of somatic and visceral afferent fibers that carry nerve impulses from sensory receptors to the CNS
- **Motor (efferent) pathway**
  Composed of motor fibers that carry responses from the CNS to effector organs

The motor pathway can be subdivided into:

- The **somatic (cerebrospinal) nervous system**

- The **autonomic (vegetative) nervous system**

5.2.1 Somatic Nervous System

Also called the **somato-motor system**, it innervates skeletal (striated) muscles and is under **voluntary control**. The cell bodies of motor neurons are located in the CNS (spinal cord), and their axons extend through spinal nerves **without synaptic relay** to reach skeletal muscles, forming the **neuromuscular junction (motor end plate)**. The neurotransmitter involved is **acetylcholine**, acting on **nicotinic receptors**.

5.2.2 Autonomic Nervous System

Also called the **vegetative nervous system**, it innervates:

- Viscera (heart, digestive tract, glands)
- Smooth muscles
- Blood vessels
- Skin structures (sweat glands, arrector pili muscles)

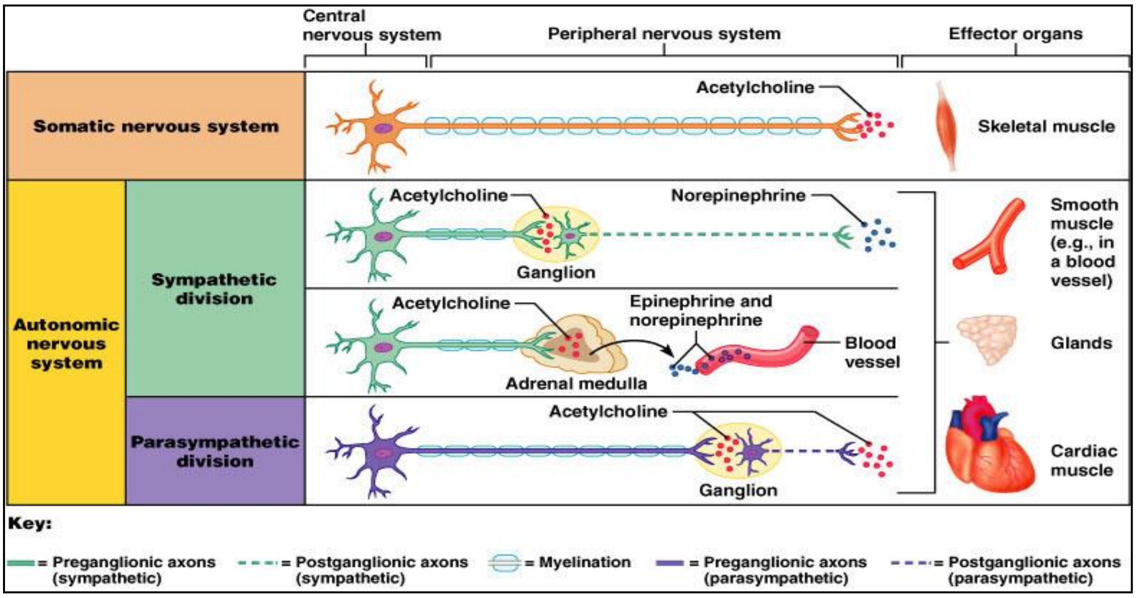
Its control is **involuntary**, but influenced by the CNS (brainstem and hypothalamus). The peripheral part of the ANS is **two-neuron (bi-neuronal)**:

- A **preganglionic neuron** originates in the spinal cord
- It synapses in a ganglion with a **postganglionic neuron**, which innervates the effector cells

The preganglionic neuron is **myelinated**, while the postganglionic neuron is **unmyelinated**.

In the ANS:

- At ganglionic synapses, the neurotransmitter is **acetylcholine**, with **nicotinic receptors**
- At the effector level, neurotransmitters are **adrenaline (epinephrine)** and **noradrenaline (norepinephrine)**, acting on **adrenergic receptors**



5.2.2.1 Anatomical and Functional Organization of the Autonomic Nervous System

The **autonomic nervous system (ANS)** is classically divided into two major systems that differ anatomically and functionally:

- **The sympathetic (orthosympathetic) system**
- **The parasympathetic system**

Most visceral organs receive **dual innervation**, except for sweat glands, arrector pili muscles and many blood vessels. These structures are **exclusively innervated by the sympathetic system**.

In addition to these two systems, there is the **enteric nervous system**, which includes all nerve plexuses of the gastrointestinal tract.

Schematically:

- The **sympathetic system** is mainly **excitatory** and is activated during **emergency or stress situations** (fight or flight).
- The **parasympathetic system** acts **antagonistically** to the sympathetic system and is responsible for routine bodily functions and **energy conservation**, promoting metabolic activities.

These two systems:

- Ensure motor activity for certain organs (e.g., the bladder, which would be paralyzed without them)
- Play a **modulatory role** in organs such as the heart and intestines

Although their functions appear antagonistic, they are actually **complementary**:

- **Opposing roles**:
  - Sympathetic → increases heart rate
  - Parasympathetic → decreases heart rate
- **Distinct roles**:
  - Blood vessels receive purely sympathetic innervation
- **Complementary roles**:
  - Parasympathetic → erection
  - Sympathetic → ejaculation

➤ Sympathetic Nervous System

The cell bodies of preganglionic sympathetic neurons **are located in the** lateral horn of the thoracolumbar spinal cord**.** These motor neurons:

- Exit via the ventral root
- Reach the paravertebral ganglionic chain via a white communicating ramus (myelinated preganglionic fibers)

- At the ganglia: Preganglionic neurons synapse with postganglionic neurons (unmyelinated)
- These fibers return to spinal nerves via **a** gray communicating ramus
- Then extend to target organs

Neurotransmitters :

Preganglionic neurons **use** Acetylcholine (ACh) and its receptor is called Nicotinic

Postganglionic neurons **use** Norepinephrine (noradrenaline) and its receptor is called Adrenergic ($\alpha 1$, $\alpha 2$, $\beta 1$, $\beta 2$)

Both **epinephrine (adrenaline)** and **norepinephrine** activate $\alpha 1$, $\alpha 2$, $\beta 1$ receptors but only **epinephrine** activates $\beta 2$ receptors

Remarks

Remark 1:
Some preganglionic sympathetic neurons pass through the paravertebral chain to reach larger ganglia:

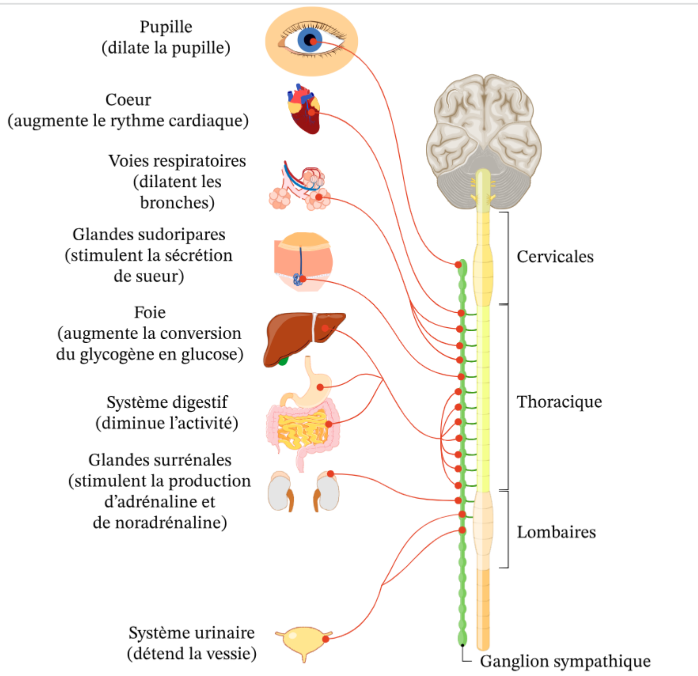
- **Celiac ganglion** → innervates liver, stomach, small intestine, kidney
- **Cranial mesenteric ganglion** → innervates large intestine
- **Caudal mesenteric ganglion** → innervates large intestine and genital organs

Remark 2:
The **adrenal medulla** is a special case:

- Preganglionic neurons synapse directly with **chromaffin cells**
- These cells secrete **epinephrine and norepinephrine**
- They function as **equivalents of postganglionic neurons**

Remark 3:
Sweat glands and some **blood vessels** are exceptions:

- Their effector cells are activated by **acetylcholine**
- Via **muscarinic receptors** (not adrenergic)



➢ Parasympathetic Nervous System

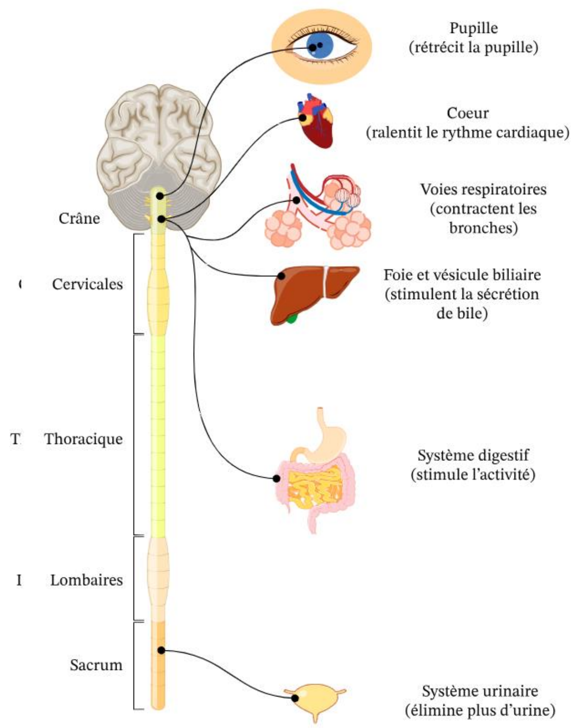
The cell bodies of parasympathetic preganglionic neurons are located in the central nervous system (CNS), specifically in the brainstem and the sacral spinal cord. Cranial parasympathetic fibers exit the CNS through cranial nerves (III (oculomotor), VII (facial), IX (glossopharyngeal), X (vagus).

Sacral parasympathetic fibers leave the spinal cord via the pelvic nerves and innervate the large intestine, the bladder, the genital organs.

The neurotransmitter of preganglionic parasympathetic neurons is acetylcholine (ACh), acting on nicotinic receptors.

Unlike the sympathetic system, parasympathetic preganglionic neurons synapse near or within the effector organs, resulting in very short postganglionic neurons.

The neurotransmitter of postganglionic parasympathetic neurons is also acetylcholine, which acts on muscarinic receptors on target cells.



5.2.2.2 Types of Receptors in the Autonomic Nervous System

➤ **Adrenergic Receptors**

- **α1 receptors**

Located on smooth muscle (except bronchial smooth muscle). Cause stimulation (contraction). Sensitive to both norepinephrine and epinephrine, but mainly activated by norepinephrine

- **α2 receptors**

Located in presynaptic nerve terminals, platelets, adipose cells, and smooth muscle. Generally produce **inhibition**.

- **β1 receptors**

Located in the **heart.** Cause **stimulation (increase in heart activity).** Sensitive to both norepinephrine and epinephrine. More sensitive than α receptors.

- **β2 receptors**

Located in vascular smooth muscle, bronchial smooth muscle and gastrointestinal tract. Cause **relaxation.** More sensitive to **epinephrine** than norepinephrine.

Note:

Low levels of epinephrine (from adrenal medulla) lead to a vasodilation (β receptors) and high levels of epinephrine provoke a vasoconstriction (α receptors)

➤ **Cholinergic Receptors**

- **Nicotinic receptors**

Located in autonomic ganglia, neuromuscular junction. They are similar but not identical in both locations. Activated by acetylcholine or nicotine and cause stimulation

- **Muscarinic receptors**

Located in the heart, the smooth muscle (except vascular smooth muscle) and glands. Activated by acetylcholine or muscarine. They have an inhibitory effect in the heart and a stimulatory effect in smooth muscle and glands. Atropine blocks muscarinic receptors.