iv. Nervous Systems

iv. Nervous Systems – Central and Autonomic nervous system, Neurophysiology and Cerebrospinal fluids

Central Nervous System (CNS)

Overview of CNS Organization

1. **Brain**
   - **Cerebrum**: Composed of the cerebral cortex (frontal, parietal, occipital, and temporal lobes), subcortical structures (basal ganglia, hippocampus, amygdala). Responsible for higher cognitive functions, sensory perception, voluntary motor control, learning, and memory.
   - **Diencephalon**: Includes the **thalamus** (major relay for sensory and motor signals) and **hypothalamus** (homeostatic regulation, endocrine control via the pituitary gland).
   - **Brainstem**: Midbrain, pons, and medulla oblongata. Houses nuclei for cranial nerves, regulates essential autonomic functions (respiration, cardiovascular control), and coordinates reflexes and arousal.
   - **Cerebellum**: Critical for motor coordination, balance, and procedural learning.
2. **Spinal Cord**
   - Extends from the medulla to the lumbar region, encased within the vertebral column.
   - Segments (cervical, thoracic, lumbar, sacral) each give rise to spinal nerves.
   - Gray matter (neuronal cell bodies) in an H-shaped core, white matter (myelinated axons) surrounding.
   - Conveys sensory information (via ascending tracts) and motor commands (via descending tracts), also controls reflexes at the segmental level.
3. **Protective Structures**
   - **Meninges**: Three layers—dura mater (outer), arachnoid mater (middle), pia mater (inner)—surround and protect the brain and spinal cord.
   - **Blood–Brain Barrier (BBB)**: Specialized endothelial tight junctions in brain capillaries restrict paracellular transport, maintaining a stable CNS environment.

Neurons and Glia

1. **Neurons**
   - Excitable cells with specialized structures: dendrites (input), soma (integration), axon (output), and synaptic terminals.
   - Functional classification: **Sensory (afferent)**, **Motor (efferent)**, and **Interneurons** (local circuit neurons).
2. **Neuroglia (Glial Cells)**
   - **Astrocytes**: Support and maintain ionic balance, contribute to BBB, modulate synaptic function.
   - **Oligodendrocytes** (CNS) and **Schwann Cells** (PNS): Produce myelin sheaths for rapid saltatory conduction.
   - **Microglia**: CNS resident macrophages, clear pathogens and debris.
   - **Ependymal Cells**: Line ventricles, help produce cerebrospinal fluid.

Autonomic Nervous System (ANS)

Divisions and General Functions

1. **Sympathetic Division**
   - “Fight or Flight” responses: Increases heart rate, dilates bronchi, mobilizes energy stores, redirects blood flow to skeletal muscles.
   - Preganglionic neurons originate in the thoracolumbar spinal cord; short preganglionic fibers, long postganglionic fibers.
2. **Parasympathetic Division**
   - “Rest and Digest” responses: Slows heart rate, stimulates digestion and glandular secretion, promotes energy conservation.
   - Preganglionic neurons arise from brainstem (cranial nerves III, VII, IX, X) and sacral spinal cord; long

preganglionic fibers, short postganglionic fibers located near target organs.

3. **Enteric Nervous System (ENS)**
    - Often considered a subdivision of the ANS, embedded in the walls of the gastrointestinal tract.
    - Operates largely autonomously but modulated by sympathetic and parasympathetic inputs.
    - Manages peristalsis, secretions, and local blood flow in the GI tract.

Neurotransmitters and Receptors

- **Sympathetic**
    - Preganglionic neurons release **acetylcholine (ACh)** onto nicotinic receptors.
    - Postganglionic neurons typically release **norepinephrine (NE)** acting on α- and β-adrenergic receptors in target tissues. **Exceptions**: Sweat glands (ACh) and adrenal medulla (epinephrine, NE secreted into blood).
- **Parasympathetic**
    - Both pre- and postganglionic neurons release **ACh**; postganglionic ACh acts on **muscarinic receptors** (M_1–M_5 subtypes) in target organs.
- **Varicosities**
    - ANS neurons often have varicosities along their axons that release neurotransmitters diffusely, influencing broad regions of tissue.

Neurophysiology

Resting Membrane Potential and Action Potentials

1. **Resting Membrane Potential (RMP)**
    - Typically ~ −70 mV inside relative to outside in neurons, due to selective permeability to K^+ (via leak channels) and the Na^+/K^+ ATPase maintaining ion gradients.
2. **Action Potential (AP)**
    - Rapid, transient change in membrane potential (depolarization → repolarization → hyperpolarization).
    - **Voltage-gated Na^+ channels** open first (fast depolarization), followed by **voltage-gated K^+ channels** (repolarization and afterhyperpolarization).
    - **Saltatory Conduction** in myelinated axons: AP jumps between nodes of Ranvier, increasing conduction velocity.

Synaptic Transmission

1. **Chemical Synapses**
    - Presynaptic terminal releases neurotransmitters (e.g., glutamate, GABA, ACh, NE) into the synaptic cleft.
    - Postsynaptic receptors transform chemical signals into electrical or second messenger responses.
    - **Excitatory (EPSP)** or **Inhibitory (IPSP)** post-synaptic potentials influence whether a neuron fires an AP.
2. **Long-Term Potentiation (LTP) and Plasticity**
    - Persistent increase in synaptic strength following high-frequency stimulation, crucial for learning and memory.
    - Mediated by changes in receptor density (e.g., NMDA, AMPA receptors for glutamate) and intracellular signaling pathways.
3. **Neuromodulators and Neuromediators**
    - Peptides (e.g., substance P, opioids), monoamines (dopamine, serotonin), and endocannabinoids modulate neuronal excitability, synaptic efficacy, and behavior.

Cerebrospinal Fluid (CSF)

Production and Circulation

1. **Choroid Plexus**
    - Specialized ependymal cells in the lateral, third, and fourth ventricles produce CSF (~500 mL/day).
    - Derived from plasma but with lower protein and a different ion composition (e.g., higher Na^+, lower K^+).
2. **Circulation Pathway**

- Lateral ventricles → Interventricular foramina (of Monro) → Third ventricle → Cerebral aqueduct → Fourth ventricle → Subarachnoid space (around brain and spinal cord).
- CSF also flows through the **central canal** of the spinal cord in small amounts.

3. **Reabsorption**
   - **Arachnoid Villi (Granulations)**: Protrude into dural venous sinuses, allowing CSF to return to venous circulation.
   - Maintains constant turnover and pressure within the cranial vault.

Functions of CSF

1. **Mechanical Protection**
   - Cushions the brain and spinal cord, absorbing impact.
2. **Chemical Stability**
   - Provides a regulated extracellular environment, removing metabolic wastes.
3. **Buoyancy**
   - Reduces effective brain weight, preventing excessive pressure on the base of the skull.

Clinical Correlations

1. **Hydrocephalus**
   - Abnormal accumulation of CSF due to obstruction of flow or impaired reabsorption.
   - Increases intracranial pressure (ICP), can damage brain tissues.
2. **Lumbar Puncture (Spinal Tap)**
   - Diagnostic sampling of CSF from the subarachnoid space in the lumbar region.
   - Measures CSF pressure, analyzes cell count, protein, glucose, potential pathogens.

Integration and Functional Significance

1. **Reflex Arcs**
   - Spinal and cranial reflexes enable rapid, involuntary responses to stimuli (e.g., patellar tendon reflex, pupillary light reflex).
   - Involve afferent sensory input, interneuronal processing, and efferent motor output.
2. **Sensory Processing and Motor Control**
   - Complex interplay among the **somatosensory cortex**, **cerebellum**, **basal ganglia**, and **motor cortex** ensures coordinated movement and posture.
   - **Descending tracts** (corticospinal, extrapyramidal pathways) modulate voluntary and involuntary motor outputs.
3. **Higher Brain Functions**
   - **Language, Cognition, and Memory** localized in specific cortical regions (e.g., Broca's and Wernicke's areas for language).
   - **The Limbic System** (hippocampus, amygdala, cingulate gyrus) underlies emotions, motivation, and the formation of long-term memories.
   - **RAS (Reticular Activating System)** in the brainstem regulates wakefulness, arousal, and sleep–wake cycles.
4. **Interactions of CNS and ANS**
   - Hypothalamus integrates autonomic and endocrine responses with behavioral states (e.g., stress response, thermoregulation).
   - The cerebral cortex can influence ANS activity (e.g., emotion-driven changes in heart rate, respiratory patterns).

Concluding Remarks

The **central nervous system**—brain and spinal cord—serves as the principal integrative network, processing sensory inputs and orchestrating motor outputs, cognition, emotion, and higher-order functions. The **autonomic nervous system** complements these functions by regulating involuntary processes (circulation, digestion, thermoregulation) crucial for homeostasis. Underlying these systems is a sophisticated **neurophysiological framework** encompassing neuronal

excitability, synaptic transmission, plasticity, and reflex architecture.

The **cerebrospinal fluid** bathes and protects the CNS, maintaining an optimal ionic and chemical environment. Disturbances in CSF dynamics or neurophysiological signaling can lead to severe disorders, underscoring the significance of these interlinked systems. Cutting-edge research continues to elucidate the precise molecular and circuit-level mechanisms that govern brain function, from synaptic plasticity and neurogenesis to integrative neural networks—a pursuit driving innovative therapies for neurological and psychiatric diseases.