Neuroanatomic Basis of Cognition

Organization of the Nervous System

Gregory P. Lee, Ph.D.

Overview of Neuroanatomy

- CNS cell types
- Phylogenetic/embryologic development
- Spinal cord
- Brainstem structures
- Cranial nerves
- Cerebellum
- Diencephalon =thalamus, hypothalamus

Overview of Neuroanatomy

- Cortical anatomy
- Cytoarchitecture of cortex
- Limbic structures (amygdala, hippocampus)
- Basal ganglia
- Ventricular system
- Blood supply to brain

Complexity of Brain

- Brain composed of > 180 billion cells
- > 80 billion of engaged in information processing
- Brain has 10 - 13 billion neurons
- Each cell receives up to 15,000 connections from other cells

Neurons & Glia

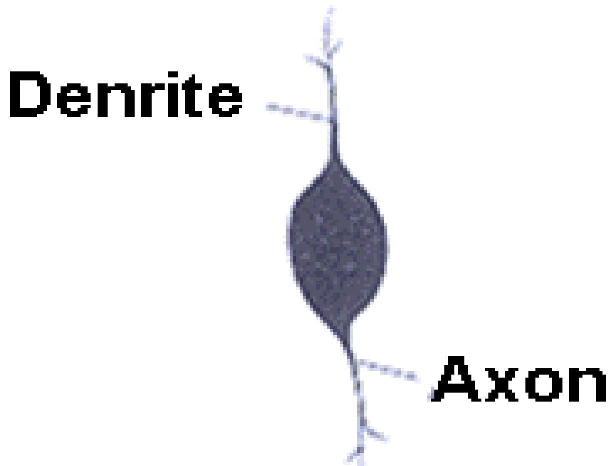
- Germinal (stem) cells in embryo evolve into two types of primitive nervous system cells:

- Neuroblasts
- Spongioblasts
- “blast” is an immature cell

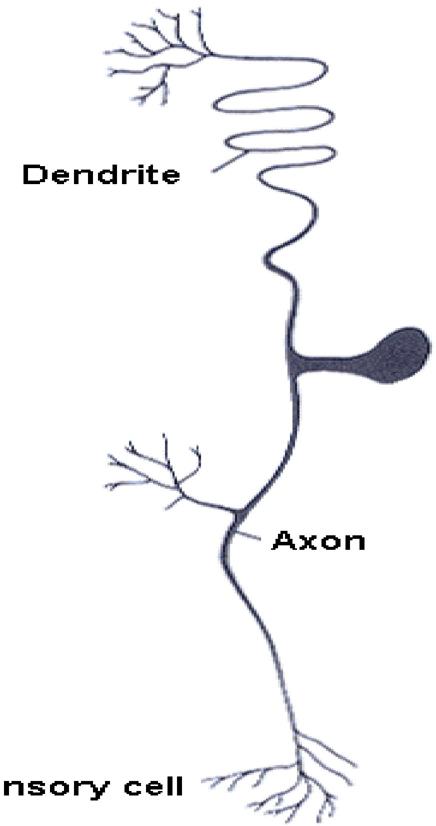
Neurons & Glia

- Neuroblasts develop into neurons (nerve cells)
- Spongioblasts develop into glial cells (provide support functions to neurons)
- Neurons consist of a cell body with a dendrite on one side and an axon on the other

Neuron - Examples

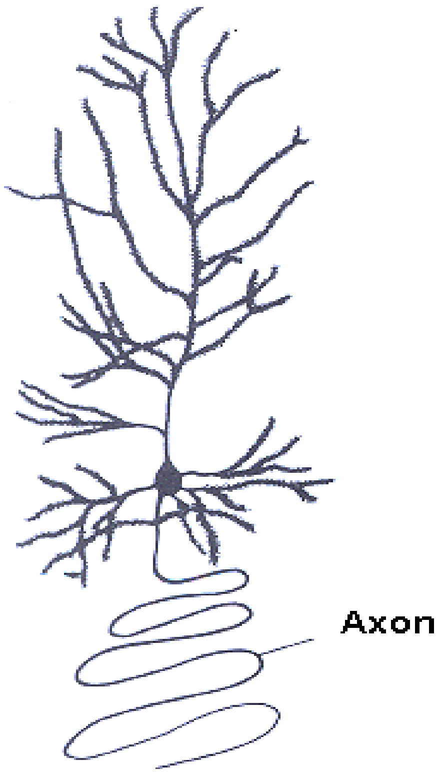


Bipolar cell (retina)

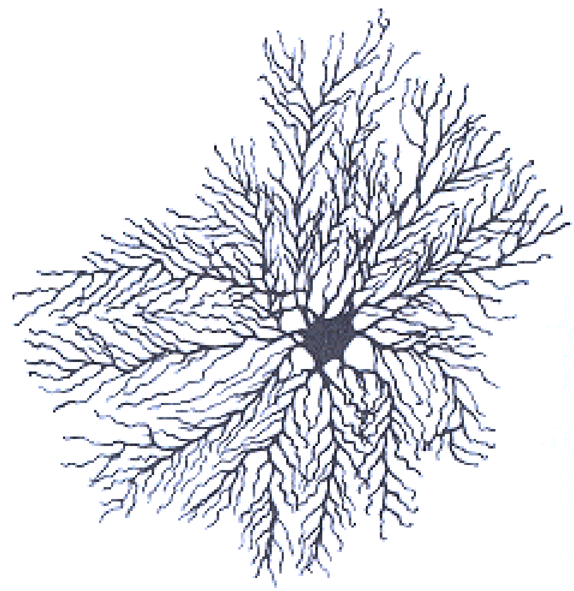


Somatosensory cell (skin)

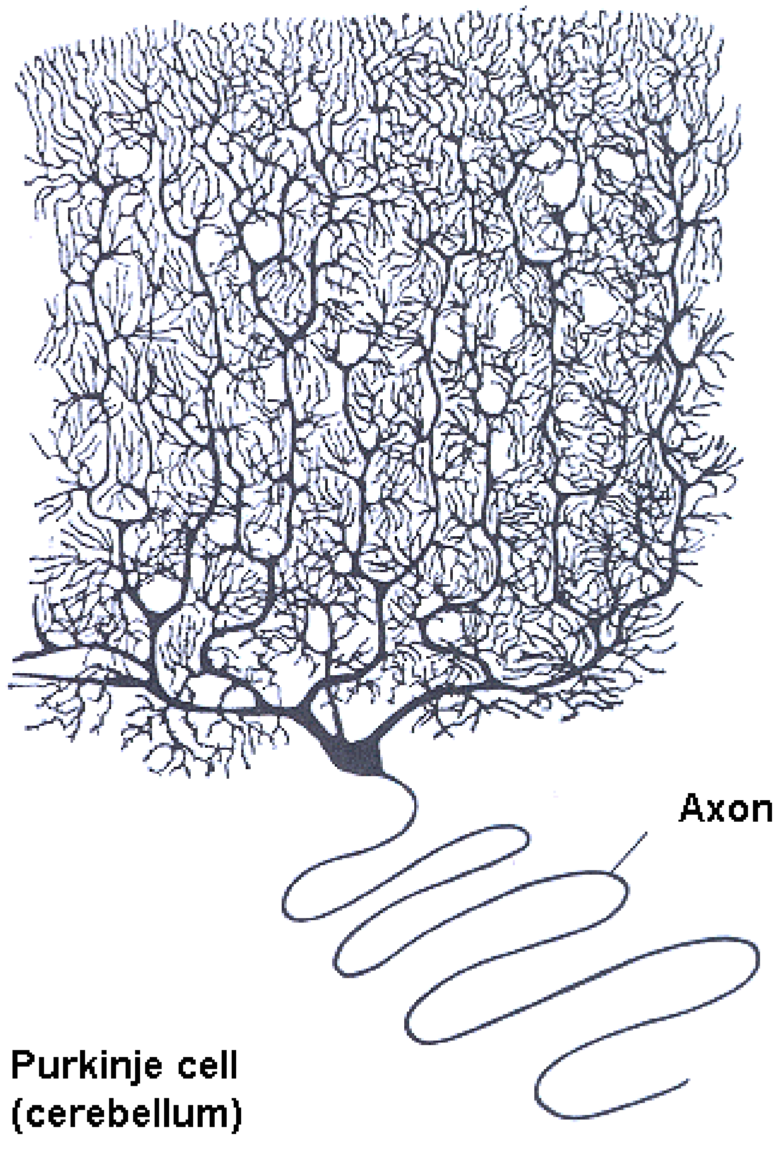
Neuron - Examples



Pyramidal cell
(cortex)



Association cell
(thalamus)


Axon
Purkinje cell
(cerebellum)

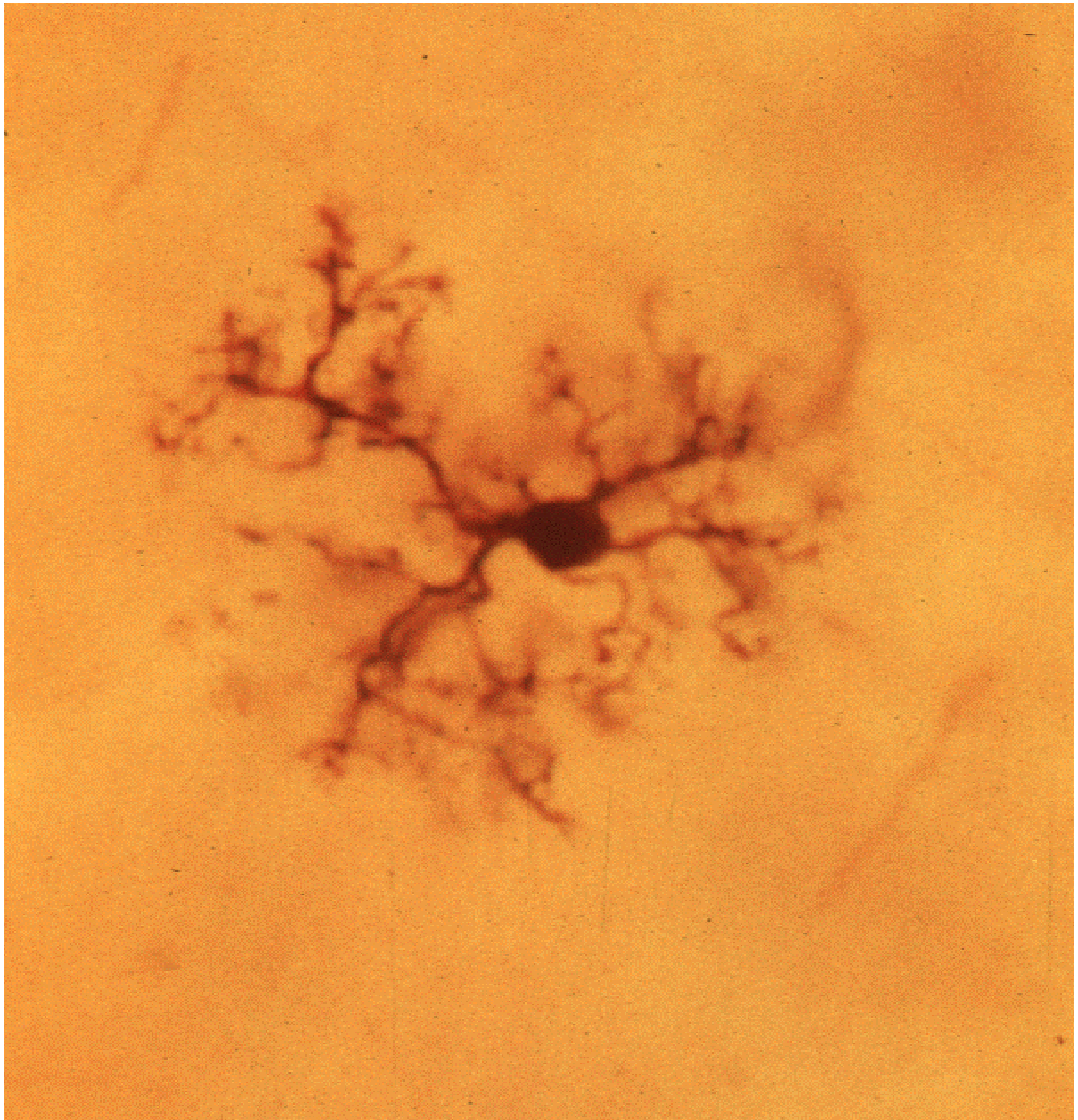
Glial Cells

- Astroglia – give structural support & repair neurons.
- Oligodendroglia – insulate & increase speed of transmission.
- Schwann cells – oligodendrocytes of peripheral nervous system

Glial Cells

- Microglia – perform phagocytosis (engulf foreign particles-lymphatic system's defenses)

- Ependymal cells – line the brain's ventricles & produce cerebrospinal fluid

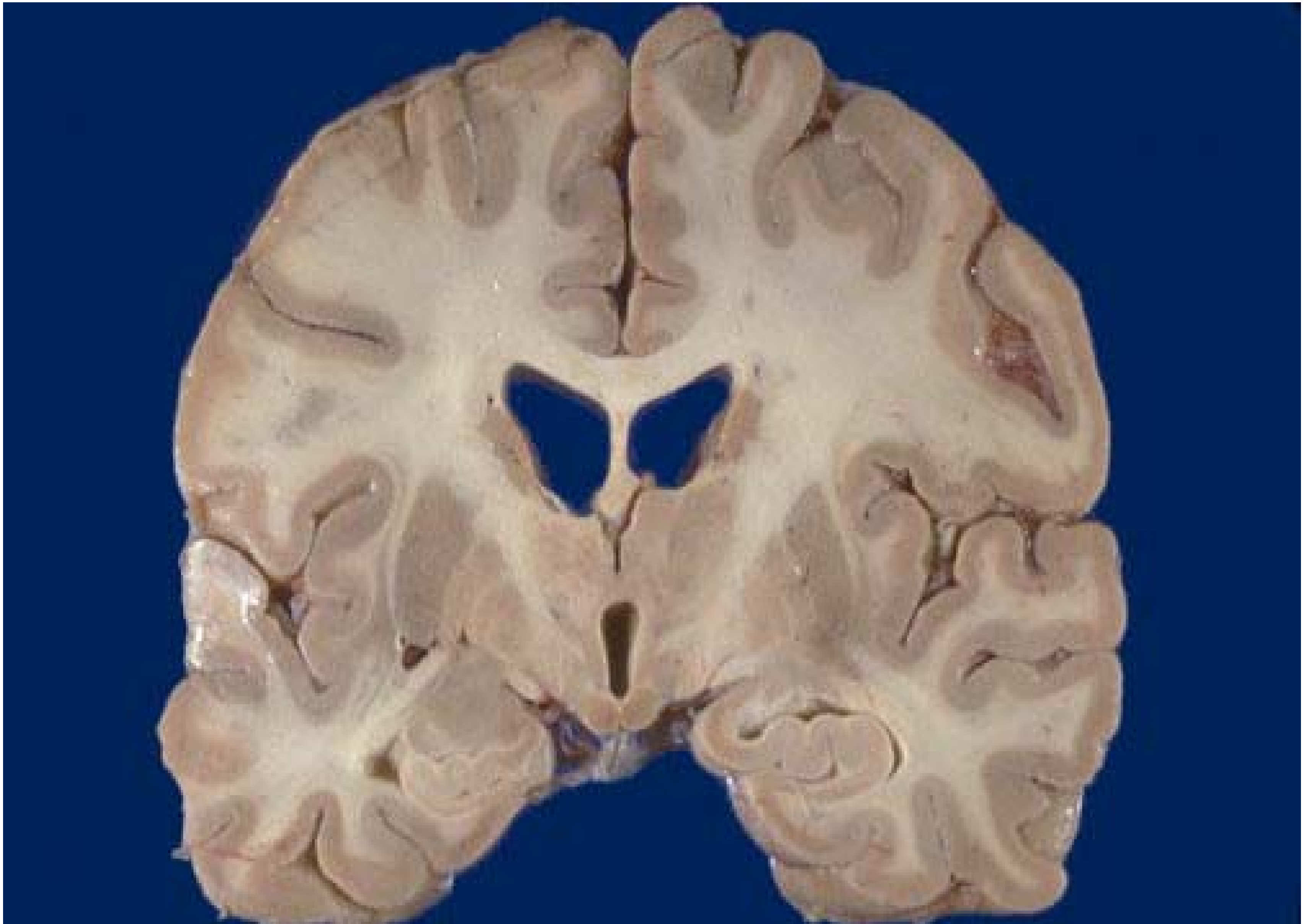


Gray & White Matter

- Gray matter – named for the color of nerve cell bodies (cortex, deep nuclei)

- White matter – axons extend from neurons to form connections with other neurons. Insulating covering (oligodendrocytes) is composed of lipids & is white in color.

Gray/White Matter in Brain



Nuclei

- In CNS, a large number of cell bodies grouped together is called a ***nucleus.***

- ***Nuclei*** have a particular function.

- In PNS, large cell body collections are referred to as ***ganglia.***

Tracts

- Large collection of axons from a nucleus is called a ***tract***
- Or fasciculi, fiber pathway
- Carries information from one place to another
- E.g., optic tract - from eye to brain

Approaches to Study of Nervous System

- ***Comparative*** (relative to other creatures)
- ***Developmental*** (changes in structure and size during individual development)

- ***Cytoarchitectual*** (architecture of cells)
- ***Biochemical*** (neurotransmitters, hormones)

Comparative Approach

- Traces development of cord and brain from simple to complex creatures.
- Phyla of animals developed through stages from floating to swimming, crawling, walking, climbing, and flying.
- Brain complexity correlated with each successive behavioral development.

Comparative Approach

- Much is still unknown
- E.g., ***limbic system*** (a middle brain layer) first developed in reptiles/amphibians
- But why is still unknown
- To control new modes of locomotion?
- Mediate new forms of social behavior?
- Support more advanced learning ability?

Comparative Approach

- This approach indicates mammals differ from other animals in large size of cortex.
- Cortex is particularly large in humans.
- Cortex is thought to confer abilities unique to mammals.
- So human neuropsychology focuses on the study of the cortex.

Developmental Approach

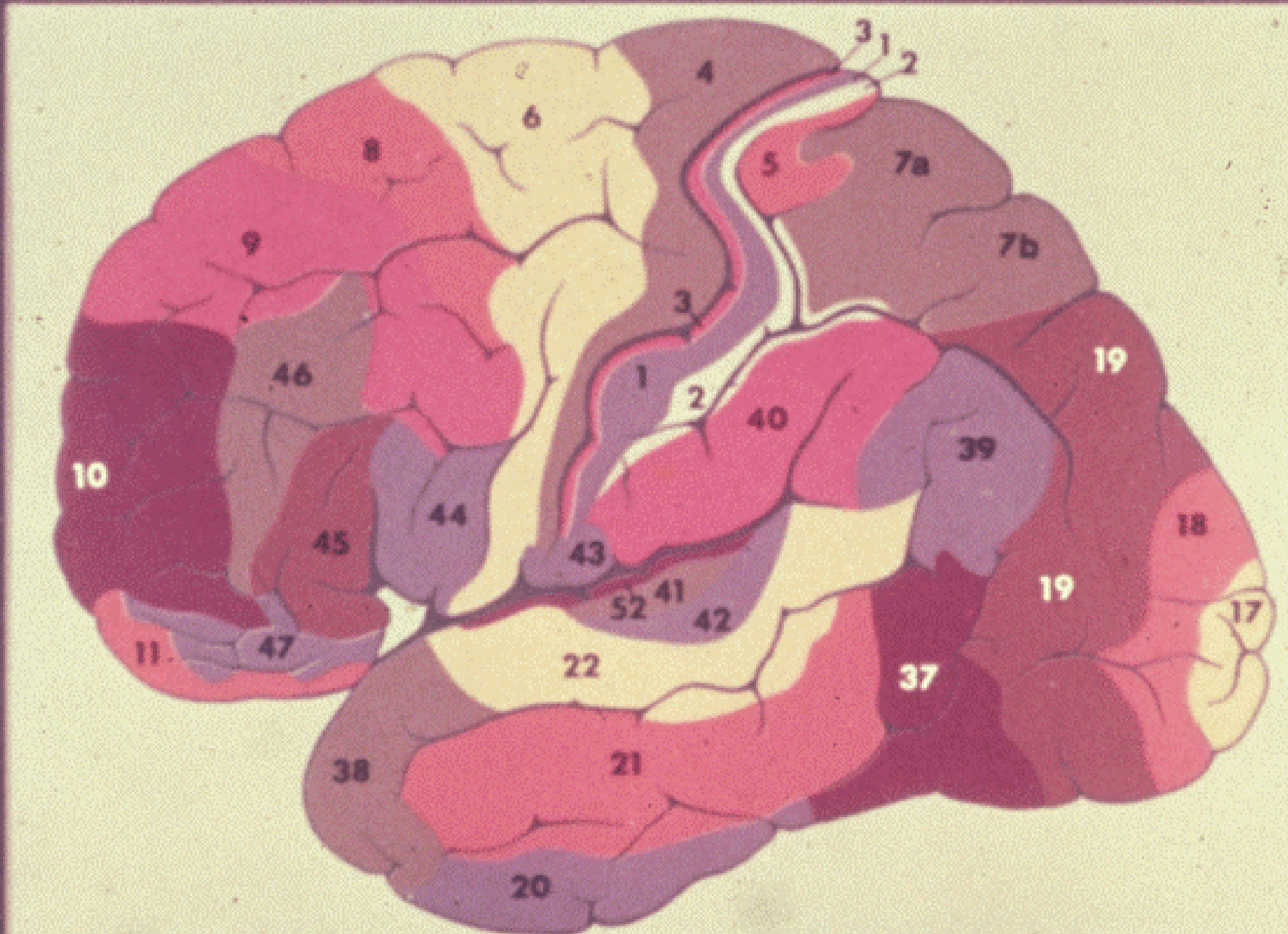
- ***Ontogenetic*** approach
- Changes in brain structure & size followed over course of development in an individual
- Individual brain development goes through the same stages as animal species do in their evolution.
- "Ontogeny recapitulates phylogeny"

Developmental Approach

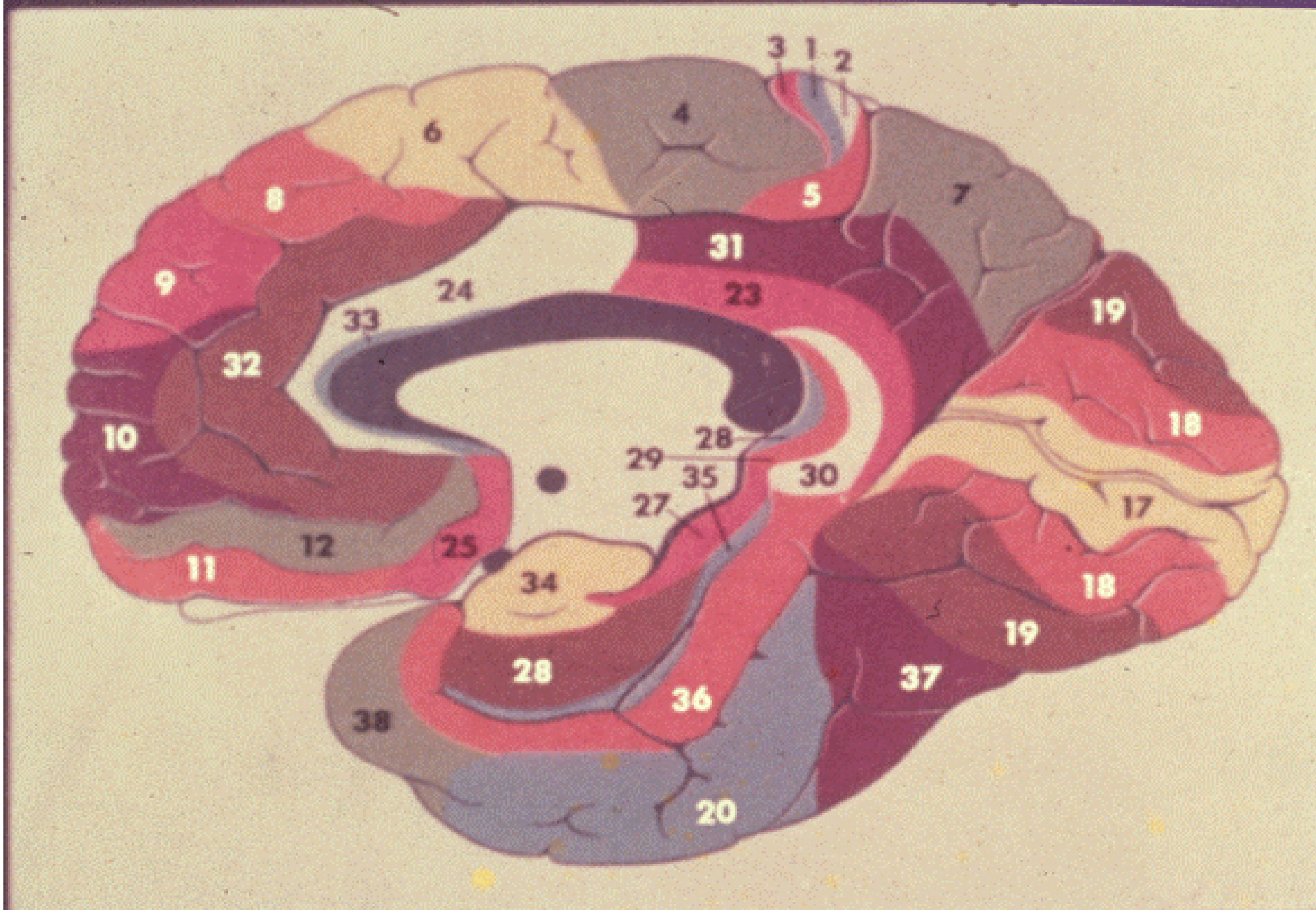
- Cortex & its connections are immature in newborn infants.
- Correlating developing brain changes with specific behaviors is a powerful method of uncovering
- Relations between brain structures and behavioral functions

Cytoarchitectonic Approach

- Neuroantomists study the architecture of cells in cortex
- Differences in cell structure, size, shape, connections and distribution throughout cortex are studied
- Produce detailed cellular maps of cortex.



61. Brodmann Cytoarchitectural Areas, Lateral View



62. Brodmann Cytoarchitectural Areas, Medial View

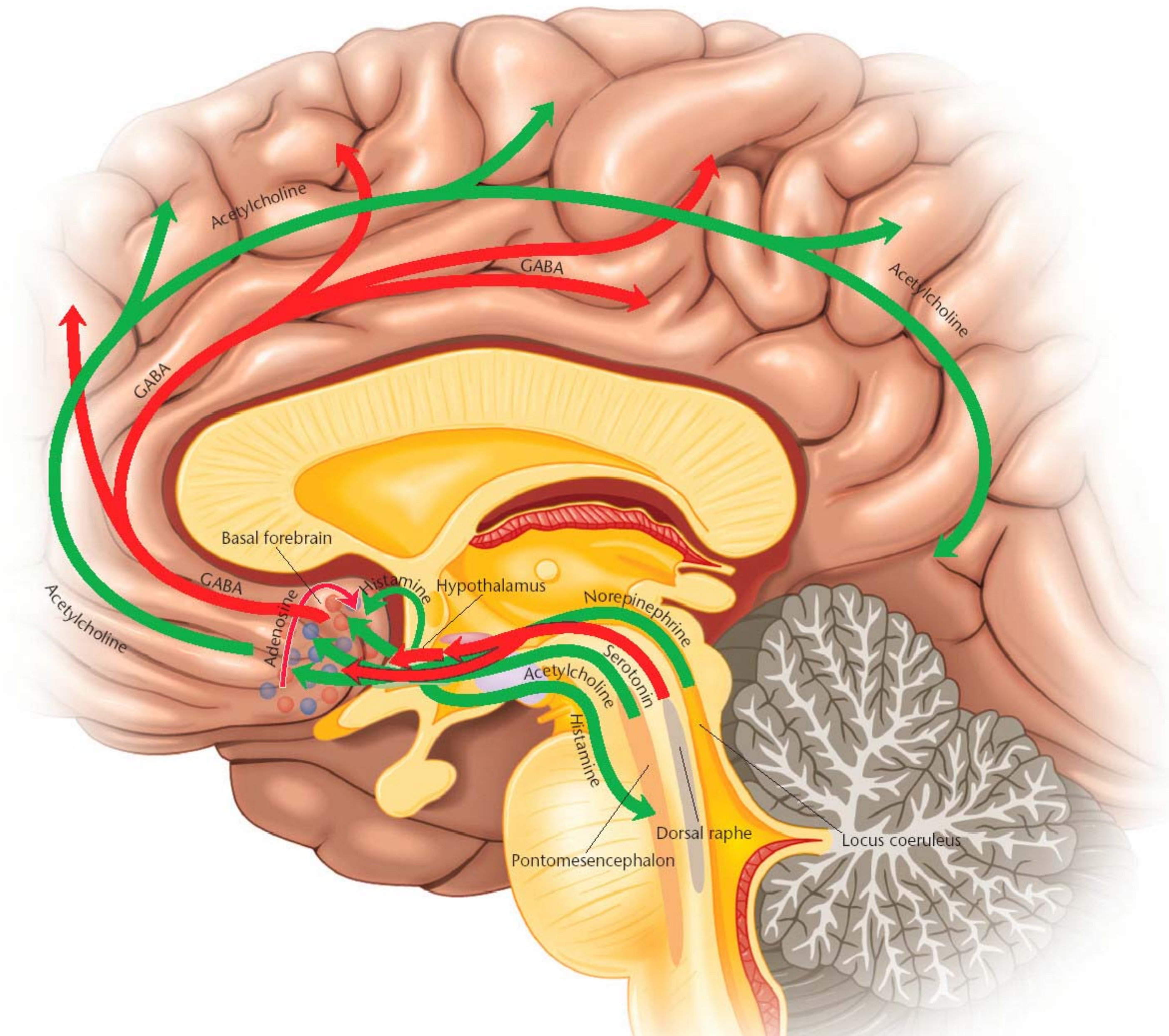
Biochemical Approach

- Cells contain specific neurotransmitters that allow them to play their special roles intracellular communication.
- Specific neurotransmitters have been related to specific behaviors and disorders
- E.g., reduction of acetylcholine (Ach) in Alzheimer's
- Decreased dopamine (DA) in Parkinson's

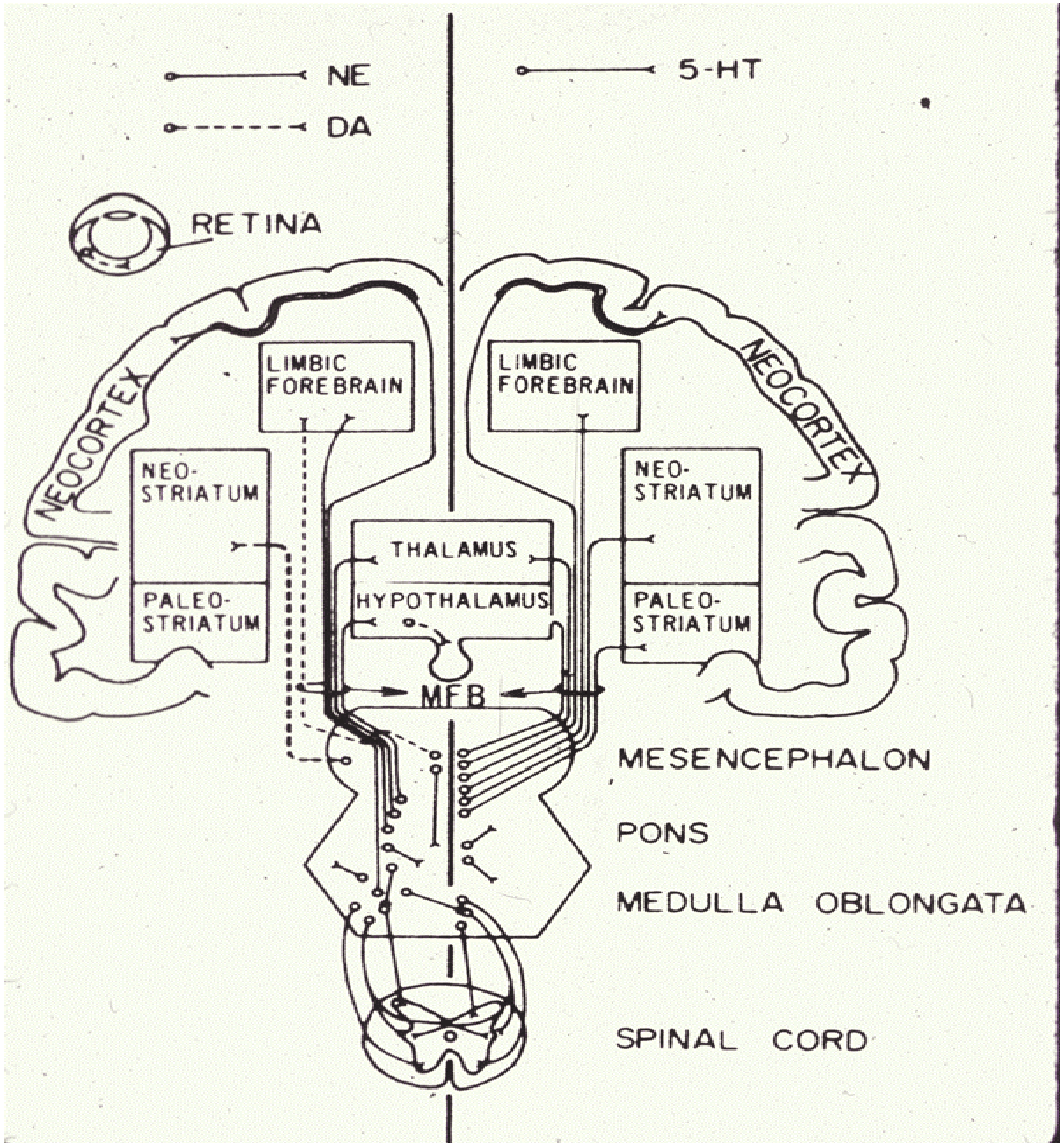
Biochemical Approach

- Increased dopamine (DA) - psychosis
- Too little serotonin (5 HT) – depression

- Identification of the types of cells and distribution of transmitters across cortex helps lead to understanding biochemical basis of behavior.



Acetylcholine
GABA
Acetylcholine
GABA
Basal forebrain
GABA
Acetylcholine
Adenosine
Histamine
Hypothalamus
Norepinephrine
Serotonin
Acetylcholine
Histamine
Dorsal raphe
Locus coeruleus
Pontomesencephalon

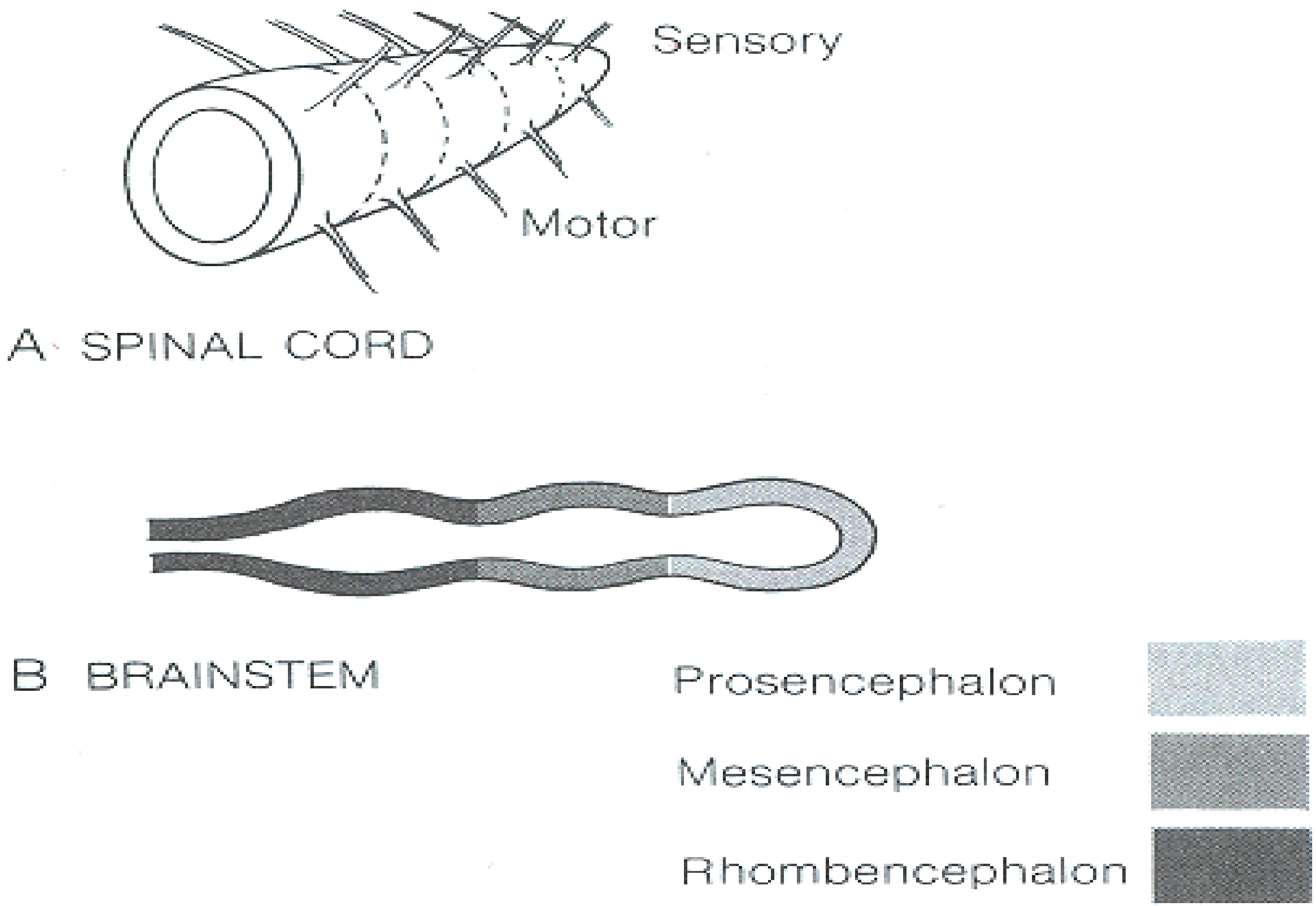


NE
DA
5-HT
RETINA
NEOCORTEX
LIMBIC FOREBRAIN
NEOCORTEX
LIMBIC FOREBRAIN
NEO-STRIATUM
PALEO-STRIATUM
THALAMUS
HYPOTHALAMUS
NEO-STRIATUM
PALEO-STRIATUM
MFB
MESENCEPHALON
PONS
MEDULLA OBLONGATA
SPINAL CORD

Development of Brain

- Nervous system was first a spinal cord.
- Fibers from each cord segment connect to each segment of the body.
- E.g., earthworm has these organizational features.

Cord & Brainstem in Embryo



Development of Brain

- In more complex animals, one end of the animal “goes first.”
- Develops variety of receptors (nose, eyes, ears) to tell it where its going.
- A brain develops at the front end of the cord to receive this sensory information.

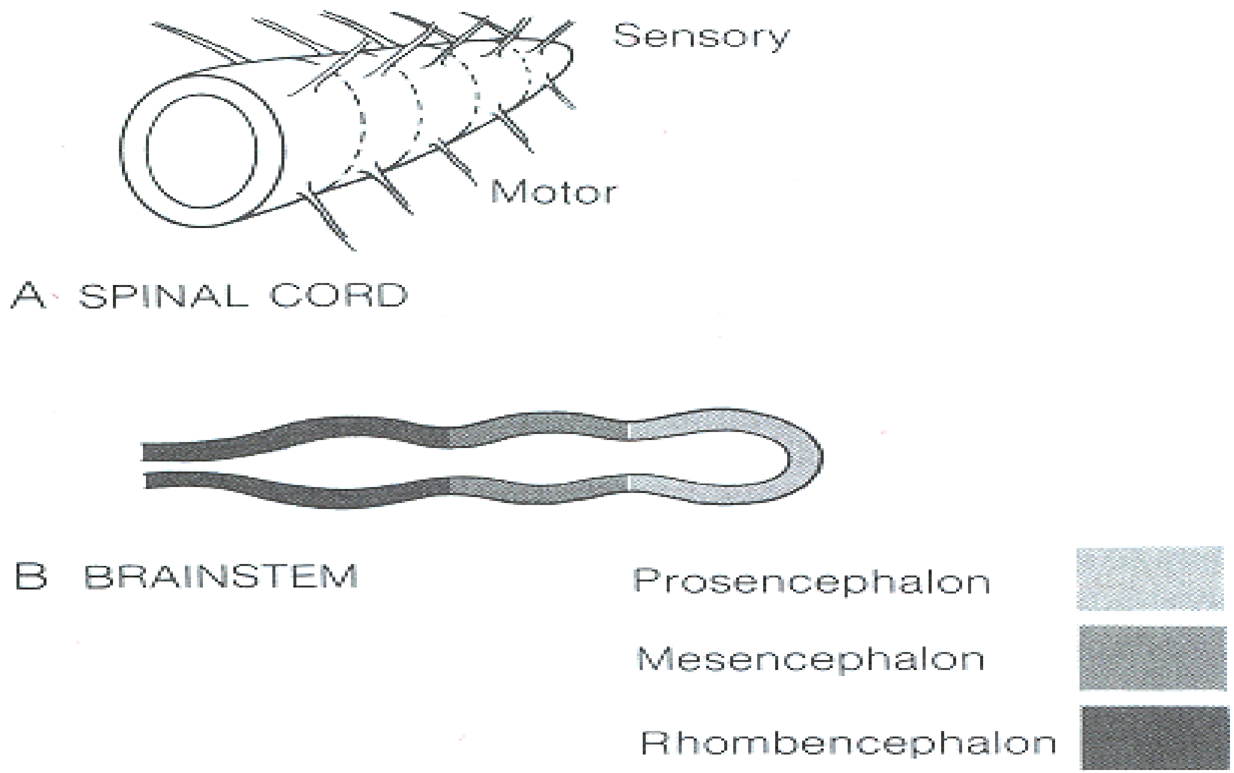
Development of Brain

- This primitive brain developed to receive information and tell the body what to do.
- E.g., a fish’s brain is representative of this stage.
- Mammalian equivalent = brainstem
- This primitive brain consists of 3 enlargements (Table 3.4, p. 53).

Primitive (Fish) Brain

- Primitive brainstem divisions:
- ***Prosencephalon*** (“front brain”)
- ***Mesencephalon*** (“middle brain”)
- ***Rhombencephalon*** (hindbrain)

Brainstem in Primitive Brain



Mammalian Brain

- In mammals, prosencephalon develops to form the
- Telencephalon (endbrain) and
- Diencephalon (between-brain)

- Midbrain (mesencephalon) stays the same

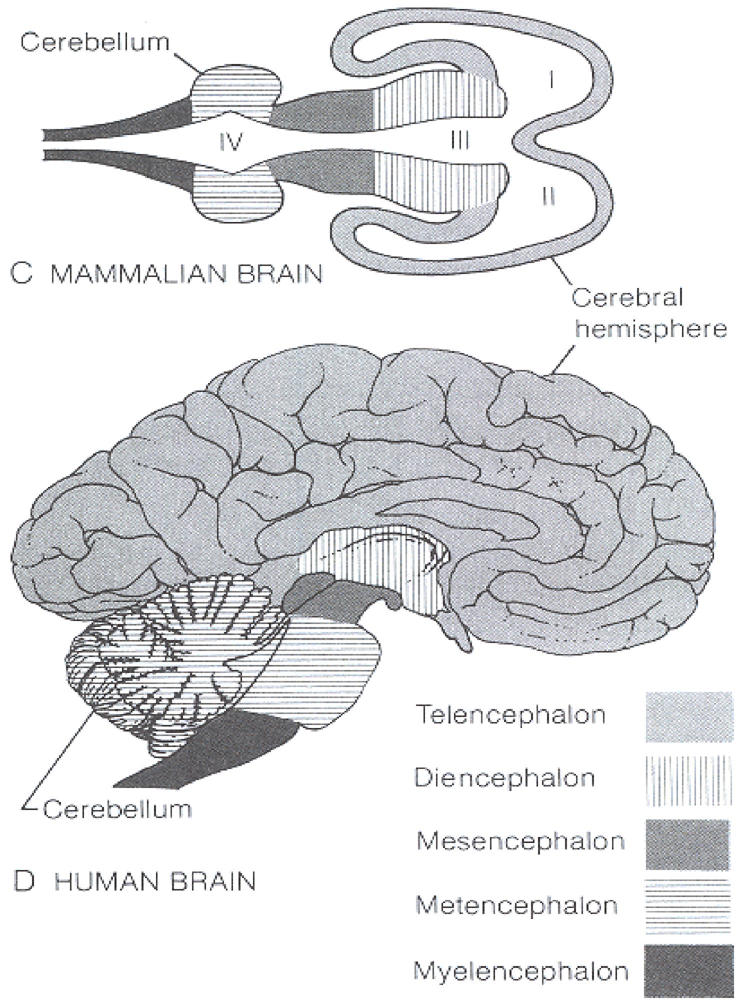
Mammalian Brain

- Back part of primitive brain (rhombencephalon) becomes:

- ***Metencephalon*** (across-brain) and

- ***Myelencephalon*** (spinal brain)

Mammalian Brain



Mammalian Brain

- TELENCEPHALON is composed of:
- Neocortex
- Basal ganglia
- Limbic system
- Olfactory bulb
- Lateral ventricles

Mammalian Brain

- DIENCEPHALON is composed of:

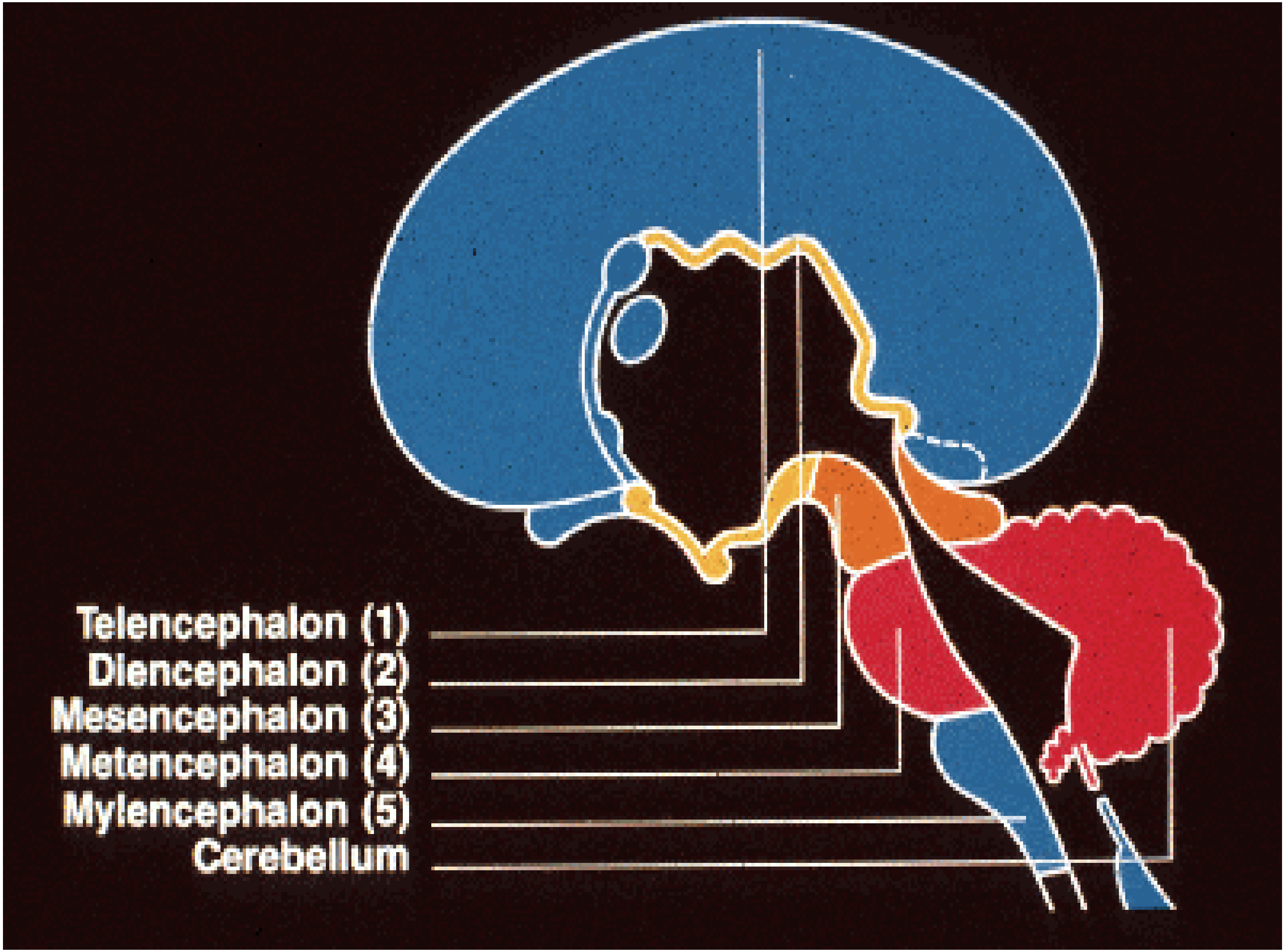
- Thalamus
- Epithalamus (pineal body)
- Hypothalamus
- Third ventricle

Mammalian Brain

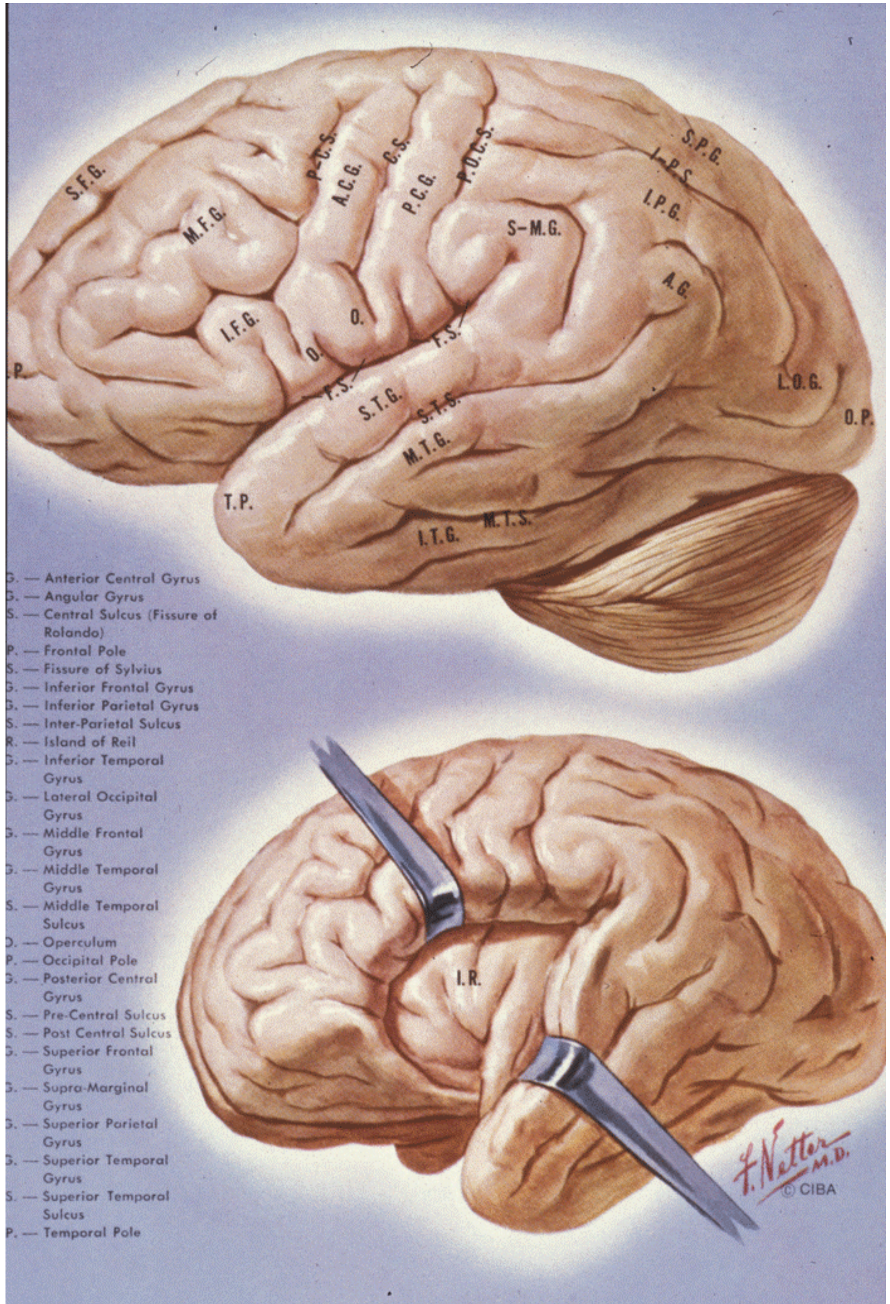
- MESENCEPHALON is composed of:
- Tectum
- Tegmentum
- Cerebral aqueduct

Mammalian Brain

- METENCEPHALON is composed of:
- Cerebellum
- Pons
- Fourth ventricle
- MYELENCEPHALON is composed of:
- Medulla oblongata
- Fourth ventricle



Telencephalon (1)
Diencephalon (2)
Mesencephalon (3)
Metencephalon (4)
Mylencephalon (5)
Cerebellum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P-C.S.
C.S.
P.O.C.S.
S.P.G.
I-P.S.
A.C.G.
P.C.G.
M.F.G.
I.P.G.
S-M.G.
A.G.
I.F.G.
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O.
F.S.
F.S.
L.O.G.
O.P.
S.T.G.
S.T.S.
M.T.G.
T.P.
M.T.S.
I.T.G.
I.R.
G. — Anterior Central Gyrus
G. — Angular Gyrus
S. — Central Sulcus (Fissure of Rolando)
P. — Frontal Pole
S. — Fissure of Sylvius
G. — Inferior Frontal Gyrus
G. — Inferior Parietal Gyrus
S. — Inter-Parietal Sulcus
R. — Island of Reil
G. — Inferior Temporal Gyrus
G. — Lateral Occipital Gyrus
G. — Middle Frontal Gyrus
G. — Middle Temporal Gyrus
S. — Middle Temporal Sulcus
O. — Operculum
P. — Occipital Pole
G. — Posterior Central Gyrus
S. — Pre-Central Sulcus
S. — Post Central Sulcus
G. — Superior Frontal Gyrus
G. — Supra-Marginal Gyrus
G. — Superior Parietal Gyrus
G. — Superior Temporal Gyrus
S. — Superior Temporal Sulcus
P. — Temporal Pole
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Orientation of Structures

- Superior (top)
- Lateral (side)
- Medial or mesial (middle)
- Ventral (towards the belly or s.t.’s bottom)
- Dorsal (towards the back or s.t.’s top)
- Anterior (front)
- Posterior (back)

Planes of the Body

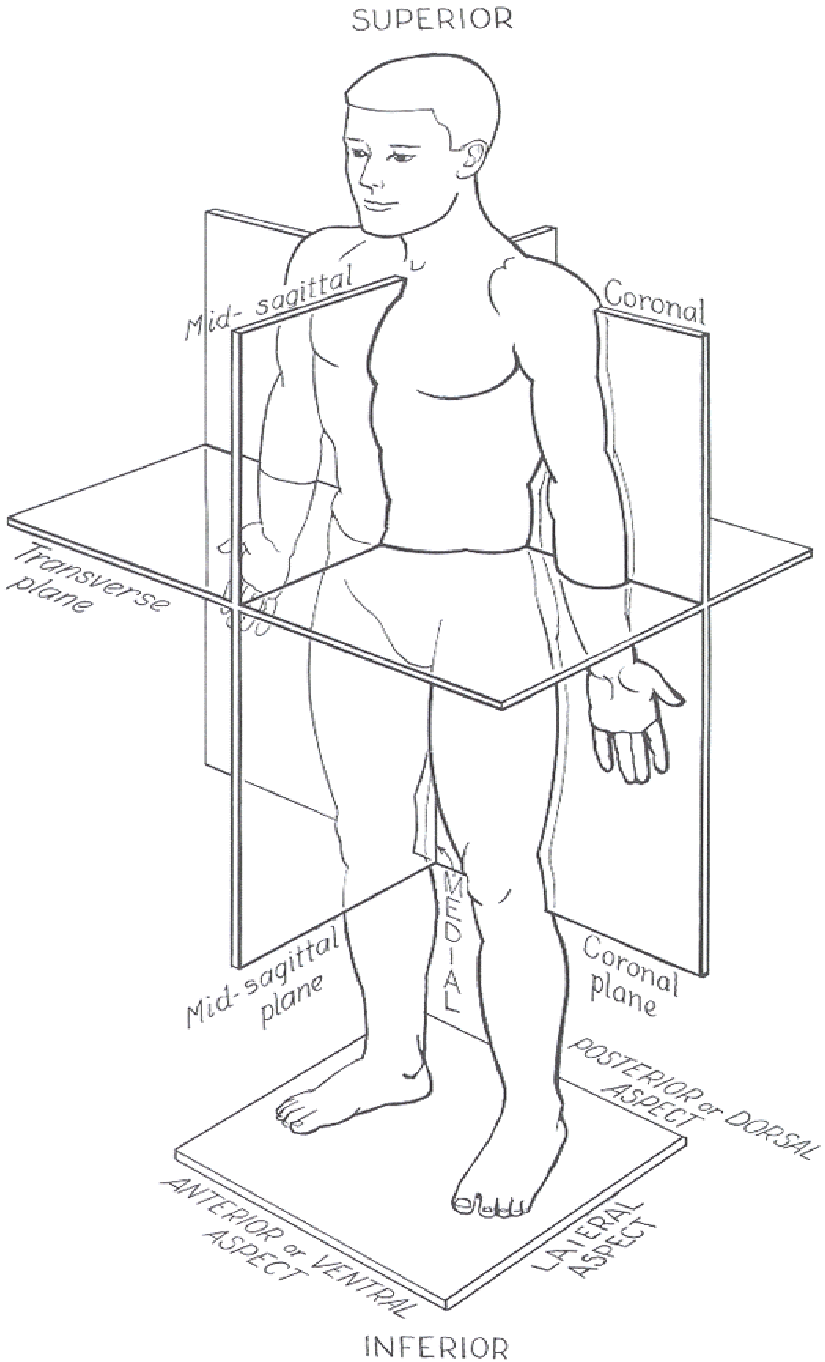
- ***Midsagittal*** – the plane vertically dividing the body through the midline into right and left halves.

- ***Sagittal*** – any plane parallel to the midsagittal line dividing the body into right and left portions.

Planes of the Body

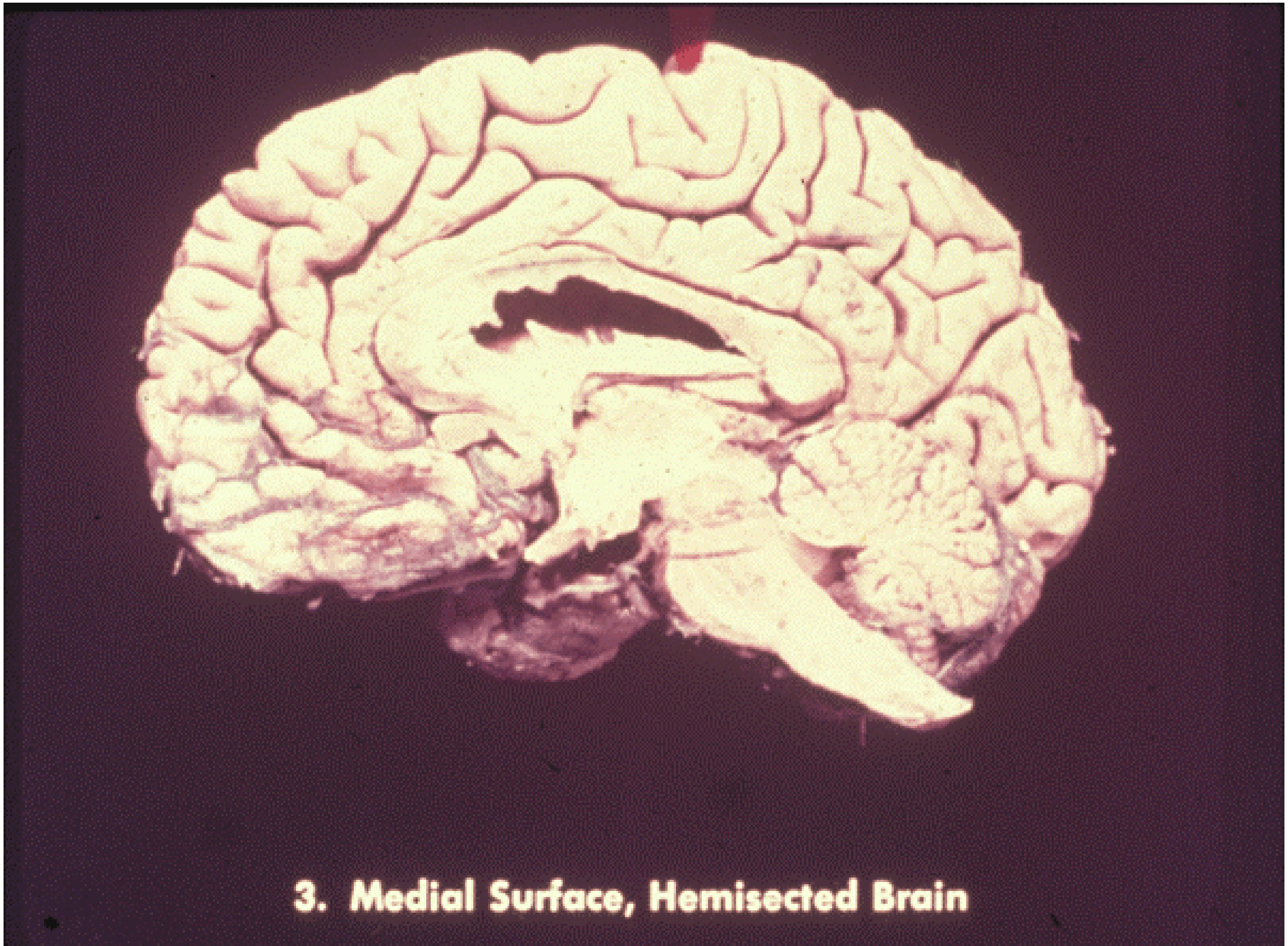
- ***Transverse (horizontal)*** – any plane dividing the body into superior and inferior portions.

- ***Coronal (frontal)*** – any plane dividing body into anterior and posterior portions; at right angle to sagittal plane.


SUPERIOR
Mid-sagittal
Coronal
Transverse plane
MEDIAL
Mid-sagittal plane
Coronal plane
POSTERIOR or DORSAL ASPECT
ANTERIOR or VENTRAL ASPECT
LATERAL ASPECT
INFERIOR

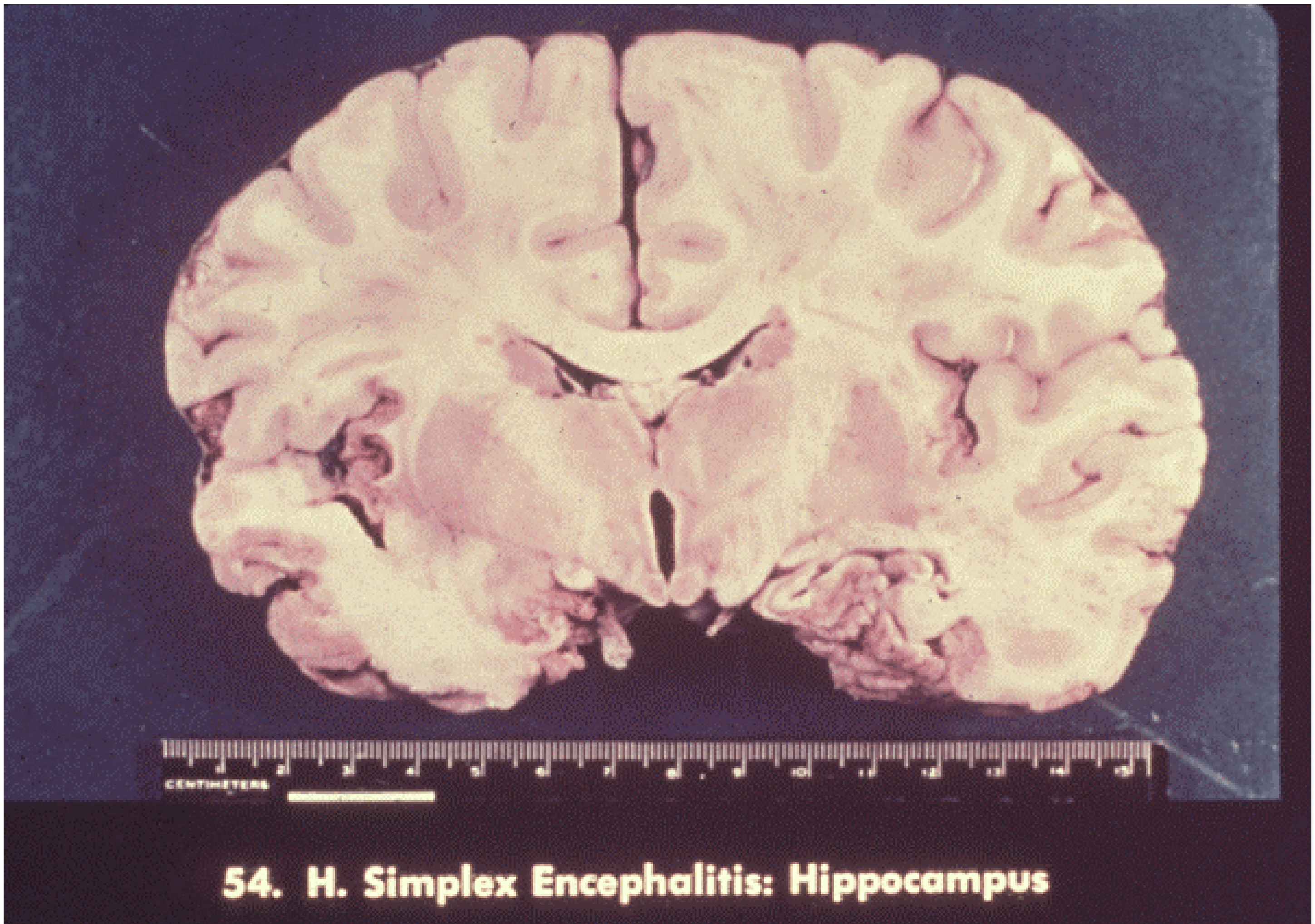
A

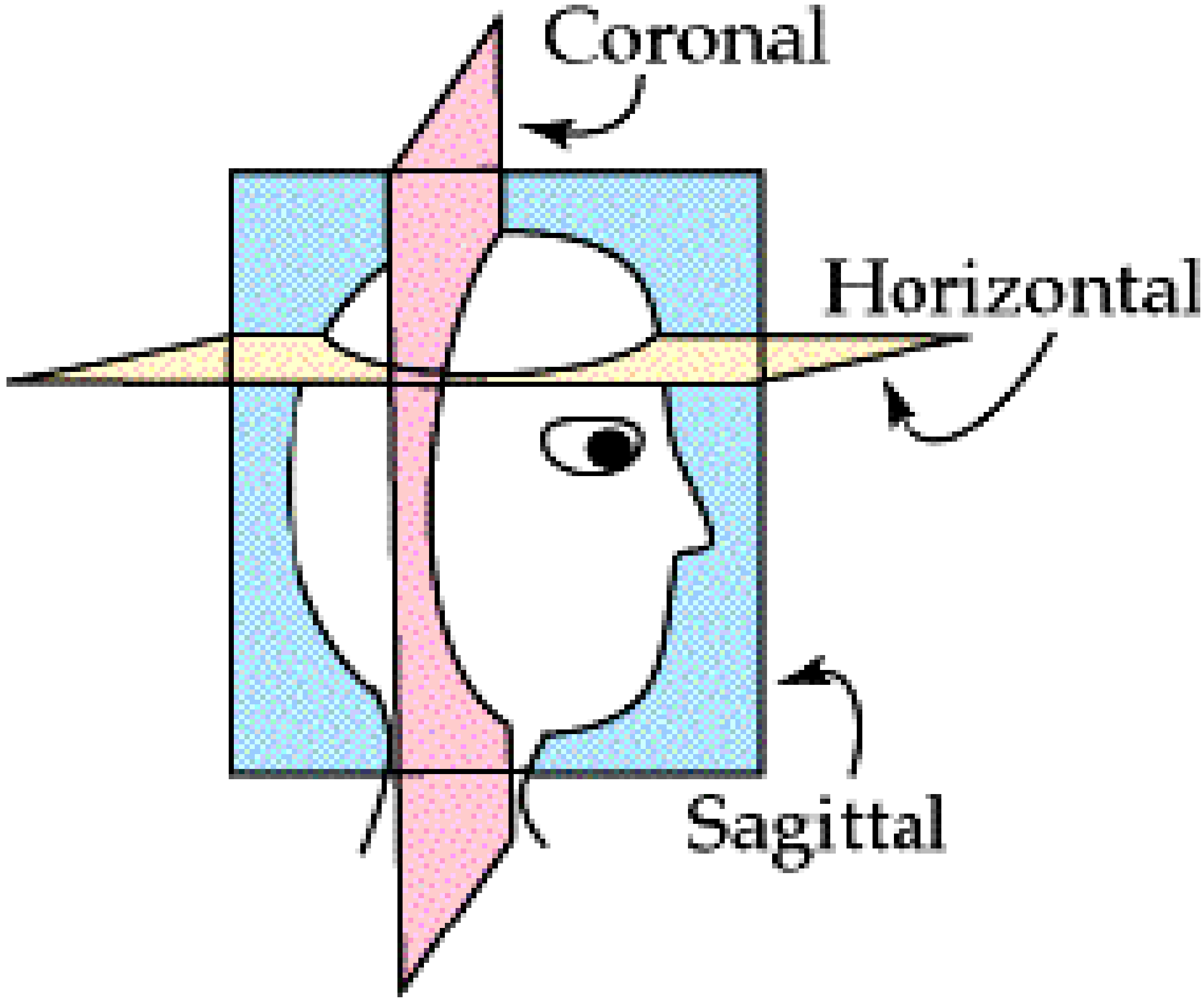
Mid-Saggital View of Brain



Transverse View of Brain

Coronal View of Brain




Coronal
Horizontal
Sagittal

Orientation of Structures

- ***Ipsilateral*** **–** when two structures lie on the same side.
- ***Contralateral*** – if they lie on opposite sides.
- ***Bilateral*** – if one is on each side.

Orientation of Structures

- ***Proximal*** – structures that are close to one another; also closer to the midline of body.
- ***Distal*** – structures that are far away from one another; also ones that are farther away from midline
- ***Afferent*** – an approaching pathway
- ***Efferent*** – pathway that is traveling away from

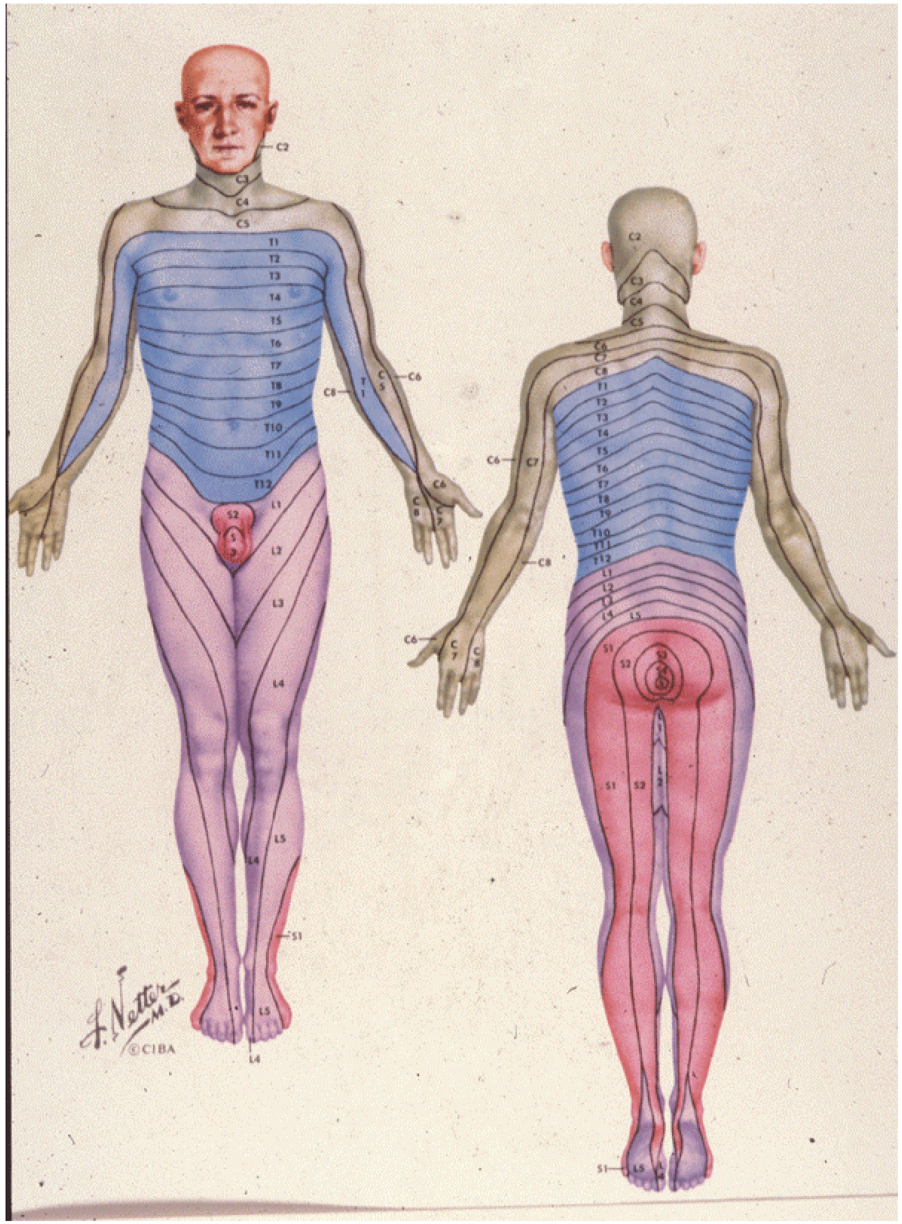
Spinal Cord

- Tube of nerve cells divided into segments.

- Each segment receives fibers from sensory receptors of the part of the body adjacent to it
- And sends back fibers to muscles in that part of the body.

Dermatomes

- Area of skin supplied with sensory (afferent) nerve fibers by a single spinal segment.
- Dermatomes encircle the body in a ring formation.
- Distorted in humans due to upright posture – imagine humans down on all fours.


C2
C3
C4
C5
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
C6
C8
L1
S2
L2
L3
L4
L5
S1
C7
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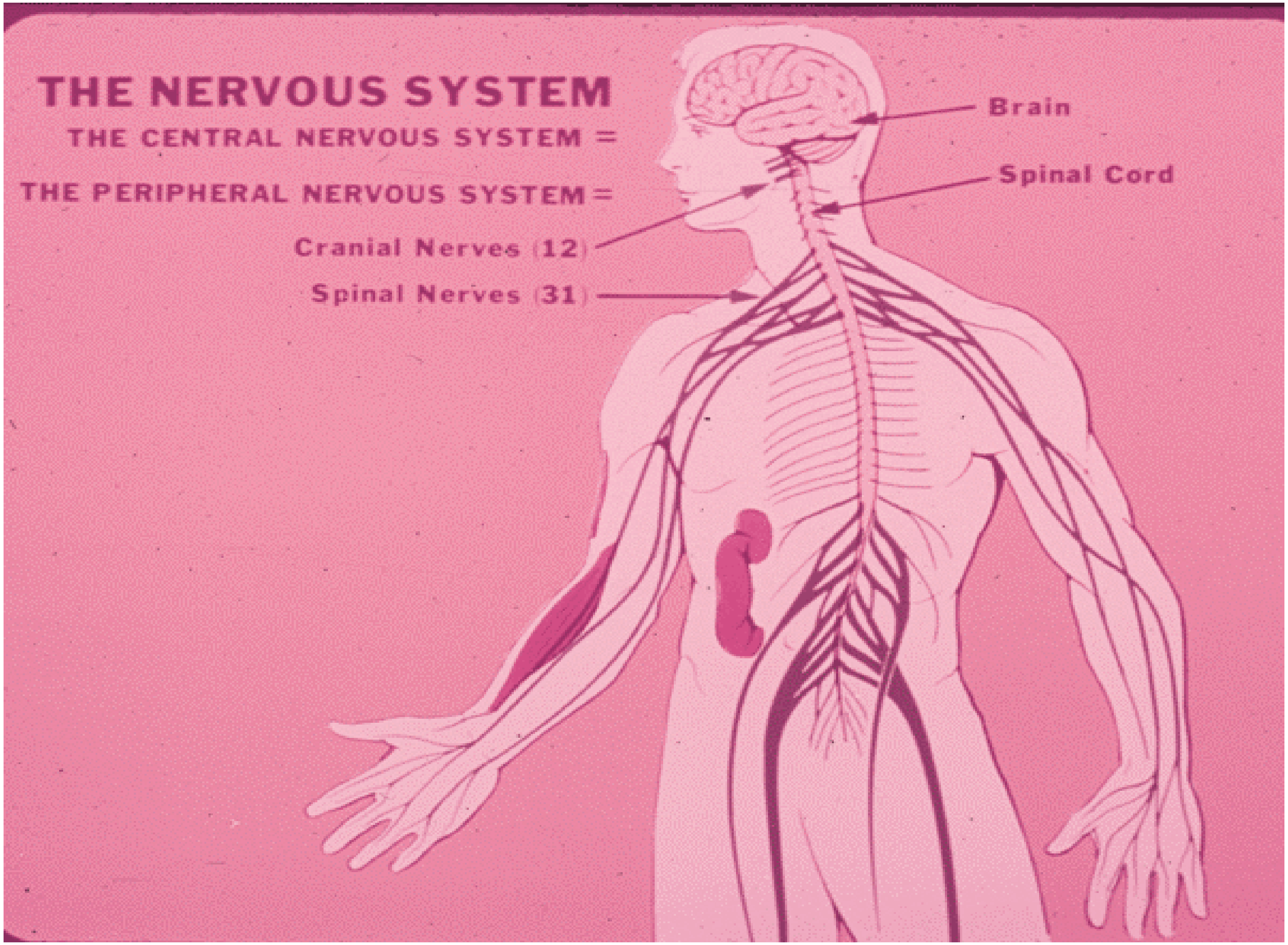
CNS & PNS

- Central Nervous System (CNS) = brain and spinal cord
- Peripheral Nervous System = 12 cranial nerves and 31 pairs of spinal nerves.

CNS & PNS

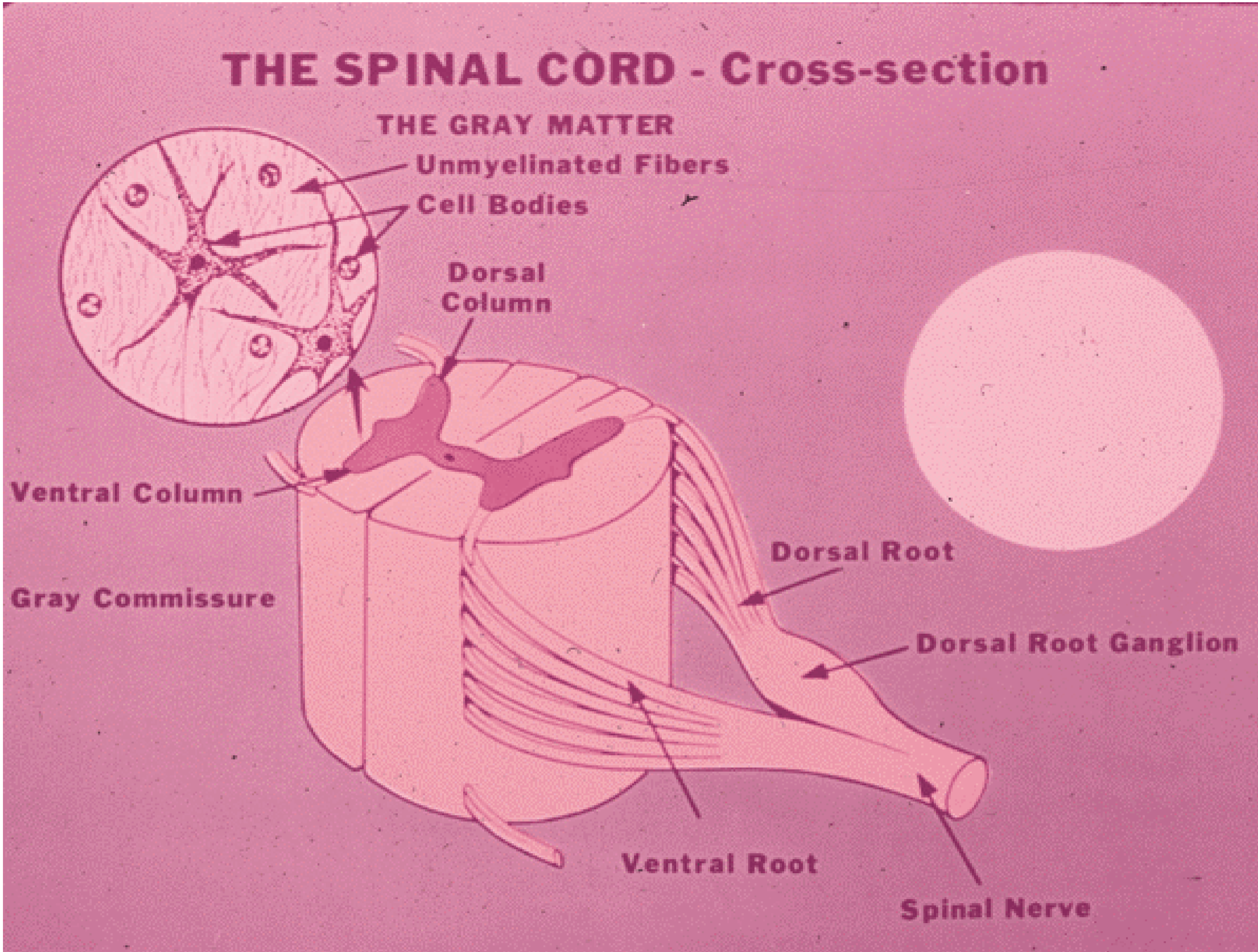

THE NERVOUS SYSTEM
THE CENTRAL NERVOUS SYSTEM =
THE PERIPHERAL NERVOUS SYSTEM =
Cranial Nerves (12)
Spinal Nerves (31)
Brain
Spinal Cord

Spinal Nerves

- 31 pairs of spinal nerves:
- 8 Cervical (C)
- 12 Thoracic (T)
- 5 Lumbar (L)
- 5 Sacral (S) and 1 Coccygeal
- Cord segments connect with body dermatomes of the same number.

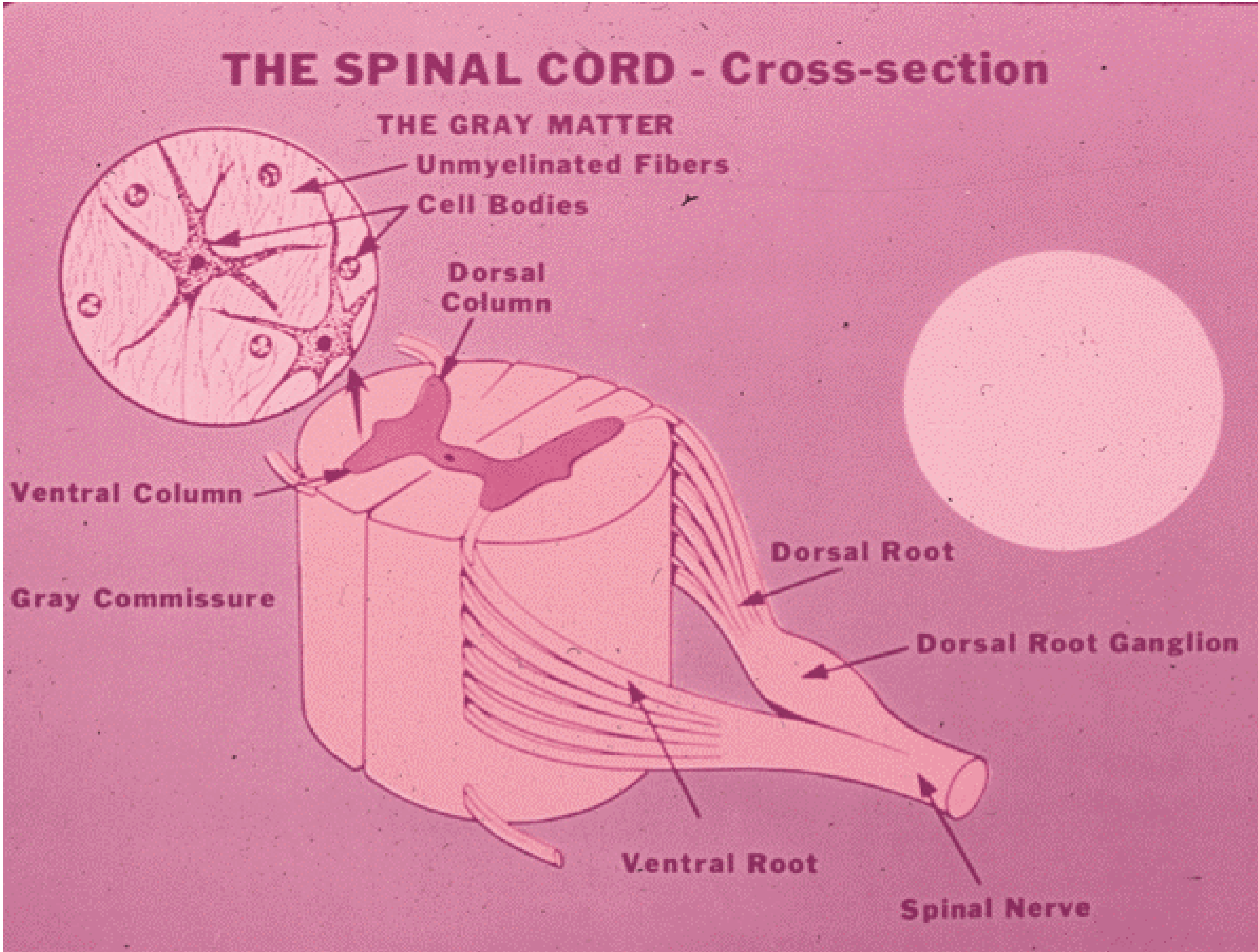
Dorsal Root

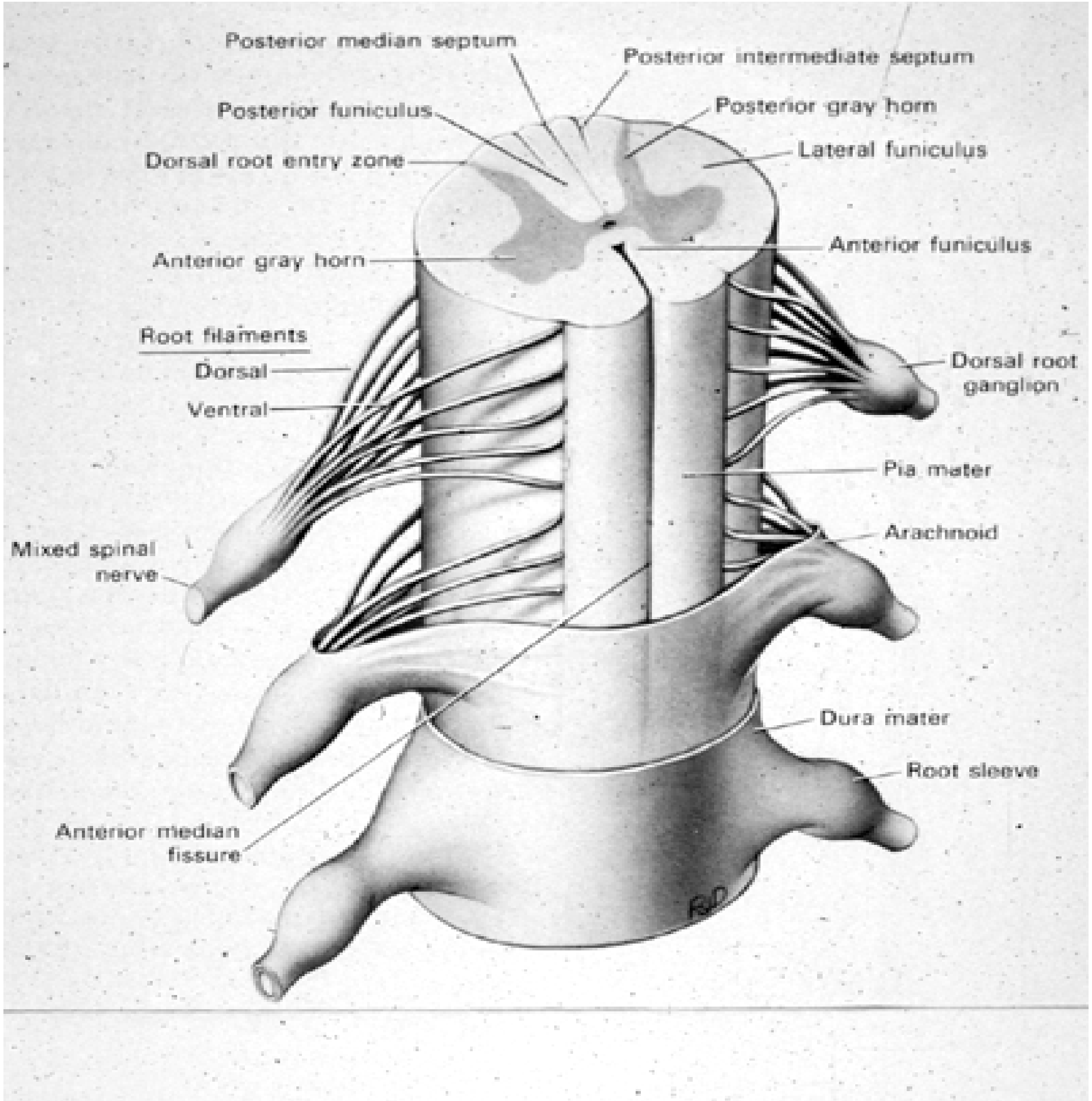
- Fibers entering the dorsal portion of spinal cord carry information from sensory receptors.
- As fibers approach cord, they collect together
- This collection is called the ***dorsal root***.
- Dorsal root = sensory


THE SPINAL CORD - Cross-section
THE GRAY MATTER
Unmyelinated Fibers
Cell Bodies
Dorsal Column
Ventral Column
Gray Commissure
Dorsal Root
Dorsal Root Ganglion
Ventral Root
Spinal Nerve

Ventral Root

- Fibers leaving the ventral (anterior) portion of cord carry information from spinal cord to muscles
- Form the ***ventral root.***
- Ventral root = motor

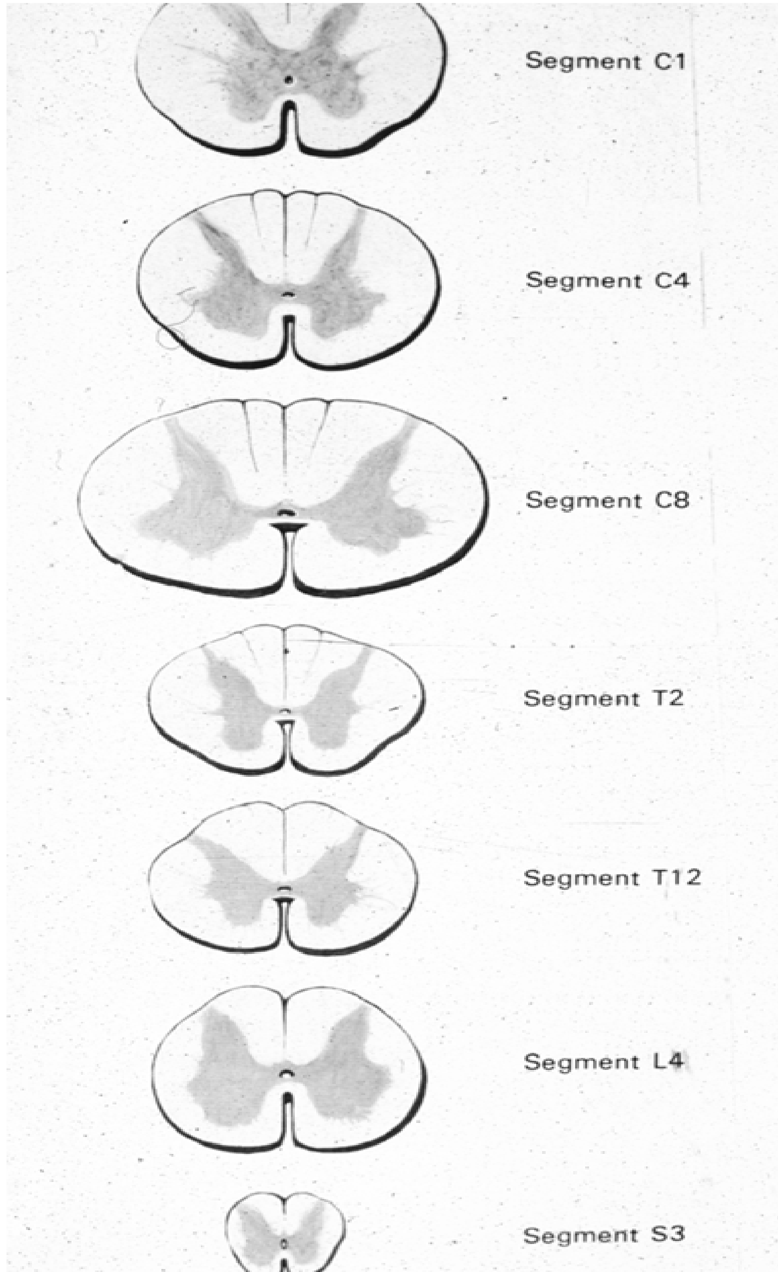

THE SPINAL CORD - Cross-section
THE GRAY MATTER
Unmyelinated Fibers
Cell Bodies
Dorsal Column
Ventral Column
Gray Commissure
Dorsal Root
Dorsal Root Ganglion
Ventral Root
Spinal Nerve



Posterior median septum
Posterior intermediate septum
Posterior funiculus
Posterior gray horn
Dorsal root entry zone
Lateral funiculus
Anterior gray horn
Anterior funiculus
Root filaments
Dorsal
Ventral
Dorsal root ganglion
Pia mater
Arachnoid
Mixed spinal nerve
Dura mater
Root sleeve
Anterior median fissure

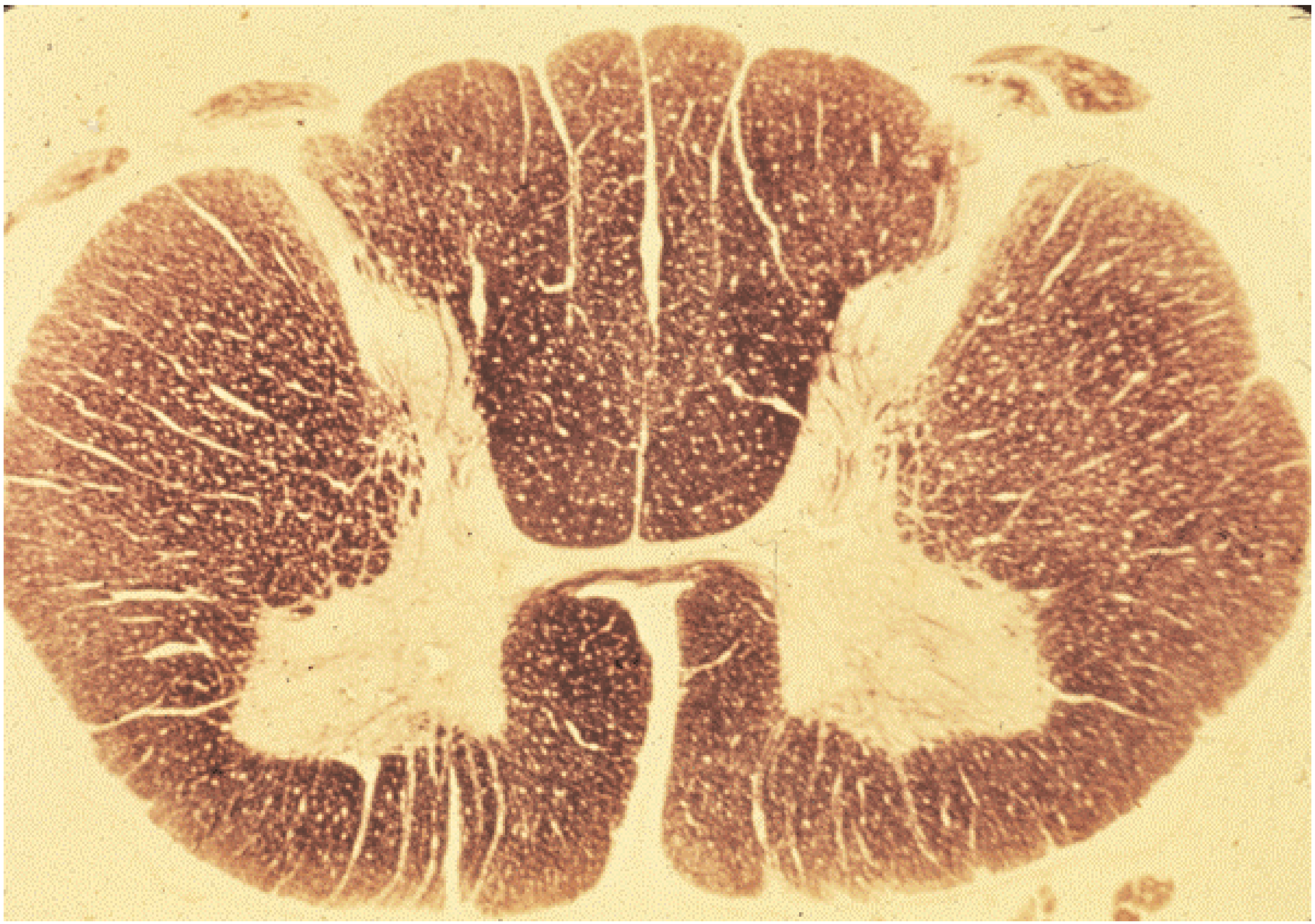
Composition of Cord

- Outer portion of cord consists of white matter or tracts.
- Inner portion consists of gray matter, composed of nerve cell bodies.



Segment C1
Segment C4
Segment C8
Segment T2
Segment T12
Segment L4
Segment S3

Spinal Cord – Cross Section



Bell-Magendie Law

- Charles Bell – Scottish neurophysiologist
- Francois Magendie – French physiologist
- Cutting dorsal root caused loss of sensation.
- Cutting ventral root caused loss of motor function.
- Entire nervous system organized in this fashion.

Dermatomes of Internal Organs

- Organs (liver, kidney, heart, lungs) in the body are also arranged segmentally
- Organs have no sensory representation in brain.

- Pain in organs is felt within the body portion of the dermatome it is represented in

Referred Pain

- Pain that is felt in a body part away from the site of disease or injury.
- E.g., pain originating from heart is felt in the left shoulder and left arm.
- E.g., kidney pain is felt in the back.
- Brain interprets pain as coming from the spinal segment the organ enters.

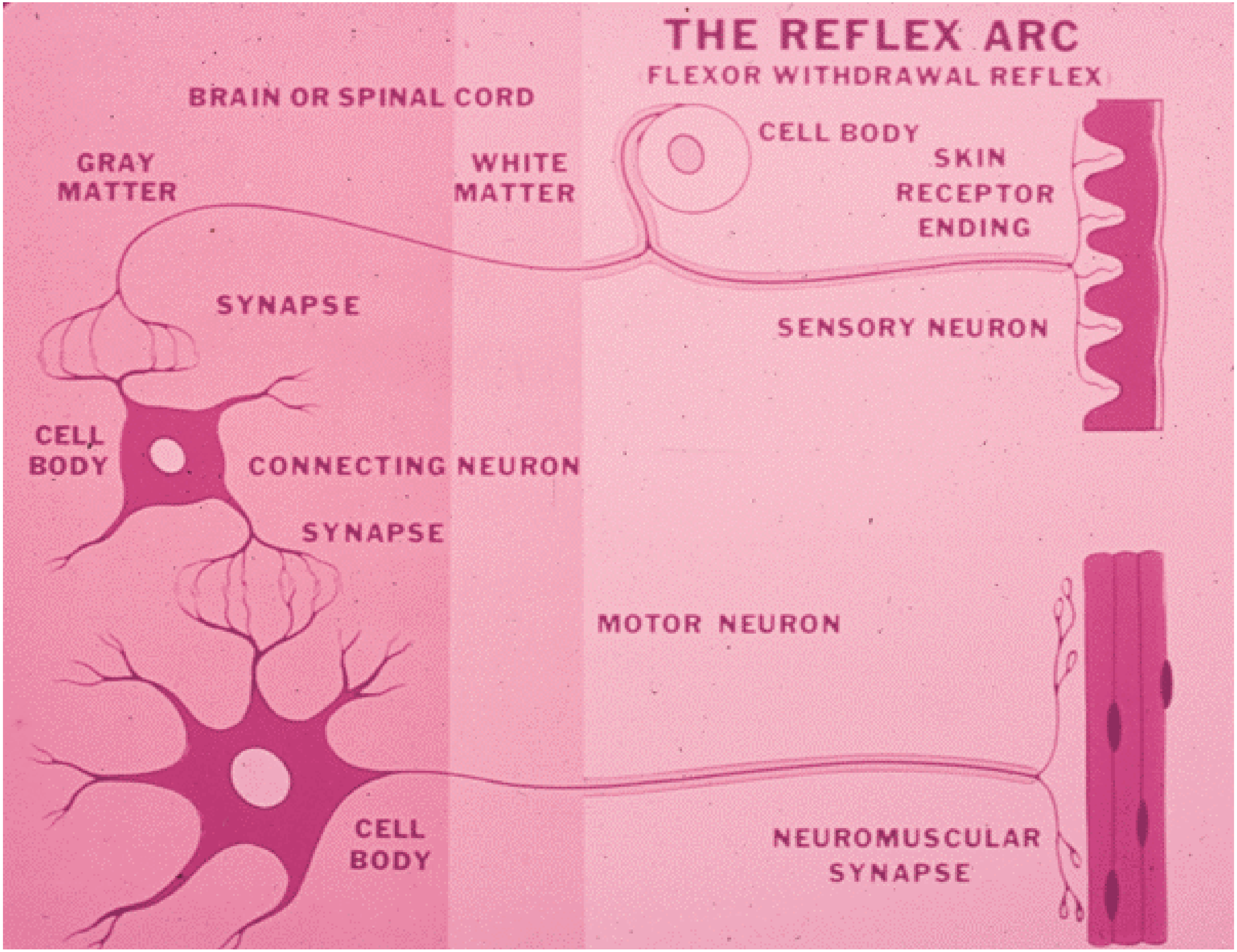
Spinal Cord Motor Defects

- If spinal cord is cut in its lower portions (lumbar, sacral), patient loses control over legs – called ***paraplegia***.

- If cord is cut at higher levels (cervical) so patient loses control over both legs and arms – called ***quadriplegia***

Spinal Reflex Arc

- Pinprick damages skin and stimulates pain receptors;
- Stimulated receptor activates a pain neuron which conducts information to cord;
- Pain fibers activate interneurons in cord;
- Interneurons activate motor neurons to muscle;
- Muscle contracts and flexes limb.



THE REFLEX ARC
(FLEXOR WITHDRAWAL REFLEX)
BRAIN OR SPINAL CORD
GRAY MATTER
WHITE MATTER
CELL BODY
SKIN
RECEPTOR ENDING
SYNAPSE
SENSORY NEURON
CELL BODY
CONNECTING NEURON
SYNAPSE
MOTOR NEURON
CELL BODY
NEUROMUSCULAR SYNAPSE

Withdrawal Reflexes

- Reflex is proportional to intensity of stimulus.
- Small pain = movement of finger or hand toward body
- Large pain = movement of entire limb bringing it toward the body.
- Stimulation of pain & temperature receptors cause flexor withdrawal reflex.

Extensor Reflexes

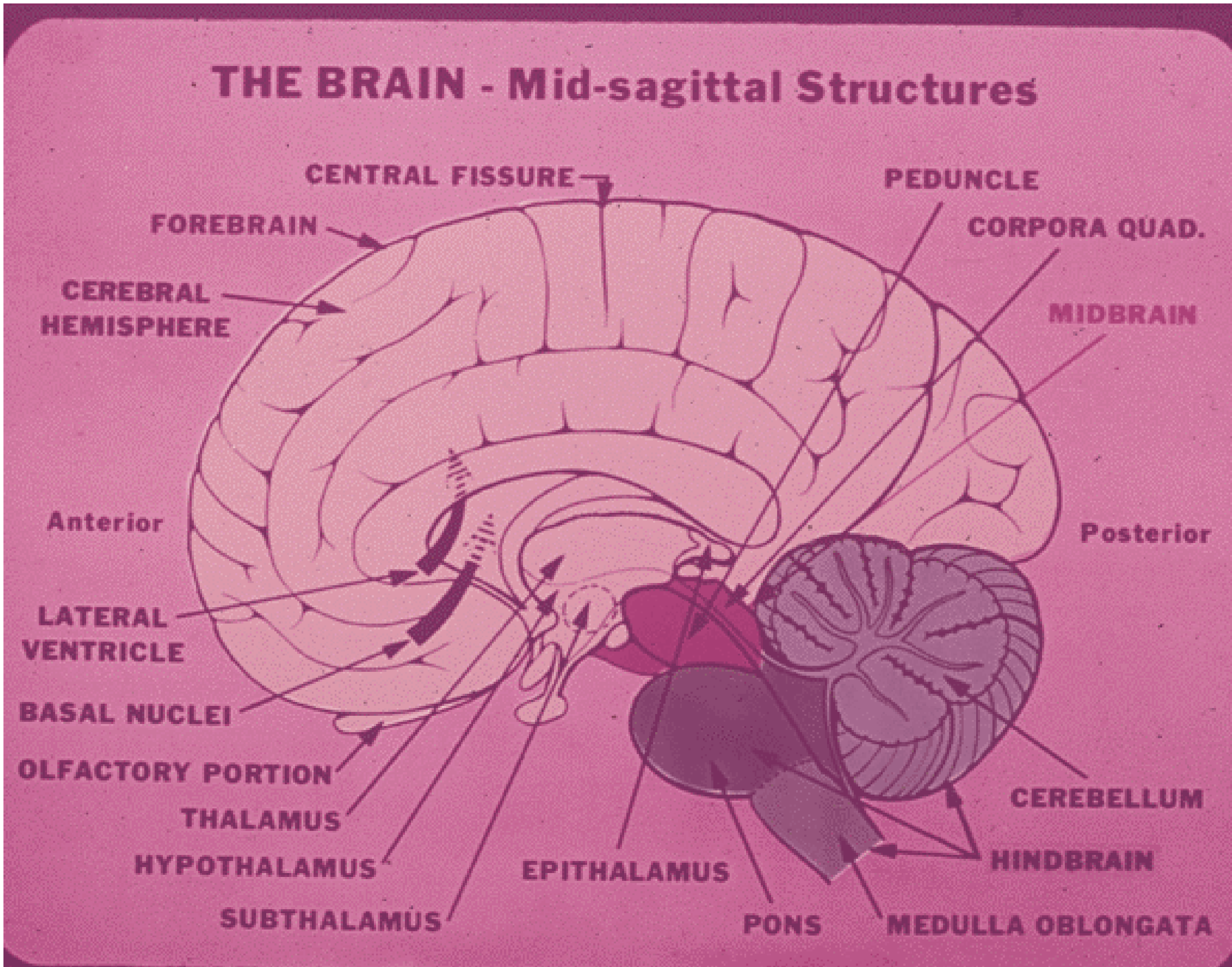
- Tactile stimulation activates tactile & pressure receptors;
- These neurons stimulate interneurons in the cord and the motor neurons then cause the limb to extend.
- Stimulating fine (discriminative) touch and pressure receptors produce extensor movements – move limb away from body.

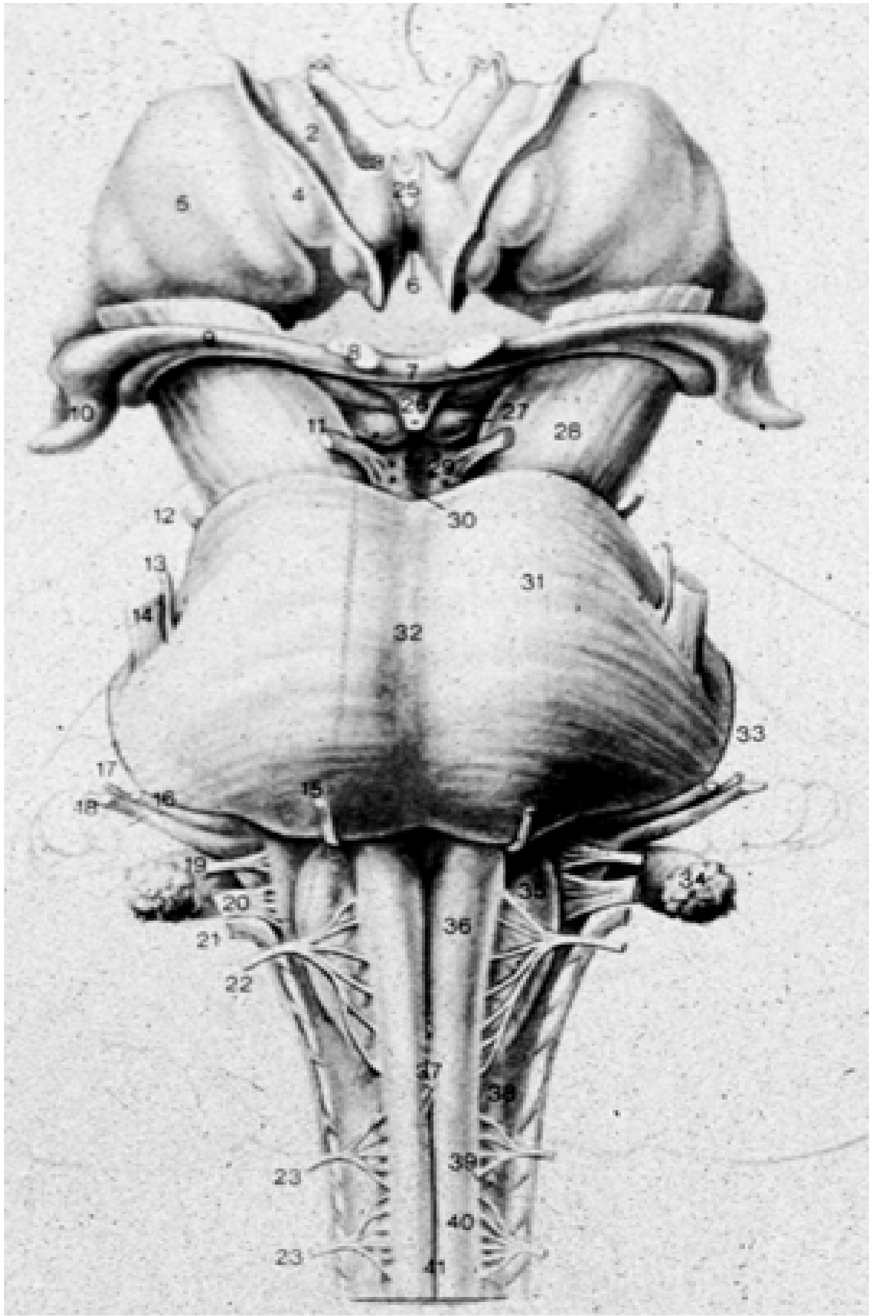
Brain Stem

- HINDBRAIN
  - Medulla Oblongata
  - Pons
  - Cerebellum

  MIDBRAIN (Mesencephalon)

Brainstem Structures

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Brainstem

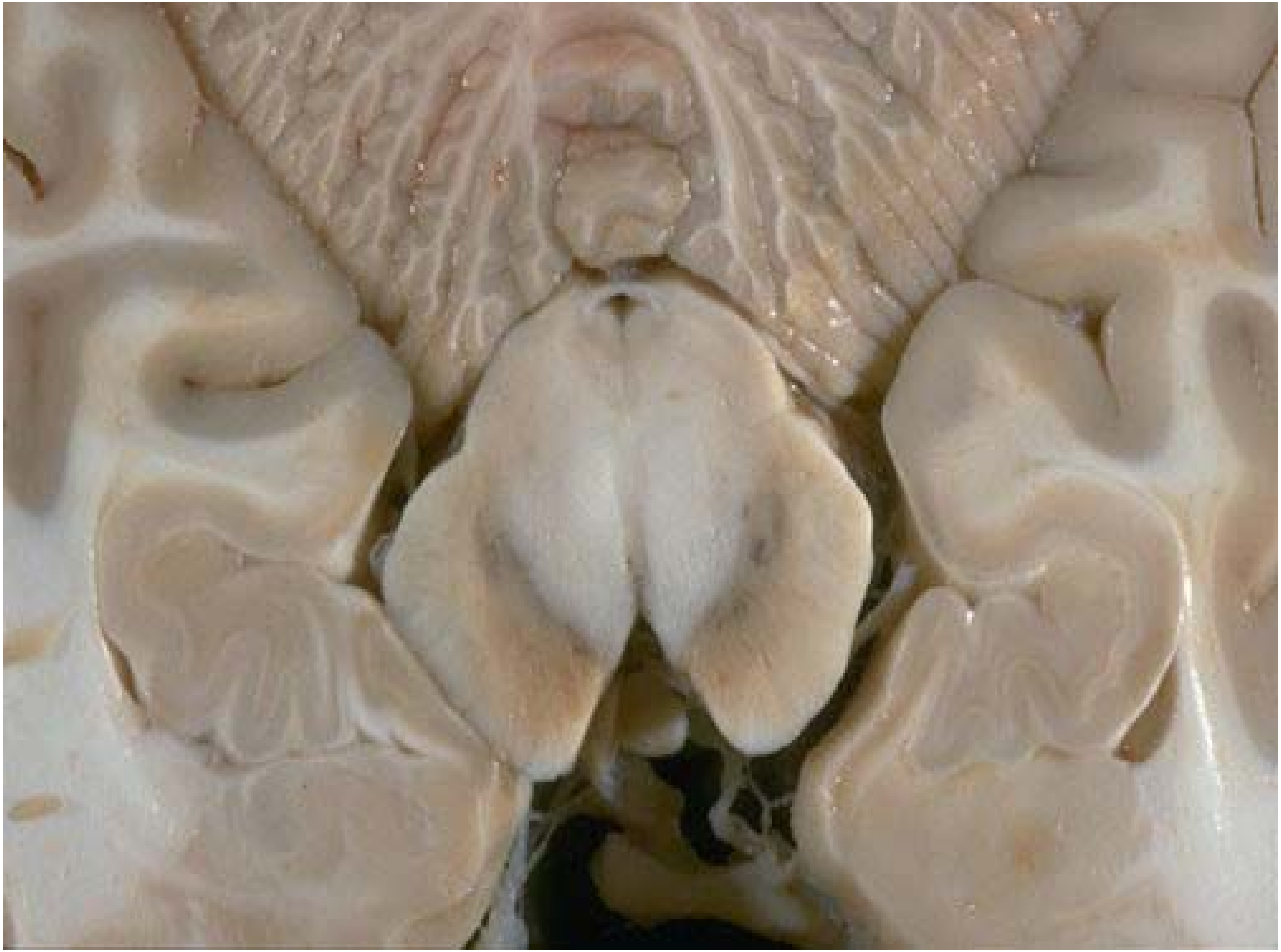
- Sensory (afferent) fibers from spinal cord on way to thalamus pass through here.
- Motor (efferent) fibers from cortex pass through on way to anterior horn of cord.
- Brainstem packed with fibers and cranial nerve nuclei;
- So even small lesions have large effects.

Reticular Activating Center

- Located in central core of brainstem in midbrain, pons, & superior medulla.
- Maintenance of consciousness
- Controls sleep and wakefulness
- Controls arousal levels
- Composed of many different brainstem nuclei

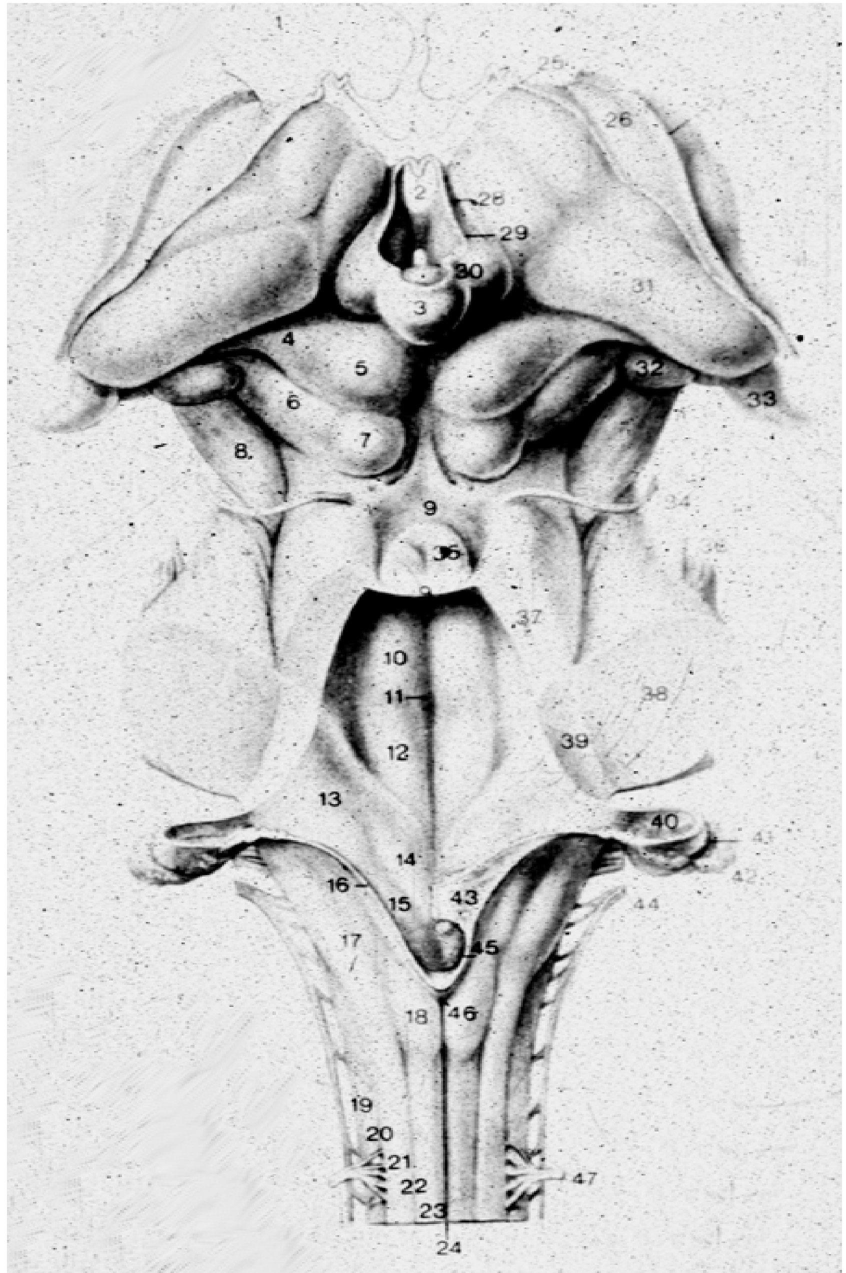
Midbrain

- Mesencephalon – two subdivisions
- Tectum (roof) – above cerebral aqueduct
- Tegmentum (floor) – below aqueduct
- Tectum contains 2 sets of bilaterally symmetrical nuclei:
  - Superior colliculi (upper hills)
  - Inferior colliculi (lower hills)



Midbrain

- ***Superior colliculi*** – receives input from retina; mediates visual behaviors.
- ***Inferior colliculi*** – input from ear; mediates auditory-related behaviors.
- Tegmentum – contains some cranial nerve nuclei (primarily motor), substantia nigra, and the VTA.



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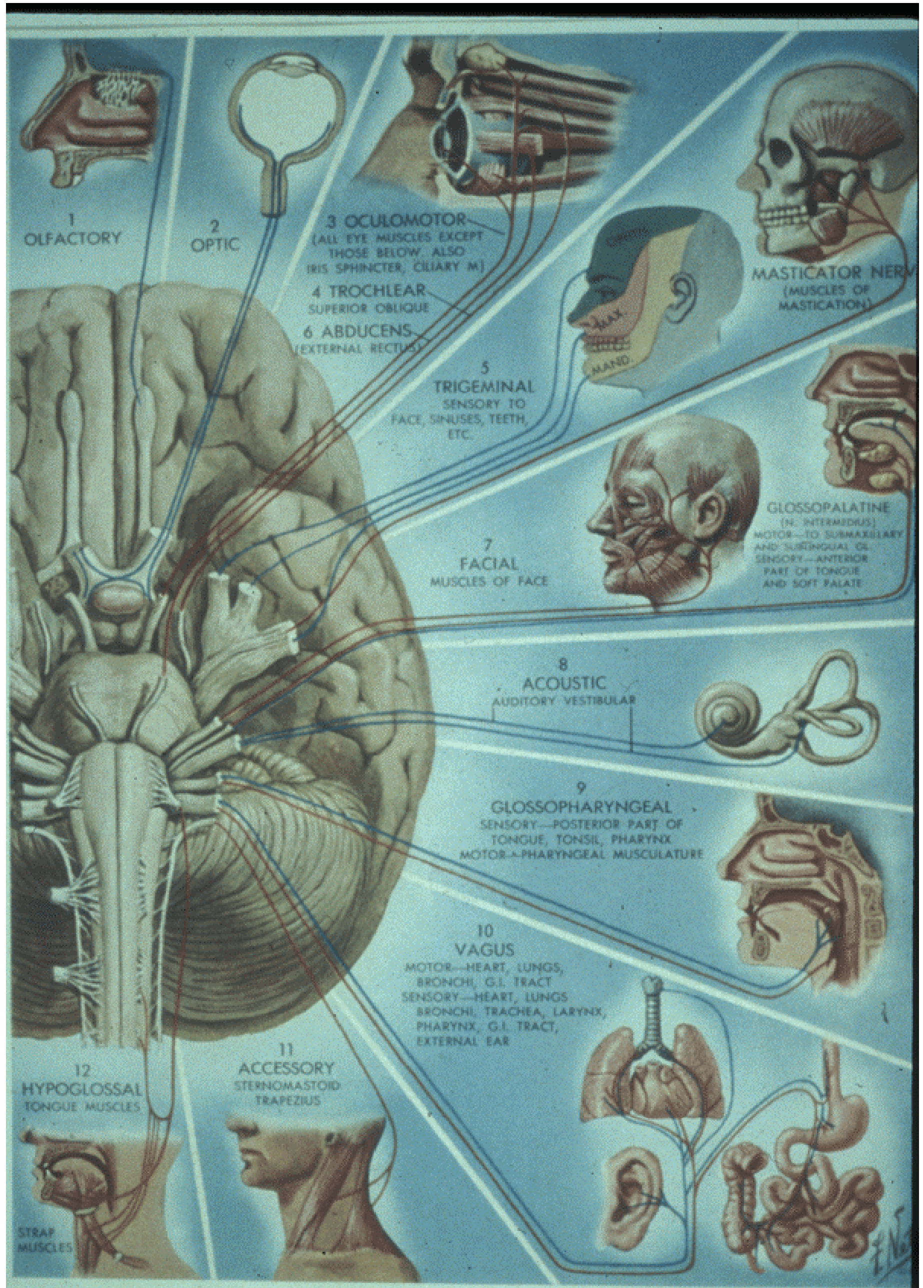
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OPTIC
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4 TROCHLEAR
SUPERIOR OBLIQUE
6 ABDUCENS
(EXTERNAL RECTUS)
5
TRIGEMINAL
SENSORY TO FACE, SINUSES, TEETH, ETC.
MAX.
MAND.
MASTICATOR NERV
(MUSCLES OF MASTICATION)
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(N. INTERMEDIUS)
MOTOR—TO SUBMAXILLARY AND SUBLINGUAL GL.
SENSORY—ANTERIOR PART OF TONGUE AND SOFT PALATE
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ACOUSTIC
AUDITORY VESTIBULAR
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SENSORY—POSTERIOR PART OF TONGUE, TONSIL, PHARYNX
MOTOR—PHARYNGEAL MUSCULATURE
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VAGUS
MOTOR—HEART, LUNGS, BRONCHI, G.I. TRACT
SENSORY—HEART, LUNGS BRONCHI, TRACHEA, LARYNX, PHARYNX, G.I. TRACT, EXTERNAL EAR
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STERNOMASTOID
TRAPEZIUS
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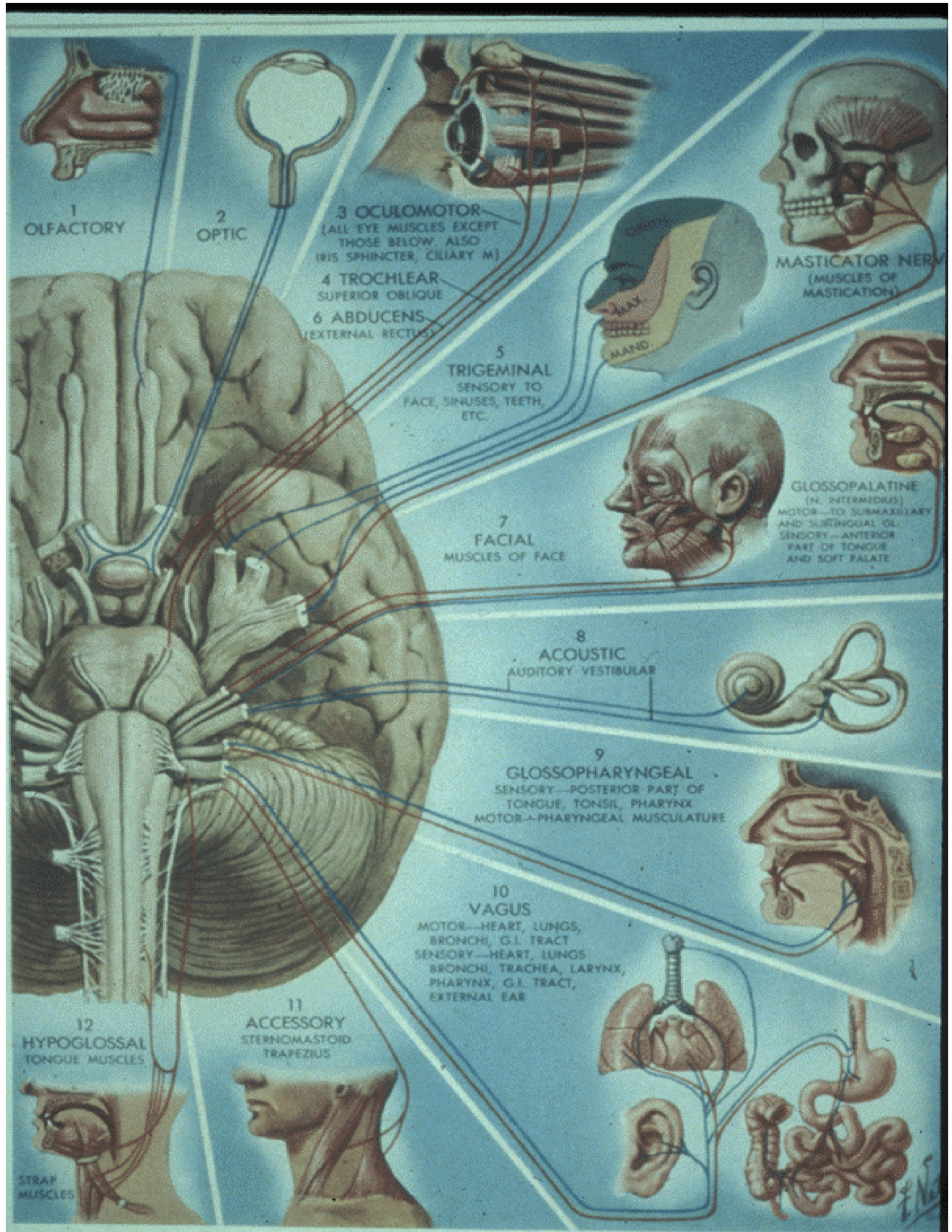
HYPOGLOSSAL
TONGUE MUSCLES
STRAP MUSCLES

Cranial Nerves

- 12 sets of nerves lying within brainstem
- Sensory information from specialized sensory systems of head to brain
- Control of muscle movement of head
- Important for neurological diagnosis and localization of lesion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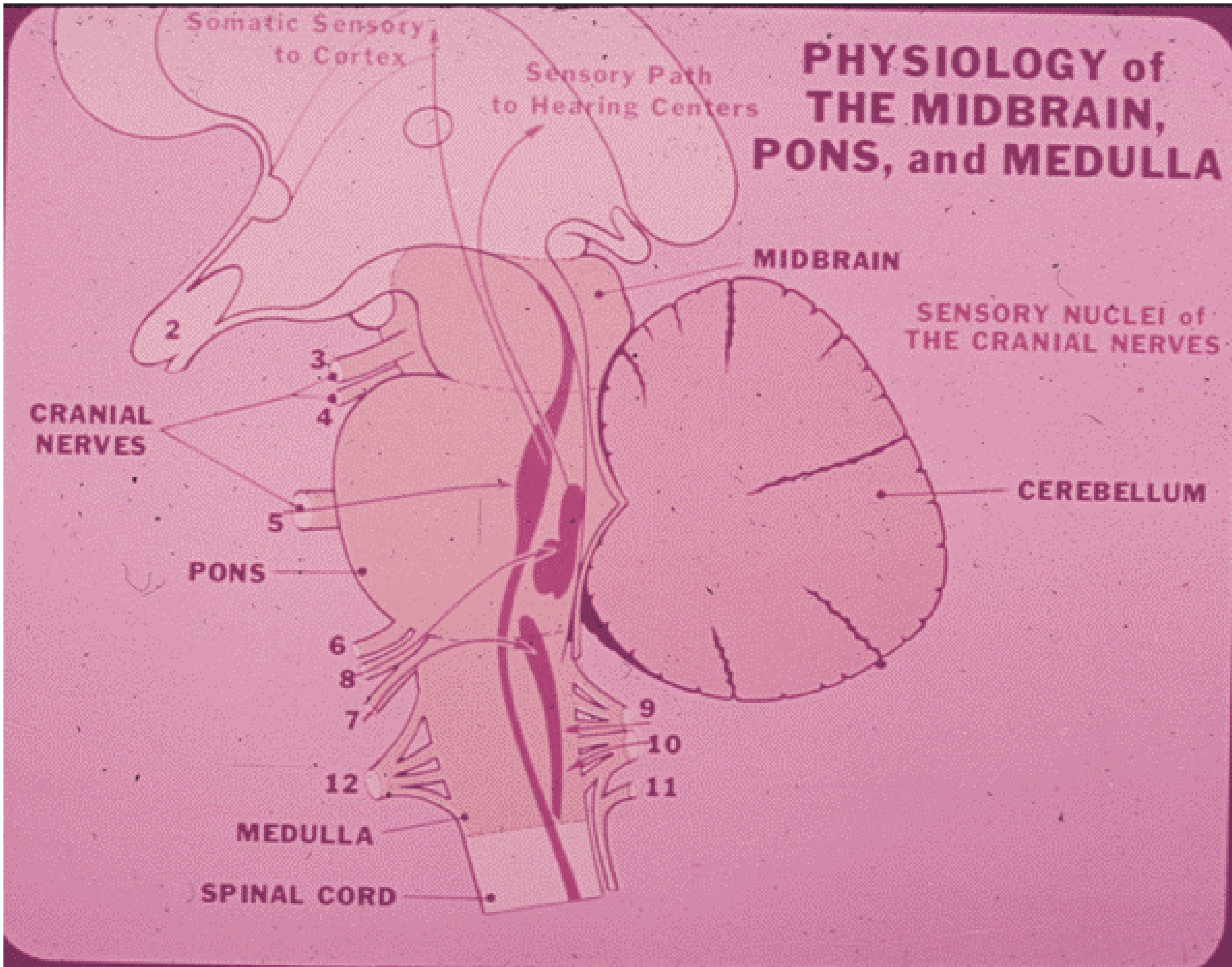
Cranial Nerves Function

- I = Olfactory – Smell
- II = Optic – Vision
- III= Occulomotor – Eye movement / pupil constriction
- IV= Trochlear – Eye movement
- V = Trigeminal –Face sensation / jaw movement
- VI = Abducens – Eye movement

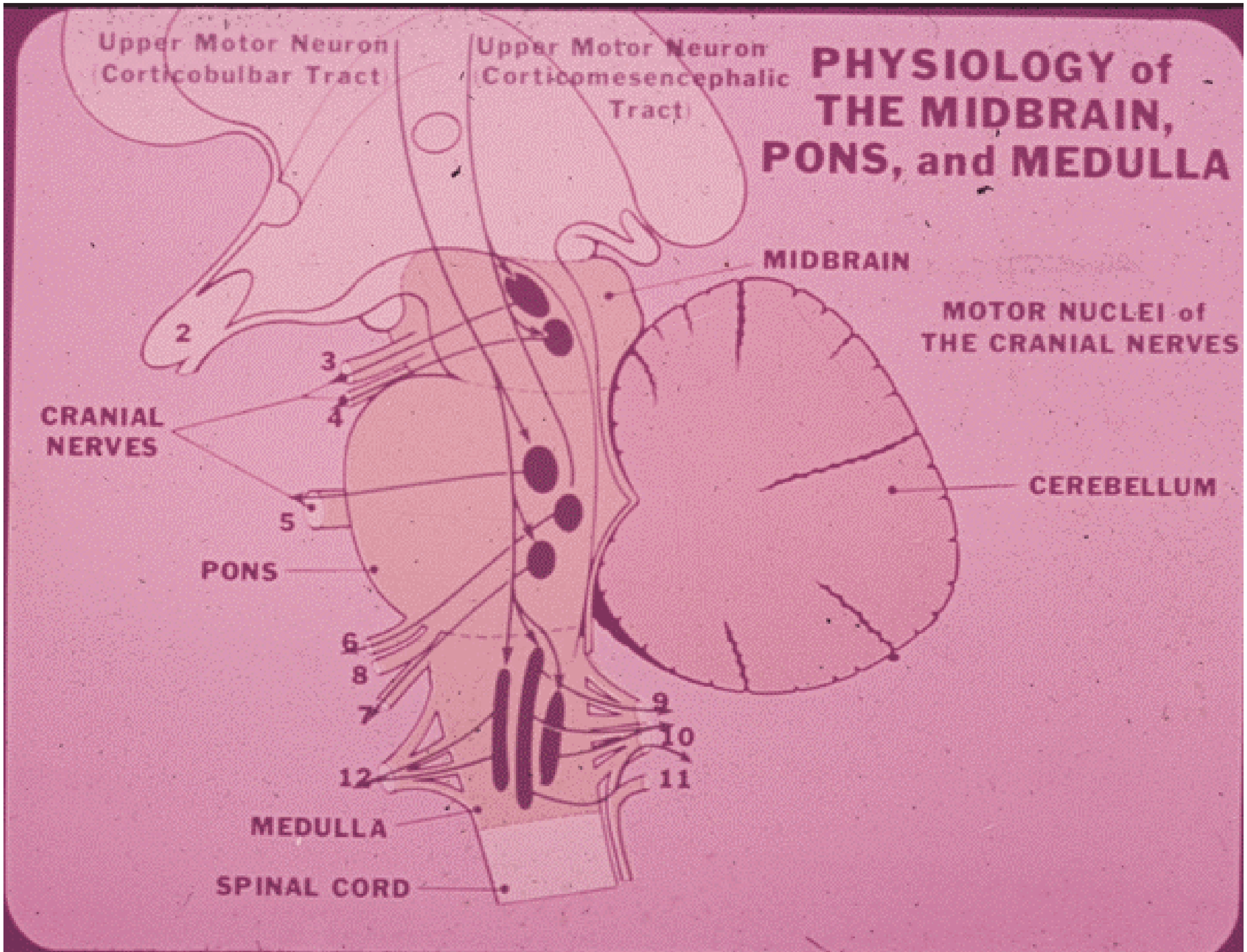
Cranial Nerves Function

- VII = Facial – Facial movement
- VIII= Cochleo-Vestibular – Hearing/ Equilibrium
- IX = Glossopharyngeal – Taste / Pharynx
- X = Vagus – Heart, vessels, viscera / movement of larynx & pharynx
- XI = Spinal Accessory – Neck muscles
- XII = Hypoglossal – Tongue muscles

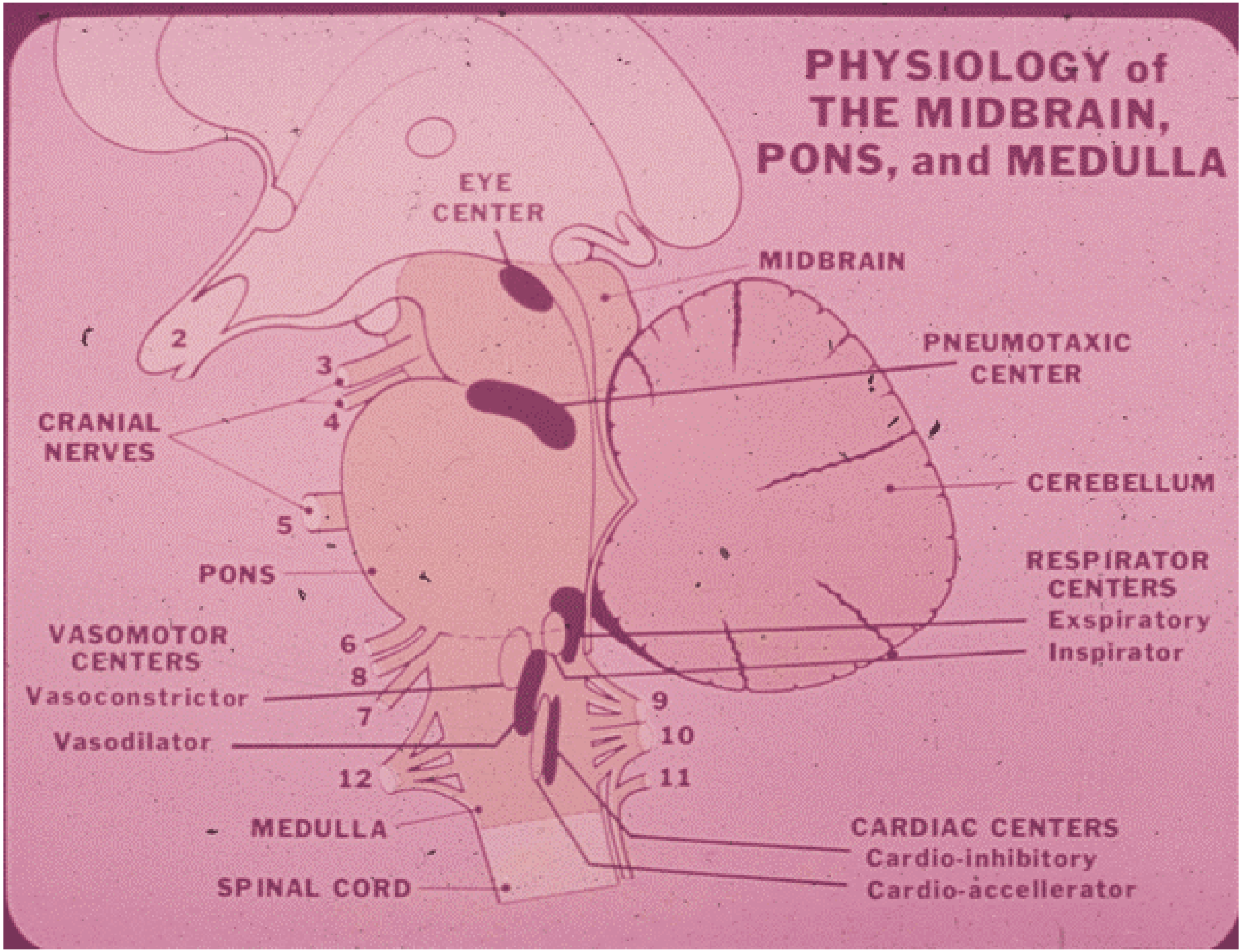
Sensory Cranial Nerve Nuclei



Motor Cranial Nerve Nuclei



Cardiac & Respiratory Centers



Cranial Nerves

- Will be discussed in detail when the motor system is presented in Chapter 9
- Symptoms of dysfunction of the cranial nerves
- And methods to examine cranial nerve function will be presented at that time.

Cerebellum

- 3 major streams of input into cerebellum

- From Cortex
- From Vestibular apparatus
- From body via spinal cord

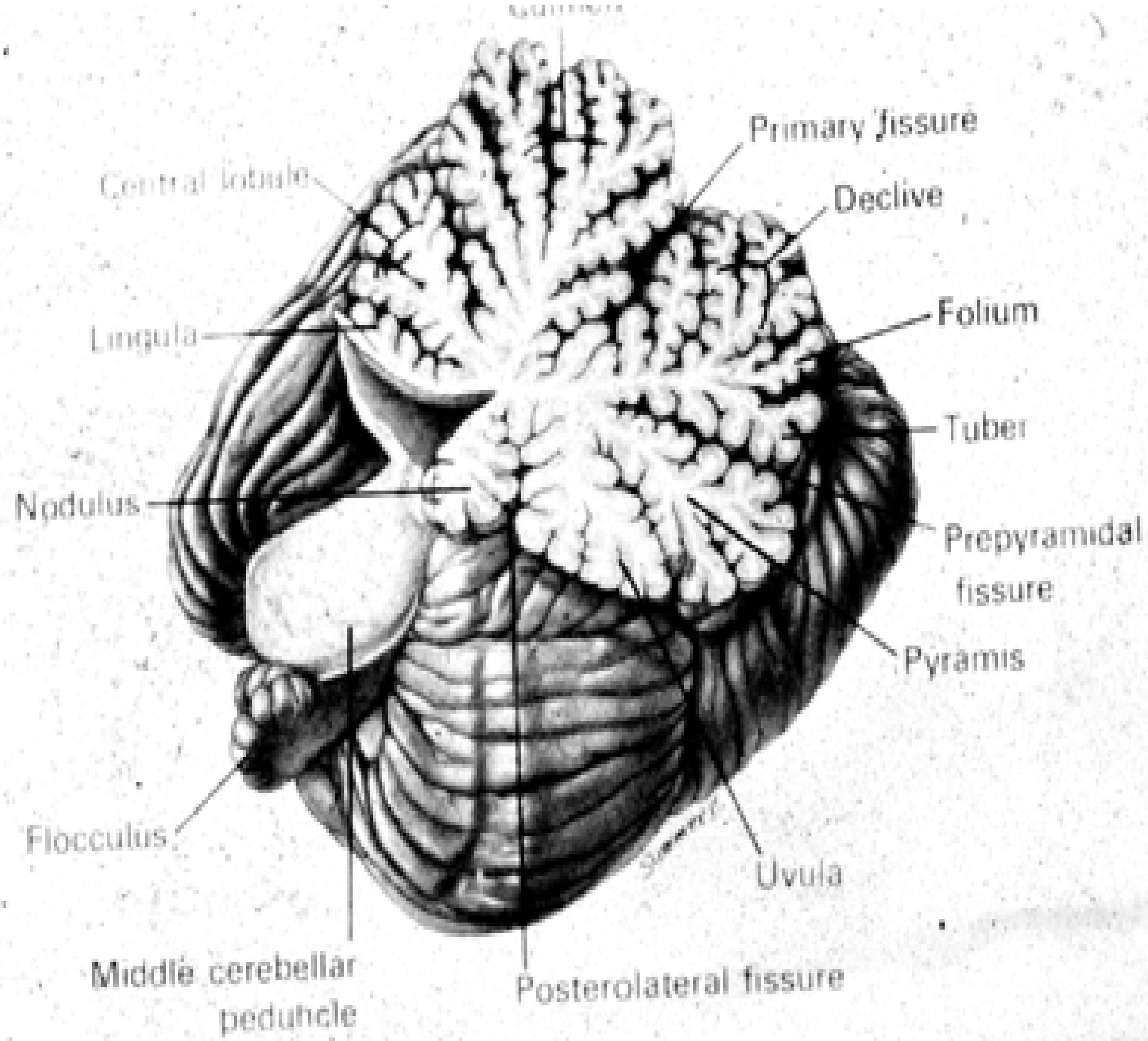
Cerebellum

Functions of Cerebellum

- Major part of cerebellum receives input from cortex = controls skilled movements.
- Other portions receives input from vestibular system = maintain body's equilibrium.
- Parts that receive input from body senses = postural reflexes & coordinating related muscle groups.

Cerebellar Anatomy

- Surface has many narrow folds called ***folia***
- Cortex of gray matter covers larger area of white matter
- Several nuclei lie within white matter.
- Connected to brainstem via 3 major fiber pathways – ***inferior, middle & superior cerebellar peduncles***.


Central lobule
Primary fissure
Declive
Lingula
Folium
Tuber
Nodulus
Prepyramidal fissure
Pyramis
Flocculus
Uvula
Middle cerebellar peduncle
Posterolateral fissure

Effects of Cerebellar Damage

- Damage causes impairments of equilibrium & skilled motor activity & postural defects.

- Smooth movement broken into jerky, sequential components;