Central Nervous System Development-Embryology

The central nervous system (CNS), comprising the brain and spinal cord, originates from the ectodermal germ layer during early embryogenesis. Its development begins in the third week of gestation with the formation of the neural plate.

Formation of the Neural Tube

Neural Plate and Groove

- The neural plate is a thickened region of ectoderm extending from the prechordal plate (anteriorly) to the caudal end of the embryonic disc.
- The lateral edges of the neural plate elevate to form neural folds, which flank a central depression known as the neural groove.
- Fusion of these folds transforms the neural groove into the neural tube, situated in the midline beneath the ectoderm.

Neuropores

- Fusion of the neural folds begins in the mid-region and progresses bidirectionally.
- Two temporary openings remain: the anterior (cranial) neuropore and posterior (caudal) neuropore.
    - The anterior neuropore closes on day 23.
    - The posterior neuropore closes on day 25.
- Closure of these neuropores is critical for the development of the brain and spinal cord. Failure results in neural tube defects (NTDs).

Neural Crest and Its Derivatives

Formation of Neural Crest

- Neural crest cells form at the junction between the neural tube and ectoderm.
- As the neural folds fuse, the neural crest cells detach and migrate ventrolaterally, forming paired longitudinal cords alongside the neural tube.

Derivatives of the Neural Crest

Neural crest cells differentiate into numerous structures, including:

- Sensory ganglia of cranial nerves V, VII, IX, X
- Autonomic ganglia (sympathetic and parasympathetic)
- Dorsal root ganglia
- Schwann cells
- Adrenal medulla (chromaffin cells)
- Melanocytes

- Pia and arachnoid mater (but not dura mater)

Development of the Spinal Cord

Early Structure

- The caudal part of the neural tube becomes the spinal cord.
- Initially, the neural tube consists of a single layer of neuroepithelial (columnar) cells surrounding a central canal.

Differentiation of Layers

The lateral walls of the neural tube differentiate into three layers:

1. **Ependymal layer (inner):**
    - Forms ependymal cells lining the central canal
    - Generates neuroblasts (primitive nerve cells)
2. **Mantle layer (middle):**
    - Contains neuroblasts and glioblasts
    - Becomes the gray matter of the spinal cord
3. **Marginal layer (outer):**
    - Contains axons of neurons
    - Forms the white matter (ascending and descending tracts)

Alar and Basal Plates

- A longitudinal groove, the **sulcus limitans** , divides the neural tube into:
    - **Alar plate (posterior):** Contains sensory neurons, forms the dorsal horn
    - **Basal plate (anterior):** Contains motor neurons, forms the ventral horn

Spinal Cord Growth

- Initially, the spinal cord occupies the entire length of the vertebral canal.
- Due to differential growth, the vertebral column elongates faster than the spinal cord.
    - At birth, the spinal cord ends around the level of L3.
    - In adults, it ends at L1–L2 intervertebral disc level.

Myelination

- Begins in the 4th month of intrauterine life.
- Completed by the end of the first year after birth.

Development of Spinal Meninges

1. **Dura mater:** Derived from mesodermal sclerotomes.
2. **Arachnoid and pia mater:** Derived from neural crest cells (ectodermal origin).

Congenital Anomalies of the Spinal Cord

1. **Spina bifida occulta:**
    - Failure of vertebral arches to fuse
    - Covered by skin, may show a patch of hair
2. **Meningocele:**
    - Meninges protrude through a vertebral defect
    - May present with mild neurological deficits
3. **Meningomyelocele:**
    - Both meninges and spinal cord herniate
    - Associated with significant neurological deficits
4. **Myelocele:**
    - Failure of neural tube closure
    - Spinal cord is exposed, severe impairment
5. **Rachischisis:**
    - Extensive failure of neural tube closure
    - Exposed, flattened spinal cord

Development of the Brain

Primary Brain Vesicles

By the end of the 4th week, three primary brain vesicles form from the cranial end of the neural tube:

1. **Prosencephalon (forebrain)**
2. **Mesencephalon (midbrain)**
3. **Rhombencephalon (hindbrain)**

Secondary Brain Vesicles

These primary vesicles further subdivide:

- **Forebrain:**
    - **Telencephalon:** Cerebral hemispheres
    - **Diencephalon:** Thalamus, hypothalamus, epithalamus
- **Midbrain (mesencephalon):** Remains undivided
- **Hindbrain:**
    - **Metencephalon:** Pons and cerebellum
    - **Myelencephalon:** Medulla oblongata

Development of the Brainstem

Structural Organization

Similar to the spinal cord, the brainstem features:

- A thin **roof plate**

- A thin **floor plate**
- A **sulcus limitans** that separates:
    - **Alar plate (dorsal):** Sensory nuclei
    - **Basal plate (ventral):** Motor nuclei

Basal Plate Columns (Motor Nuclei)

1. **Somatic efferent (medial):**
    - Innervates skeletal muscles (e.g. CN III, IV, VI, XII)
2. **Branchial (special visceral) efferent:**
    - Muscles of pharyngeal arches (e.g. CN V, VII, IX, X, XI)
3. **General visceral efferent:**
    - Autonomic fibers (parasympathetic)
        - Edinger-Westphal nucleus (CN III)
        - Superior/inferior salivatory nuclei (CN VII, IX)
        - Dorsal nucleus of vagus (CN X)

Alar Plate Columns (Sensory Nuclei)

1. **General visceral afferent:** From thoracic and abdominal viscera
2. **Special visceral afferent:** From taste receptors
3. **General somatic afferent:** From skin and mucosa
4. **Special somatic afferent:** From inner ear (hearing and balance)

Clinical Relevance

Neural Tube Defects (NTDs)

Failure of proper neural tube closure results in conditions like:

- Anencephaly (failure of anterior neuropore closure)
- Spina bifida (failure of posterior neuropore closure)

Prevention

Folic acid supplementation before conception and during early pregnancy significantly reduces the risk of NTDs.