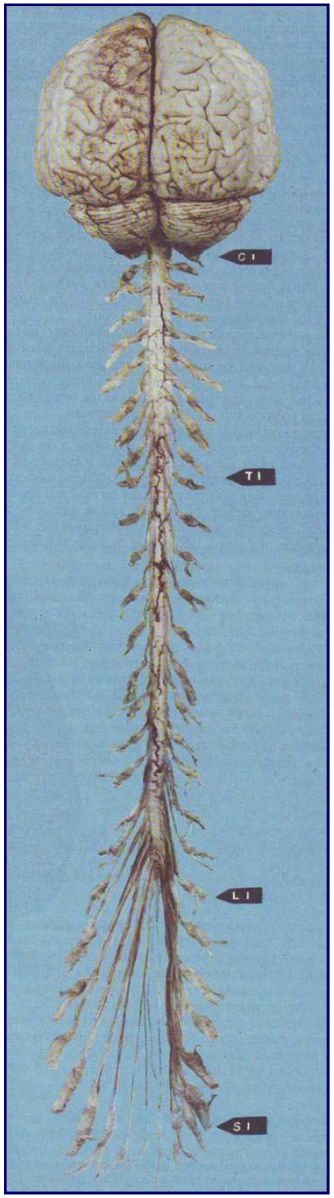
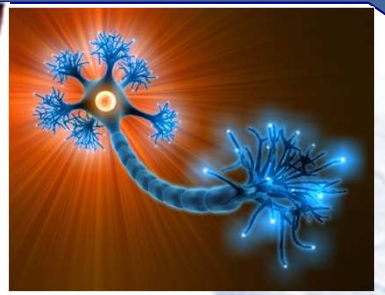




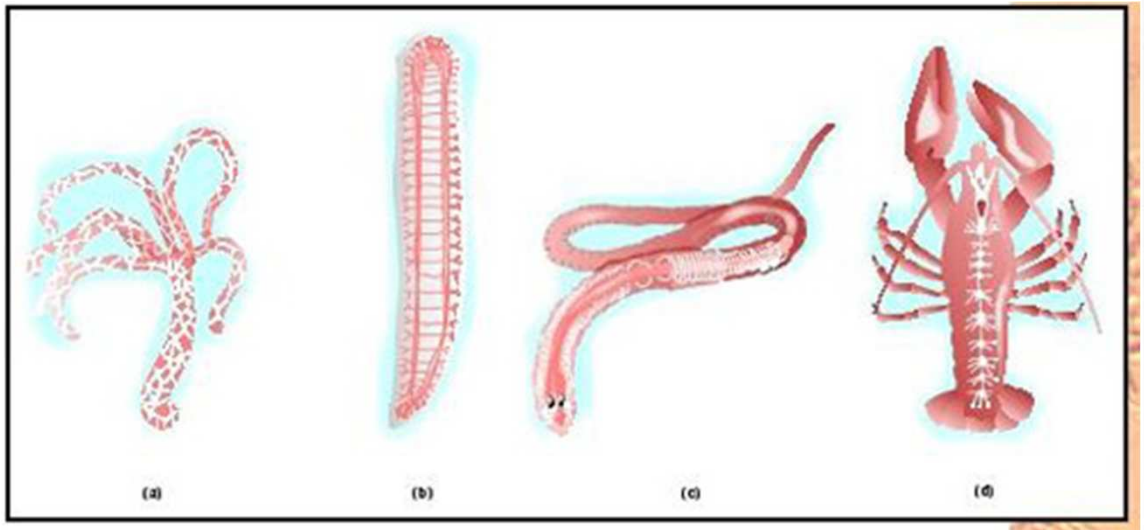
Development of the nervous system

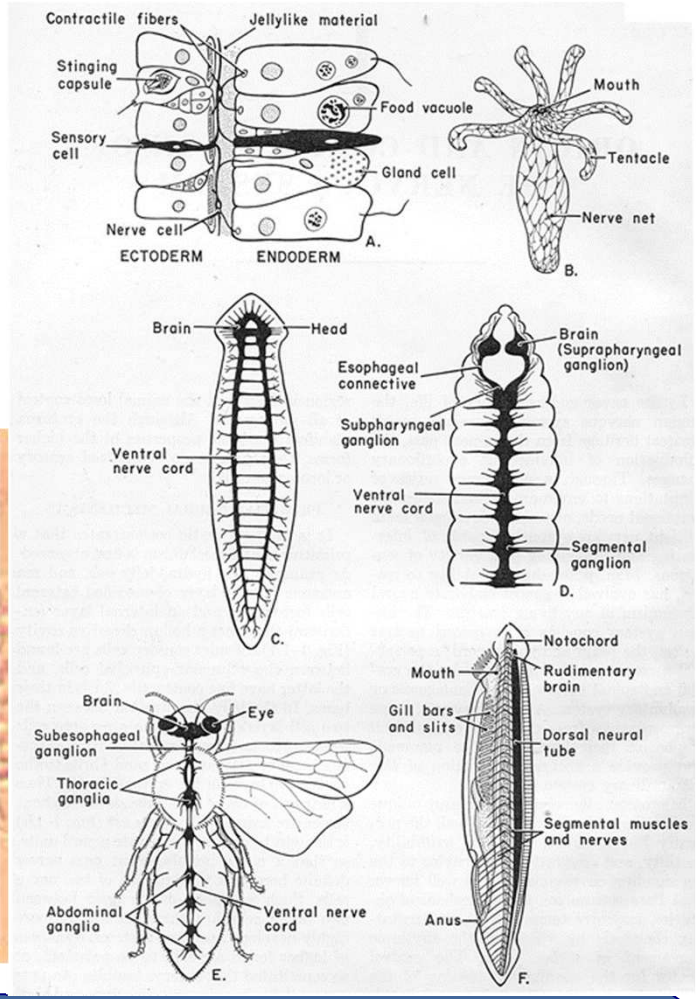
Spinal cord

1. Phylogenetic evolution of the nervous system
2. Ontogenesis of the nervous system
3. Principles of neural organization
4. Histogenesis of the nervous tissue
5. Spinal cord – external structure
6. Spinal cord meninges and blood supply of the spinal cord
7. Internal structure of the spinal cord:
   - ✓ grey matter – nuclei and laminae
   - ✓ white matter – nerve fiber tracts
8. Reflex apparatus of the spinal cord

Phylogenetic evolution of the nervous system

- Invertebrate nervous systems – types
  - ✓ reticular – “nerve net” – hydras and jellyfish (cnidarians)
  - ✓ ganglionic – worms, insects and mollusks
    - ➢ neuronal cell bodies in clusters (ganglia)
    - ➢ anterior (head) end – primitive brain
- Vertebrate nervous systems – lower vertebrates and mammals
  - ✓ tubular

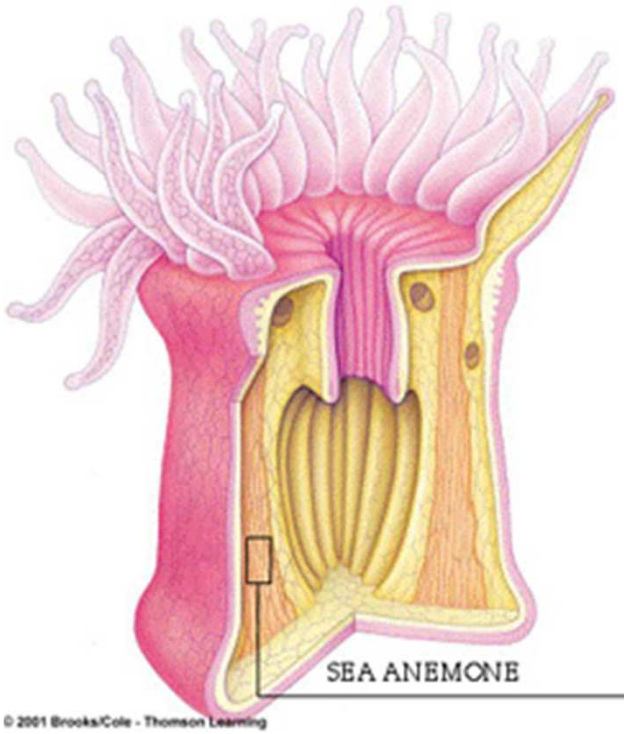




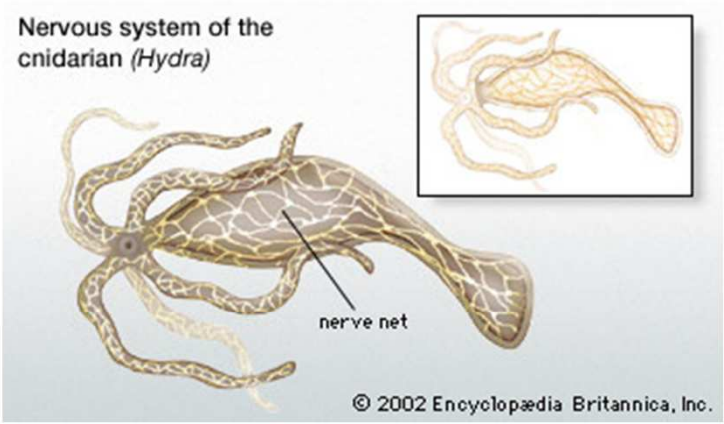
Nerve net

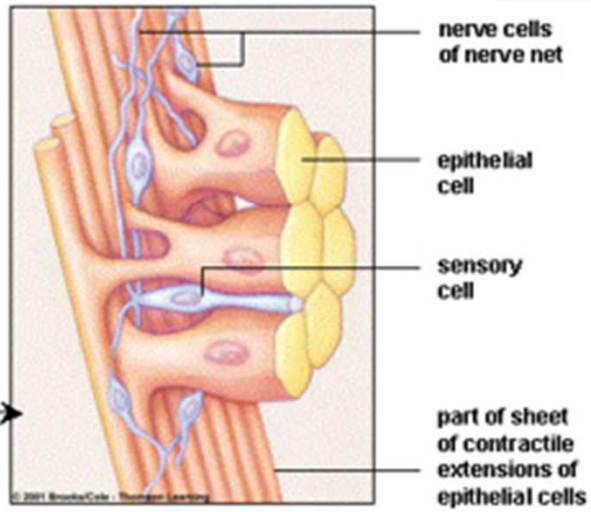
- ✓ the simplest type of nervous system
- ✓ lack anything that resembles a brain

Nerve Net



- Diffuse mesh of nerve cells that take part in simple reflex pathways
- Nerve cells interact with sensory and contractile cells





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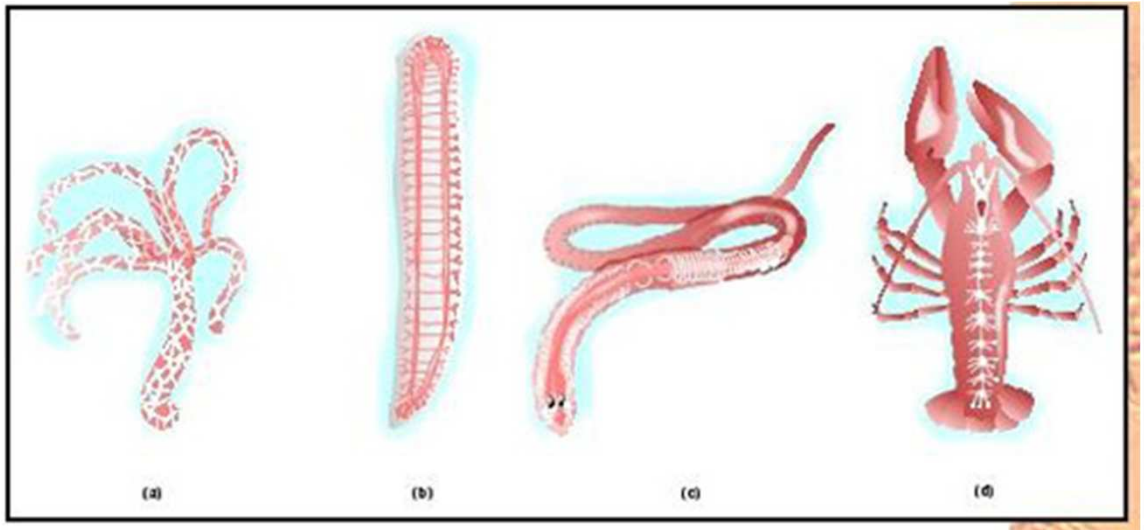
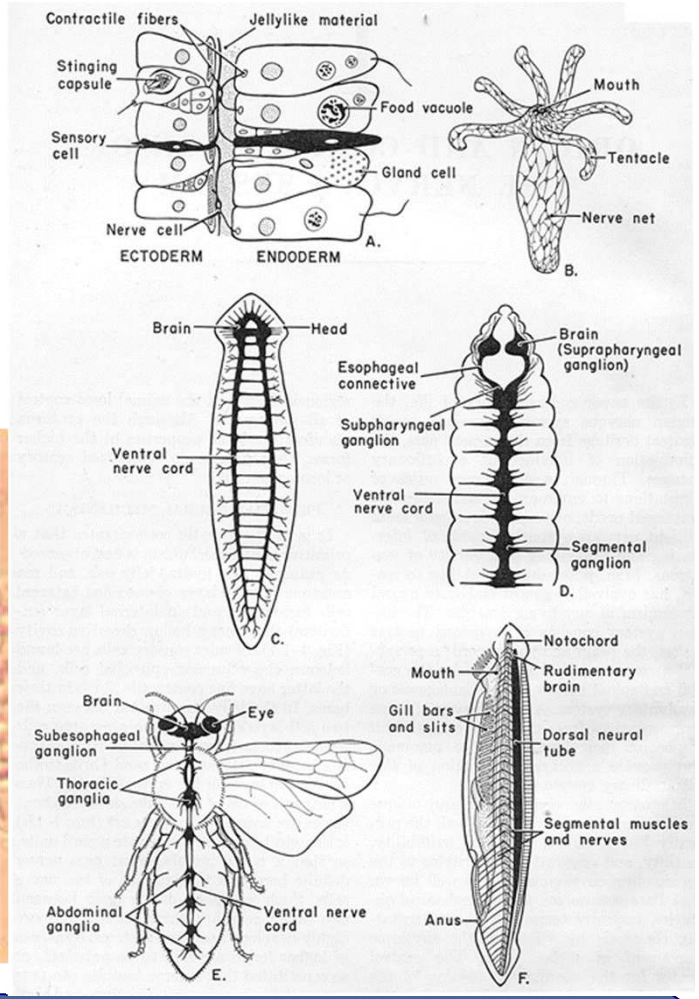
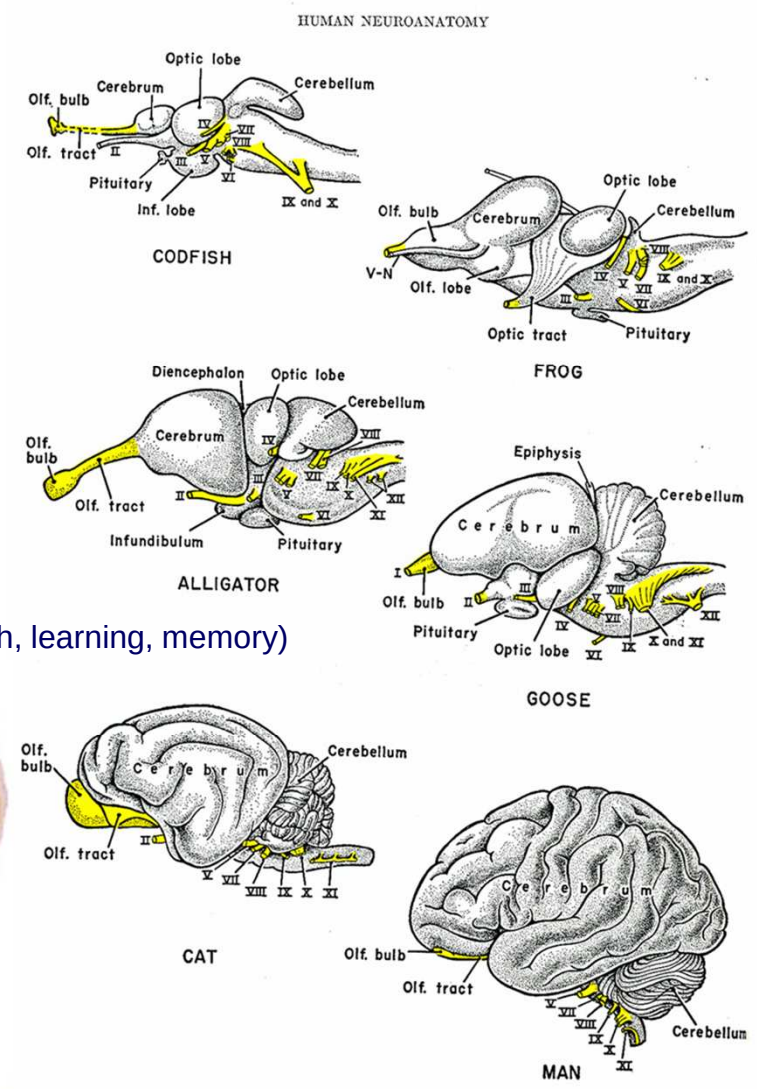
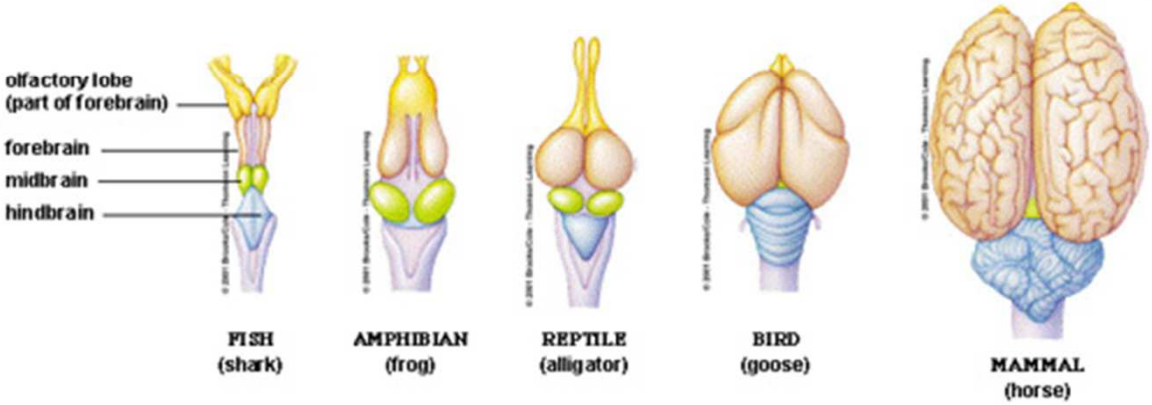




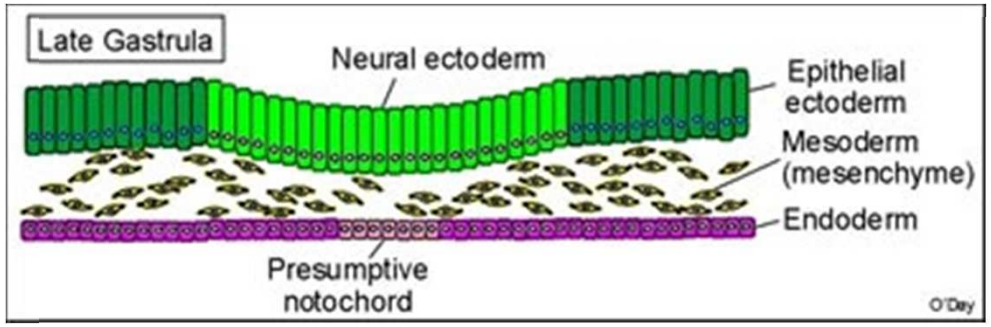
Phylogenetic evolution of the CNS

- primitive vertebrates – fish
  - ✓ hindbrain – the largest region
    - ➢ cerebellum – well developed (swimming&balance)
  - ✓ small midbrain (processing of visual information)
  - ✓ small forebrain (sense of smell, olfaction)
- amphibians – frog
  - ✓ hindbrain – more enlarged
    - ➢ cerebellum – reduced in size (simple locomotion)
  - ✓ forebrain – still small (olfaction)
- reptiles and birds
  - ✓ cerebellum and midbrain – enlarged
  - ✓ forebrain regions – more developed
- mammals, incl. human
  - ✓ cerebellum – increased
  - ✓ telencephalon – cerebral cortex, cognition (speech, math, learning, memory)

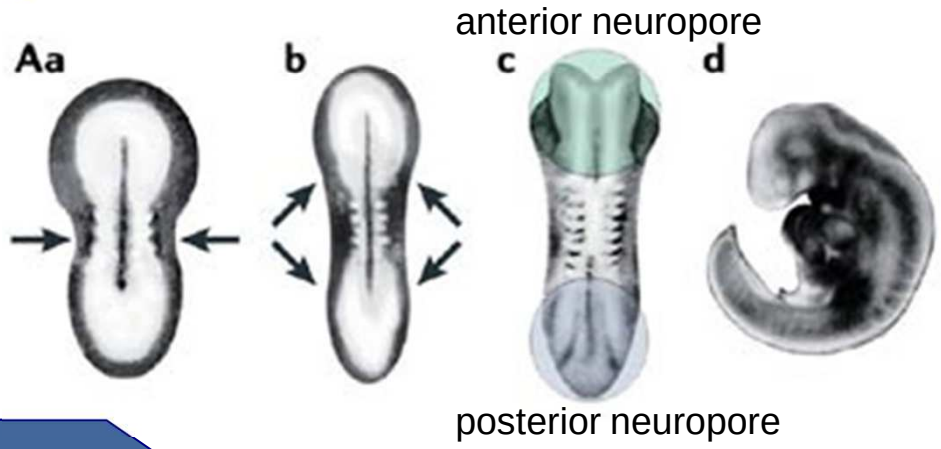


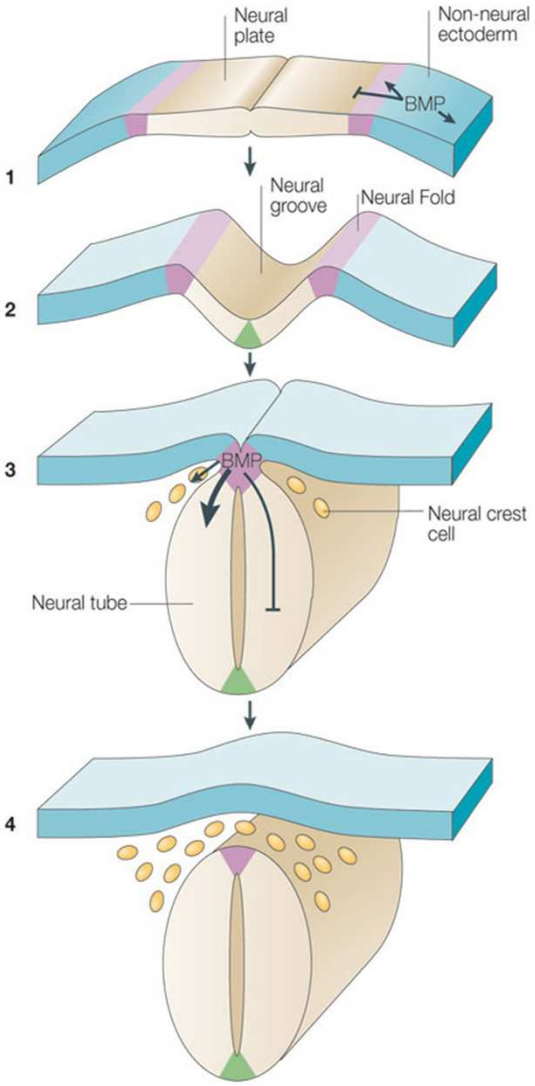


Embryonic development of the nervous system



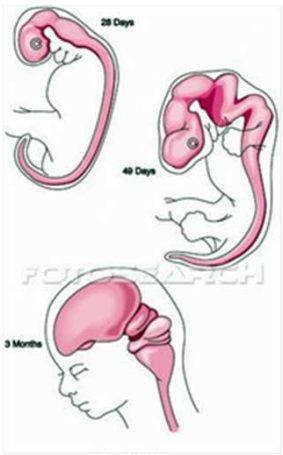
- begin – E17
- embryonic origin – ectoderm (neuroectoderm)
- formation of neural tube (neurulation) – neural induction (primary embryonic induction)
  - ✓ neural plate
  - ✓ neural groove
  - ✓ neural folds
  - ✓ neural tube
  - ✓ neural crest
- transverse segmentation of neural tube

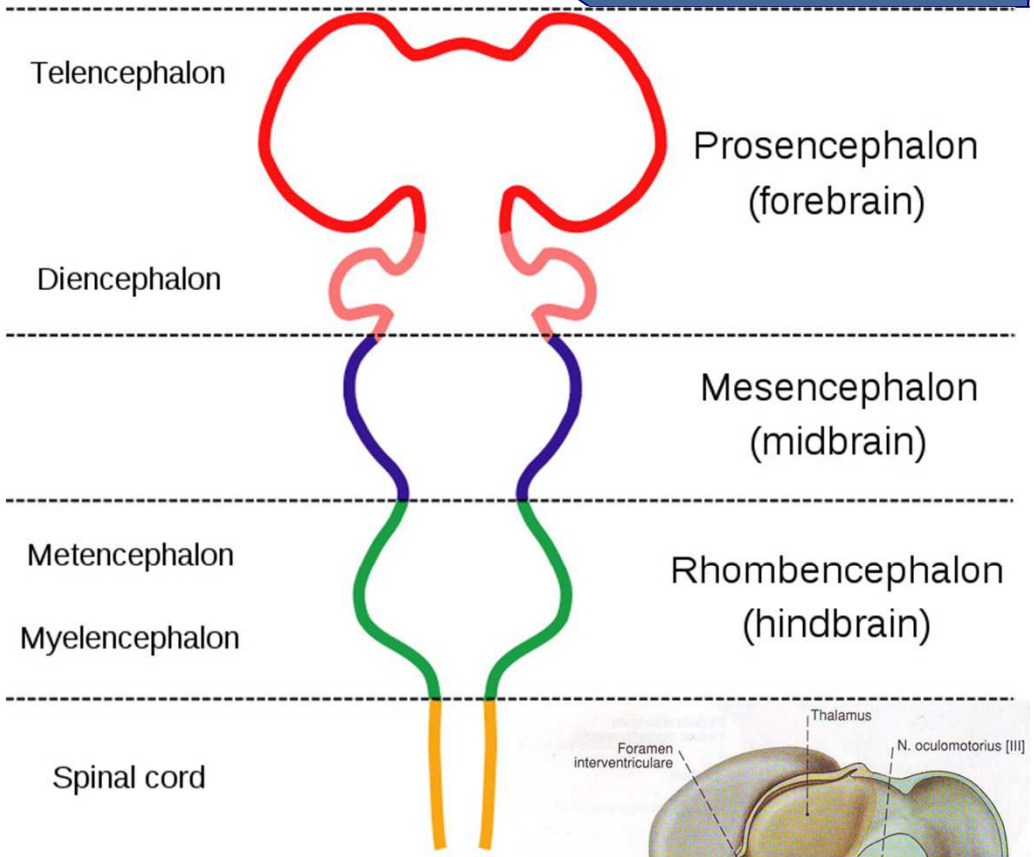


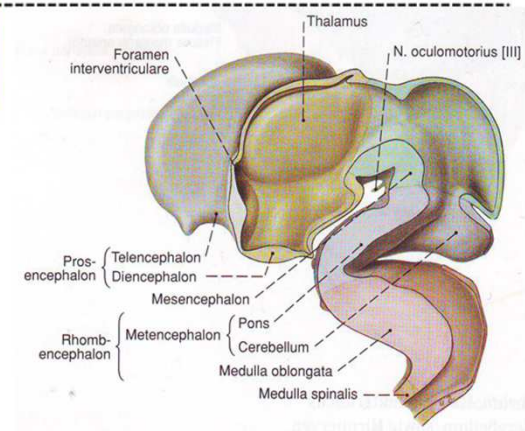


Development of the brain

- three primary embryonic vesicles:
  - ✓ prosencephalon (forebrain)
  - ✓ mesencephalon (midbrain)
  - ✓ rhombencephalon (hindbrain)
- five secondary brain vesicles:
  - ✓ telencephalon
  - ✓ diencephalon
  - ✓ mesencephalon
  - ✓ metencephalon
  - ✓ myelencephalon
- two proteins, BERT and ERNI, control brain development

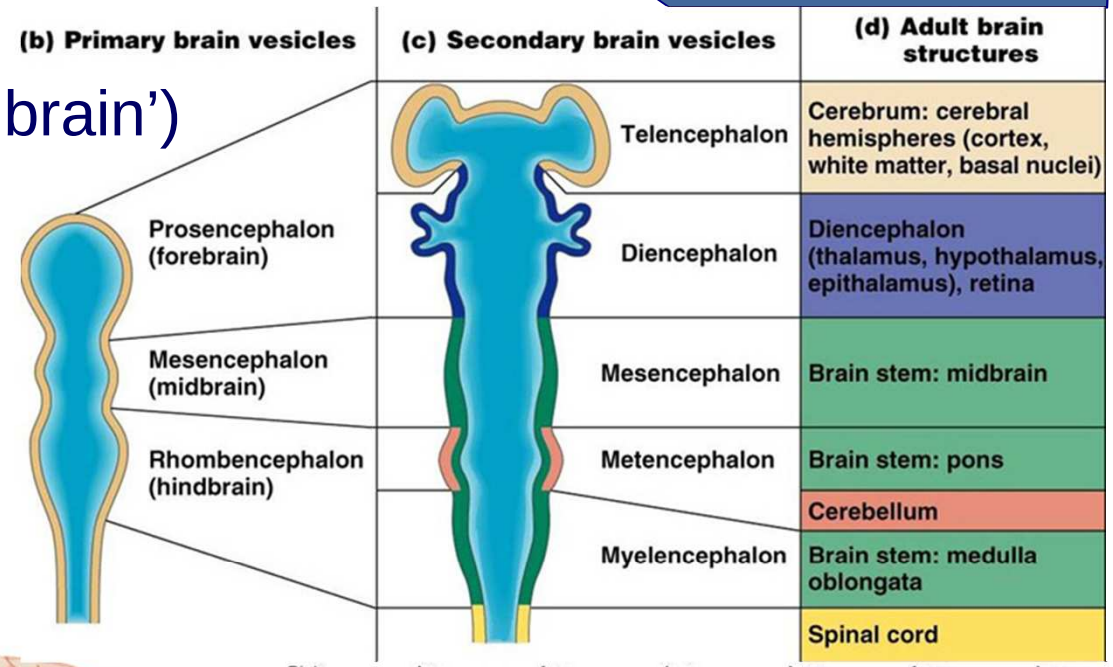


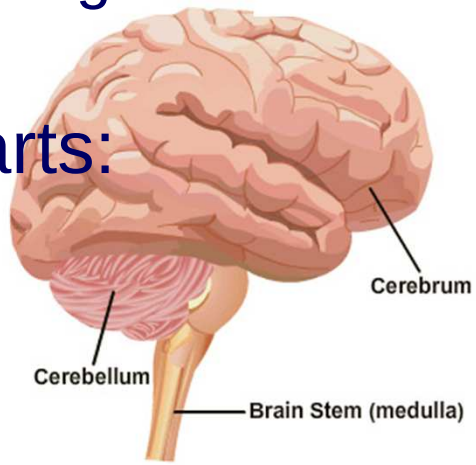


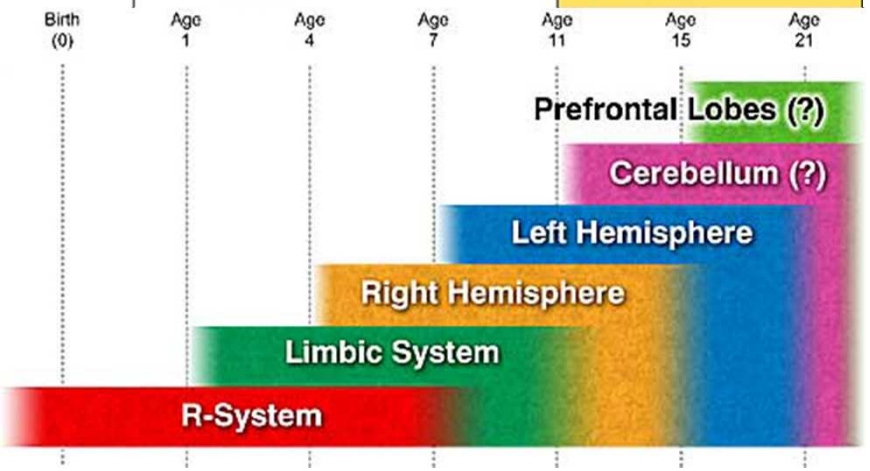


Adult brain structures

- encephalon (brain):
  - ✓ telencephalon (‘endbrain’)
  - ✓ diencephalon (‘between brain’)
  - ✓ mesencephalon (midbrain)
  - ✓ pons
  - ✓ cerebellum
  - ✓ medulla oblongata
- spinal cord
- functional parts:
  - ✓ cerebrum
  - ✓ brain stem
  - ✓ cerebellum

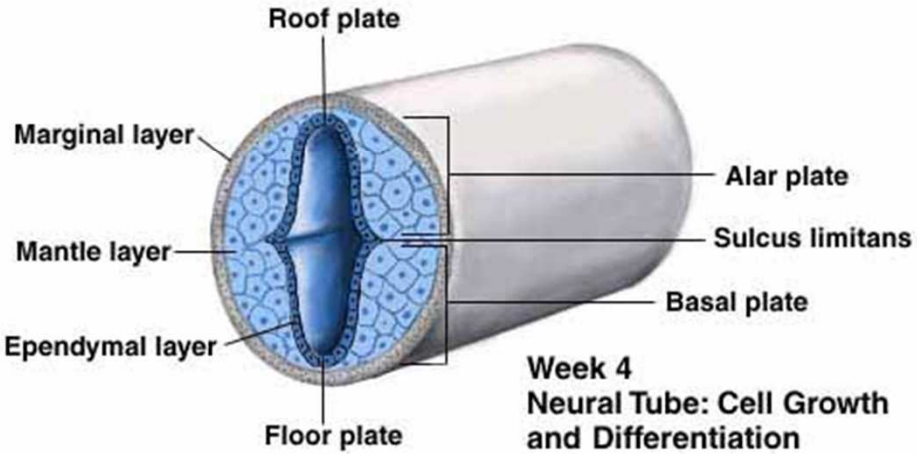


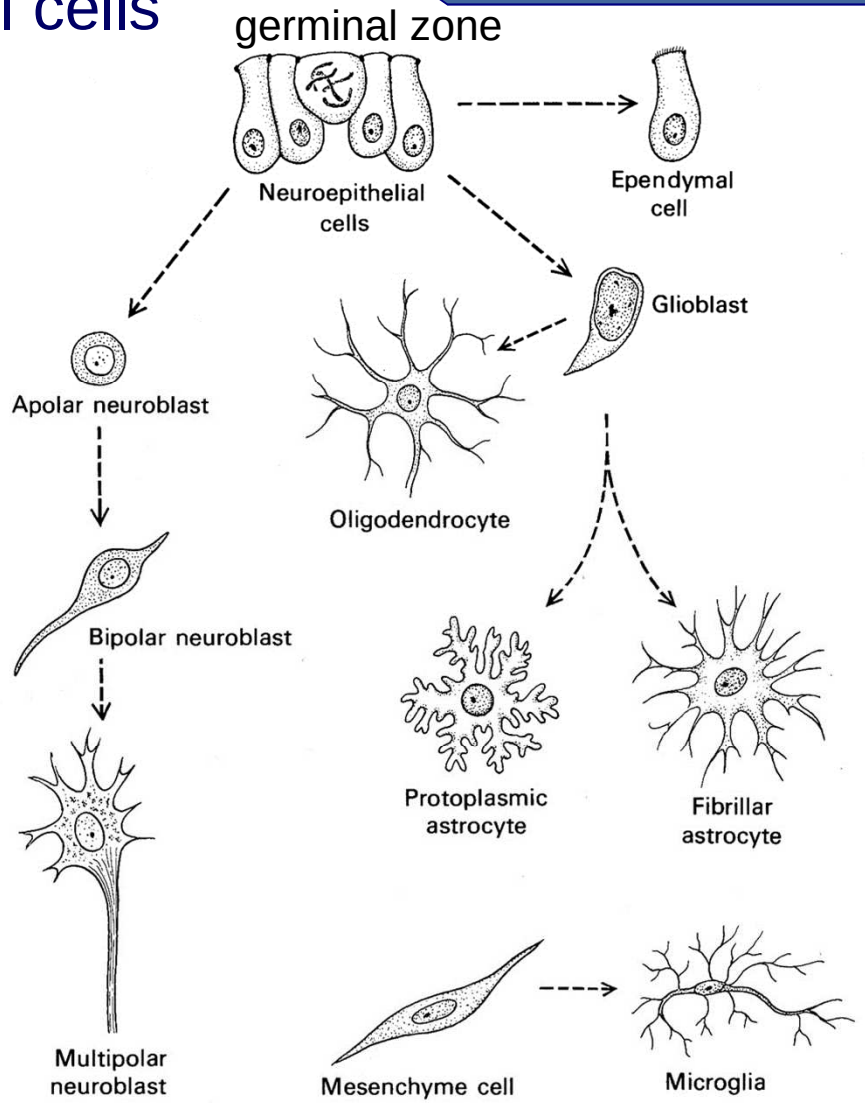




Histogenesis of the nervous tissue

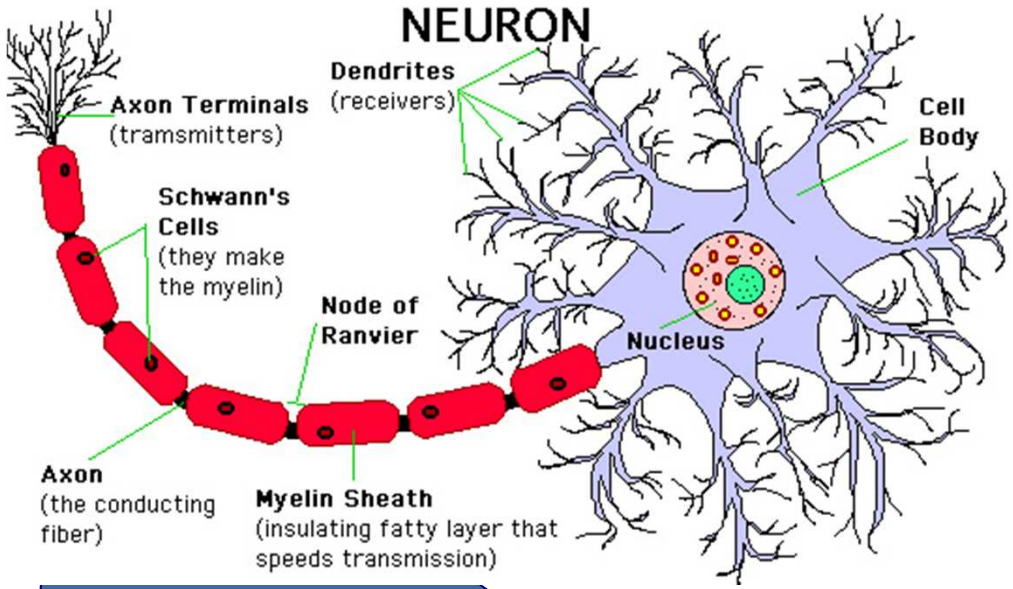
- undifferentiated neuroepithelial cells (stem cells) – pluripotential:
  - ✓ neuroblasts (immature neurons)
    - ➢ apolar, bipolar and multipolar
  - ✓ glioblasts (glial cells precursors)
    - ➢ oligodendrocytes
    - ➢ protoplasmic astrocytes
    - ➢ fibrillar asrocytes
  - ✓ ependymal cells
- microglia ⇦ mesodermal origin



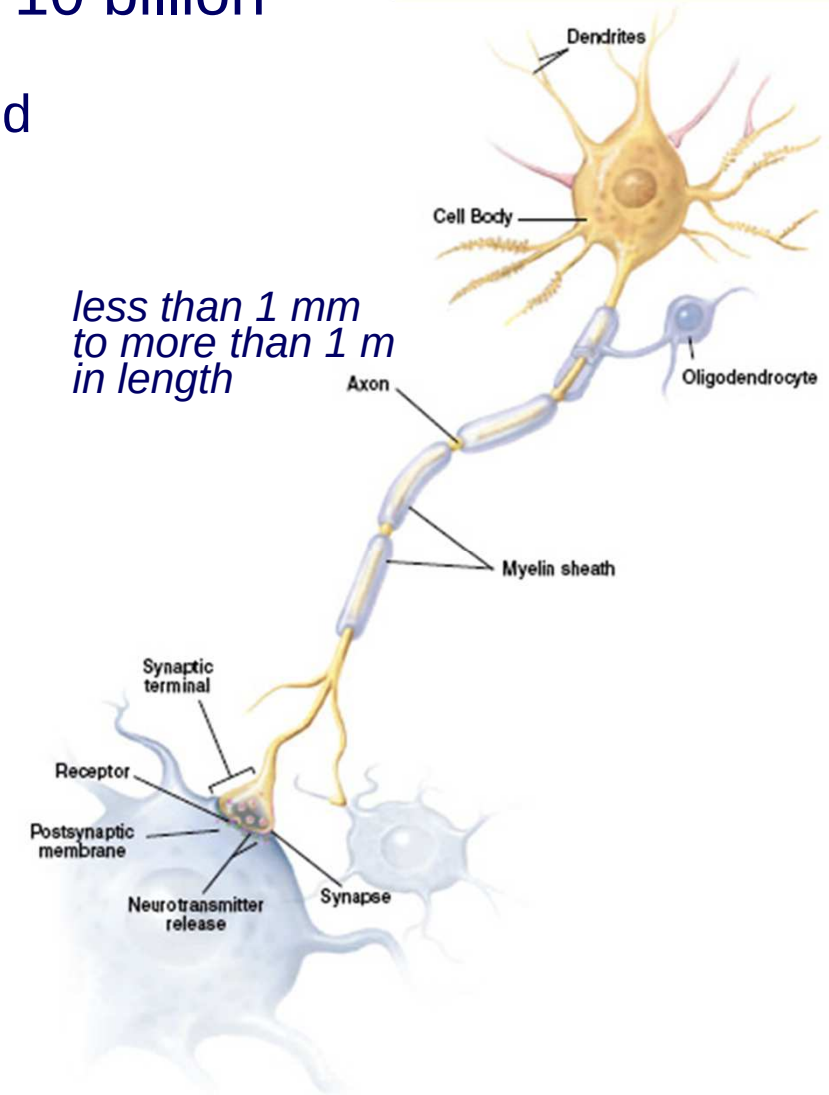


Principles of neural organization

- nerve cells (neurons) – at least 10 billion
  - ✓ cell body (perikaryon, soma)
  - ✓ axon – myelinated or unmyelinated
  - ✓ dendrites
- glial cells (neuroglia):
  - ✓ astrocytes
  - ✓ oligodendrocytes, Schwann cells
  - ✓ microglia
  - ✓ ependymal cells

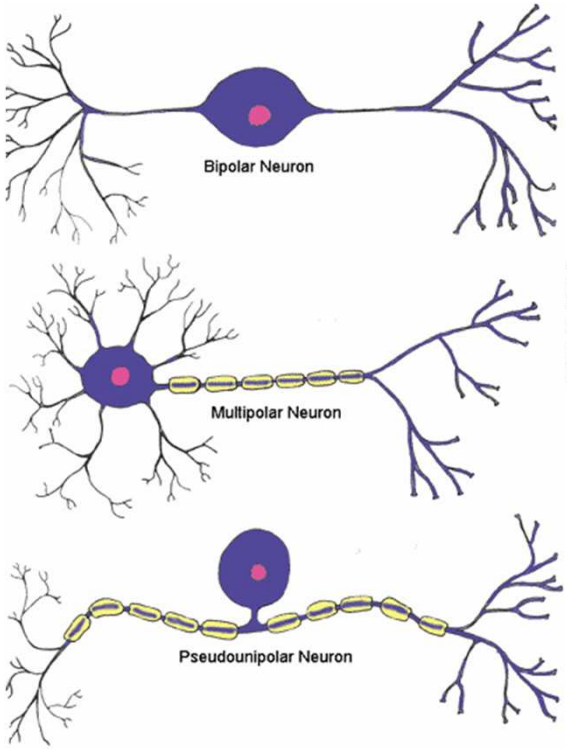


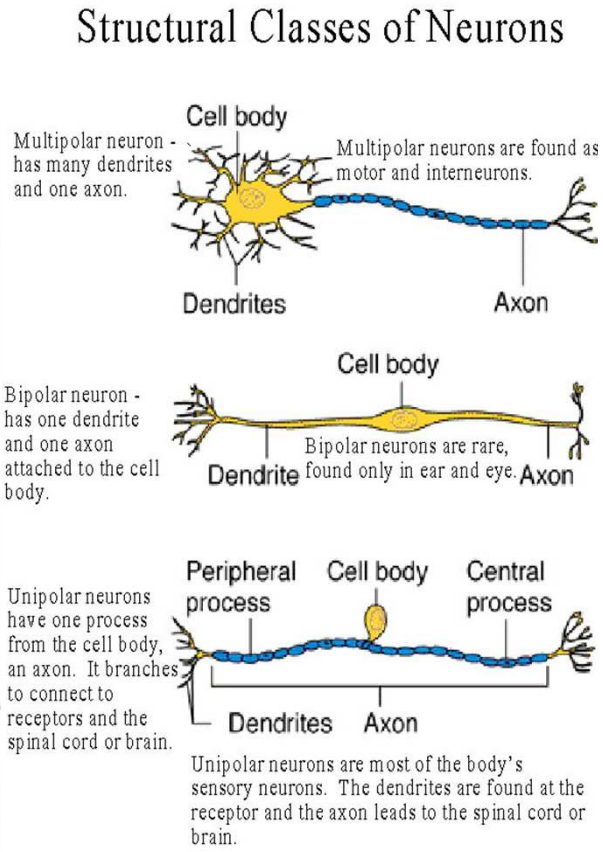
less than 1 mm to more than 1 m in length

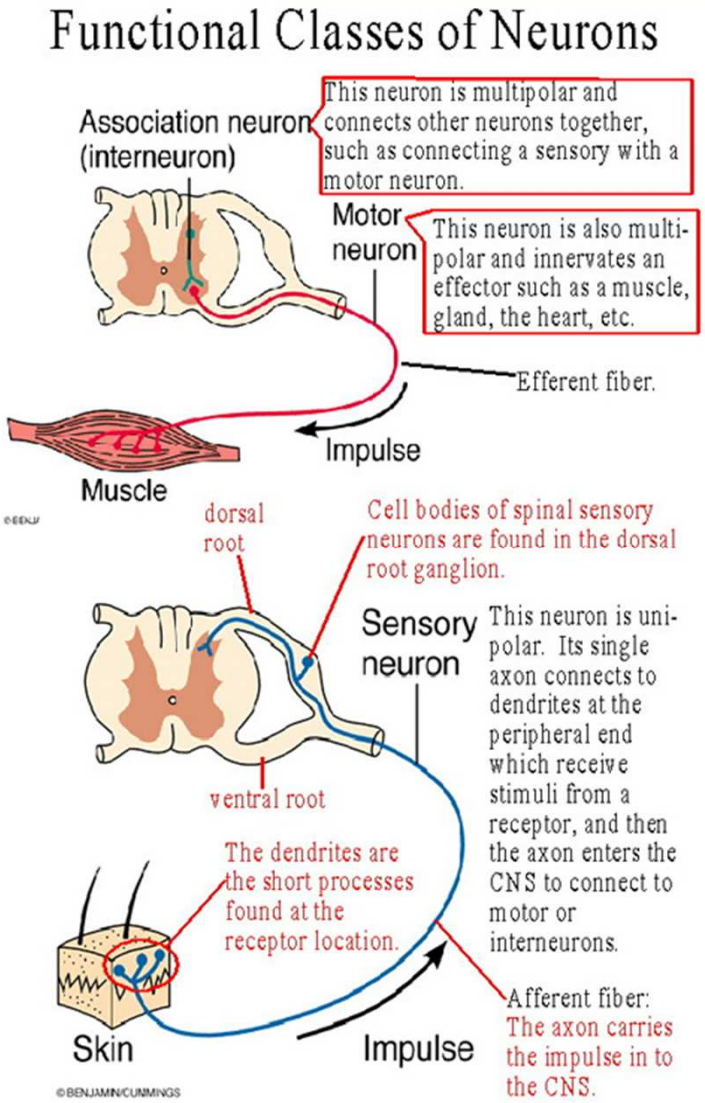


Principles of neural organization

- basic neuron types:
  - ✓ (pseudo)unipolar
  - ✓ bipolar
  - ✓ multipolar

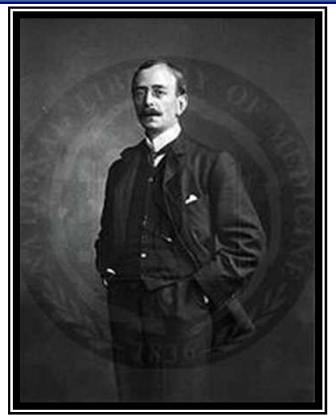




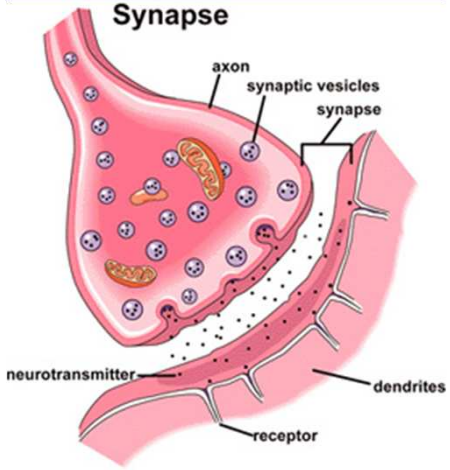


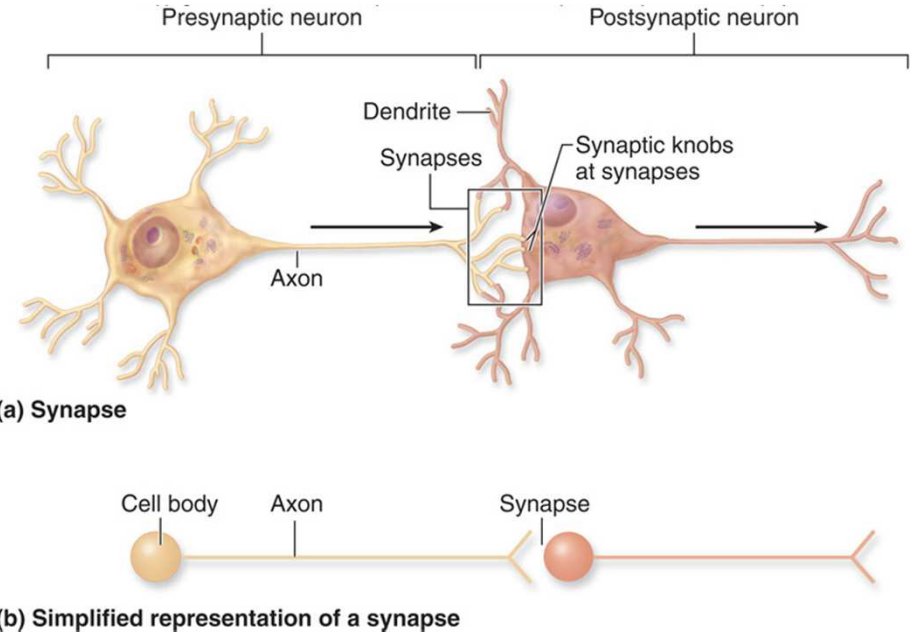
Principles of neural organization

- synapses – structure:
  - ✓ synaptic end bulb (terminal bouton)
    - ➢ presynaptic membrane
    - ➢ synaptic vesicles
  - ✓ synaptic cleft (20-30 nm)
  - ✓ postsynaptic membrane
- synapse types:
  - ✓ axodendritic, axosomatic, axoaxonic etc.
  - ✓ electrical and chemical:
    - ➢ neurotransmitters
    - ➢ transporters
    - ➢ receptors
  - ✓ excitatory and inhibitory
  - ✓ asymmetric (type I) and symmetric (type II)



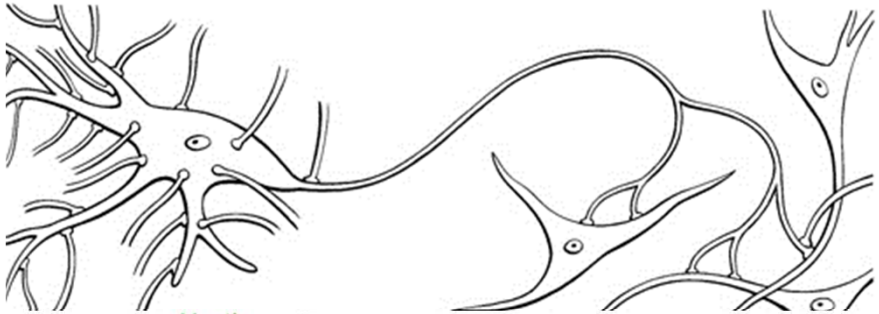
C.S. Sherrington
1857–1952

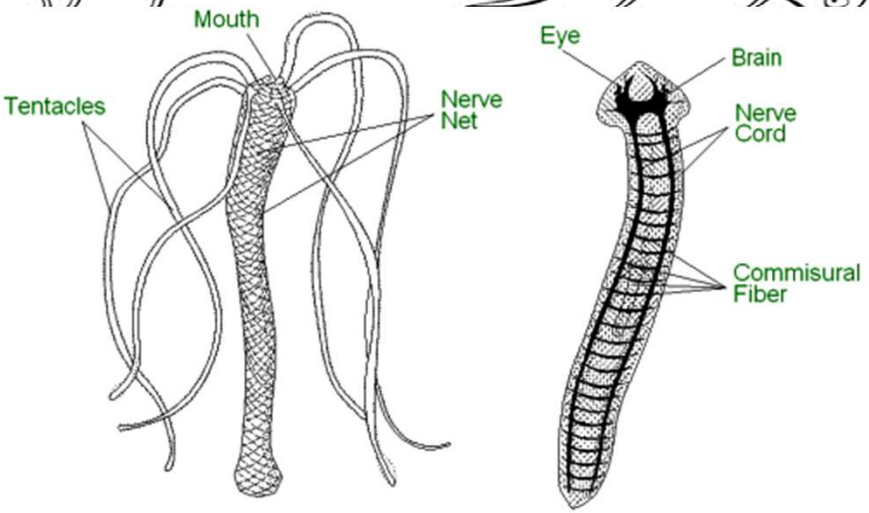


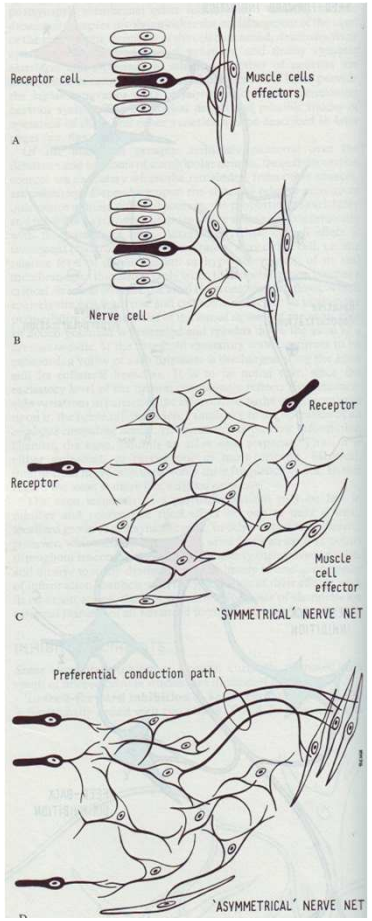


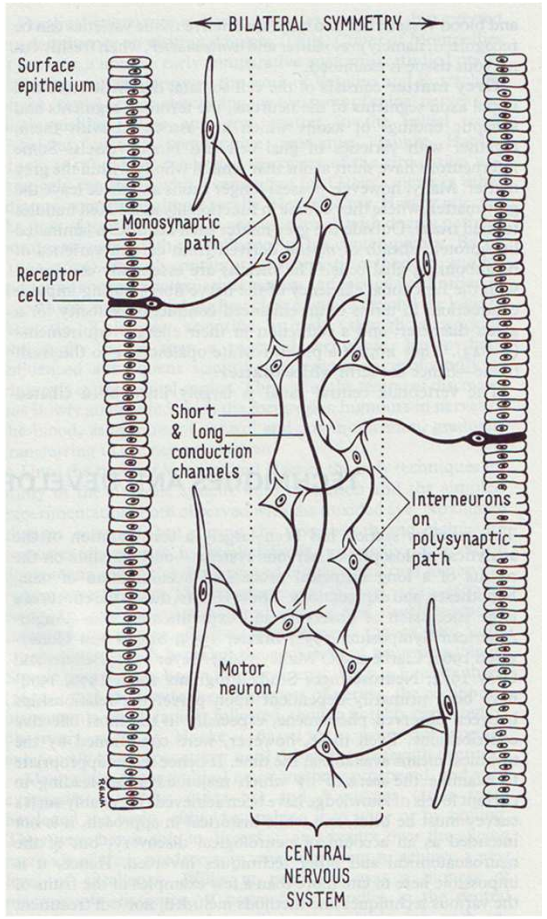
Comparative anatomy of neural organization

- The principles of convergence and divergence



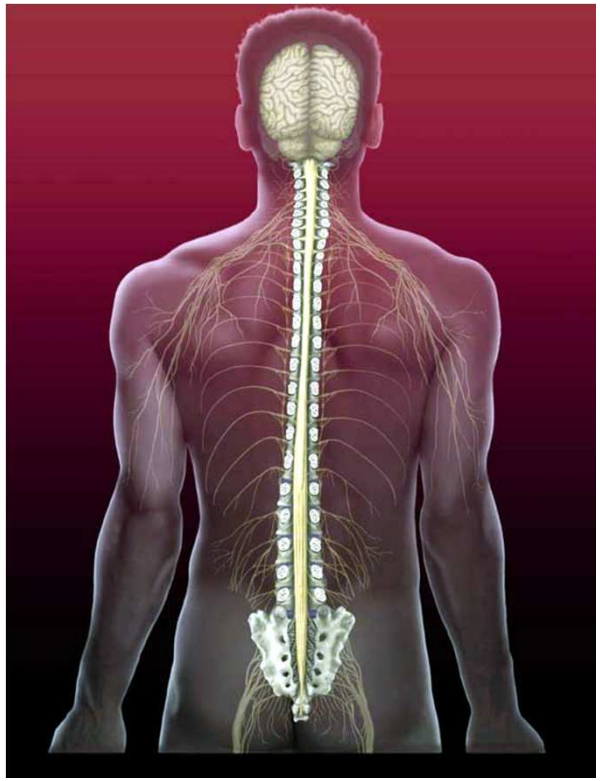


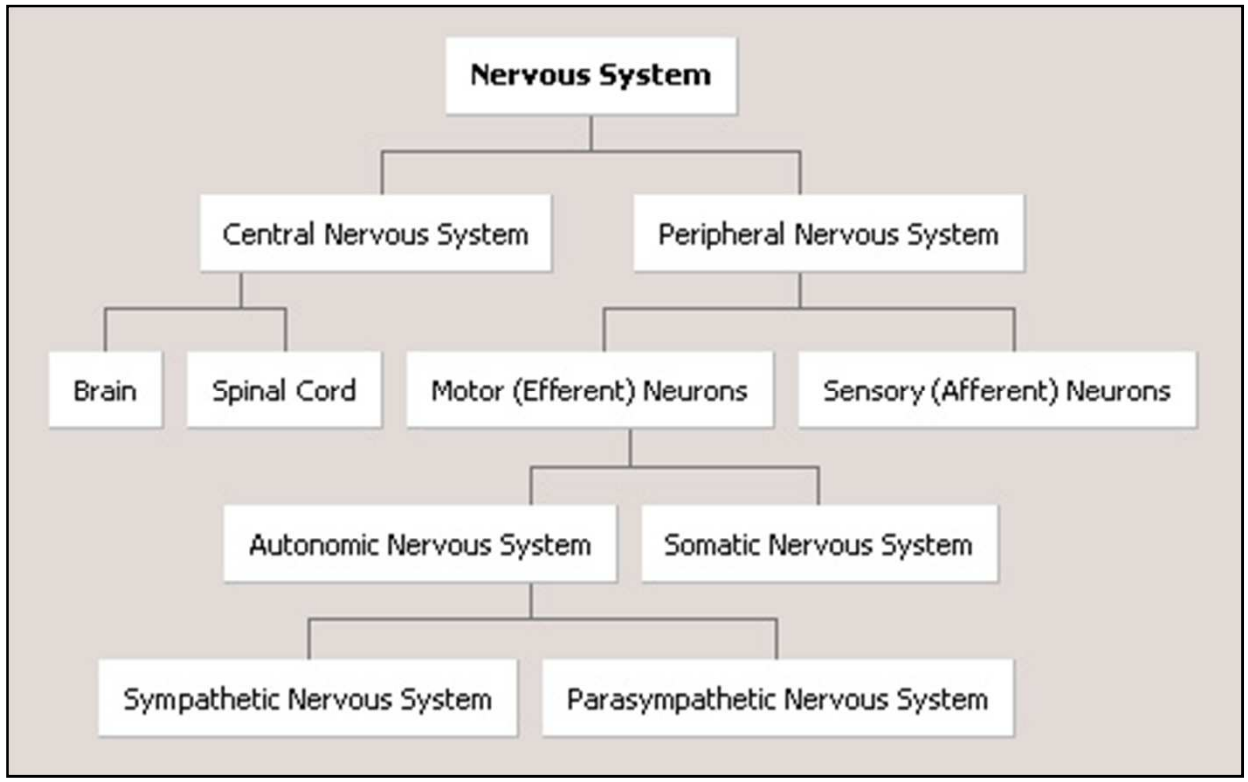




- Nervous system of a radial vs. a primitive organism with bilateral symmetry

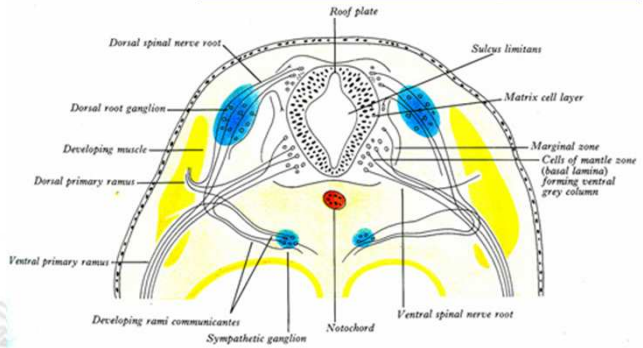
Classification of the nervous system

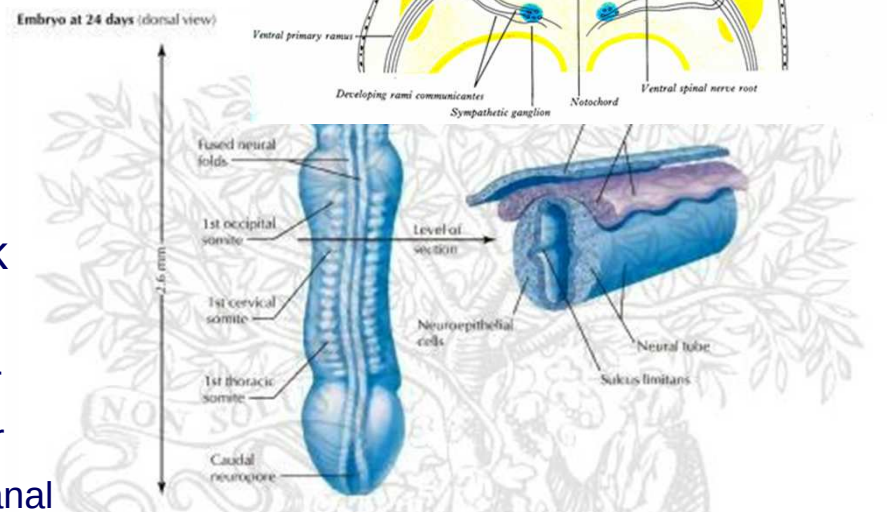


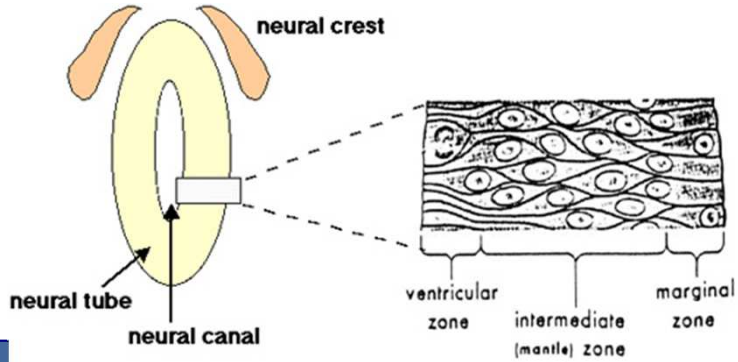


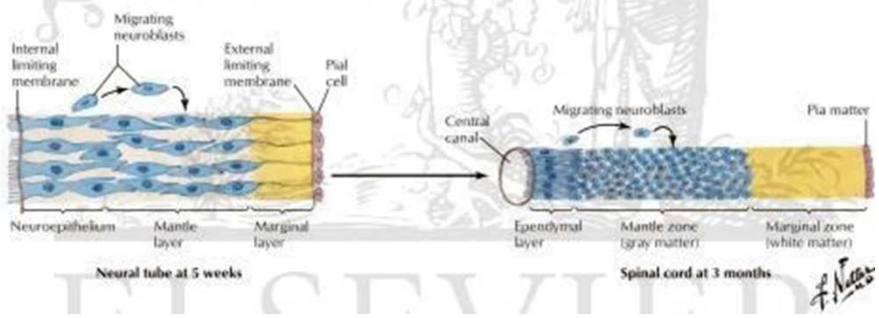
Embryogenesis of the spinal cord

- origin: neuroectodermal
  - ✓ caudal part of the neural tube
- begin of formation: 3rd week
- developmental stages: *basal plate and alar plate*
  - ✓ neural plate
  - ✓ neural groove
  - ✓ neural tube
  - ✓ nerve crest
- closure of posterior neuropore: 4th week
- histogenesis – zones in the wall:
  - ✓ marginal layer ⇨ white matter
  - ✓ intermediate (mantle) layer ⇨ grey matter
  - ✓ ventricular (ependymal) layer ⇨ central canal



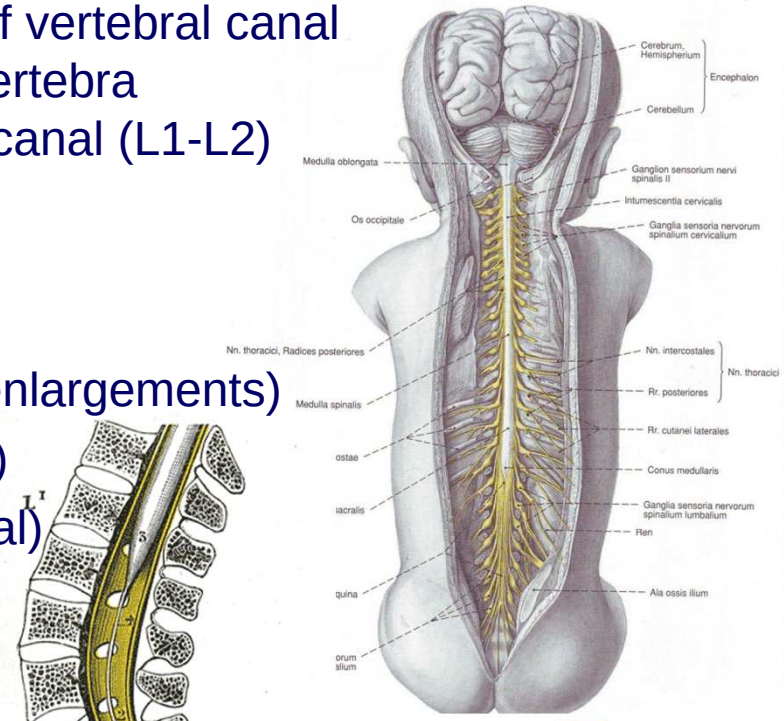


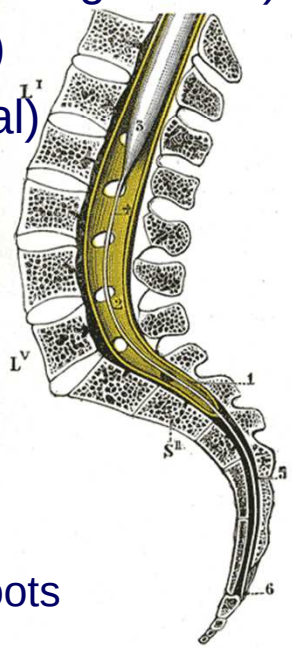


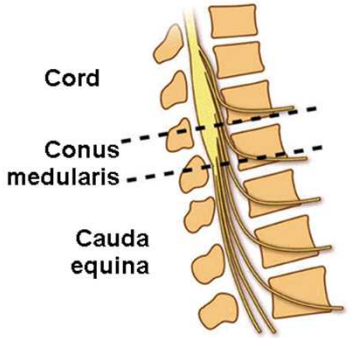


Topographic location, size and extent

- topography and levels – in the vertebral canal
  - ✓ fetal life – the entire length of vertebral canal
  - ✓ at birth – near the level L3 vertebra
  - ✓ adult – upper ⅔ of vertebral canal (L1-L2)
- average length:
  - ✓ ♂ – 45 cm long
  - ✓ ♀ – 42-43 cm
- diameter ~ 1-1.5 cm (out of enlargements)
- weight ~ 35 g (2% of the CNS)
- shape – round to oval (cylindrical)
- terminal part:
  - ✓ *conus medullaris*
  - ✓ *filum terminale internum* (cranial 15 cm) – S2
  - ✓ *filum terminale externum* (final 5 cm) – Co2
  - ✓ *cauda equina* – collection of lumbar and sacral spinal nerve roots

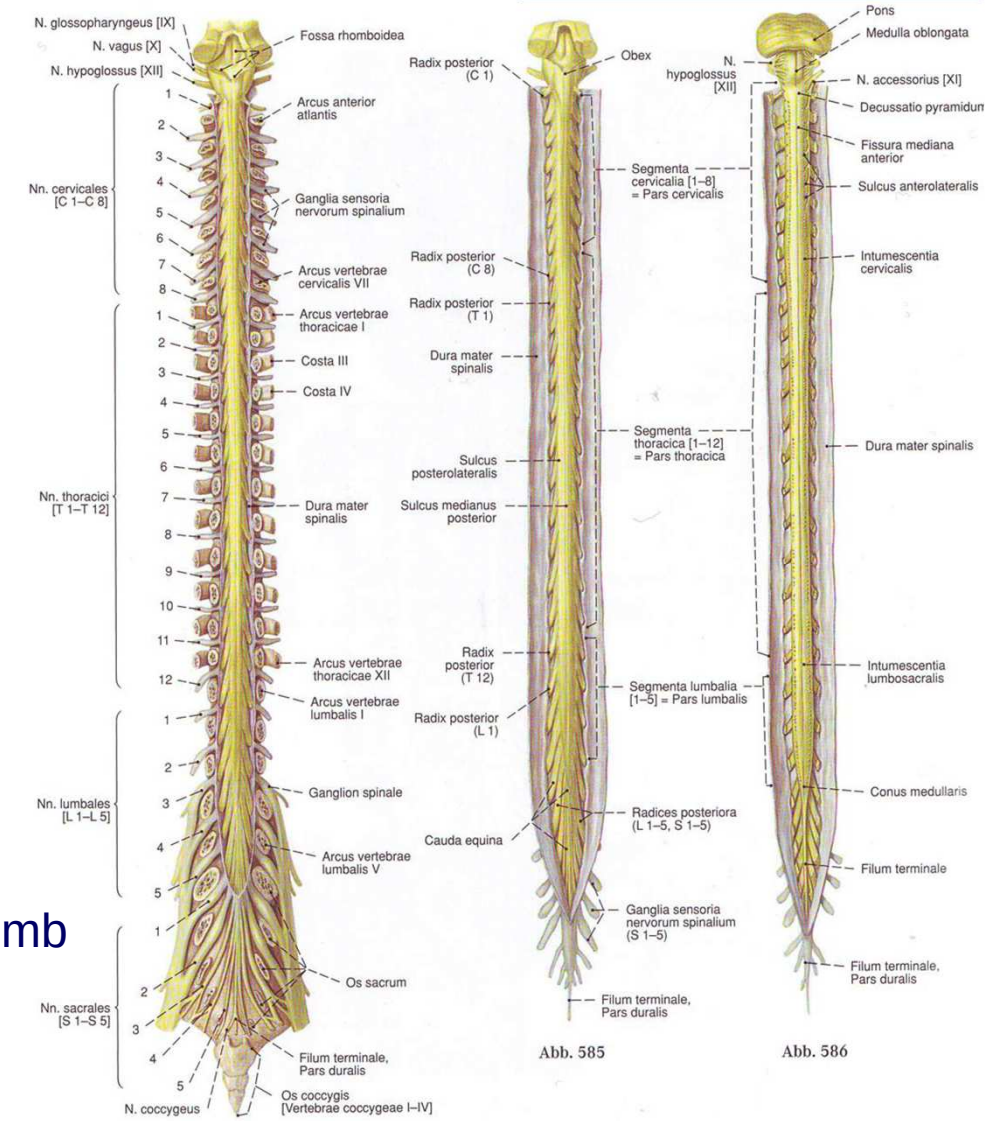






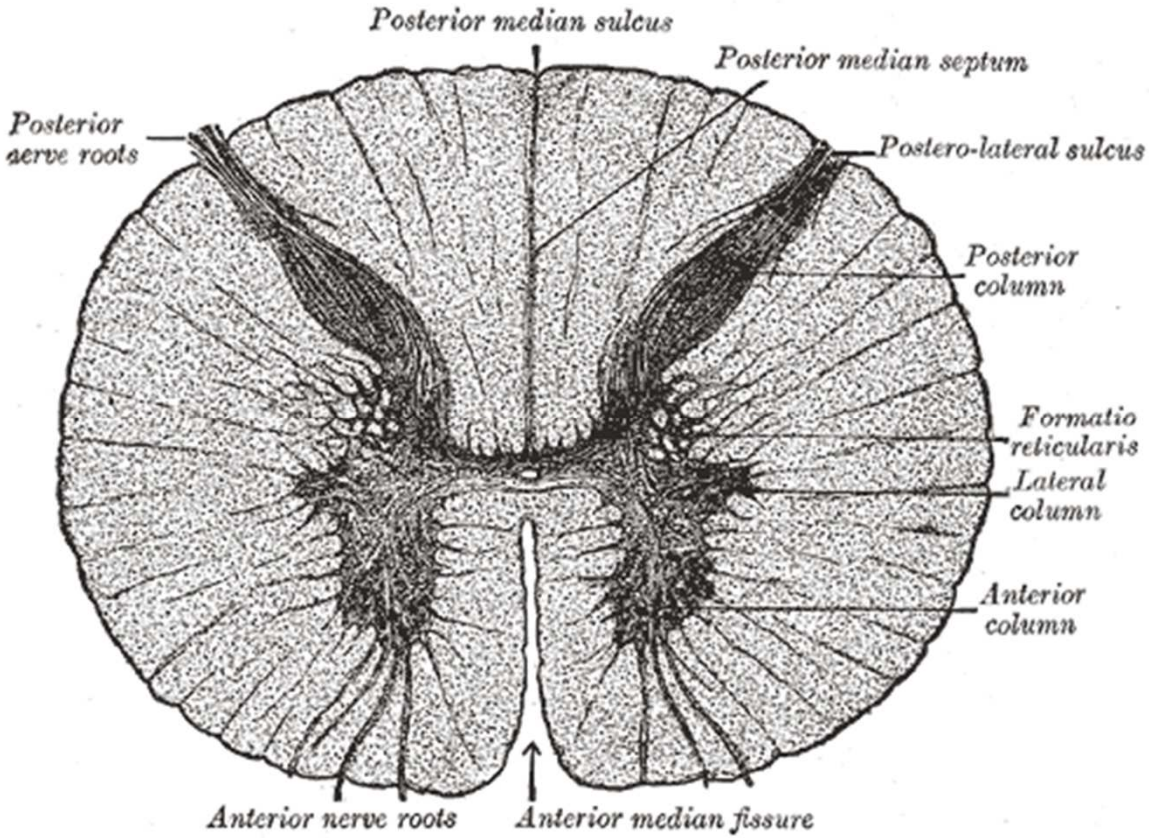
Macroscopic anatomy – enlargements

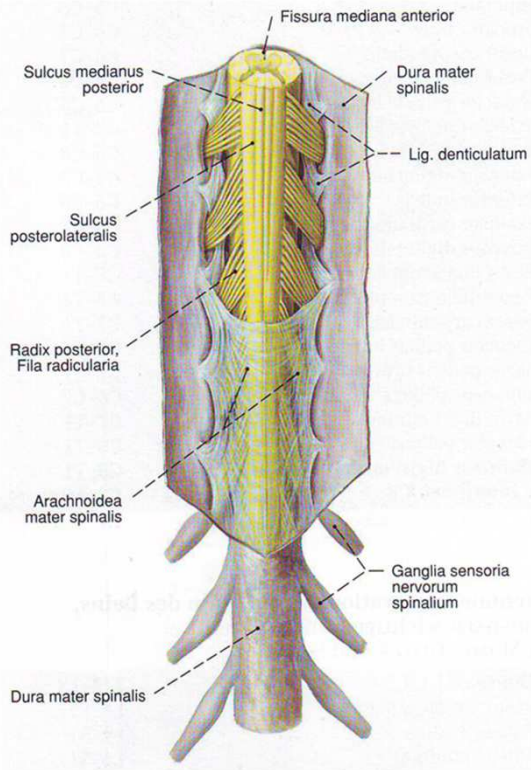
- cervical enlargement, *intumescentia cervicalis:*
  - ✓ spinal segments (C4-Th1)
  - ✓ vertebral levels (C4-Th1)
  - ✓ provides upper limb innervation (brachial plexus)
- lumbosacral enlargement, *intumescentia lumbosacralis:*
  - ✓ spinal segments (L2-S3)
  - ✓ vertebral levels (Th9-Th12)
  - ✓ segmental innervation of lower limb (lumbosacral plexus)



External surface structure

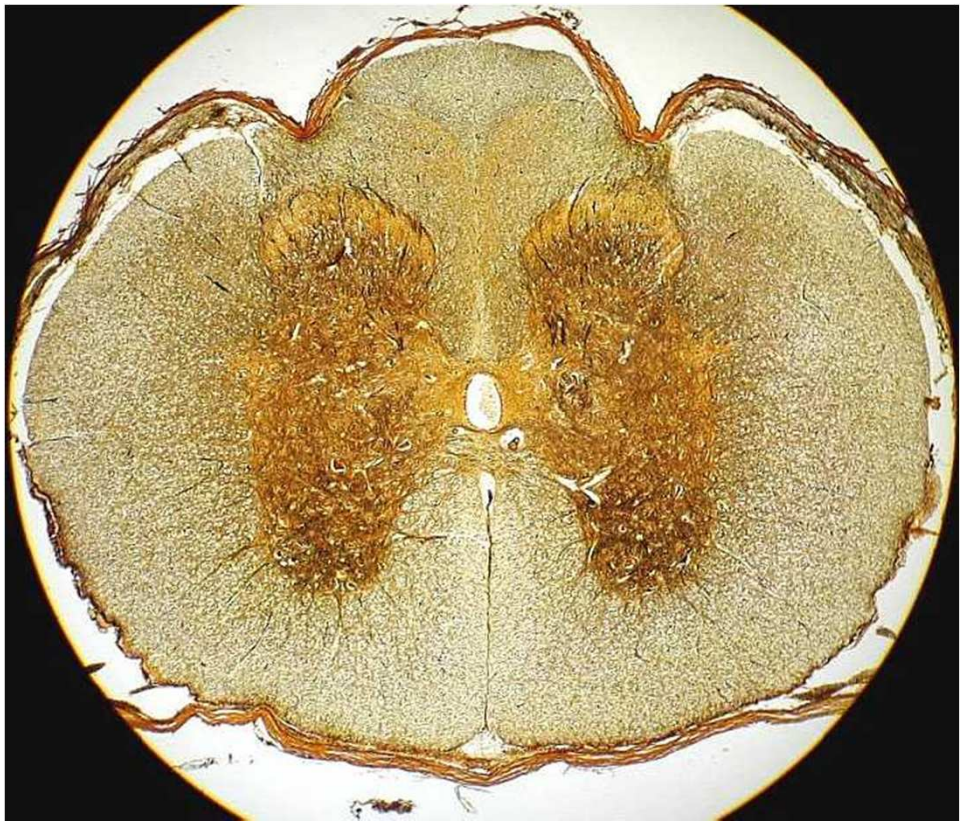
- **Two symmetrical halves**:
  - ✓ divided by two external longitudinal grooves:
    - ➢ a deeper anterior median fissure
    - ➢ a shallower posterior median sulcus (less prominent)
  - ✓ joined by a commissural band of nervous tissue





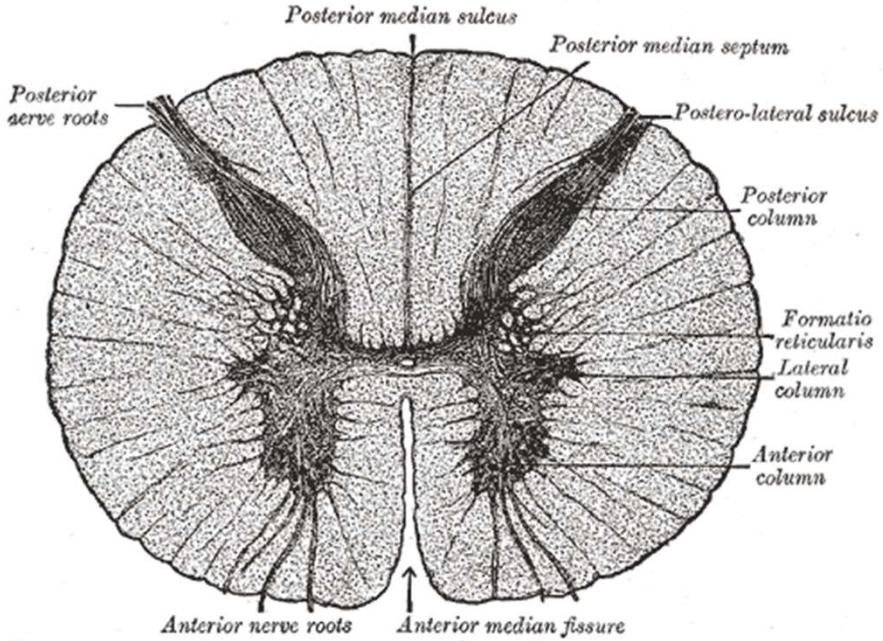
Anterior median fissure

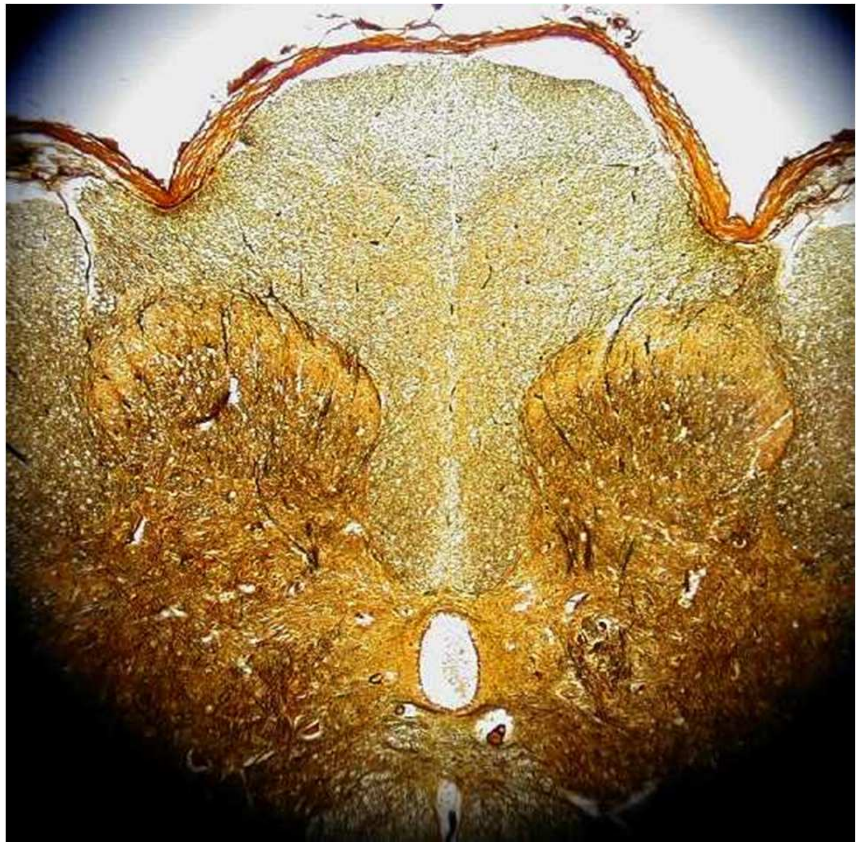
- average depth ~ 3 mm:
  - ✓ deeper at more caudal levels
- roof:
  - ✓ a reticulum of *pia mater*
- floor:
  - ✓ a lamina of nerve fibers, anterior white commisure
- anterior spinal artery
- anterolateral suclus – ventral nerve root



Posterior median septum

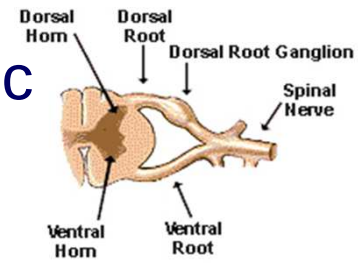
- average depth ~ 4-6 mm:
  - ✓ diminishing caudally
- neuroglial partition:
  - ✓ reaching the gray matter
- posterolateral suclus – dorsal nerve root



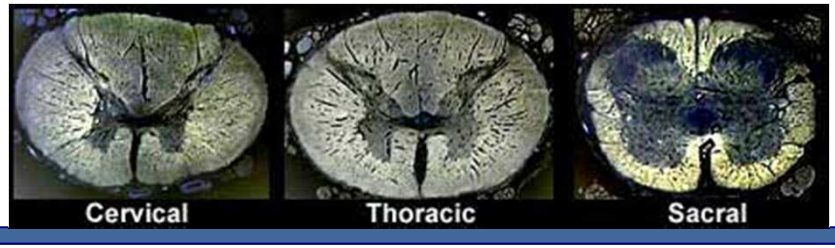


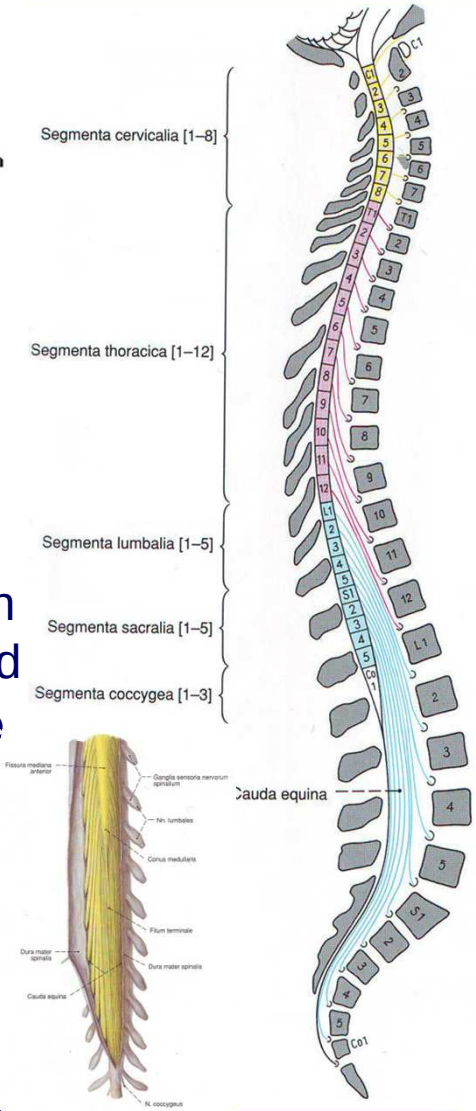
Segmental structure

- 31 segments:
  - ✓ 8 cervical
  - ✓ 12 thoracic
  - ✓ 5 lumbar
  - ✓ 5 sacral
  - ✓ 1 coccygeal



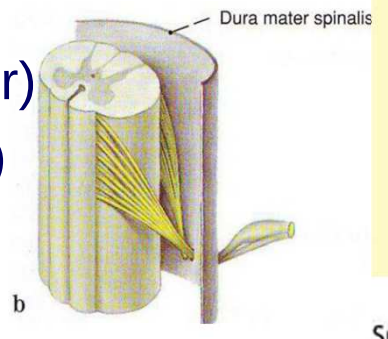
- segment ≠ vertebra:
  - ✓ growth of the vertebral column exceeds that of the spinal cord
  - ✓ all segments terminate **above** level L1/L2 ⇨ *cauda equina*
  - ✓ vary in diameter and length

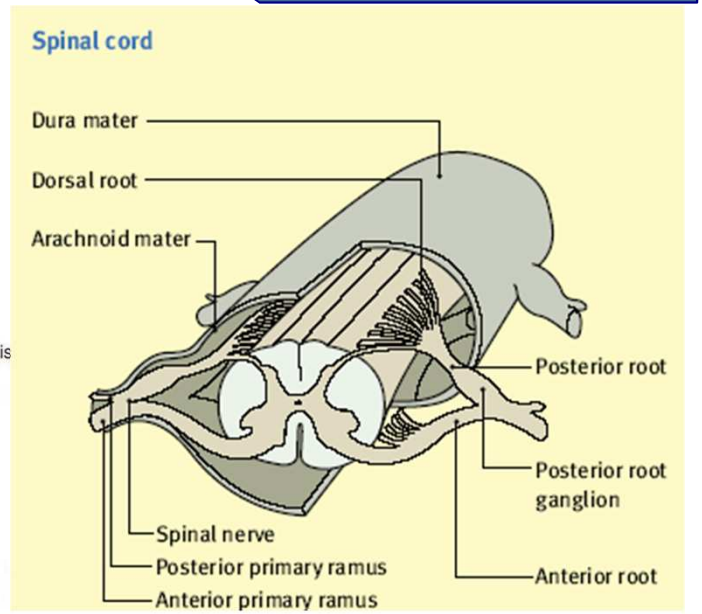


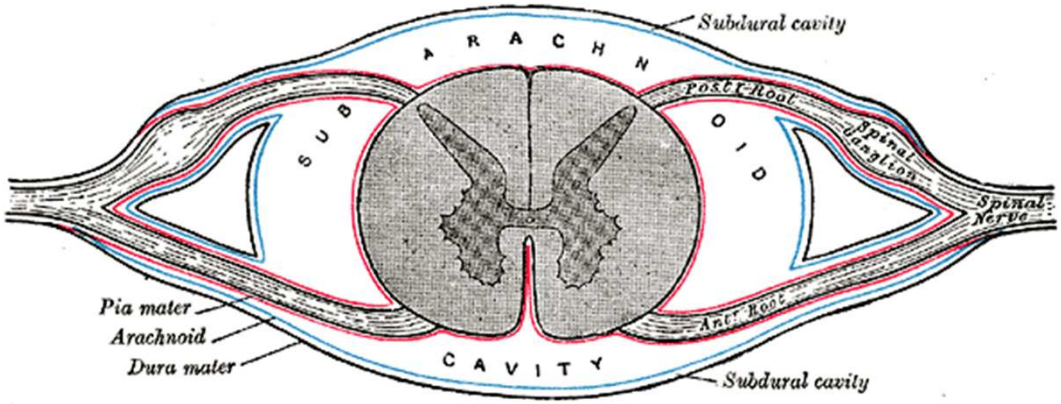


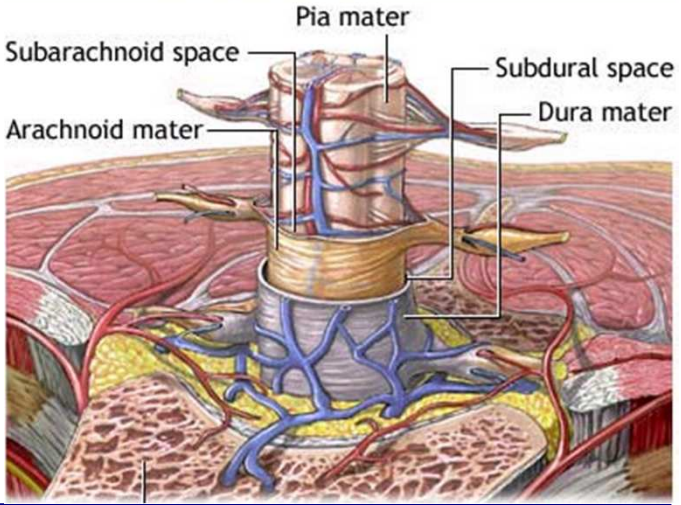
Meningeal coverings

- three meninges:
  - ✓ *spinal dura mater*
    - ➢ epidural and subdural spaces
  - ✓ *arachnoid mater*
    - ➢ subarachnoid space ⇨ cerebrospinal fluid (liquor)
  - ✓ *pia mater (leptomeninges)*
    - ➢ perivascular spaces ⇨ spinal blood vessels



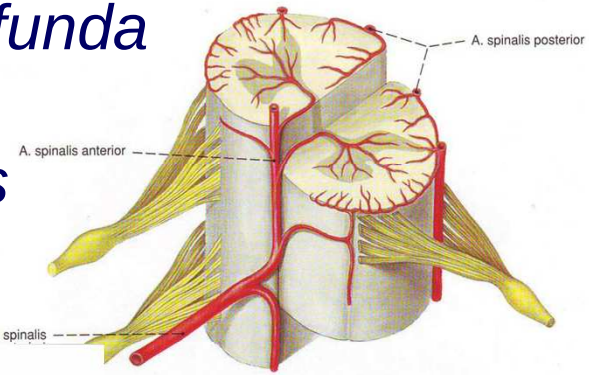


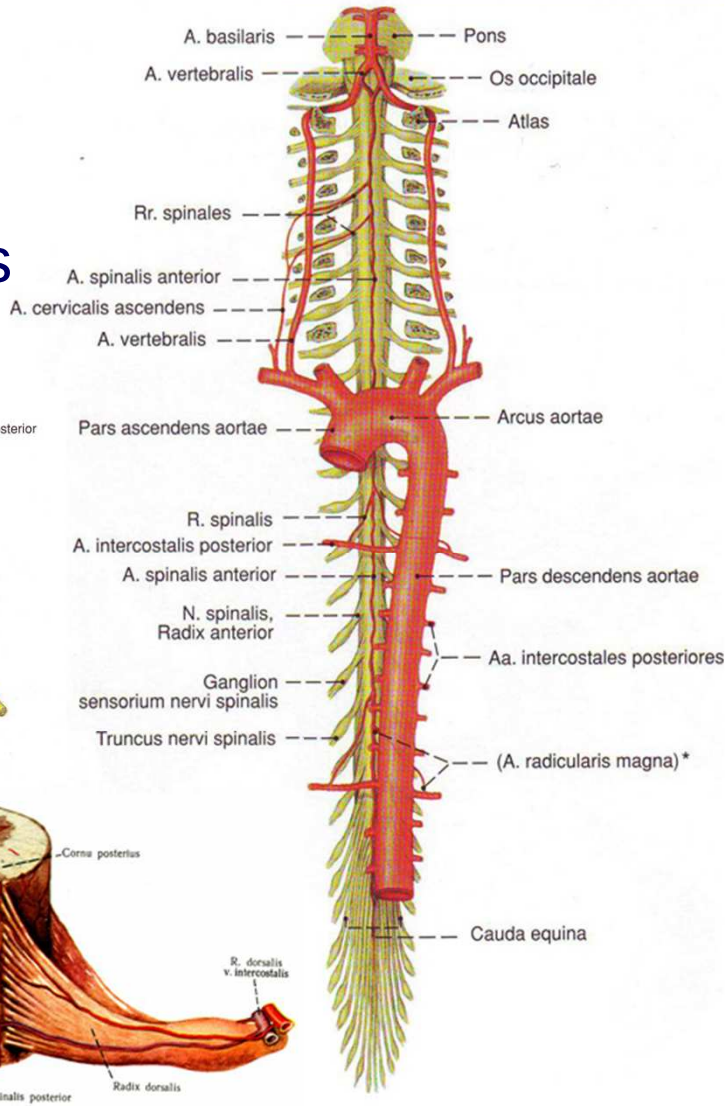


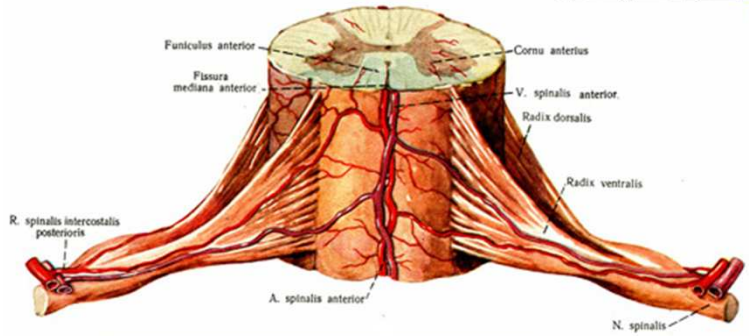


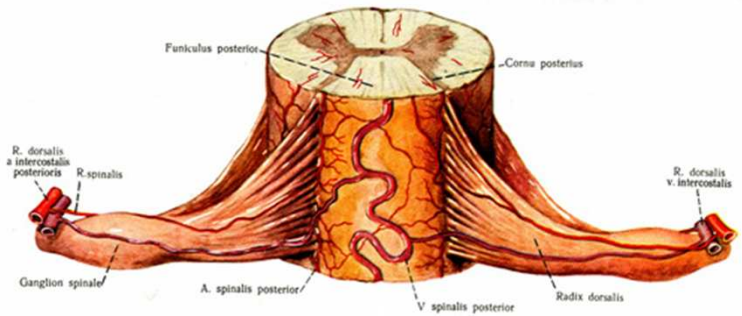
Arterial blood supply

- longitudinal trunk (*a. vertebralis*):
  - ✓ unpaired *a. spinalis anterior*
  - ✓ *aa. spinales posteriores*
- segmental supply: radicular arteries
  - ✓ *a. cervicalis ascendens*
  - ✓ *a. cervicalis profunda*
  - ✓ *a. vertebralis*
  - ✓ *aa. intercostales posteriores*
  - ✓ *aa. lumbales*



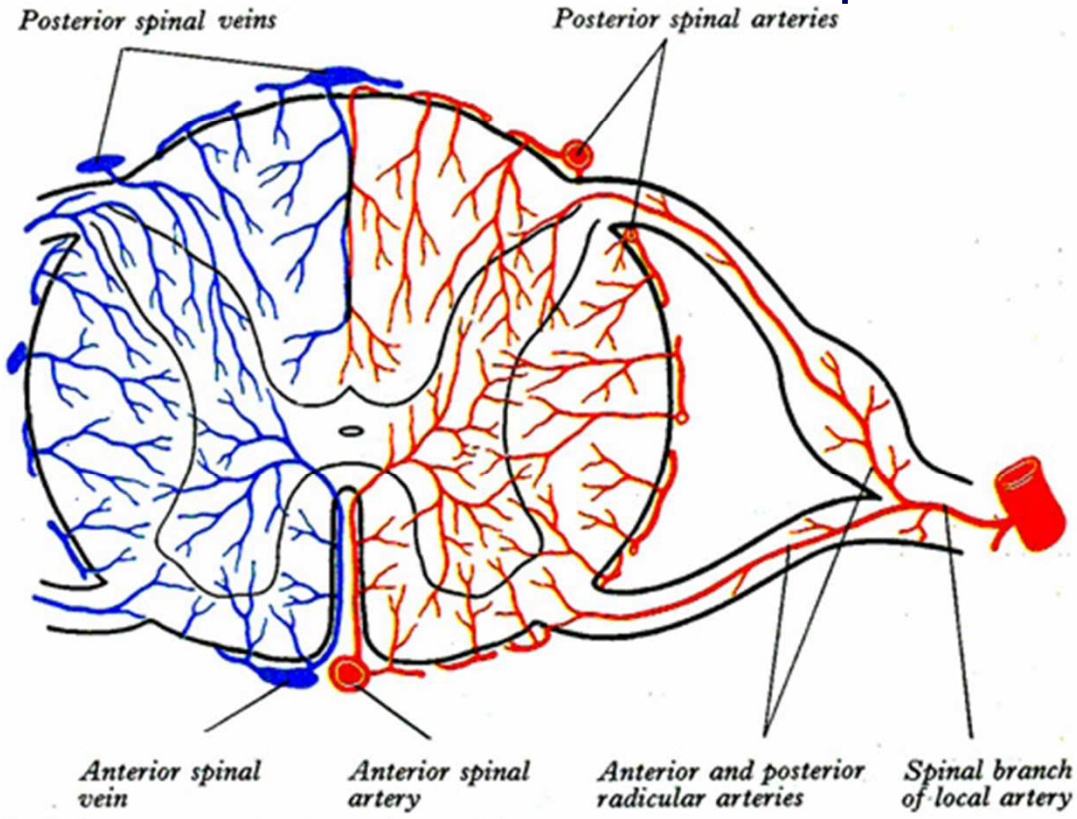


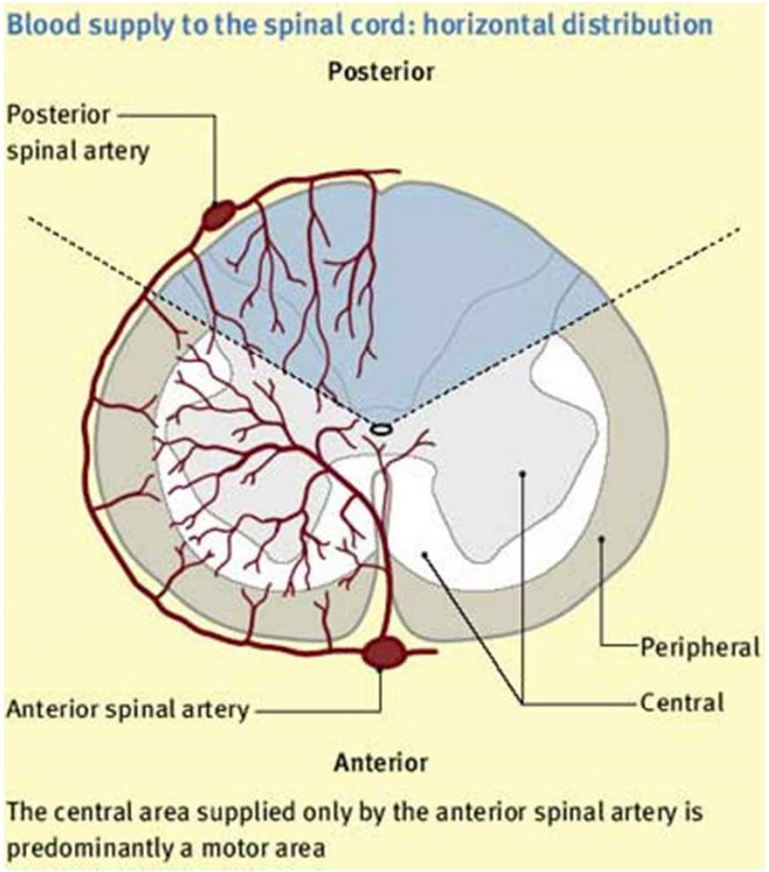




Intrinsic blood vessels

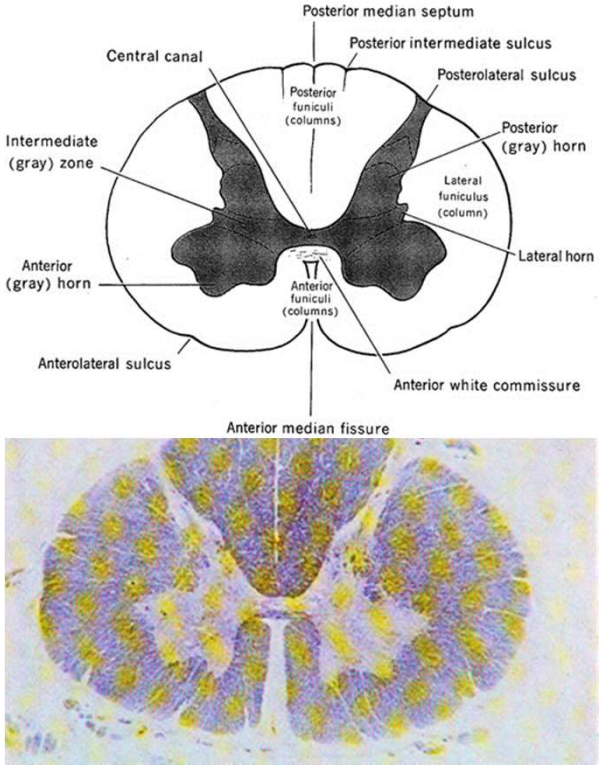
- Venous drainage – 6 channels:
  - ✓ anterior longitudinal trunks
  - ✓ posterior longitudinal trunks
  - ✓ internal vertebral venous plexuses

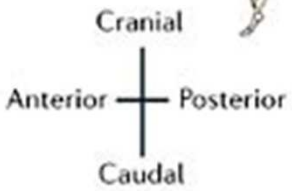


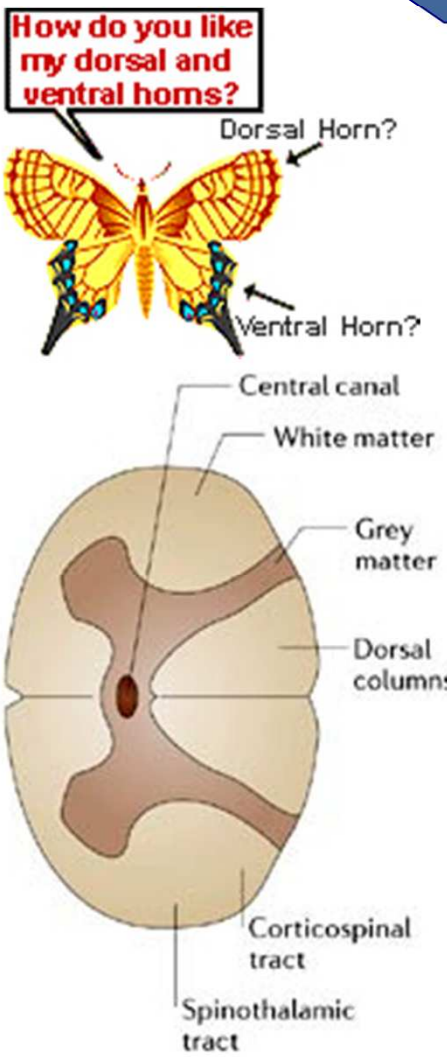


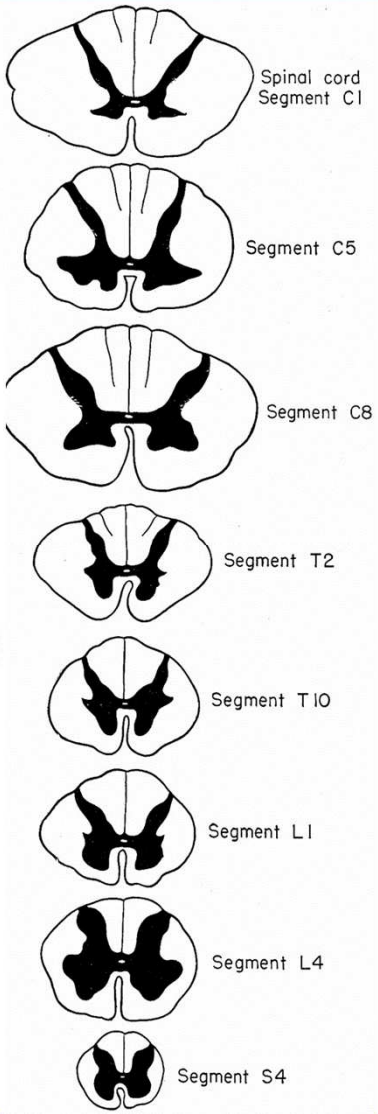
Internal structure of the spinal cord

- grey matter, *substantia grisea*
  - ✓ butterfly-like or H-shaped
- white matter, *substantia alba*
- vary in diameter and length at different levels



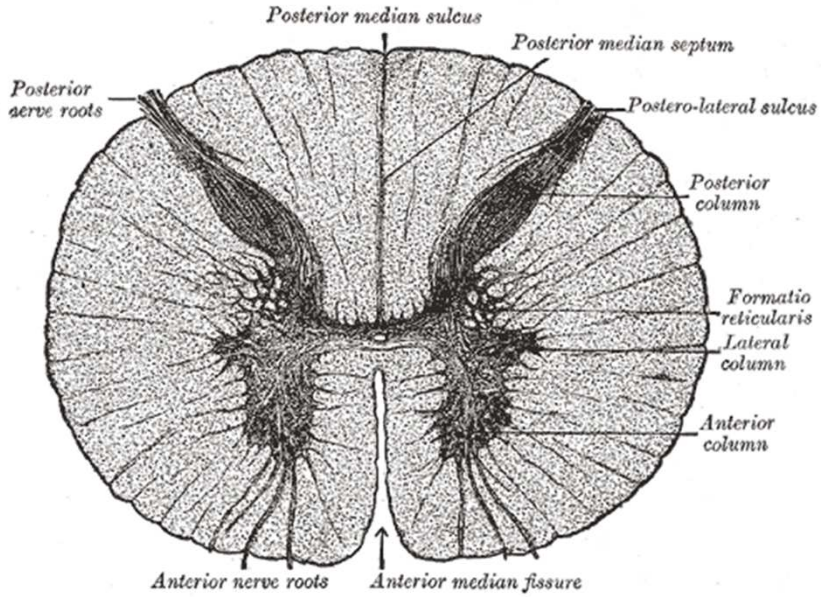






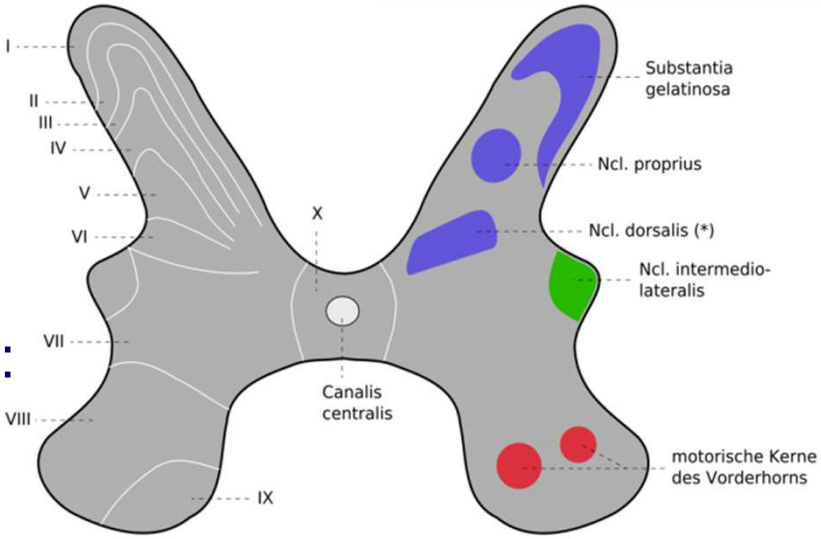
Grey matter, *substantia grisea*

- composition:
  - ✓ neuronal perikarya
  - ✓ dendrites with their synapses
  - ✓ glial supporting cells
  - ✓ blood vessels
- anterior (ventral) column:
  - ✓ *cornu anterius (columna anterior)*
- posterior (dorsal) column:
  - ✓ *cornu posterius (columna posterior)*
- lateral column:
  - ✓ *cornu laterale – Th1-L2; S2-S4 (columna intermedia)*
- central canal:
  - ✓ *canalis centralis* ⇨ *liquor cerebrospinalis*
  - ✓ *substantia gelatinosa centralis*
- grey commissure:
  - ✓ *commissura grisea*



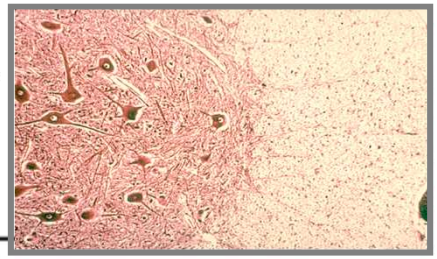
General structure of the grey matter

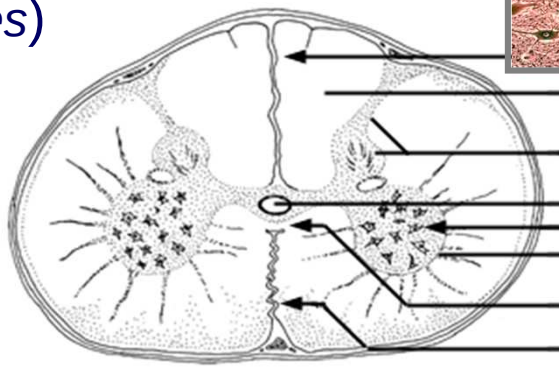
- posterior column (dorsal horn):
  - ✓ *apex, caput, cervix, basis*
  - ✓ projection neurons *(neurocyti funiculares)* and interneurons *(neurocyti interni)*
- lateral column (intermediolateral horn):
  - ✓ visceromotor neurons
    - ➢ parasympathetic
    - ➢ sympathetic
- anterior column (ventral horn):
  - ✓ motor neurons (*neurocyti radiculares*)
    - ➢ large alpha motoneurons (ACh)
    - ➢ small gamma motoneurons (ACh)
    - ➢ Renshaw cells (Gly) (inhibitory interneurons)



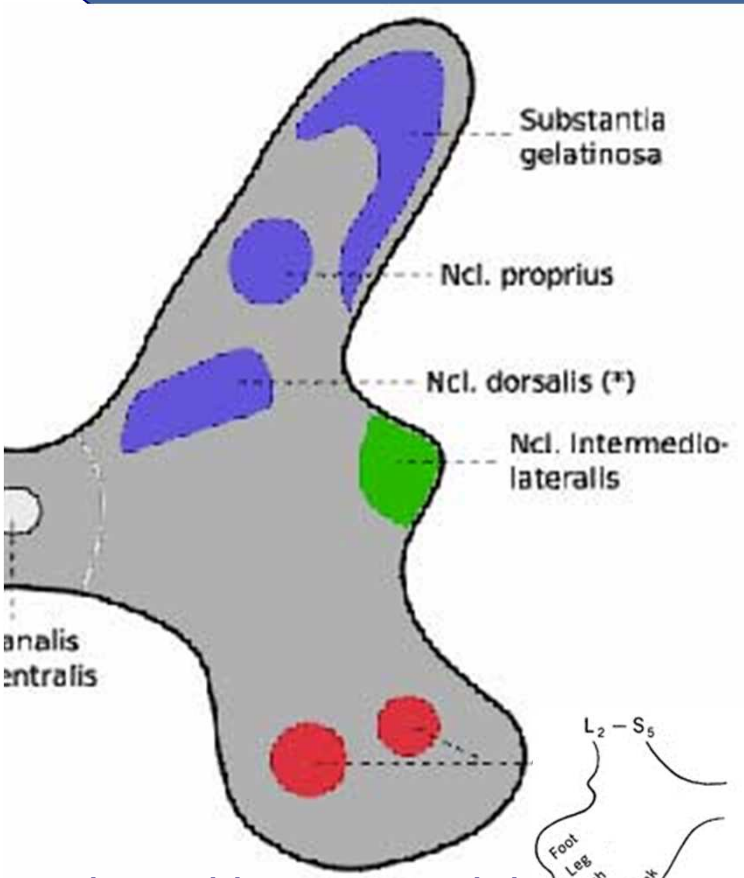
Schichtengliederung (Laminae)

* auch *Ncl. thoracicus posterior* bzw. *Stilling-Clarke*



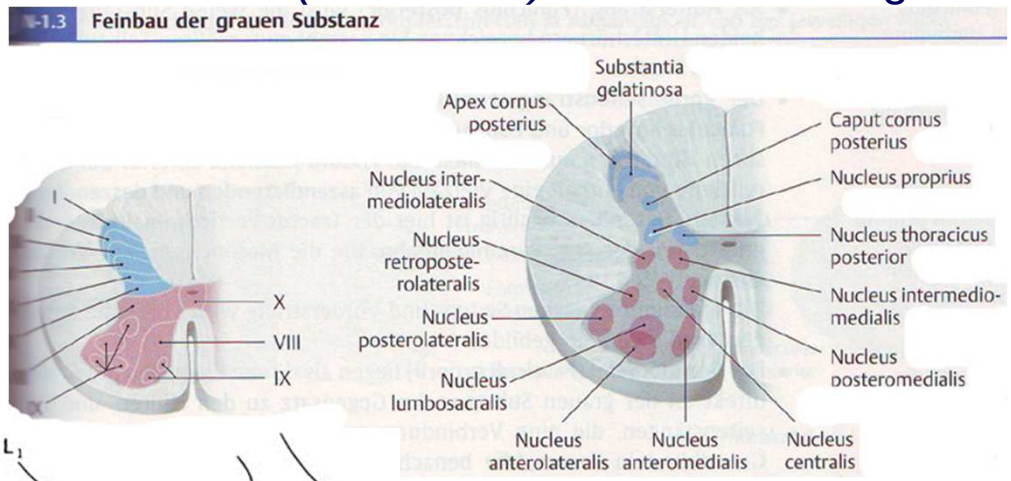


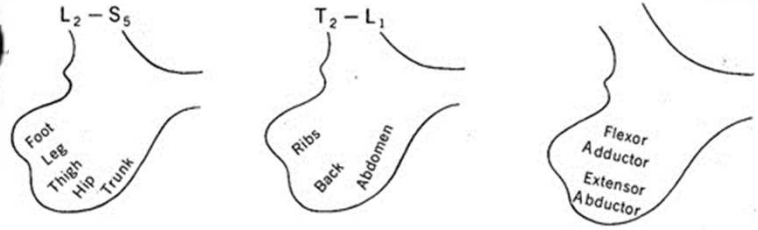
Grey matter – nerve cell groups



dorsal horn: 4 nuclei

- ✓dorsomarginal nucleus (*zona spongiosa*)
- ✓*substantia gelatinosa* of Rolando
- ✓*nucleus proprius* ⇨ receive pain impulses
- ✓*nucleus dorsalis (thoracicus)* of Clarke-Stilling





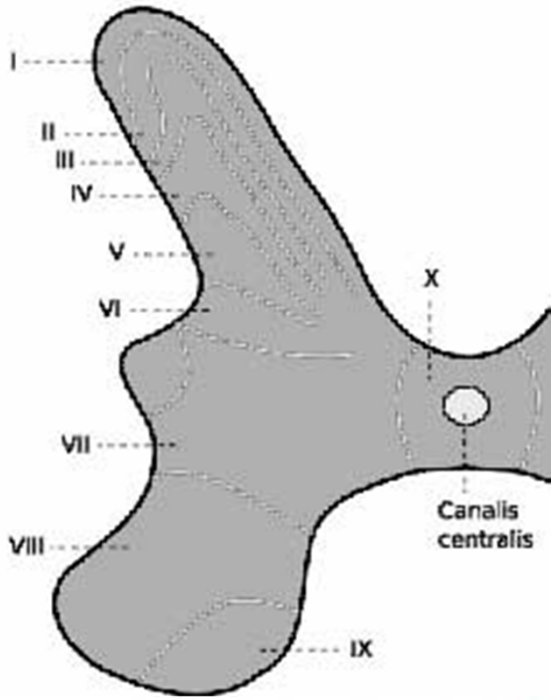
ventral horn: 5 nuclei

- ✓medial group
  - ➢ventromedial nucleus
  - ➢dorsomedial nucleus
- ✓lateral group
  - ➢ventrolateral nucleus
  - ➢central nucleus
  - ➢dorsolateral nucleus

lateral horn: 2 nuclei

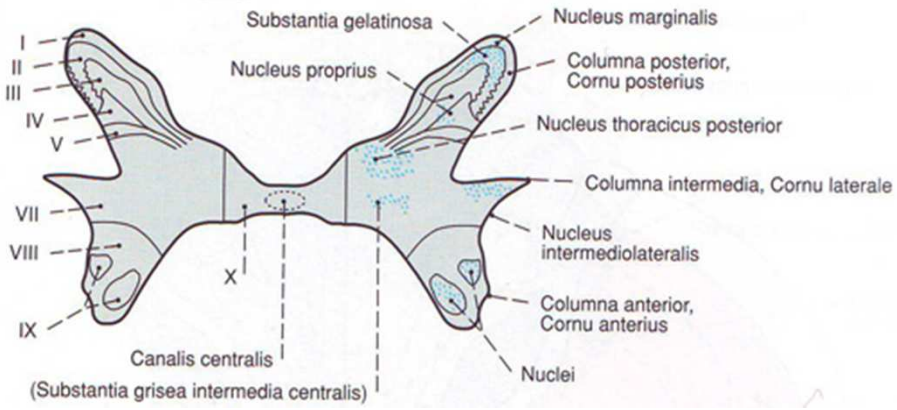
- ✓sympathetic: intermediolateral nucleus (Th1-L2)
- ✓parasympathetic: intermediomedial nucleus (S2-S4)
  - ✓spinal reticular nucleus

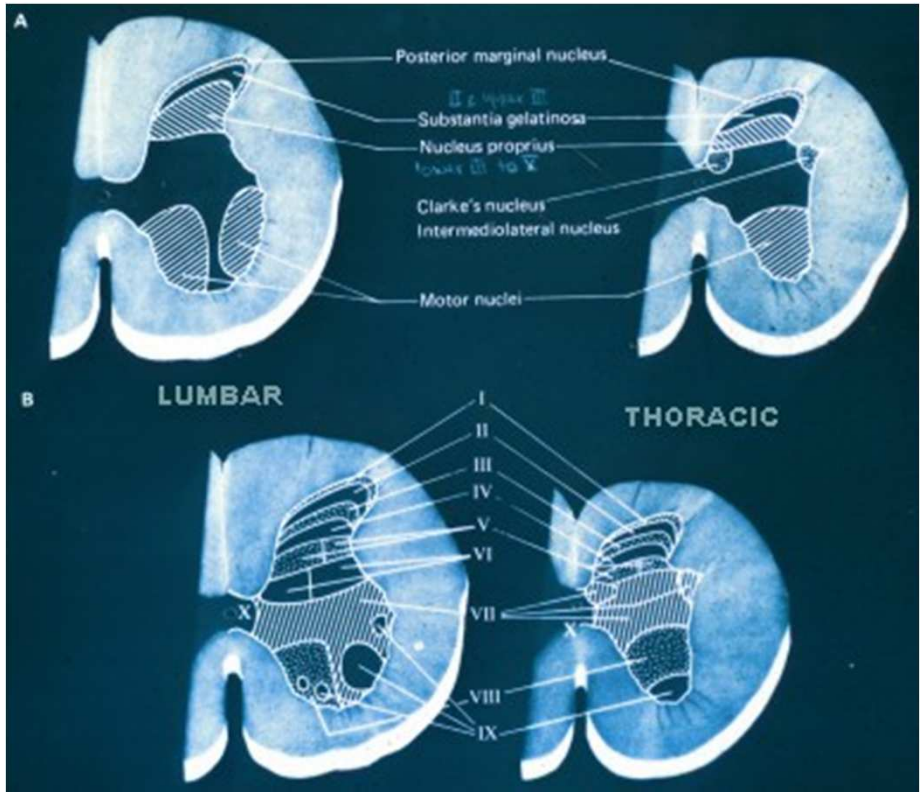
Grey matter – laminar architecture



10 distinct cellular laminae of Rexed:

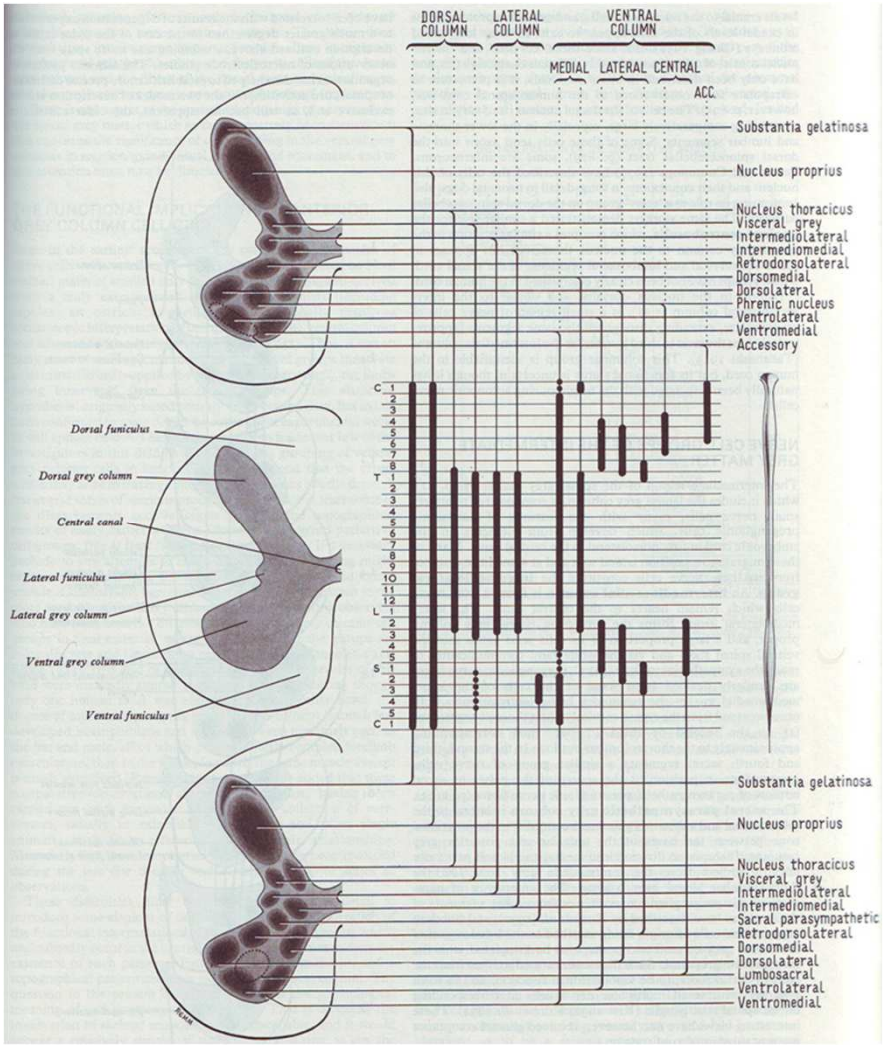
- ✓I-VI: dorsal horn
- ✓VII: intermediate zone and lateral horn
- ✓VIII-IX: ventral horn
- ✓X: central canal + substantia gelatinosa (of Rolando)





Grey matter – functional organization

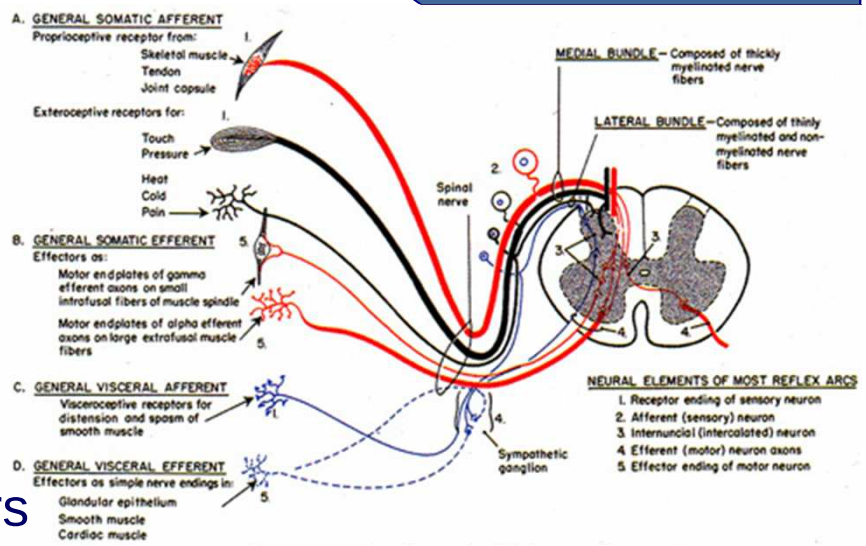
- different sensations – different neurons (the law of Bell and Magendie)
- the theory of nerve components:
- dorsal horn mediates sensation
  - ✓ general somatic afferents
  - ✓ general visceral afferents (GVA)
- ventral horn mediates motor function
  - ✓ general somatic efferents (GSE) for the ventral roots
- intermediate horn
  - ✓ receives GVA axons
  - ✓ originates GVE axons
- the perikarya in various nuclei differ in size, shape and connections
- nuclear groups in grey columns vary in longitudinal extent

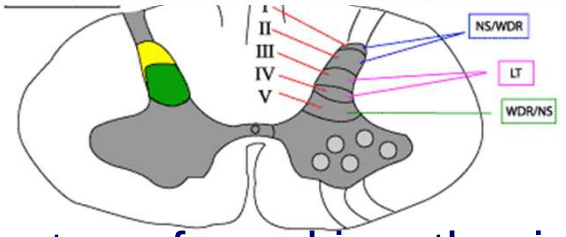


Longitudinal extent of the nuclei

Functional organization

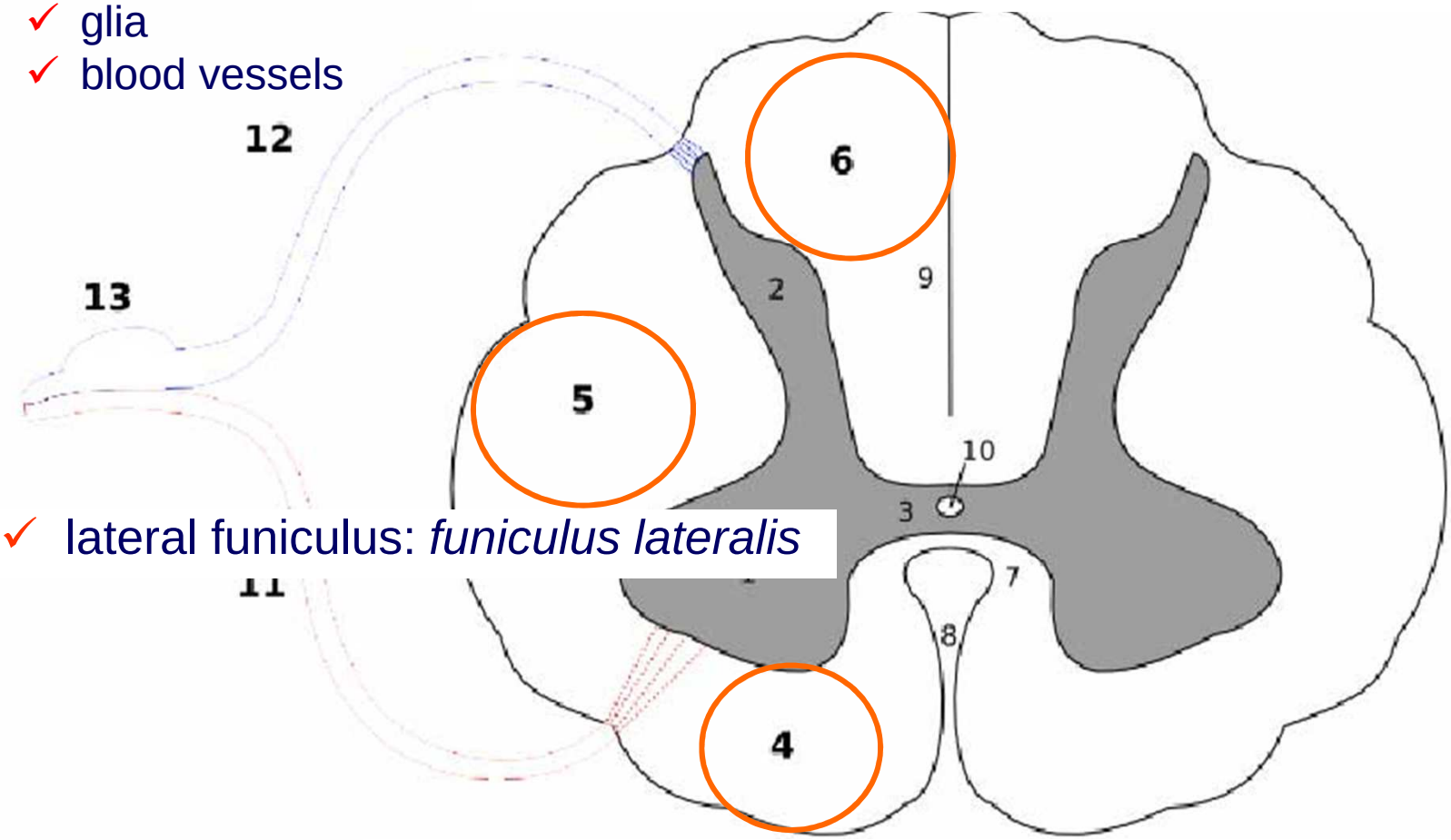
- dorsal horn axons segregates into:
  - ✓ lateral bundle
  - ✓ medial bundle
- each dorsal root axon trifurcates into:
  - ✓ horizontal branches
  - ✓ ascending branches
  - ✓ descending branches
- lateral division of the dorsal roots
  - ✓ consists of small unmyelynated C fibers
  - ✓ mediate pain and temperature sensation
  - ✓ terminate in nuclei of the dorsal horn
- medial division of the dorsal roots
  - ✓ consists of larger, heavily myelynated A fibers
  - ✓ mediate discriminatory sensory modalities – touch, texture, form, kinesthesia
  - ✓ ascending branches terminate on the nuclei gracilis and cuneatus
  - ✓ horizontal branches go to substantia gelatinosa and nucleus proprius – touch
  - ✓ some horizontal branches go to nucleus dorsalis of Clarke – proprioception
  - ✓ many synapse upon GSE motoneurons to mediate monosynaptic muscle stretch reflexes





White matter composition

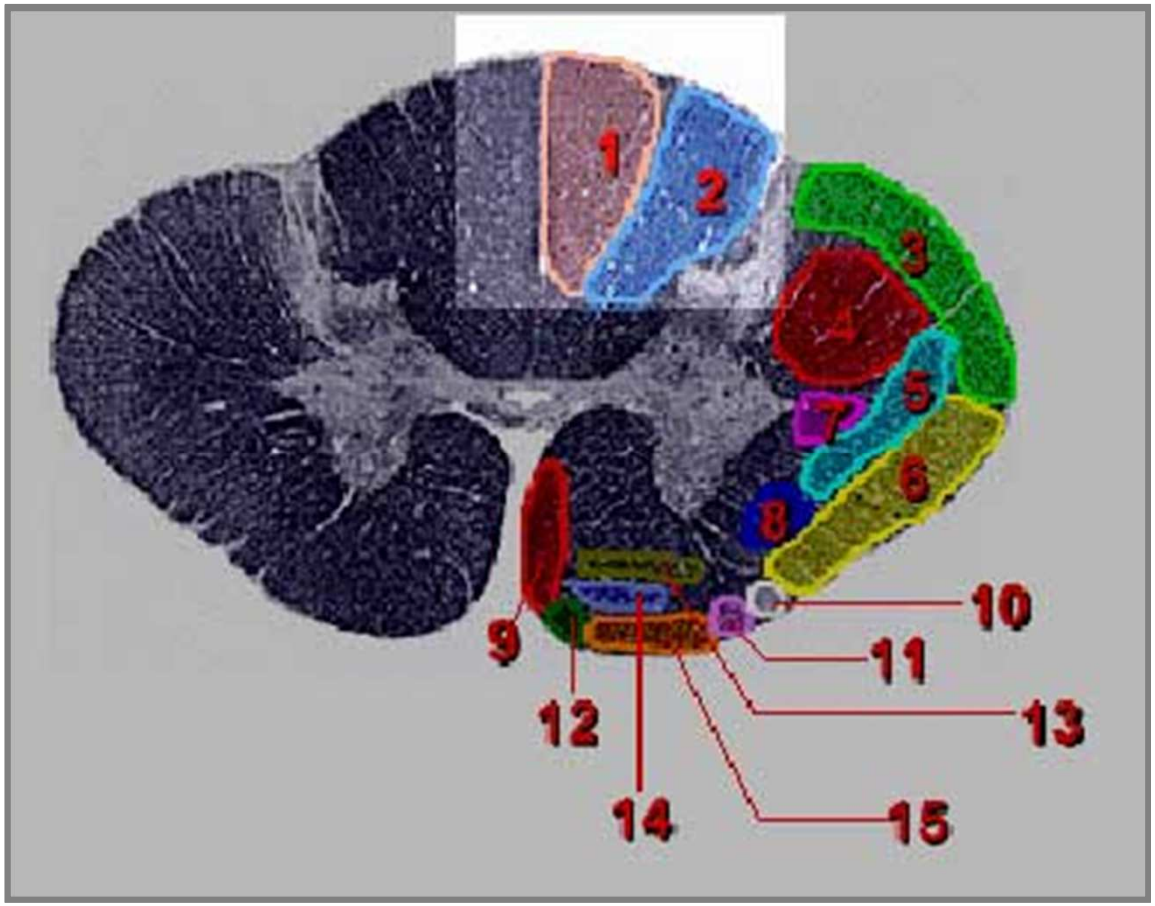
- composition:
  - ✓ nerve fibers
  - ✓ glia
  - ✓ blood vessels
- 3 columns (funiculi) – ascending and descending tracts
  - ✓ posterior funiculus: *funiculus dorsalis (posterior)*



- ✓ lateral funiculus: *funiculus lateralis*
- ✓ anterior funiculus: *funiculus ventralis (anterior)*

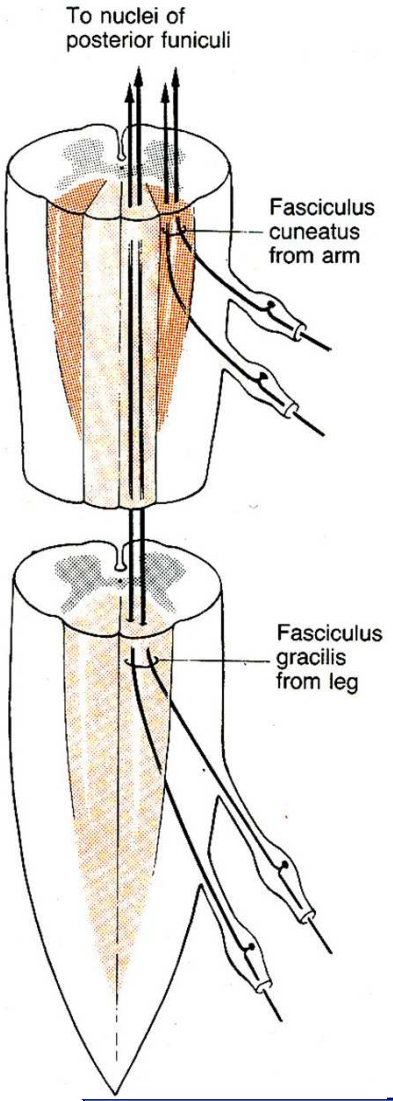
Dorsal column tracts

- Ascending pathways:
  1. *Fasciculus gracilis* (of Goll)
  2. *Fasciculus cuneatus* (of Burdach)

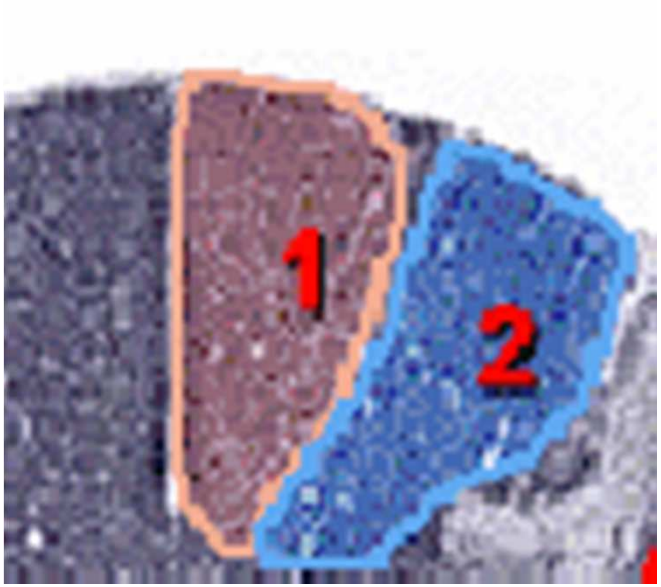


- Descending pathways:
  1. *Fasciculus interfascicularis, s. semilunaris* (of Schultze) = Interfascicular fasciculus
  2. *Fasciculus septomarginalis* (of Flechsig)

Fasciculus gracilis

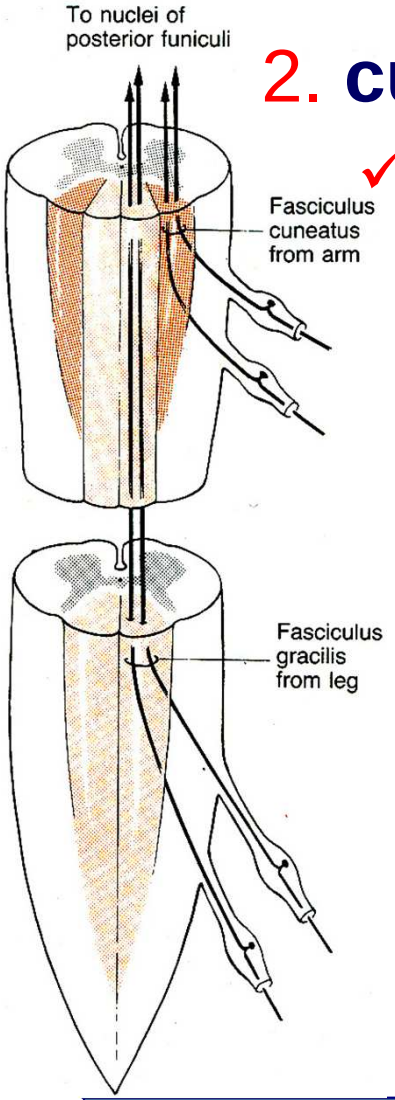


1. **gracile fascicle**, synonym: Goll's column
   - ✓ medial part of the posterior funiculus



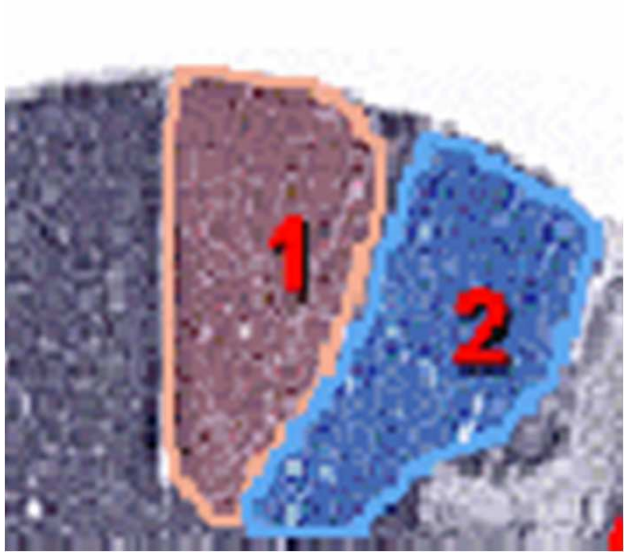
- ✓ present at **all spinal levels**
- ✓ terminates somatotopically upon the nucleus gracilis
- ✓ subserves **superficial sensitivity (discriminative modalities) and deep sensitivity (kinesthesia)** from the lower part of the trunk and from the leg
- ✓ interruption of this tract causes
  - ➢ loss of position sense resulting in posterior column **'sensory ataxia'**

Fasciculus cuneatus



2. **cuneate fascicle**, synonym: Burdach's column

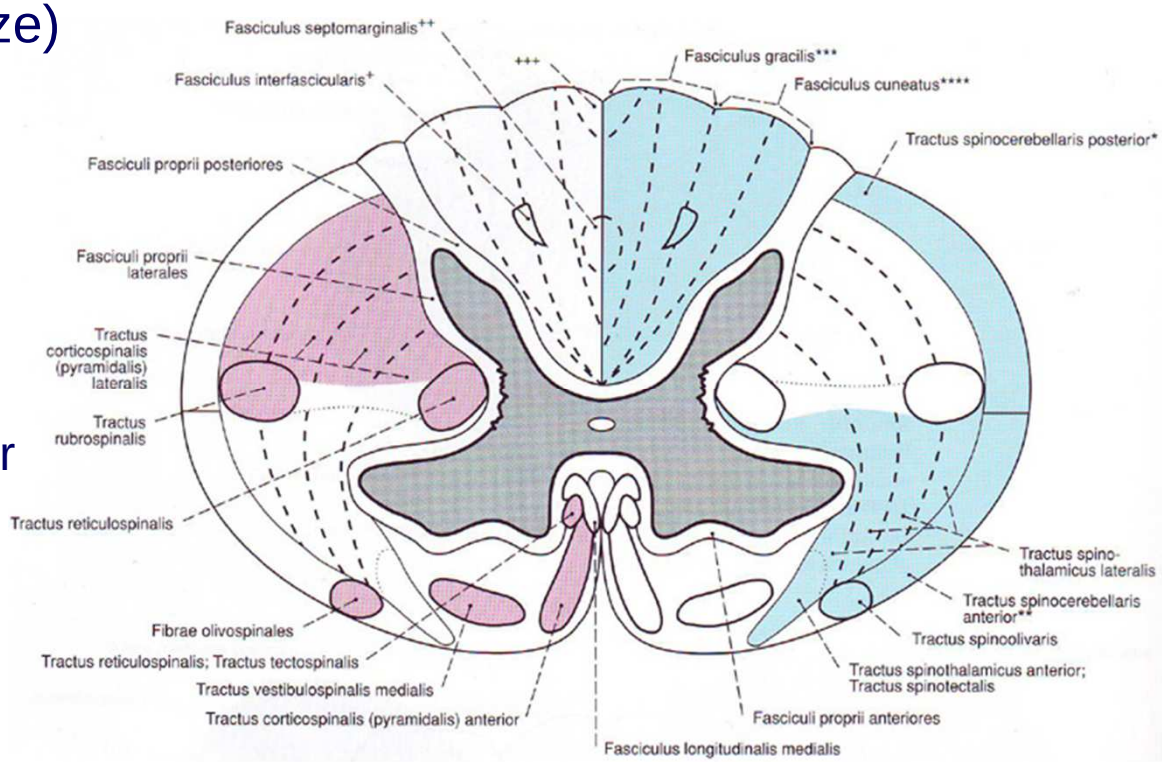
- ✓ lateral part of the posterior funiculus



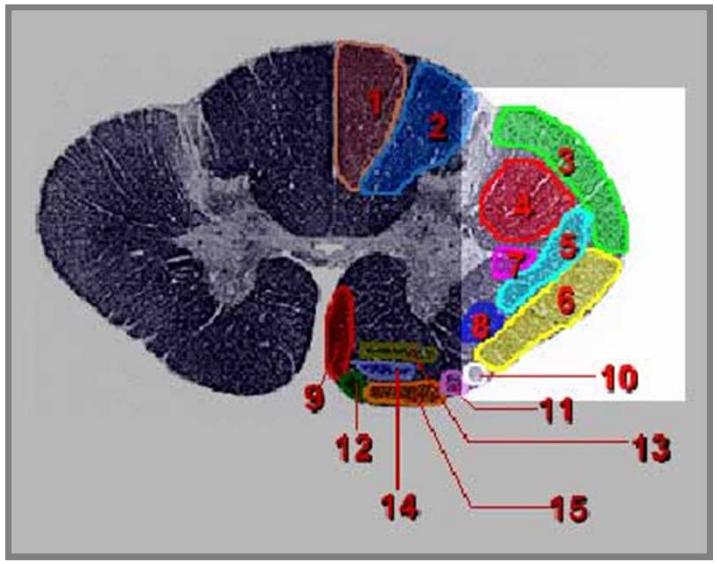
- ✓ first appear at about **Th6**
- ✓ contains long ascending branches of the **upper six thoracic and all cervical** dorsal roots
- ✓ **deep sensitivity (proprioception)** from the upper part of the trunk and from the arm
- ✓ **superficial sensitivity** – touch, pressure and vibration
- ✓ interruption of this tract causes
  - ➢ loss of position sense resulting in **'sensory ataxia'**

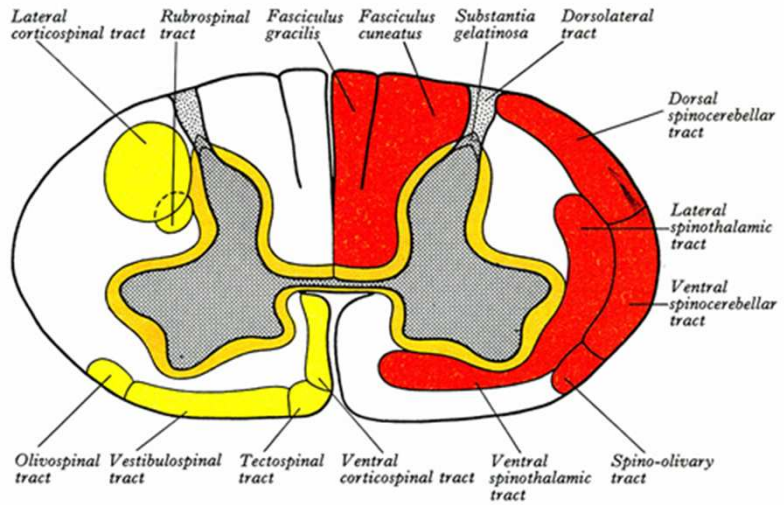
Posterior funiculus

- Descending tracts:
  1. Interfascicular fascilulus, semilunar tract (comma tract of Schultze)
     - ✓ in the medial part of the cuneate tract
     - ✓ extending through cervical and upper thoracic levels
  2. Septomarginal tract (oval field of Flechsig)
     - ✓ bordering the posterior median septum
     - ✓ in lower thoracic segments
     - ✓ propriospinal fibers
- Intersegmental tracts:
  - ✓ Posterior intersegmental tract



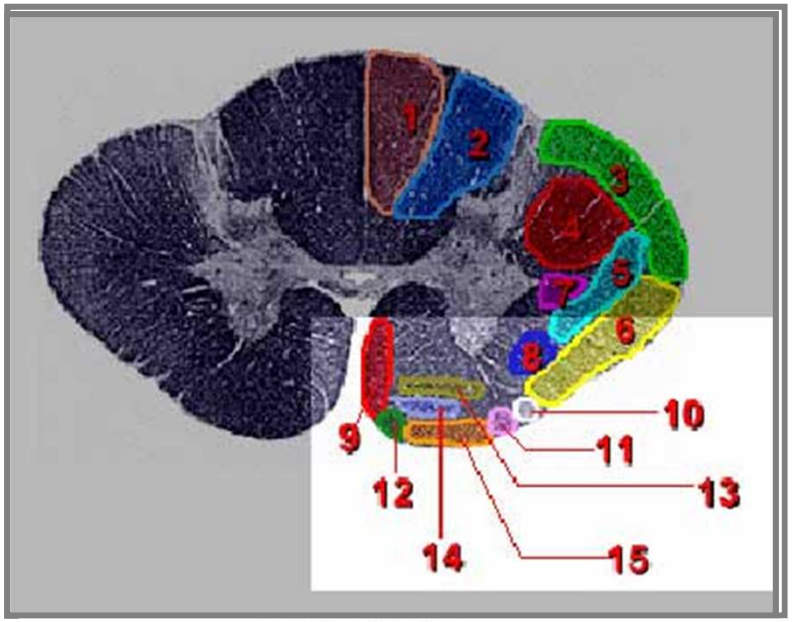
Lateral funiculus

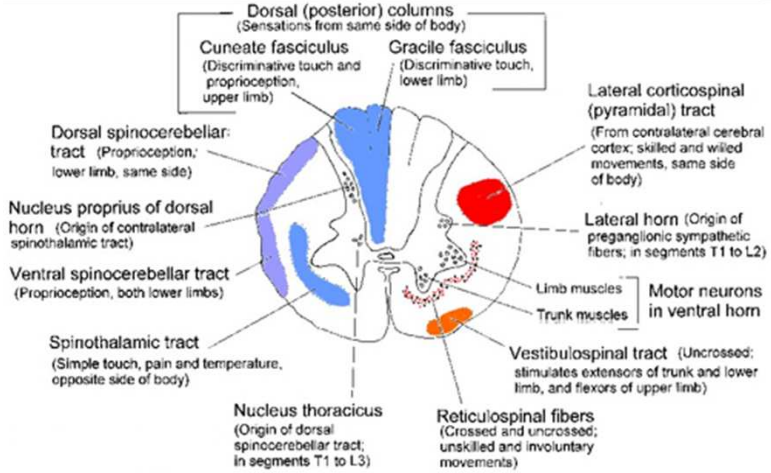




- **Ascending tracts:**
  1. Dorsal spinocerebellar tract (of Flechsig)
  2. Ventral spinocerebellar tract (of Gowers)
  3. Lateral spinothalamic tract (of Edinger)
  4. Spinotectal tract
  5. Spino-olivary tract
  6. Spinoreticular fibers
  7. Dorsolateral tract (of Lissauer)
- **Descending tracts:**
  1. Lateral corticospinal tract
  2. Rubrospinal tract
  3. Tectospinal tract
  4. Lateral reticulospinal tract
  5. Olivospinal tract (of Helweg) – only in animals
- **Intersegmental tracts:**
  1. Lateral intersegmental tract

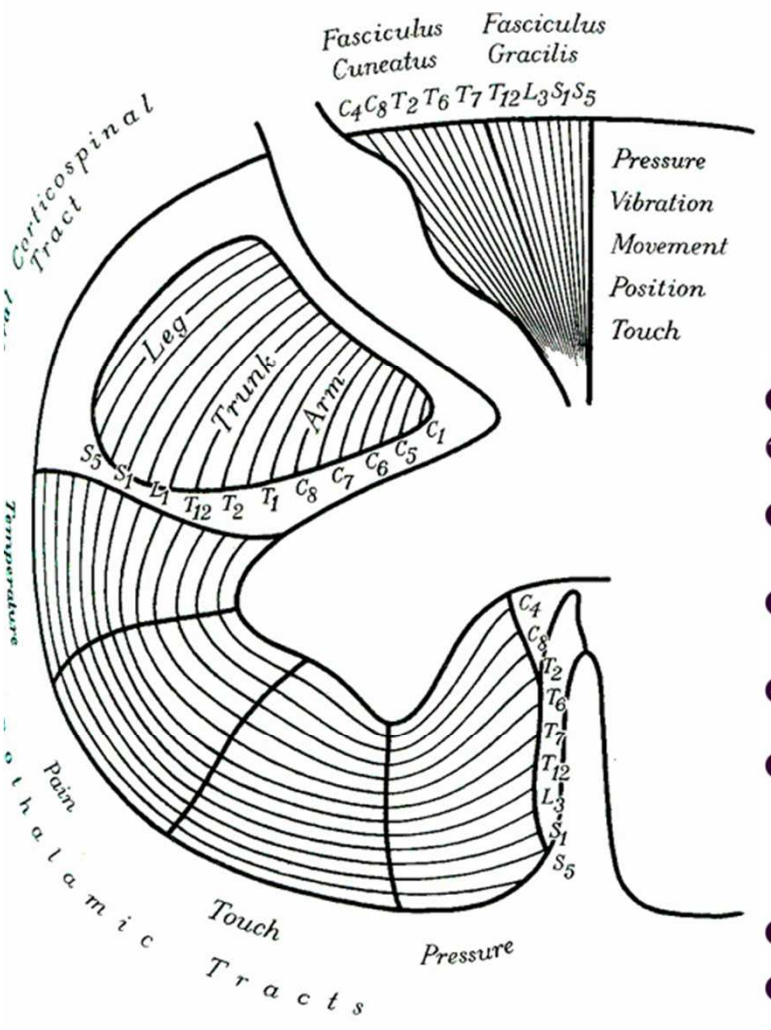
Anterior funiculus





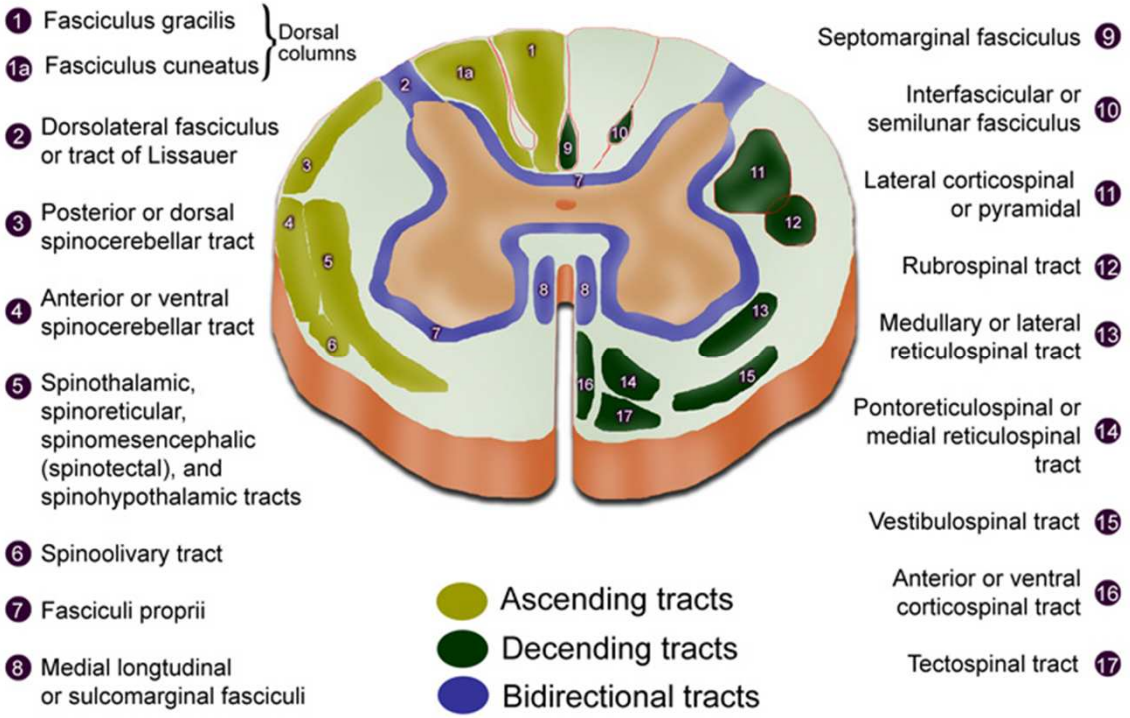
- **Ascending tracts:**
  1. Anterior spinothalamic tract
- **Descending tracts:**
  1. Anterior corticospinal tract (bundle of Türk)
  2. Reticulospinal tract
  3. Vestibulospinal tract (medial and lateral)
  4. Medial longitudinal fasciculus
  5. Interstitiospinal tract
  6. Solitariospinal tract (of Cajal)
- **Intersegmental tracts:**
  1. Anterior intersegmental tract

Functional topography of pathways



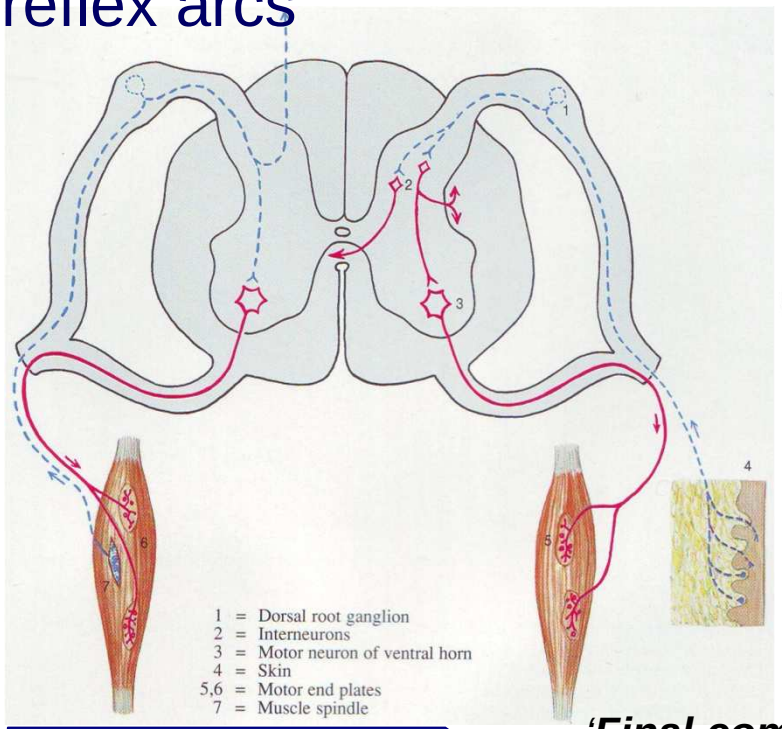
Posterior (dorsal funiculi) columns:

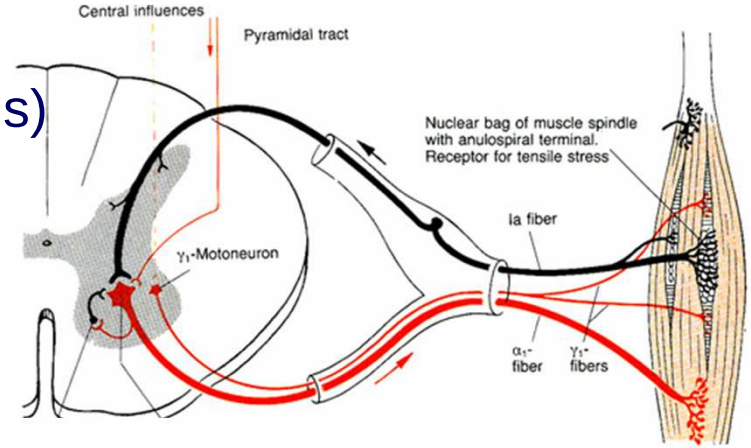
- ✓proprioception (position sense)
- ✓vibratory sense
- ✓discriminative touch

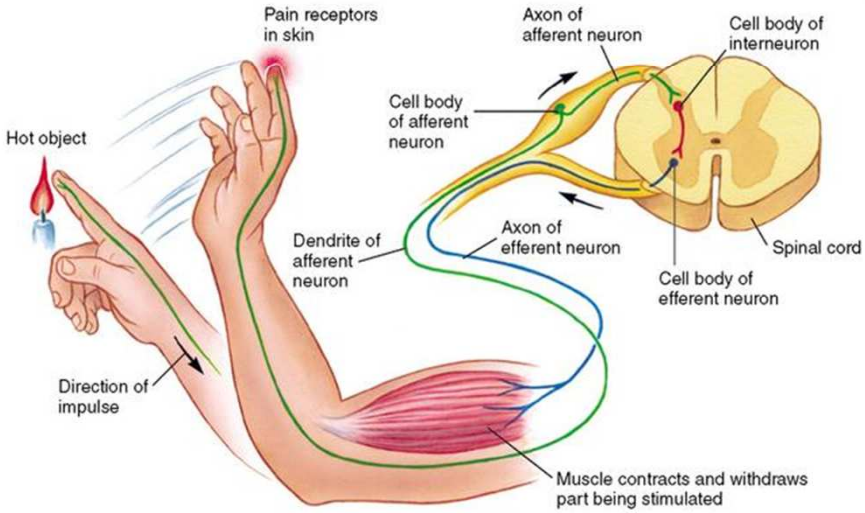


Reflex arcs of the spinal cord

- reflex arc – the neural pathway that mediates a reflex action
- two types of reflex arcs:
  - ✓ autonomic reflex arc (affecting inner organs)
  - ✓ somatic reflex arc (affecting muscles)
- monosynaptic vs. polysynaptic reflex arcs







*'**Final common** path(**way**)' (of Sherrington)*

Patellar Reflex Testing