Neuroanatomy

A New Course A New Way

Julianne Dullock

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Senior Project
Dr. Kosciuszko

Neuroanatomy a New Way

For my senior project I would like to design a new way to teach beginning neuroanatomy for the entering optometry students. I feel that neuroanatomy is a very important course for the clinical understanding of many optometric related situations. The purpose of this objective is to incorporate computer technology and self education into the general comprehension of this complicated course.

I plan to research for a newer up to date book that is easy to follow and has colored diagrams to assist in learning. I would also like to put together a slide presentation to go along with class lecture to make the learning experience more visible. I want to build a web page with links to other neuro sites and also make more automated labs that students can access on their own time. The collection of data will involve searching for computer sites that pertain and formatting them into a web page.

The first year of optometry school can be quite overwhelming. The amount of material a student is expected to learn and retain for clinical use and instant recall for national boards is excessive. Neuroanatomy historically was a course students struggled with due to its content. It is also one of the courses in the optometry program that a solid base of understanding is crucial because it provides the foundation that later supports clinical application. Knowing that the course was going to be taught by a new instructor I saw a window of opportunity to be involved in the reconstruction of the course. My goal was to create a neuroanatomy course that was educational, concise, and geared towards preparation for Part I of National Boards and further needed clinical applications.

The first objective was to look at the content that had been previously covered in the course and the material National Boards of Examiners in Optometry (NBEO) expected a student to know. The content covered in the past was found in Dr. Colladay's course outline (Appendix A) and the NBEO requirements were located in the neuroanatomy portion of the Basic Sciences under the web page for National Boards Part I (http://optometry.org) Most of the information was presented in both outlines, although sometimes one outline was more concentrated on a topic than the other. Having had been a previous student in the course and National Boards participant, it appeared some topics needed more emphasis than others.

The second objective was to create an outline for the course that followed the exact format of the National Boards. Knowing that most of the students at Michigan College of Optometry use the Berkley Guide to prepare for Part I of National Boards the Berkley Guide served as a template (Appendix B). The outline in the Berkley guide does not directly follow the outline provided by the NBEO, thus does not correlate with the student's class notes. The new outline is modified so that the headings and subheadings follow a step-by-step process that links the Berkley guide to the NBEO outline. Included in the outline under a separate column next to each heading labeled NBEO is the outline section letter and subheading number that correlates to its place in the outline in the National Board of Examiners of Optometry found on the web site.

The third objective was to find a new book for the course. The book needed to be one that correlated with the national boards outline on the web site and also correlated with the notes provided by the previous years instructor of the class. There was a concern to have a book that included more diagrams and histological slides due to the fact the new class would not offer a lab. The book was found by using a literature search to look at various neuroanatomy class teaching styles and ways to incorporate interactive software in the classroom (Appendix C). Most of the information was found from searches on the Internet under various publishing companies (Appendix D). It was difficult to judge a book by the cover so book requests were sent to the companies or area representatives. The books were sent to Dr. Kosciuszko for viewing and evaluation. The goal was to find a book that offered either a supplemental CD ROM or one that offered a slide presentation for students. Although this ideal book was not found, 4 books were received free of charge from various publishers:

Fundamental Neuroscience by Duane E. Haines

Medical Neuroscience by Benarroch, Westmoreland, Daube, Reagan, and Sandok
Concise Text of Neuroscience by Robert Kingsley
Neuroscience, Exploring the Brain by Bear, Conners, and Paradiso

Next, an evaluation form was made to rate the books (Appendix E). A scale of 1 to 5 was used, 1 being poor, and 5 being excellent. The categories considered were content, diagrams, organization, readability, comprehension level, and clinical relevance. Based on the evaluations, the book selected was Fundamental Neuroscience. This books organization was very similar to the outline in National Boards. It had some diagrams of human cadavers, which were a good supplementation for not having a wet lab with the class. Although some of the diagrams were quite busy it was thought too information was better than not enough. The book was geared towards a graduate medical school level, which in the long run would benefit the student as courses grow harder and textbooks are used for references. Clinical relevance was not as applicable as hoped for but it did contain some case scenarios. Overall, this book was the best one to include all the necessary objectives.

The fourth objective was to go back to the handout for the students that included the material covered by national boards, the direct outline number under which it is found on the web site, and incorporate the correlating page number the information was covered on in their book (Appendix F). The point of this was to provide a simple handout as a study guide to prepare for the neuroanatomy section on boards. This condensed packet would help to consolidate the important information and eliminate the stress of having a lot of material to cover.

The fifth objective in the process of redesigning the neuroanatomy class was the teaching of the course. Here Dr. Kosciuszko had to look over the book and the outline and sculpt his lectures toward covering the necessary information in the given timeline. (Study questions, tests, and power point)

The sixth objective was to have the class evaluate the book and course. The evaluation asked questions relating to feelings on the book content and presentation, the course lectures, the class web site, and changes that could be made to make the course better (Appendix G). Out of the 34 students 20 found the diagrams to be most helpful in learning the material, 8 thought the chapter readings were the best, 3 thought the case scenarios were better, and 3 of the students weren't sure what book the evaluation was asking about. The area the students found to be least helpful in learning the material was 12 for the book, 11 for the chapter readings, 6 for case scenarios, and 5 for the diagrams. However, most of the students seemed to agree that the book was affordable for how much they did use it. Almost all the students agreed that a computer interactive softwear program to go along with the course would be beneficial and thought that computer interactive softwear would aid in the understanding of neuroanatomy. Out of the class 27 students did use the web site for the course with 23 of them finding it helpful. Most of the class appeared not to consider lecture of much educational value but appreciated the study guide questions that were provided by the instructor. Almost all of the class found the exams to be comprehensive and fair with the exception of the final. They remarked it

was very different from the first two tests. Some of the recommended changes the class would like to see would be to have 3D models to look at of the structures discussed, to have tests over 2 chapters at a time due to content over load, to have a wet lab, to have fill in the blank notes, and to include the diagrams in a course packet instead of having to write in their books. Most of the students seemed to complain that there was an overwhelming amount of material that needed to be covered in the semester. The students did not seem to like that the lectured followed along with the book readings.

The seventh objective was to have Dr. Kosciuszko evaluate how he thought the course went and how helpful the new text was in class instruction. This was the first time Dr. Kosciuszko had taught the course so his only real comparison to the class material was to recall when he took the course years previous. This gave an unbiased opinion and is helpful to evaluate the success of the selected book.

The last step will be the performance reflected by the Class of 2004 when Part I of National Boards is completed. The results will carry on over into the Clinical Neuro-Optometry course that is taken first semester of third year. Future questions that will need to be addressed are: Will students have found themselves adequately prepared for the National Boards? Did the students use the study outline to prepare for boards? Will the students be clinically at the expected level as 3rd year optometry students? How many students have consulted the text to answer clinical questions? As one can see this is an on going project. The objectives stated have been accomplished but there is still a need to find a soft wear program to emphasize the computer interactive learning with this course. At the time of the project no soft wear encountered met the needs of the course and the student. It was the goal of this project to tailor a beginning neuroanatomy course for optometry students that met the needs of supplying the knowledge base for taking National Boards Part I and a start to clinical understand neuroanatomy's relationship to clinical optometry.

Appendix A

OPTM 430, NEUROANATOMY, COURSE OUTLINE

WEEK	COURSE CONTENT
1	1. Classification of the Nervous System 2. Development of the Nervous System 3. Histogenesis of Neural Tube 4. Structure and Classes of Nervous 5. Supporting Cells of the Nervous System a. Neuroglia b. Ependymal Cells c. Choroid Plexus 6. Meninges 7. Cranial Blood Supply 8. Cerebrospinal Fluid/Brain Ventricles a. Characteristics b. Production c. Dynamics d. Hydrocephalus 9. Blood-Brain Barriers 10. Introduction to Brain Regions a. Telencephalon b. Diencephalon c. Mesencephalon d. Metencephalon e. Myelencephalon
2	1. Introduction to Telencephalic Structures a. Lateral Aspect: 1) Surface markings and features 2) Lobes 3) Functionally defined areas: a) Motor cortex (area 4) b) Somesthetic Cortex (area 3,2,1) c) Auditory cortex (area 41,42) d) Visual cortex (area 17) (1) Retinal projections (2) Lateral Geniculate Nucleus (LGN,LGB) (3) Optic radiations e) Visual association cortex (area 18,19) f) Voluntary eye movements (area 8) g) Broca's speech area h) Olfactory cortex i) Gustatory cortex (area 43) 4) Areas of special emphasis: a) Pre-central gyrus b) Post-central gyrus c) Middle frontal gyrus d) Transverse gyri of Heschl b. Medial aspect: 1) Corpus callosum 2) Limbic lobe 3) Areas of special emphasis: a) Calcarine fissure b) Cuneate gyrus c) Lingual gyrus

c. Fiber systems:
    1) Projection fibers
    2) Association fibers
    3) Commissural fibers
    4) Areas of special emphasis:
        a) Inferior longitudinal fasciculus
            (1) Optic radiations
        b) Interal capsule
            (1) Posterior Limb
                (a) Optic radiations

d. Basal Ganglia
    1) General statements
    2) Component groups
    3) Functional relationships
    4) Parkinson's Disease
        a) Substantia nigra
            (1) Dopamine neurotransmitter
        b) Replacement therapy
            (1) L-Dopa

3

1. Spinal Cord Gross Anatomy
2. Segmentation and Peripheral Innervation
3. Mixed Spinal Nerve
    a. Dorsal root
        1) Dorsal root ganglion
    b. Ventral root
    c. Ramus communicans (White and Grey)
    d. Paraventebral ganglia
    e. Component fibers:
        1) GSA
        2) GVA
        3) GVE
        4) GSE
4. Spinal Nerve Plexi and Distribution Pattern
5. Receptors and Effectors
    a. Receptors:
        1) Classification systems covering:
            a) Mechanoreceptors
            b) Tactile receptors
            c) Thermoreceptors
            d) Photoreceptors
            e) Chemoreceptors
            f) Proprioreceptors
            g) Nociceptors
    b. Effectors:
        1) Muscles
            a) Smooth muscle
            b) Cardiac muscle
            c) Striated muscle
        2) Glands
            a) Exocrine
            b) Endocrine
6. Nerve Injury and Repair
    a. Afferent fiber injuries
        1) Partial anesthesia
        2) Complete anesthesia

b. Efferent fiber injuries
    1) Topics:
        a) Paresis
        b) Paralysis
        c) Atrophy
        d) Reaction of degeneration
        e) Fasciculations
        f) Fibrillations
c. Degeneration/Regeneration
    1) Wallerian degeneration
    2) Retrograde degeneration
    3) Dynamics of regeneration and recovery

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1. Spinal Cord Reflexes and Terminology
2. Spinal Cord Tracts/Tract Lesions
    a. Ascending tracts:
        1) Fasciculus gracilis and faciculus cuneatus
            a) Epicritic tactile/proprioception
        2) Lateral spinothalamic
            a) Pain and temperature
        3) Ventral spinothalamic tract
            a) Protopathic tactile
        4) Secondary Ascending Visceral Tract
            a) Visceral pain
        5) Spinotectal tract
            a) Pain input to superior and inferior colliculus
        6) Dorsal & Ventral Spinocerebellar
            a) Non-conscious proprioception
    b. Romberg test of proprioception
    c. Descending tracts:
        1) Lateral & Ventral Corticospinal
            a) Voluntary motor
        2) Tectospinal
            a) Reflex motor responses to visual and auditory input
        3) Medial Longitudinal Fasciculus (descending component)
            a) Vestibular input to spinal cord levels
        4) Rubrospinal
            a) Cerebellar input for motor functions at spinal cord levels
        5) Vestibulospinal
            a) Cerebellar input for motor functions at spinal cord levels
    d. Terminology and Syndromes
        1) Flaccid paralysis
        2) Spastic paralysis
        3) Brown-Sequard Syndrome
            a) Spinal cord hemi-section

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1. Features of the Medulla
    a. Motor decussation (nuclei, tracts)
    b. Sensory decussation (nuclei, tracts)
    c. Inferior Olvary Nuclear Complex (nuclei, tracts)

d. Cranial Nerves and Cranial Nerve Nuclei
    1) Nucleus of the Spinal Tract of V
    2) Glossopharyngeal (IX)
    3) Vagus (X)
    4) Spinal accessory (XI)
    5) Hypoglossal (XII)
e. Syndromes
    1) Hypoglossal Alternating Hemiplegia

2. Features of the Pons
a. Dorsal pons
    1) Cerebellar peduncles
    2) Juxtarestiform body
b. Introduction to cerebellar organization

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1. Cranial Nerves and Cranial Nerve Nuclei of Pons
a. Trigeminal (V)
    1) Chief sensory nucleus
    2) Mesencephalic nucleus
    3) Motor nucleus
    4) Nucleus of the Spinal Tract of V
b. Abducens (VI)
    1) Parabducens nucleus
    2) Facial colliculus
c. Facial (VII)
    1) SVE motor
        a) Muscles of facial expression
    2) GVE motor (ANS)
        a) Salivary glands
            (a) Sublingual
            (b) Submandicular
        b) Lacrimal gland
    3) SVA sensory
        a) Taste
        b) Anterior two-thirds of tongue
    4) GSA sensory
        a) Somatic sensory
        b) External auditory meatus
d. Vestibulocochlear (VIII)
    1) Auditory component:
        a) Cochlea
        b) Cochlear nuclei
        c) Auditory pathway
        d) Medial geniculate body
        e) Thalamocortical projections
        f) Auditory cortex (area 41,42)
    2) Vestibular component:
        a) Vestibular apparatus
        b) Vestibular nuclei (4)
        c) Cerebellar input
        d) Cerebellar output
        e) Tracts:
            (1) Vestibulospinal
            (2) Ascending Medial Longitudinal Fasciculus
                (a) Vestibular input to:
                    (1) Oculomotor nuclear complex
                    (2) Trochlear nerve
                    (3) Abducens
                    (4) Interstitial Nucleus of Cajal

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1. Special Reflexes
   a. Corneal reflex
      1) Pathway involving CN V and SVE of VII
      2) Lesions:
         a) CN V
         b) CN VII
         c) Differential diagnosis
   b. Tearing reflex
      1) Pathway involving CN V and GVE of VII
      2) Lesions
   c. Oculocardiac reflex
      1) Pathway involving CN V and GVE of X
      2) Cardiac response
2. Basal pons
   a. Descending longitudinal fibers:
      1) Corticospinal
      2) Corticopontine
      3) Corticobulbar
   b. Pontine nuclei
3. Examination

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1. Features of the Cerebellum
   a. Surface features
   b. Regional/functional divisions:
      1) Archicerebellum/vestibular function
      2) Paleocerebellum/stereotyped movements
      3) Neocerebellum/fine coordination
   c. Cortical layers
      1) Molecular
      2) Purkinje
      3) Granular
   d. Fiber systems
      1) Excitatory fibers
      2) Inhibitory fibers
      3) Mossy fibers
      4) Climbing fibers
   e. Nuclei (output)
      1) Dentate
      2) Globose
      3) Emboliform
      4) Fastigial
   f. Cerebellar peduncles
      1) Brachium conjunctivum
      2) Brachium pontis
      3) Restiform body
   g. Cerebellar lesions and testing
      1) Ataxia
      2) Dysmetria
      3) Past-pointing
      4) Rebound phenomenon
      5) Intention tremor
      6) Nystagmus
      7) Tonic muscular seizures (rigidity)

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1. Features of the Mesencephalon
   a. Tectum
      1) Inferior colliculus
         a) Auditory relay station
      2) Superior colliculus
         a) Visual relay station involving:
            (1) Optic tract (post chiasmal)
            (2) Frontal eye fields (area 8)
            (3) Association visual cortex (area 18,19)
         b) Functional considerations
            (1) Motion detection
            (2) Reflex following movements
            (3) Reflex eye movements
   b. Tegmentum
      1) Trochlear Nerve (IV)
         a) Pathway
         b) Innvervates contralateral superior oblique muscle
         c) Lesion signs
            (1) Vertical diplopia upon downward gaze to opposite side
      2) Oculomotor Nuclear Complex
         a) GSE motor nuclei
            (1) Innervate extraocular muscles
            (2) Innervates levator palpebrae superioris
         b) GVE motor nuclei
            (1) Edinger-Westphal Nucleus
            (2) ANS (parasympathetic)
            (3) Involved with:
               (a) Light reflex
               (b) Accommodation
               (c) Convergence

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1. Pretectal region
   a. Pretectal nuclei:
      1) Principal pretectal nucleus
      2) Nucleus of the optic tract
      3) Sublentiform nucleus
      4) Nucleus of the pretectal area
2. Reflexes of the Tectal/Pretectal area
   a. Light reflex
      1) Direct
      2) Consensual
   b. Accommodation-Convergence Reaction
      1) Events:
         a) Medial recti contraction
         b) Ciliary muscle contraction
         c) Pupil constriction
      2) Pathway involvement:
         a) Retina
         b) Cortical areas 17,18,19,8
         c) Superior colliculus
         d) Pretectal nuclei
         e) Edinger-Westphal nucleus
         f) Ciliary ganglion

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1. Other Tegmental Structures
    a. Components:
        1) Red Nucleus
        2) Substantia Nigra
        3) Crus Cerebri
            a) Corticospinal fibers
            b) Corticobulbar fibers
            c) Corticopontine fibers
2. Lesions of the Mesencephalon
    a. Argyll-Robertson Pupil
        1) Light reflex loss
        2) Accommodative pupil reflex retained
    b. Oculomotor Alternating Hemiplegia (Weber's Syndrome)
        1) Oculomotor nerve
        2) Corticospinal nerves
    c. Oculomotor nerve lesion
        1) External strabismus
        2) Ptosis
        3) Mydriasis
        4) Ocular reflex deficits
    d. Benedikt's Syndrome
        1) Oculomotor nerve paresis
        2) Extrapyramidal ataxia
    e. Parkinson's Disease (Paralysis Agitans)
        1) Lesion of the Substantia Nigra
        2) Loss of neurotransmitter

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1. Features of the Diencephalon
    a. Dorsal Thalamus
        1) Nuclei (25)
        2) Connections
        3) Functions
    b. Epithalamus
        1) Components
    c. Subthalamus
        1) Components
        2) Relationship to Basal Ganglia
    d. Hypothalamus
        1) Optic Chiasma
        2) Components
        3) Connections
        4) Relationship to ANS

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1. Visual Pathway
    a. Visual fields
    b. Retinal fields
    c. Optic nerve
    d. Optic chiasm
        1) Nasal fibers
        2) Temporal fibers
        3) Anterior loops
        4) Posterior loops
    e. Lateral Geniculate Nucleus (Body)
        1) Cell types
        2) Projection patterns

f. Striate cortex
    1) Cell types
    2) Projection patterns
    3) Cuneate gyrus
    4) Calcarine fissure
    5) Lingual gyrus
g. Parastriate cortex
    1) Visual association
    2) Area 18
    3) Commissural connections
    4) Frontal lobe connections (area 8)
h. Peristriate cortex
    1) Visual association
    2) Area 19
    3) Commissural connections
    4) Frontal lobe connections (area 8)
i. Sample field defects
    1) Hemianopsia
    2) Quadrantanopsia

14 1. Basal Ganglia
a. Structural components
b. Fiber connections
c. Functional considerations
d. Characteristic lesions:
    1) Tremor
    2) Athetosis
    3) Chorea
    4) Ballism
    5) Parkinson's Disease

15 1. Cerebral Cortex
a. Anatomical components
    1) Cell types
    2) Layering of cortex
    3) Fiber systems
b. Cortical areas
    1) Sensory areas:
        a) Somesthetic cortex
        b) Striate (visual) cortex
        c) Auditory cortex
        d) Gustatory cortex
        e) Olfactory cortex
        f) Association cortex
    2) Motor areas:
        a) Primary motor
        b) Motor association
        c) Frontal eye fields
c. Cortical dominance
    1) Significance to language functions
d. Cortical disturbances:
    1) Classes of agnosia
    2) Classes of aphasia
    3) Classes of apraxia

2. Autonomic Innervation of the Head
    a. Sympathetics
    b. Parasympathetics
    c. Lesions
        1) Horner's Syndrome

16 Final Examination

OPTM430.trc

Appendix B

SECTION 1.2
NEUROSCIENCE

A. NEUROHISTOLOGY

1. Histogenesis in the nervous system

- Neural plate, neural fold, neural groove, neural tube, neural vesicles

a. Neural plate:
After the trilaminar embryo has developed, the neural plate is formed by the thickening of the ectoderm at the midline at 3 weeks of development.

b. Neural groove:
By mid-third week, the growth rate at the sides of the neural plate is faster than at the midline. Hence, the neural plate invaginates along its central axis to form a neural groove with neural folds on each side.

c. Neural fold:
Formed by the rapid proliferation of the sides of the neural plate.

d. Neural tube:
By the end of the third week, the neural folds begin to move together and fuse, converting the neural plate into a neural tube. Fusion begins centrally and proceeds posterior and anterior. The neural tube will produce the CNS (brain and spinal cord).

- Derivatives of neural crest (ganglia, glia, adrenal medulla, melanocytes)

As the neural folds fuse, some ectodermal cells lying along the crest of each neural fold lose their attachments to neighboring cells. As the neural tube separates from the surface ectoderm, these ectodermal neural crest cells migrate inwardly and invade the mesoblast on each side of the neural tube. Neural crest cells form a temporary intermediate layer between the neural tube and the overlying surface ectoderm. Neural crest cells give rise to the spinal ganglia, ganglia of the autonomic nervous system, part of the ganglia of the cranial nerves (V, VII, IX and X), the sheaths of nerves (Schwann Cell), the meningeal covering of the brain and the spinal cord (pia mater and arachnoid), pigment cells and the suprarenal (adrenal) medulla.

a. Ganglia
- Dorsal root ganglia
- Sensory neurons of the cranial nerve ganglia (nerves V, VII, IX and X)
- Sympathetic ganglia
- All sensory cells and fibers of the peripheral sensory system
- Most of the peripheral cells of the autonomic nervous system.

b. Glial cells

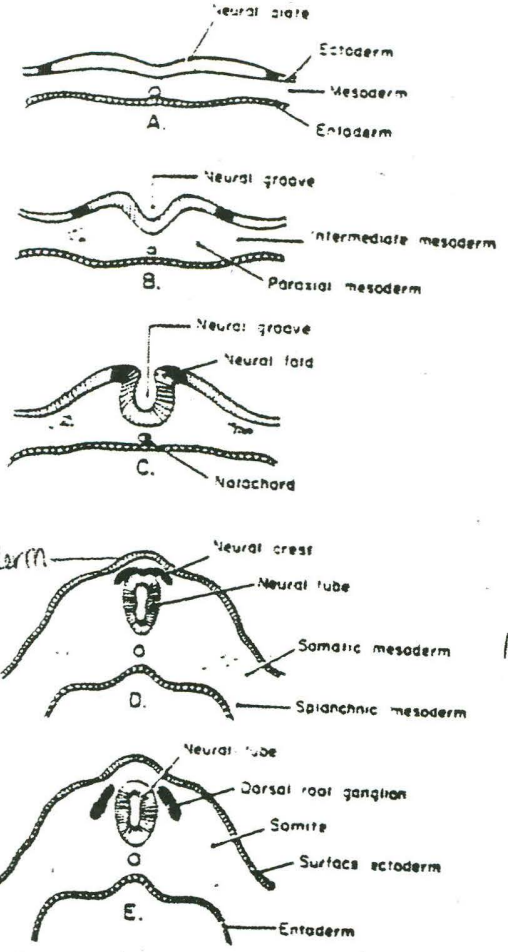
- Schwann cells which form myelin sheaths in the PNS
- Oligodendrocytes which form myelin sheaths in the CNS
- Astrocytes which support the tissue of the nervous system
- Ependyma which lines the inside of the spinal cord and the ventricles of the brain.

• Neural Plate (ectoderm)
• Neural Groove
• Neural Crest Fold
• Neural Tube

PNS

Schwann - myelin - PNS
Oligodendrocytes - myelin - CNS

Neural Crest cells give rise to:
- spinal ganglia
- ganglia of ANS
- part of ganglia of CN 5, 7, 9, 10
- sheaths of nerves
- meningial covering of brain and spinal cord (~~pia~~ pia + arachnoid)
- pigment cells and suprarenal (adrenal) medulla.



overlying surface ectoderm

Neural Tube forms CNS (brain and spinal cord)

FIG. 3-2. Diagrams of transverse sections of embryos at different ages to show development of the spinal cord. *A*. Neural plate stage. *B*. Early neural groove stage. *C*. Late neural groove stage. *D*. Early neural tube and neural crest stage. *E*. Neural tube and dorsal root ganglion stage.

Source: Rodieck, 1998

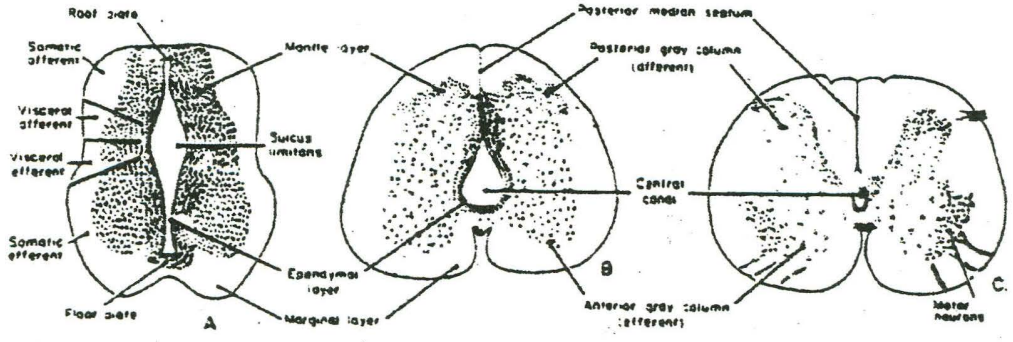


FIG. 3-3. Diagrams of differentiating layers of the spinal cord. *A*. Section through spinal cord of a 5-week human embryo. *B*. Cervical spinal cord of an 8-week human embryo. *C*. Cervical spinal cord of a 10-week human embryo (after Keibel and Mall, '12).

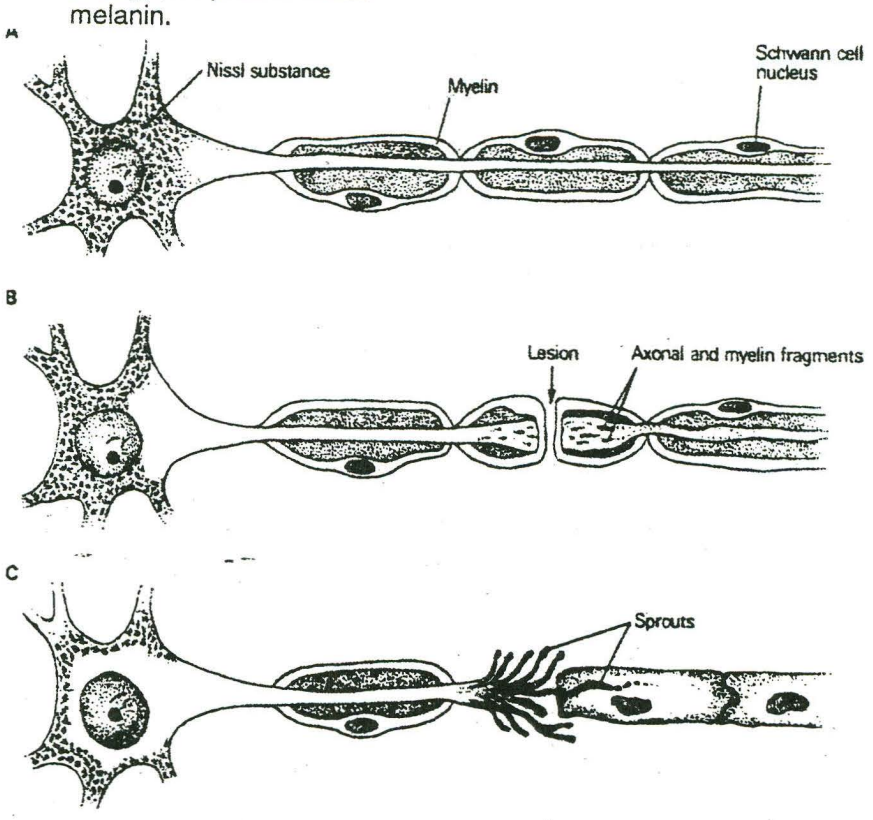
Source: Rodieck, 1998

adrenal medulla - chromaffin cells
ACh ⇒ release of norepi and epi into blood

c. Adrenal medulla
Chromaffin cells are cells of the adrenal medulla (also known as the suprarenal medulla). ACh is released by pre-ganglionic sympathetic fibers and combines with receptors on chromaffin cells, resulting in the release of norepinephrine and epinephrine directly into the blood.

d. Melanocytes (pigment cells)
Found throughout the basal layer of the epidermis. Melanocytes produce pigment granules composed of a type of protein called melanin.

- Layers of neural tube (ependymal, mantle, marginal)
The columnar ectoderm is converted to the nervous tissue of the spinal column. The histogenic changes of this process are as follows: the neural tube closes and is formed by a single layer of columnar cells; it proliferates forming a neuroepithelium several layers thick. Large ovoid cells near the center of the canal form a germinal layer in which rapid cell division takes place. Newly formed undifferentiated cells migrate peripherally and assume a three layer appearance.



17–3 When an axon is severed, there are changes in the distal axon segment and in the parent neuron after the terminal has degenerated. A. Normal cell body and portion of axon. (The axon terminal and its changes are omitted.) B. Retrograde cell reaction and Wallerian degeneration. About 2–3 days after the axon is severed, the cell body begins to swell, and the nucleus swells and migrates. About 1 week after axotomy, the myelin sheath withdraws from the axon and fragments; the axon swells and beads, and then fragments. C. Retrograde cell reaction and axon regeneration. The cell body and nucleus continue to swell, and finally, the Nissl substance undergoes chromatolysis in preparation for regeneration of the proximal axon segment.

Source: Kandel & Schwartz, 1985

a. Ependymal layer
Columnar cells that are arranged radially around the central canal and the ovoid germinal cells undergoing mitosis. The innermost layer lining the central canal.

b. Mantle layer
Middle layer which will become the gray matter of the spinal cord. Contains glioblasts to form glial cells and neuroblasts to form neurons. The mantle layer is later divided into 2 parts: an alar plate which forms the posterior horn of gray (sensory) and a basal plate which forms the lateral and anterior horn of gray (motor).

alar plate = sensory posterior horn of gray matter
basal plate = motor. lateral and anterior horn of gray

c. Marginal layer
External layer composed of processes of the cells in the mantle and ependymal layers. This layer will become the white matter of the spinal cord.

2. Degeneration and regeneration in the nervous system.

- Degenerative reactions following a transection may be divided into changes in the following three areas

a. Cell body
The cell body is the metabolic center of the neuron and any process that detaches from it disintegrates. The cell body swells and becomes turgid. The nucleus is displaced to the side of the cell body. The Nissl bodies undergo "dissolution" or chromatolysis and disperse against the cell membrane. Chromatolysis is indicative of the enhanced protein synthesis in the cell body.

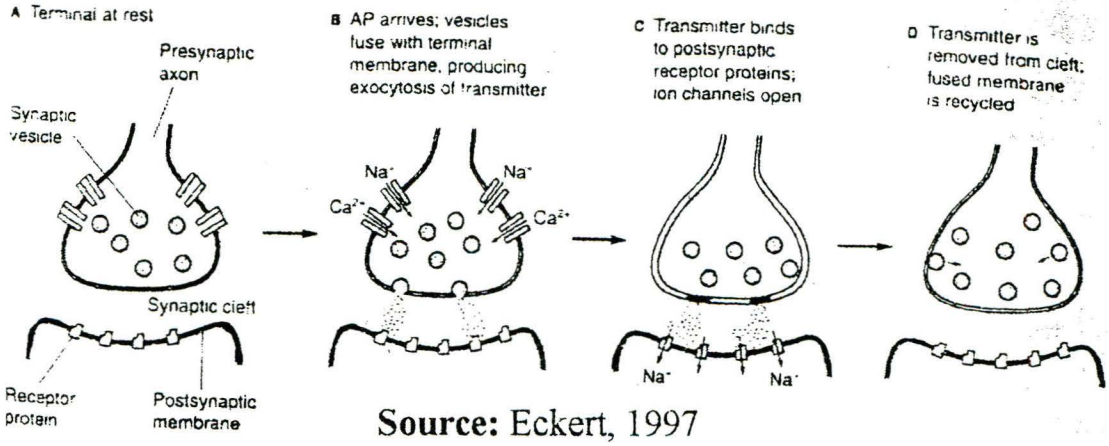
b. Primary degeneration
Nerve fibers on the side of the cell body proximal to the trauma usually show only a few degenerative changes. The axon swells and fragments at 12 hours. The myelin sheath fragments. Axonal changes begin with an accumulation of mitochondria at the Nodes of Ranvier, followed by a breakdown of the axoplasm and mitochondria. Schwann cells become hypertrophic and divide.

c. Secondary or Wallerian degeneration (nerve fiber distal to the trauma).
The myelin sheath breaks up after a few days into elongated segments and, during the next few weeks, into spherical and oval fragments. Macrophages phagocytize these breakdown products and remove them from the nerve.

Anterograde degeneration is what happens to the segment distal to the trauma. Retrograde degeneration is what happens to the segment proximal to the trauma and the cell body.

— Chromatolysis occurs pg 68 Neuro colladay

Anterograde degeneration = distal to trauma
Retrograde degeneration = proximal to trauma



Source: Eckert, 1997

- Regeneration
  Regeneration of the central nervous system is essentially a process of differentiation and growth.

  a. The neurilemma cells in the segment near the trauma and those throughout the entire distal segment undergo mitotic activity. The proliferating neurilemma cells form continuous cords or tubes of cells that maintain the orderly longitudinal pattern of the nerve. These cells also migrate into the gap between the distal and proximal stumps and may form a bridge between the two stumps.

  b. The severed axon tip forms a new cell membrane and, within a few days, several axonal branches extend from each original nerve process. Each of these regenerating processes will contact a neurilemmal cord. This cord will act as a guide; the regenerating axon will grow along the cord to a nerve ending.

  c. Later, the neurilemma cells surround the regenerating nerve fibers. Some regenerating fibers become myelinated within 10 days. Each regenerated nerve fiber tends to have an internodal length, a diameter and a conduction velocity of about 80% of the original fiber.

  d. The survivors are those axons that terminate in the proper nerve endings and in functional endings. Motor fibers, for example, will eventually degenerate if they are located in a neurilemma cord that terminates in a sensory ending.

  e. Collateral nerve regeneration: collateral branches from an axon may sprout from an intact, undamaged nerve and enter into an adjacent denervated neurilemma cord. This is known as collateral nerve regeneration.

     - The nearby degenerating nerve may exert some stimulus to which the normal nerve responds by forming a collateral branch. This stimulus is probably elicited by chemical substances released by degenerating nerve fibers, interstitial cells or denervated structures.

     - Collateral nerve regeneration occurs in

both the peripheral and the central nervous system.

f. Full recovery takes 3 to 6 months depending on the mass of axon to be reconstituted.

g. Summary of process: Each axon splits into numerous fine strands or fibers. These fibers traverse the scar and reach the Schwann tube of the degenerating stump. These fibers may take considerable time. This occurs only if the regenerating axon makes sensory or motor contact with the appropriate receptor or the effector endings in the periphery.

h. Some factors hamper regeneration in both the CNS and PNS: the size of the gap, hemorrhage, and scar formation.

B. ELECTROPHYSIOLOGY OF THE NEURON

1. Basis of resting potential (ionic balance, transport mechanisms)
Each nerve cell has a potential difference across its surface membrane that is characteristic of its resting state. This resting potential typically lies between –30 and –100 millivolts (mV). Two factors play a roll in the origin of the resting potential. The first is the unequal distribution of inorganic ions between the cell interior and cell exterior, caused by active transport. The second factor is the presence of open ion channels in the cell membrane permeable to some of the ions present. The electrochemical gradient of a given ion species has no effect on the membrane potential if the membrane is impermeable to that species. An ion that is only slightly permeable should have a smaller effect on the membrane potential than an ion that can diffuse across the membrane more freely. It is the relative ease with which different ions can cross the membrane that determines their relative contributions to the membrane potential. The cell membrane permeability is relatively high to K^+ as compared to other ions, due to the abundance of potassium-selective channels open in the resting membrane. Large changes in extracellular Na^+ have little effect on the resting potential, because of the low permeability of the cell membrane to sodium ions. The major portion of the negative resting potential of a cell arises directly from the high intracellular potassium concentration relative to extracellular potassium concentration and also to the tendency of K^+ to leak out of the cell through numerous potassium channels. Sodium contributes little to the resting potential, because the resting membrane has relatively few open sodium-selective channels. The indirect and ultimate basis for the resting potential is the metabolically energized active transport of Na^+ out of the cell in exchange for K^+. The Na/K pump, maintains a low intracellular Na^+ concentration and allows K^+ to be the most abundant intracellular cation. A small fraction of the resting potential also arises as a direct result of the pumping of Na^+ out of the cell.

2. Basis of action potential (ionic balance)
Three separate phenomena essential to the production of an action potential (excitation of the nerve cell membrane) can be identified:

- Active transport of ions by membrane pumps causes a build up of unequal ion concentrations across the membrane.

- The existence of an electrochemical gradient is due to the unequal transmembrane distribution of an ion species.

- The gating of ion channels causes an ionic current to flow through the channels across the membrane. This current is driven by the electrochemical gradient of the ion species. Action potentials are an all-or-none response that occur when the membrane depolarizes and approaches threshold. As the membrane potential approaches the threshold potential, sodium channels begin to open, and Na^+ ions carry a current into the cell. Below the threshold potential, the K^+ efflux through the K^+ channels (open at rest) is sufficient to cancel the charge carried into the cell by Na^+ influx. The potential at which Na^+ influx begins to exceed K^+ efflux is the threshold potential. (+ on inside)

$Na^+ > K^+$ = threshold potential

3. Action potential conduction
After the membrane reaches threshold, the net inward current of Na^+ causes a further depolarization (potential becomes more positive) of the cell membrane. This depolarization becomes regenerative, causing new sodium channels to open and a further increase in the inflow of Na^+. As the membrane potential approaches Na^+ equilibrium, the electrical forces acting on the Na^+ become smaller. The membrane then reaches maximum depolarization around +40 mV. The open Na^+ channels close, and the potassium channels begin to open. The efflux of potassium repolarizes (potential becomes more negative) the membrane.

It is important to note that the ionic movements responsible for the potential changes of a single action potential are extremely small and do not appreciably change the intracellular concentrations.

4. Synapses, classification, transmission.

There are two major categories of synapses: chemically transmitting and electrically transmitting. At an electrical synapse, the pre- and post-synaptic membranes are in close apposition and form gap junctions, through which electric current can flow directly from cell to cell. Since the current can flow across the gap junctions, an electrical signal in the pre-synaptic cell produces a similar but somewhat attenuated signal in the post-synaptic cell by simple conduction through the junction. At a chemical synapse, a transmitter substance is used for communication between the pre- and post-synaptic neurons. When the action potential reaches the synapse, calcium channels in the pre-synaptic membrane are activated, and Ca^{2+} enters the pre-synaptic membrane. The rise in Ca^{2+} concentration causes the exocytosis of vesicles containing the transmitter substance. These spill their contents into the extracellular space, and the transmitter diffuses across the synapse to the receptor molecules in the post-synaptic membrane. The binding of the transmitter activates ion channels associated with the receptor molecules, allowing the ions to carry a post-synaptic current. The post-synaptic current produces a post-synaptic potential. If the potential change is sufficient enough to exceed the threshold potential, it initiates an action potential.

5. Membrane physiology, receptors, membrane channels

The transmitter in a chemical synapse interacts with the post-synaptic membrane to produce permeability changes to certain ions. This interaction must entail two major events:

- The transmitter must bind to a receptor molecule in the post-synaptic membrane.
- There must be an interaction between the receptor molecule and transmitter that causes a previously closed ion channel to open.

When a channel opens in response to the transmitter-receptor binding, a current passes through the open channel. A large number of these single-channel currents sum to produce the large synaptic current that flows in response to the release of transmitter molecules form the pre-synaptic terminal.

A synaptic event that increases the probability of initiation of an action potential in the post-synaptic cell is called an excitatory post-synaptic potential (EPSP). An inhibitory post-synaptic potential (IPSP) reduces the probability that an action potential will occur. Inhibitory synaptic currents are carried by channels permeable to K^+ or Cl^-. Excitatory current is carried through channels that are permeable to Na^+ or Ca^{2+}, and often to K^+.

Spatial and temporal summations both depend on the passive electrical properties of the neuron. If a neuron is stimulated a second time before the first excitatory post-synaptic potential dies away, the second synaptic potential adds to the previous one and creates a greater depolarization than from the one synapse alone. This is called temporal summation since the input signals arrive at the same cell at different times. In spatial summation, two inputs occur at different locations on the same cell. The summation of these multiple excitatory post-synaptic potentials can bring the membrane to threshold so that action potentials are initiated.

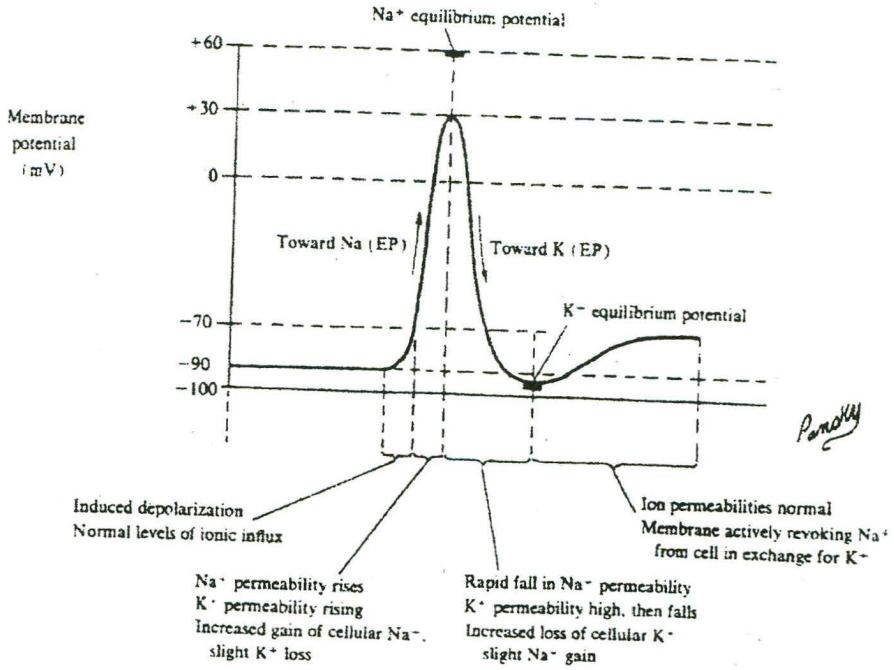
6. Strength-duration curve

C. NEUROANATOMY

1. Spinal cord

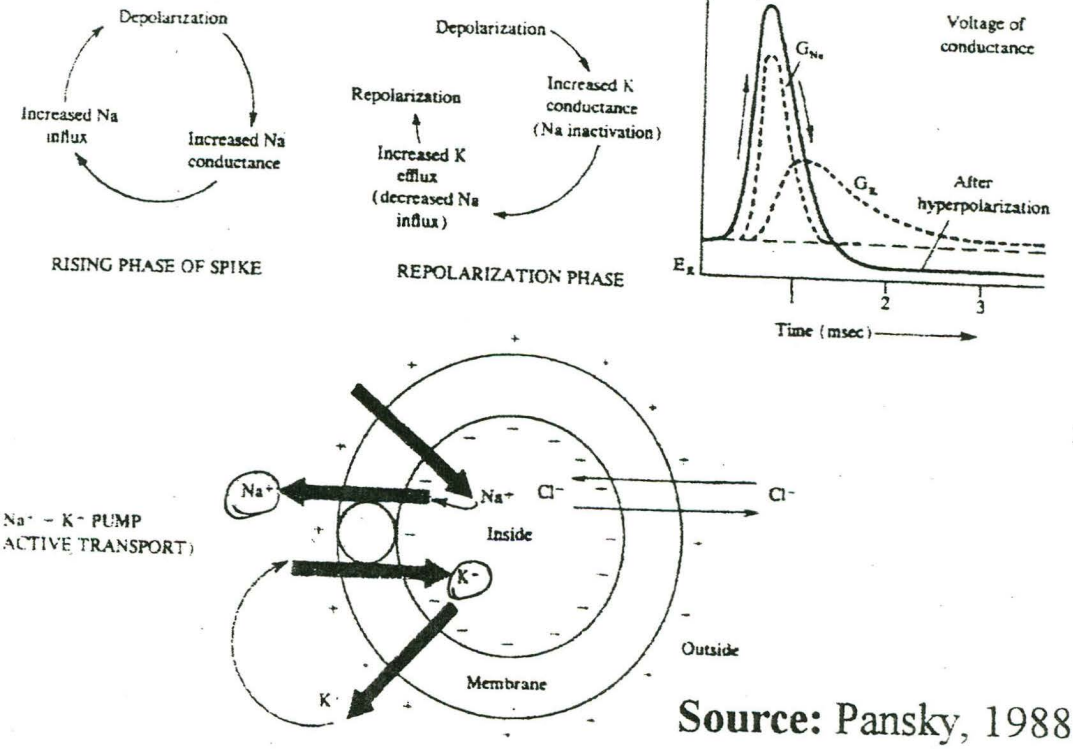
Gray matter (cell bodies)
It is the butterfly-shaped gray portion of the spinal cord that consists of large masses of densely packed neuron cell bodies, dendrites of association and efferent neurons, and unmyelinated axons. Gray matter is also rich in blood vessels and glial cells. Gray matter is subdivided into sections called columns or horns.

- Root cells lie in the anterior and lateral horns and exit via the ventral horn to innervate somatic tissue. Posterior (Dorsal) Horn neurons are sensory. Lateral and Ventral (Anterior) Horn neurons are motor.
- Column cells are neurons confined within the CNS and are classified as central, internuncial, commissural or associated neurons.

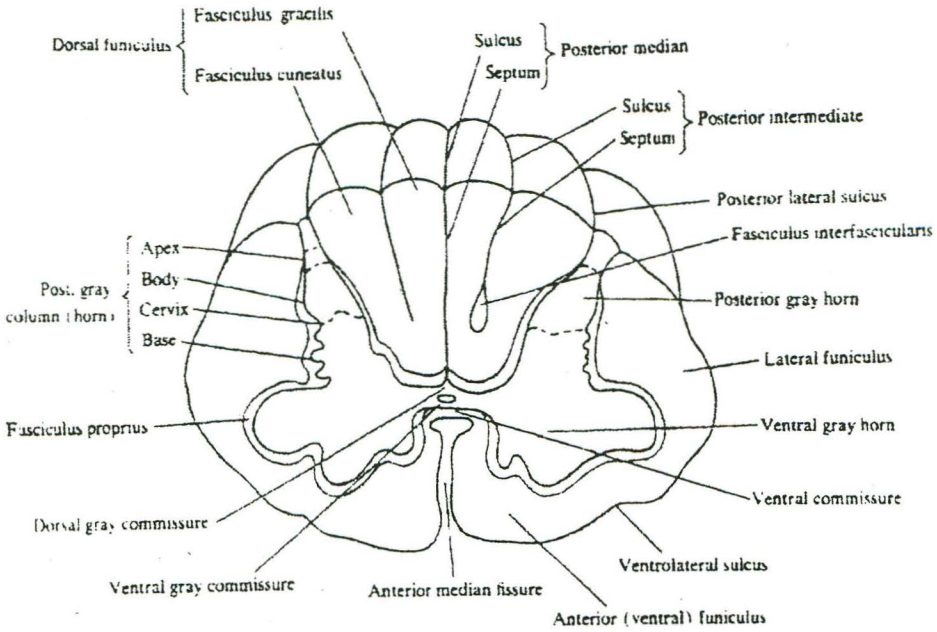


MEMBRANE ION PERMEABILITY CHANGES DURING AN ACTION POTENTIAL

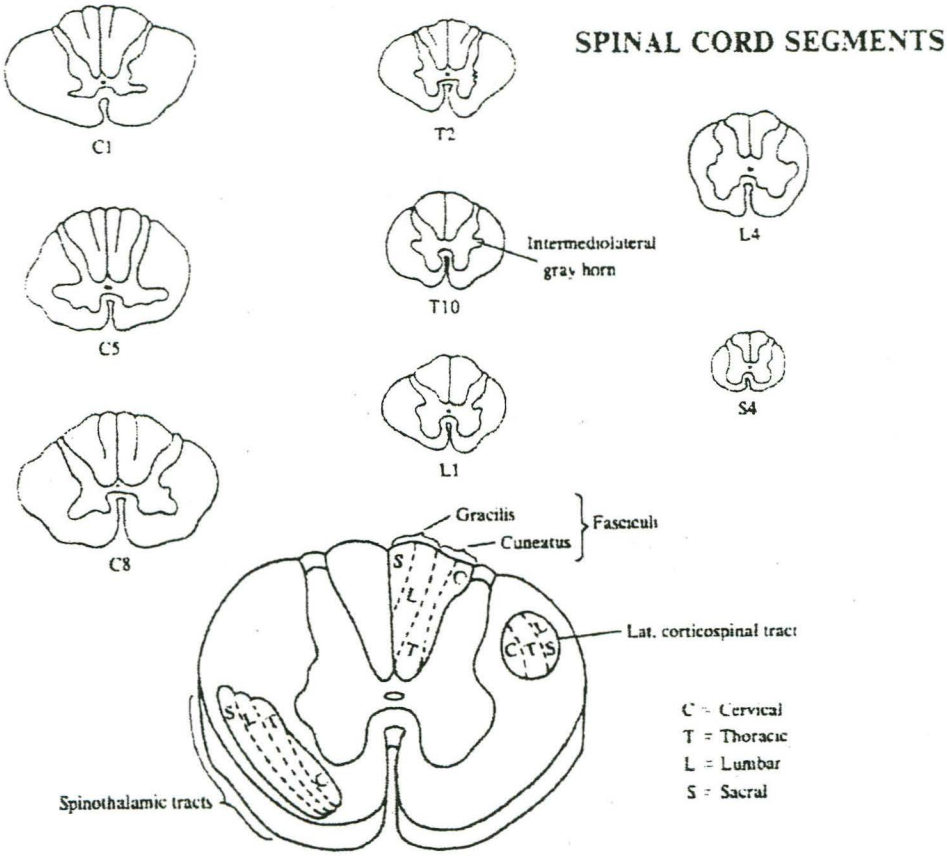
Source: Pansky, 1988



Source: Pansky, 1988



X-SECTION OF SPINAL CORD



SPINAL CORD SEGMENTS

SOMATOTOPIC ARRANGEMENT OF FIBERS IN SPINAL CORD

Source: Pansky, 1988

- Gray commissure connects the wings of gray matter and surrounds the central canal. The central canal is lined by ependymal cells and is continuous with the ventricles, containing cerebrospinal fluid (CSF). Nuclei are gray matter within the brain stem associated with various special senses and visceral functions. The brain stem extends downward from the base of the cerebrum to the level of the magnum foramen. The parts of the brain stem include the diencephalon, midbrain, pons and medulla oblongata.

6. Inhibitory and excitatory post-synaptic potentials (including concepts of spatial and temporal summation)

White matter (axons)
The white matter consists of myelinated axons arranged in bundles called fasciculi, occupying the outer part of the spinal cord. The white matter is divided into three basic masses of fibers called funiculi. The posterior funiculus contains the fasciculus gracilis and fasciculus cuneatus. The lateral funiculus contains that anterior and posterior spinocerebellar, spinotectal, lateral spinothalamic, lateral corticospinal, and rubrospinal. Lastly, the anterior funiculus contains the anterior spinothalamic, anterior corticospinal, tectospinal, vestibulospinal, and reticulospinal.

Posterior funiculus
- fasciculus gracilis
- fasciculus cuneatus

Lateral funiculus
- anterior spinocerebellar
- posterior spinocerebellar
- spinotectal
- lateral spinothalamic
- lateral corticospinal
- rubrospinal

Anterior funiculus
- anterior spinothalamic
- anterior corticospinal
- tectospinal
- vestibulospinal
- reticulospinal

- Ascending pathways

a. Tracts that carry sensory information from body parts to the brain. The nerve fibers within these tracts are axons. The ascending pathways consist of three neurons:

Body Parts → Brain

* 1st order neuron – cell body in dorsal root ganglion
* 2nd order neuron – connecting 1st and 3rd order neurons
* 3rd order neuron – cell body in thalamus and travels to cortex.

b. Principal ascending tracts:
① - spinothalamic
② - fasciculus gracilis and fasciculus cuneatus
③ - posterior spinocerebellar
- anterior spinocerebellar

- Descending pathways

a. These tracts conduct motor impulses from the brain to the muscles and glands

Brain → Body Parts

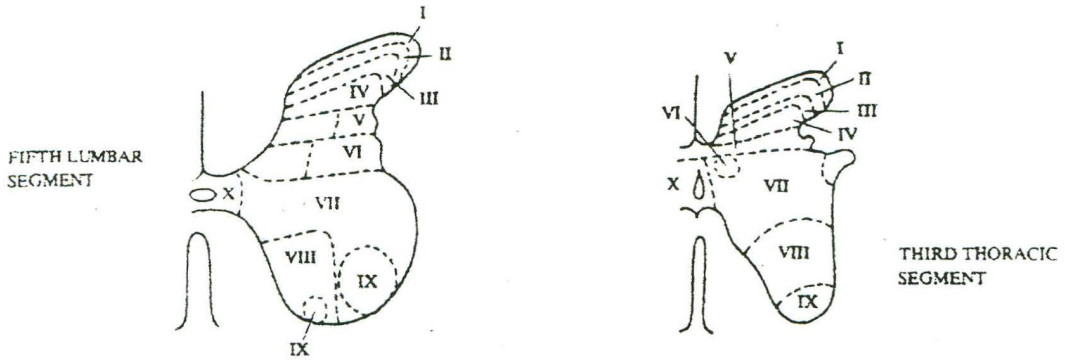
b. Principal descending tracts

① Pyramidal tracts
* lateral corticospinal
* anterior corticospinal

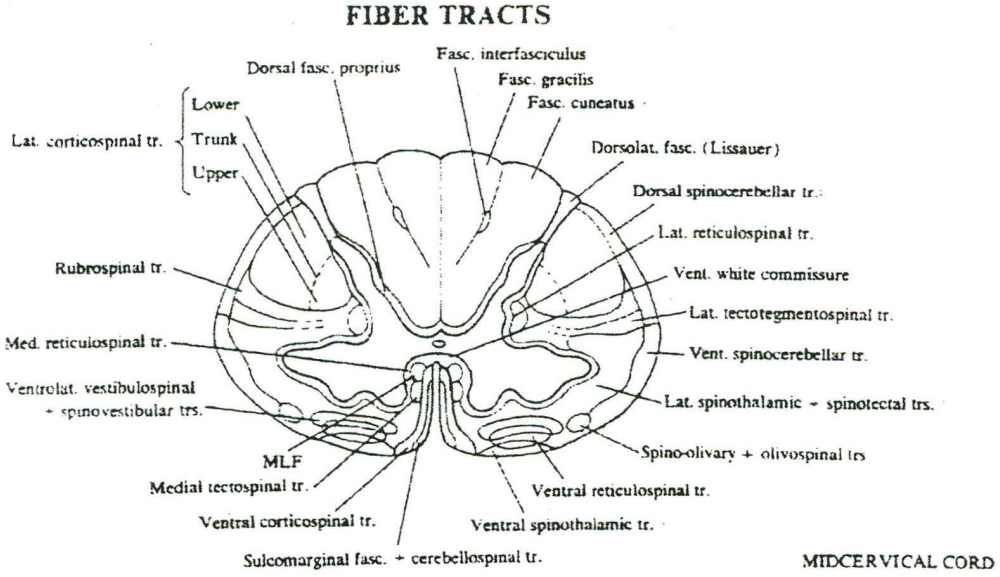
② Extrapyramidal tracts
a) * rubrospinal
b) * reticulospinal
c) * vestibulospinal
d) * tectospinal

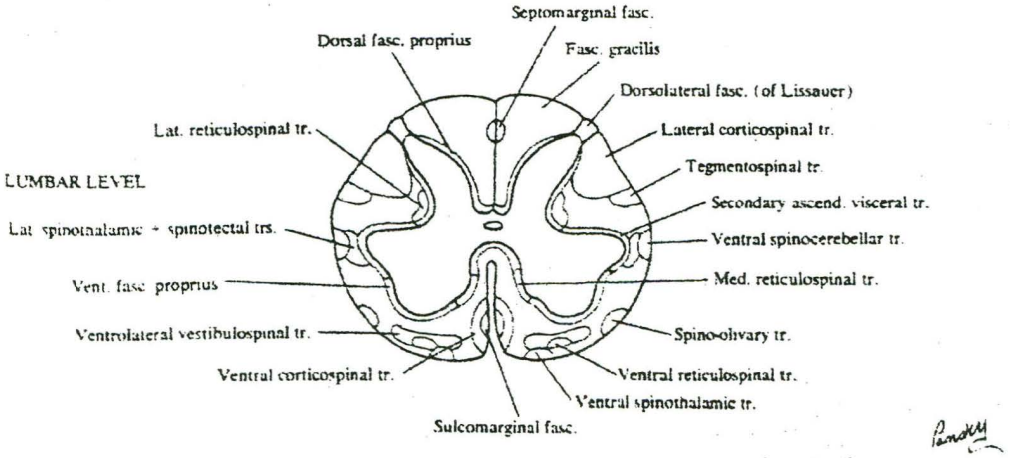
Spinal Nerves
There are 31 pairs of spinal nerves which are part of the peripheral nervous system. For each spinal segment, there is a pair of spinal nerves except for the first pair of cervical spinal nerves which exits from between the occipital bone and the atlas. There are 8 pairs of cervical nerves, 12 pairs of thoracic nerves, 5 pairs of lumbar nerves, 5 pairs of sacral nerves and 1 pair of coccygeal nerves.

Spinal nerves are mixed nerves having both sensory and motor fibers. Spinal nerves are formed from the union of the dorsal root (sensory) and ventral root (motor).

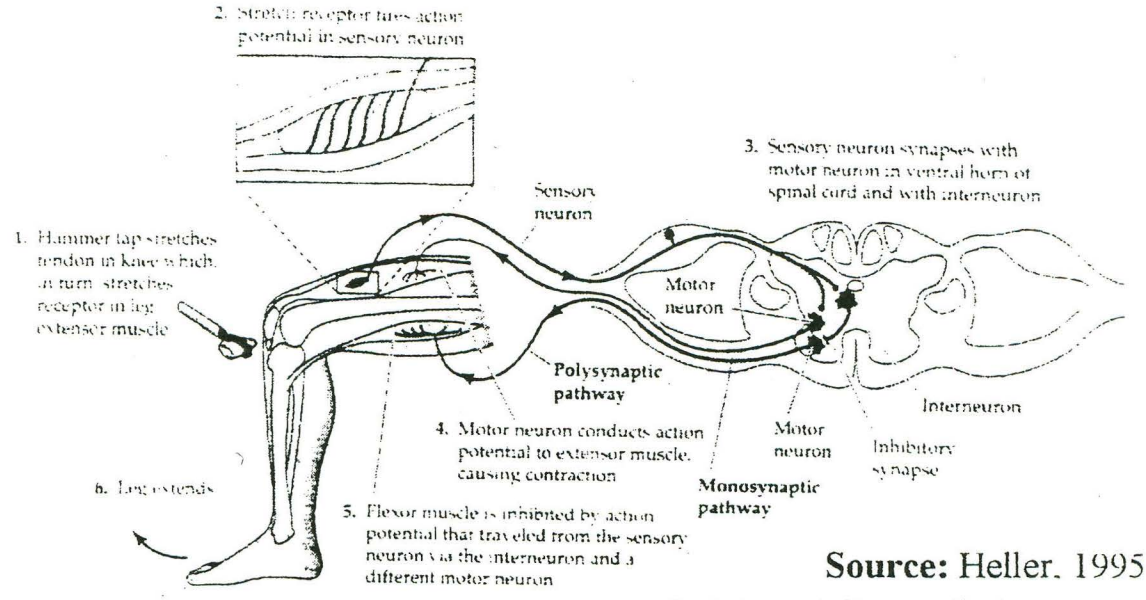


Source: Pansky, 1988





Source: Pansky, 1988



Source: Heller. 1995

Branches of the spinal nerves:

- Meningeal branch (sensory and vasomotor) - innervates the dura mater of the spinal cord
- Dorsal Primary Rami (mixed) - innervate dorsal musculature of trunk
- Ventral Primary Rami (mixed) – innervate ventral musculature of trunk and entire musculature of extremities

Rami communications connect the ventral root with the sympathetic trunk.

The ventral primary rami do not go directly to the body. With the exception of the ventral primary rami of the thoracic nerves which go directly to the body, all of the other axons come together to form plexuses:

- Cervical plexus (C1-4)- innervates the neck
- Brachial plexus (C5-8 & T1)- innervates upper extremities
- Lumbosacral plexus- Lumbar(L1-4)- innervates anterior thigh Sacral (L4-5 & S1-3)-innervates posterior thigh, leg, and foot
- Pudental plexus (S2-4 to pelvic floor)- innervates pelvic floor

2. Autonomic Nervous System

- Parasympathetic
  The parasympathetic nervous system is a cranio-sacral system because the parasympathetic nuclei are located in the brain and one nucleus originates from a sacral segment of the spinal cord.

a. Cranial Nuclei include:
   - Nucleus of Edinger Westphal (CNIII)
   - Salivatory Nuclei- (CN VII, IX)
   - Dorsal Motor Nucleus of Vagus (CN X)

b. Preganglionic fibers originate from the CNS and travel a long way to various ganglia where post ganglionic fibers originate and travel to final target located near the ganglia. Long pre-ganglionic neuron, short post-ganglionic neuron.

c. Function of parasympathetic system is to maintain visceral functions in a restful state.

- Sympathetic
  The sympathetic nervous system is a thoraso-lumbar system because the Nucleus Intermediolateralis originates from the spinal cord in the thoracic and lumbar region

a. Preganglionic fibers originate from Nucleus Intermediolateralis and travel a short way to the paravertebral or prevertebral ganglia where the fibers can either synapse or travel up and down the paravertebral column to synapse at a prevertebral ganglion. Short pre-ganglionic fibers, long post-ganglionic fibers.

b. Function of sympathetic system is to maintain autonomic junctions in the excited state.

- Neurotransmitters

  a. Cholinergic-Acetylcholine is a neurotransmitter of pre- and post-ganglionic neurons to sweat glands (this is sympathetic) and blood vessels for dilation, and of motor end plates

  b. Adrenergic-Norepinephrine (noradrenaline) is a neurotransmitter of sympathetic post-ganglionic fiber

     - Epinephrine (adrenaline)- same as above
     - Dopamine- high concentration in Substantia Nigra
     - Serotonin- in brain stem

  c. GABA-(gamma-aminobutyric acid) inhibitory neurotransmitter

3. Medulla

The medulla is the most inferior portion of the brainstem and is continuous caudally with the spinal cord. The dorsal or posterior aspect is flattened to form the floor of the 4th ventricle. The medulla consists of white matter and gray matter. The white matter consists mainly of nerve tracts passing between the spinal cord and the various portions of the brain. Because of its position, all nerve tracts passing between the spinal cord and the upper divisions of the brain must pass through the medulla. The gray matter consists mainly of various nuclei. The medullla is part of the myelencephalon and contains vital centers that control heartbeat, respiration and blood pressure.

-Level of motor decussation (nuclei, tracts)

a. The anterior (ventral) surface of the medulla consists mainly of two prominent bulges of white matter known as the pyramids.

b. The pyramids contain descending fibers of the pyramidal tracts that pass from the cerebrum to the spinal cord. Superior to the junction of the medulla with the spinal cord, about 80% of the pyramidal fibers cross, or decussate, forming what is called the decussation of the pyramids.

c. The pyramidal (lateral and anterior corticospinal) tracts are the major voluntary motor pathways through which nerve fibers from the cerebrum pass through the brain and down the spinal cord.

d. Decussation within the pyramids rearranges the nerve fibers so that the right side of the brain controls the movement of the left side of the body and vice versa. Injury above this crossover may cause paralysis of the contralateral extremities.

- Level of sensory decussation (nuclei, tracts)

sensory decussation
motor decussation

  a. Above the level of motor decussation, you have the level of sensory decussation. Posterior (dorsal) region of medulla consists partly of the ascending spinal tracts: the fasciculi gracilis and the fasciculi cuneatus. Recall that these tracts convey information regarding touch, pressure and body position

  -Most of the fibers of the fasciculi gracilis end within the prominent nucleus gracilis in the posterior

portion of the medulla. At the nuclei, the fibers synapse with neurons that convey the information to other areas of the brain.

-Similarly the fibers of the fasciculi cuneatus synapse with neurons in the nucleus cuneatus, also located within the posterior portion of the medulla.

b. From nuclei gracilis and cuneatus, myelinated fibers arise which sweep anterior and across the median. These fibers are known as internal arcuate fibers.

-After crossing they form a well defined ascending bundle, the medial lemniscus. These fibers then pass on to the cerebellum or the thalamus, terminating in the ventral posterolateral nucleus (VPL) in the latter case.

-The medial lemniscus makes up the second neuron of the posterior column nerve pathway conveying kinesthetic sense and discriminating tactile sense to higher levels.

-Decussation of the medial lemniscus provides part of the anatomical basis for sensory representation of half of the body in the contralateral cortex.

-Injury to the medial lemniscus causes kinesthetic and tactile deficits on the opposite side of the body.

c. Lateral to the cuneate nucleus is a group of large cells known as the accessory cuneate nucleus.

-These cells do not cross, but give rise to uncrossed cuneocerebellar fibers that at higher level enter the cerebellum via the inferior cerebellar peduncle.

-These fibers convey impulses from receptors in the muscles of the upper extremity and neck and are the upper limb equivalent of the posterior spinocerebelllar tract (from the lower extremities).

- Level of the inferior olives (nuclei, tracts)

a. The olive is a flattened oval mass on each upper lateral surface of the medulla. It is composed of the inferior olivary nucleus and two accessory olivary nuclei.

b. The inferior olivary nucleus is the largest of the medullar-cerebellar relay nuclei. This complex consists of:

-The principal inferior olivary nucleus

-The medial accessory olivary nucleus

-The dorsal accessory olivary nucleus

c. Fibers emerging from the inferior olivary nuclei traverse the medial lemnisci and course both through and around the opposite inferior olivary nuclei. They traverse the leticular formation and parts of the trigeminal complex to enter the contralateral inferior cerebellar peduncle.

-The olivocerebellar projections are remarkable specific.

-Olivocerebellar fibers end as climbing fibers (fibers which ascend Purkinje cell dendrites) in the cerebellar cortex.

- Level of high medulla (nuclei, tracts)

a. A vast complex of intermingled gray and white matter known as the reticular formation extends from the spinal cord through the medulla and upward through the brainstem and thalamus. It constitutes a matrix in which specific nuclei and tracts are embedded.

-The reticular formation is important in keeping the cerebrum conscious and alert. That is, it acts as a filter for incoming sensory impulses, activation the cerebral cortex into a state of wakefulness.

-It also plays a role in regulating various motor activities so muscle movements are coordinated and smooth.

b. Raphe nuclei are considered a part of the reticular formation. It is a group of cells situated along the midline of the medulla, pons and midbrain. Many of its neurons synthesize serotonin.

c. Within the reticular formation of the medulla are several vital reflex centers.

-Cardiac center controls heart rate. Impulses from here can cause the heart to beat slower or faster.

-Vasomotor center controls blood pressure by regulating the diameter of the blood vessels.

-Respiratory center-initiates and regulates breathing

-Other non-vital reflex centers are also located within the medulla. These include vomiting, sneezing, coughing and swallowing.

d. Because the medulla contains these vital centers, a blow to the back of the head that damages the medulla may be fatal.

- Cranial nerves IX through XII originate within the medulla, and their nuclei are located there.

-Cranial nerve IX (glossopharyngeal) relays information regarding taste, salivation and swallow.

-CN X (vagus) conveys information to and from many thoracic and abdominal organs.

-CN XI (spinal accessory) delivers messages governing movement of the head and shoulders.

-CN XII (hypoglossal) delivers messages from the medulla to the tongue muscles.

-CN VIII (vestibulocochlear) is synaptically connected to nuclei located in both the medulla and pons. This is a sensory nerve that delivers messages regarding hearing and equilibrium.

- Auditory system (CN VIII and connections)

a. The vestibulocochlear nerves are sensory cranial nerves consisting of two branches: the cochlear and vestibular. The cochlear, also called auditory, branch transmits auditory information from the ear.

cochlear
- auditory info from ear
- organ of Corti
↓
cochlear nuclei (medulla)
↓
inferior colliculi
↓
medial geniculate nuclei (thalamus)
↓
auditory areas w/in temporal lobes

-Impulses from the organ of hearing (organ of Corti) in the cochlea of the inner ear are transmitted to the cochlear nuclei within the medulla and then to the inferior coiliculi.

-From there information is transmitted to the medial geniculate nuclei of the thalamus and then to the auditory areas within the temporal lobes.

b. Cochlea

The primary auditory nerve fibers arise from the spiral ganglia. The cell bodies of these bipolar cells are located near the cochlea.

primary aud. nerv. fib. (spiral ganglia)
↓ dorsal & ventral cochlear nuc.
↓ except cells w/in organ of Corti

-One end connects to the receptor cells, which consist of a row of hairs within the organ of Corti.

-The other end terminates upon two nuclei, the dorsal and ventral cochlear nuclei, located close to the inferior cerebellar peduncle and in the medulla.

-Secondary auditory nerve fibers arise from these cochlear nuclei and

2° aud. nerve fibers (cochlear nuclei + acoustic striae)

central nucleus of inf. colliculus
↑ terminate in
2° auditory nerve fibers (cochlear nuclei + acoustic striae) project to ↓ auditory relay nuclei (medulla)

from acoustic striae. The fibers of these striae project to auditory relay nuclei within the medulla (nuclei of the superior olivary complex), but the main bundle enters the opposite lateral lemniscus directly and projects upward to terminate in the central nucleus of the inferior colliculus. En route, most of the uncrossed fibers terminate in the reticular formation, the superior olivary nuclei and others. Only crossed fibers ascend.

-The afferent fibers continue ascending to the temporal lobe for auditory interpretation.

-Above pathways are afferent, but there is also an efferent cochlear bundle which projects from the olivocochlear bundle of the brain stem back to the cochlea.

c. Lesions interrupting the ascending auditory pathways result in diminished hearing, especially on the opposite side.

-Although meaningful conscious hearing requires the neural activity of the cerebral cortex, the cortex is not essential for the auditory reflexes. In other words, even without the cerebrum you can respond to sounds.

-Tinnitus (buzzing or flinging in ears) is a common symptom of damage to the cochlear nerves.

- Vestibular system (CN VIII, connections, reflexes)

-The vestibular system is the special proprioceptive system that functions to maintain equilibrium and to preserve a constant plan of vision.

-The information required by the nervous system to sustain posture and equilibrium is obtained from three afferent sources: the eyes, the general proprioceptor throughout the body and the vestibular membranous labyrinth.

-The specific receptors in the membranous labyrinth that sense the critical stimuli are the crista in the ampulla of the semicircular canals, the crista of the utricle and the crista macularis of the saccule.

-The vestibular branch is the other branch of the vestibulocochlear nerve (CN VIII). Impulses are transmitted from the organs of equilibrium (the semicircular canals, saccule and utricle) of the inner ears to the vestibular nuclei in the medulla. From there, messages are dispatched to the cerebellum and spinal cord.

Equilibrium organs → vestibular nuclei → cerebellum and spinal cord

a. Connections

-The primary vestibular fibers have their cell bodies located in the superior and inferior vestibular ganglia located near the semicircular canals of the inner ear.

-The vestibular receptor at one end of these bipolar cells is located in the neuroepithelial hair cells of the crista ampullaris.

-The other end of these cells traverse portions of the pairs of vestibular nuclei, located in the floor of the 4th ventricle just below the middle cerebellar peduncle.

-Eye movements and the vestibular system

-The functional interaction of the vestibular receptors resulting in the eye movements is mediated by ascending fibers that project from the vestibular nuclei to the medial longitudinal fasciculus of the same and opposite side and ascent to the midbrain

-The superior, medial and lateral vestibular nuclei project fibers to form the "vestibuloencephalic pathway." Its connections with the nuclei of the extraocular muscles (CN III, IV, and VI) form a basis of coordinated (conjugate) eye

movements. Synchronized movements of both eyes to the side (lateral gaze) up (upward gaze) or down (downward gaze) are mediated via this pathway. Phenomenon of nystagmus is related to the imbalance of synchronized impulses from vestibular sources.

-Head and body movements and the vestibular system. The vestibular nuclei project crossed and uncrossed fibers that descend in the medial longitudinal fasciculus. This pathway (vestibulospinal) terminates in the spinal cord and helps to maintain head position in space in response to labyrinthine stimuli. This pathway also has a role in the muscular activities of the body and extremities associated with postural movements and balance.

- Vestibular connections with the cerebellum and with the reticular formation.

vestibular nerve → vestibular nuclei → puxtarestiform body → terminate archicerebellum and fastigial nuclei of cerebellum

-The fibers that project from the vestibular nerve and the vestibular nuclei to the cerebellum pass through the puxtarestiform body (medial portion of the inferior cerebellar peduncle) and terminate in the archicerebellum (flocculonodualar lobe) and in the fastigial nuclei of the cerebellum. The fastigial nuclei project fibers to the vestibular nuclei.

-Efferent fibers from the fastigial nucleus of the cerebellum and from the vestibular nuclei pass through the vestibular nerve and terminate on the hair cells of the membranous labyrinth. These vestibular efferent neurons probably exert inhibitory influences and ameliorate the effects of motion sickness and nystagmus.

-Injury to the vestibular branch may result in vertigo (an illusion of movement or sensation that the external environment is revolving around the patient). Injury may also result in ataxia (failure of muscular coordination) and nystagmus (involuntary, rapid movement of the eyeball).

b. Reflexes

-Static Equilibrium

-The organs of static equilibrium are located in the utricle and saccule, two expanded chambers of the membranous labyrinth inside the vestibule.

-The stimulus is gravity. The receptor is the macula of the utricle. The macula also has hair cells embedded in the gelatin and calcium carbonate particles called otoliths on top of the gelatin. When the head is tilted the otoliths will move bending the cilia which send impulses to the vestibular nuclei indicating the head tilt. The impulses are sent to the other destinations to aid in maintaining equilibrium.

stimulus - gravity
cupola
receptor - macula of utricle

-Dynamic Equilibrium
The stimulus is angular acceleration. The receptors are the crista ampullaris of the semicircular canals. The crista consists of hair cells with the cilia embedded within the cupola, a gelatinous mass. When the head is rotated to the right, relative flow of the endolymph is to the left stimulating the right crista and inhibiting the left crista. The impulses from the crista travels to the vestibular nuclei, and via the MLF, the impulses are sent to the nuclei of the extraocular muscles. This produces a right nystagmus (fast phase to the right, slow phase to the left).

stimulus - angular acceleration
receptors - crista ampullaris of semicircular canals

-Other sensory structures aid in balance, proprioceptor supply information concerning position of body parts, and visual information is also important

- Pons

medulla - pons - midbrain

The pons separates the medulla from the midbrain; it is derived from the metencephalon

a. Low or Caudal Pons

-Divided into two portions: the dorsal portion called the pontine tegmentum, and the ventral portion

-Nuclei- CN VI, VII and VIII

-Contents include:

Longitudinal Bundles of Pons which carries corticospinal, corticopontine, and corticobulbar fibers

Pontine Gray cell bodies of pons where corticopontine fibers synapse

Transverse Fibers (pontocerebellars)- originate in pontine gray, cross midline, and go to cerebellum via the middle cerebellar peduncle

b. Abducens nerve (6) -
CN VI innervates the lateral rectus muscle. The CN VI has a long course, traveling in close proximity to the following structures. Therefore, lesions in these structures may affect the lateral rectus.

-anterior inferior cerebellar artery
-pyramids
-meninges
-inferior petrosal dural venous sinus
-petrous portion of temporal bone (inner ear infection)
-cavernous sinus- internal carotid artery
-superior orbital fissure- Annulus of Zinn
-orbital cavity

The central connections of the CN VI include afferent fibers from the vestibular nuclei via the medial longitudinal fasciculus and from the cortex via the contralateral corticobulbar fibers.

- Mid Pons

Nucleus Reticularis Pontis Oralis- ascending fibers from reticular formation sent to activate cortex.

Nucleus Reticularis Tegmenti Ponti- receive fibers from cortex to cerebellum

-Contents include: Medial Lemniscus, Lateral Lemniscus Spinothalmic, Rubrospinal Spinotectal Tracts, MLF, Medial tectospinal Tract, Superior Cerebellar Peduncle, Descending autonomics

a. Trigeminal Nerve – CN V

-Chief Sensory and Spinal Nucleus- receives sensory information from face and teeth.

-Mesencephalic Nucleus of V receives information from chewing muscles and teeth

-Motor Nucleus (Masticator Nucleus) innervates chewing muscles

-Trigeminal Ganglion – associated with the sensory aspect of CN V; three division: Ophthalmic branch from orbit, Maxillary branch from upper jaw and nose, Mandibular branch from lower jaw. Central connections include afferent fibers from CN IX and X, posterior fasciculus, primary somatosensory area of the cortex and corticobulbar fibers. Efferent fibers synapse in the thalamus, cerebellum, and reticular formation.

b. Facial Nerve – CN VII

-Motor Nucleus of VII – innervates facial muscles Stylohyoid, and Stapedius

-Salivatory Nucleus – innervates submandibular and sublingual glands

-Lacrimal Nucleus – innervates lacrimal gland

-Nucleus Solitarius – receives taste information from anterior 2/3 of tongue

-Spinal Nucleus of V – receives fibers from CN VII for sensory information of small patch of skin behind the ear. Central connections include afferent fibers from the superior colliculus, reticular formation and the cortex for the motor nucleus.

- Midbrain
  Derived from mesencephalon. The midbrain is divided into multiple parts:

  Tectum – the roof of the cerebral aqueduct; the two superior colliculi and two inferior colliculi

  Cerebral Peduncle Tegmentum – ventral to cerebral aqueduct

  Crus Cerebri – lateral and ventral to Tegmentum

  a. Level of Inferior Colliculus

  -This level has the reflex centers for the auditory system in the tectum – contains CN IV and lateral lemniscus. In the tegmentum – contains same tracts as in the mid pons plus the presence of the Substatia Nigra

  -In the Crus Cerebri: middle 3/5 – corticobulbar and corticospinal, lateral 1/5-corticopontine from parietal, occipital, and temporal lobes of cortex; medial 3/5 – frontopontine from the frontal lobe of the cortex

  b. Trochlear Nerve – CN IV innervates the superior oblique muscle. CN IV is the only nerve that exits on the dorsal side of the brain stem and it totally crosses the midline after it leaves its nucleus. Central connections include afferent fibers from cortex via the corticobulbar fibers and vestibular nuclei via the MLF.

  c. Level of Superior Colliculus
  This level has the reflex centers for auditory, visual and tactile information

  Nuclei:
  Red Nucleus
  EW Nucleus
  Oculomotor Complex
  Substantia Nigra
  Brachium of Inferior Colliculus

  Contents include:
  Medial Lemniscus, Later Lemniscus
  Spinothalamic and Spinotectal MLF

  d. Oculomotor Nerve – CN III

  -Caudal Central Nucleus – innervates the Levator muscle

  -Dorsal Nucleus – innervates inferior rectus muscle

  -Intermediate Nucleus – innervates inferior oblique muscle

  -Ventral Nucleus – innervates medial rectus muscle

  -EW Nucleus – Contains parasympathetic preganglionic cell bodies of neurons to Ciliary Ganglion. The CN III travels close to the posterior cerebral artery and continues through the middle cranial fossa in the cavernous sinus and then divides into two divisions: the superior division goes to the levator and SR, and the inferior division goes to the MR, IR and IO.

  e. Level of pretectum
  This level contains the direct and consensual pupillary light reflex centers.

  When light is shown into the left eye, the left retina is stimulated, messages travel to the optic nerve → optic chiasm → optic tract → fibers then go to the Brachium of the Superior Colliculus and synapse in the pretectal nuclei → send fibers to the ipsilateral and contralateral EW Nuclei → fibers then travel to the Ciliary Ganglion with the inferior division of CN III → to short ciliary nerves → to constrictor muscles of both eyes.

- Diencephalon
  One of the most important sensory centers of the brain; impulses set up in exorecptors reach the lateral nucleus of the thalamus where they

are relayed to the sensory areas of the cerebrum.

a. Dorsal Thalamus
The anterior nucleus of the thalamus is a relay station for impulses initiated in the olfactory organ. The posterior end of the thalamus has two small elevations, the lateral and medial geniculate bodies, relay stations for visual and auditory pathways, respectively. The thalamus is an important relay center for sensory information. It is derived from the diencephalon.

lateral geniculate body (visual pathways) medial geniculate body (auditory pathways)

b. Hypothalamus – Forms the floor of the 3rd ventricle. Externally, it is marked by the optic chiasm, behind which is the infundibulum. Functions of the hypothalamus include regulation of body temp; regulation of fat, water, and carbohydrate metabolism; sleep, sex and emotions are also influenced.

c. Epithalamus – Forms the thin rood of the 3rd ventricle. Contains vascular structure, the choroid plexus, which produces cerebrospinal fluid. Some fibers may connect to the superior colliculus.

d. Subthalamus – Associated with the relay of sensory information to cortical regions concerned with vision, audition, and equilibrium.

- Cerebrum
The largest mass of the brain. It is derived from the telencephalon. The cerebrum is divided into an outer gray matter called the cerebral cortex, a middle layer of white matter containing axons of the cerebral cortex, and an internal gray matter called the Basal Ganglia.

a. Gray matter

-Cell Types:
Pyramidal nerve cells: Named for the pyramidal shape of the cell bodies. They have two extensions of dendrites, apical dendrites which extend towards the cortical surface and basal dendrites which extend laterally, which both branch many times. One axon lies at the base of the cell.

Stellate nerve cells (granule cells): Small size and granular appearance. Usually, one axon and 4-6 dendrites.

Martinotti cells: Small, multipolar with localized dendritic fields and long axons running centrifugally to the plexiform lamina, producing short horizontal collaterals, en route. Upside down pyramidal cells (axon at apex).

Horizontal cells: Small and fusiform with dendrites that spread short distances in two opposite directions. Their axons often stem from a dendrite.

Pleomorphic cells: Considered to be modified pyramidal cells with axons entering the white matter.

- Cytoarchitecture (lamina) of the Neocortex: listed from superficial to deep

I. Molecular lamina (molecular & zonal layer): contains sparsely scattered horizontal cells surrounded by a compacted mass of tangential fibers, derived from pyramidal cells (dendrites), Stellate cells (axons), cells of Marinotti (axons) and cortical afferent fibers.

II. The external granular lamina: Cell bodies of Stellate and small pyramidal neurons with traversing axons and dendrites from subjacent layers.

III. The pyramidal lamina: Cell bodies of medium sized pyramidal neurons. Some Stellate cells also occur.

IV. Internal granular lamina: Mostly cell bodies of Stellate neurons with occasional small pyramidal neurons. Traversed by a horizontal band of fibers called the external band of Baillarger.

V. The multiform lamina: Contains a range of cells, however most cells are small and considered to be modified pyramidal elements.

-Lobes of the cerebral cortex: frontal, parietal, temporal and occipital

-Fissures: Deep cracks on the surface of the cerebral cortex. For example: Sylvian fissure (also call the lateral sulcus): separates temporal lobe. Calcarine fissure: separates the occipital lobe.

-Sulci: Cracks on the surface of the cerebral cortex. For example:
Sagittal sulcus: separates right and left hemispheres.
Cingulate sulcus: runs parallel to the Corpus Callosum medially, above the Cingulate gyrus.
Parietal-occipital sulcus (joins the Calcarine fissure): Separates the occipital lobe from the parietal lobe.

-Gyri: Bulges on the surface of the cerebral cortex.For example:
Precentral and Dostcentral gyrus: in front of and behind the central sulcus.
Cingulate gyrus: between the corpus callosum and Cingulate sulcus.

-Brodmann's cortical areas: Brodmann mapped and divided the cerebral cortex into 47 distinctive areas. The current theory includes no less that 52 "Brodmann maps." The specific functions are known for some of them, such as:
Frontal lobe (specifically the precentral gyrus): contains area 4 which is the motor area
Parietal lobe (postcentral gyrus): areas 1-3, which is the area of general sensation.
Occipital lobe: area 17, which is the visual area.

- **White matter**

Consists of fiber tracts that fall into 3 categories: associational, commissural, and projection.

-Associational
Connects cortical areas within the same hemisphere. Divided into short association fibers, which lie immediately beneath the gray matter of the cortex and connect one gyrus to the next gyrus, and long association fibers, which run deeper in the cerebrum and connect on lobe with another.

-Commissural
Connect cortical areas between the two hemispheres. The corpus collosum is the largest commissural bundle connecting almost all cortical areas.

-Projection fibers
Connect cortical areas with subcortical areas. Consists of ascending (afferent) tracts, whose cell bodies are located mostly in the thalamus, and descending (efferent) tracts, whose cell bodies are found in all areas of the cortex. The vast expanse of these fibers in the cerebrum is called the corona radiata. The internal capsule contains both ascending and descending fibers and it is a broad mass of fibers that lie between the caudate nucleus and lentiform nucleus. The optic radiations connect the LGN with the visual cortex.

- Cerebellum

The cerebellum lies in the posterior cranial fossa, below the posterior part of the cerebrum. It's the second largest part of the brain and it consists of two lateral masses called hemispheres and a connecting portion, the vermis. The two hemispheres are partially separated by a fold of dura mater, the falx cerebelli. The outer layer of the cerebellum, called the cerebellar cortex, consists of gray matter. The surface of the cerebellum is pushed up into numerous long parallel folds called rolla cerebelli. These are separated from the one another by grooves called fissures. Thus, in midsagittal cross section, the inside surface of the cerebellum has a tree-like appearance and is called arbor vitae (tree of life). About 30 million large neurons called

Purkinje cells are found in the cerebellar cortex. Their axons, which are the only output from the cerebellar cortex, carry impulses to the nuclei of the cerebellum and to the lateral vestibular nuclei of the brainstem. The inner layer of the cerebellum contains the deep cerebellar nuclei embedded within the white matter.

a. Nuclei

Embedded in the white matter (called corpus medullar) of each half of the cerebellum are four nuclear masses, the deep cerebellar nuclei. Efferent fibers arise from these nuclei, by which the cerebellum is placed in communication with other parts of the nervous system.

Dentate Nucleus: It's the largest of the nuclei. It lies in the white matter close to the vermis at midline. It is found as a definite nucleus only in mammals and is greatly enlarged in man and apes.

Emboliform Nucleus: It's a wedge shaped grey mass close to the dentate nucleus and is often difficult to delimit from the dentate nucleus.

Globose Nucleus: It lies between the fastigial and emboliform nuclei.

Fastigial Nucleus: It's the most medial nucleus, lying near the midline of the roof of the fourth ventricle. It's the second largest nucleus.

b. Connections

The cerebellum receives input from numerous brain stem nuclei (i.e. spinocerebellar or pontocerebellar), which enters mainly via the cerebellar peduncles. The information is processed in the cerebellar cortex, which then sends messages to the deep cerebellar nuclei via the Purkinje cells. Messages are then sent from the nuclei to other parts of the nervous system via the peduncles.

-Afferent connections: The cerebellum receives afferent impulses from virtually all kinds of receptors from all parts of the body. They are relayed to the cerebellum by nuclei within the spinal cord and brain stem. Input impulses include cutaneous, stretch, vestibular, visual and other receptors. Afferents from the vestibular system appear unique in that they pass directly into the cerebellum. Afferent fibers exceed efferent fibers within the cerebellum by a ratio of 40:1. Afferent : Efferent

-Cerebellar Peduncles: the cerebellum is connected to the brain stem by three bands of called the cerebellar peduncles (inferior, middle, and superior).

1-Inferior peduncle: Carries connection for impulses to and from the medulla oblongata and spinal cord. medulla oblongata and spinal cord

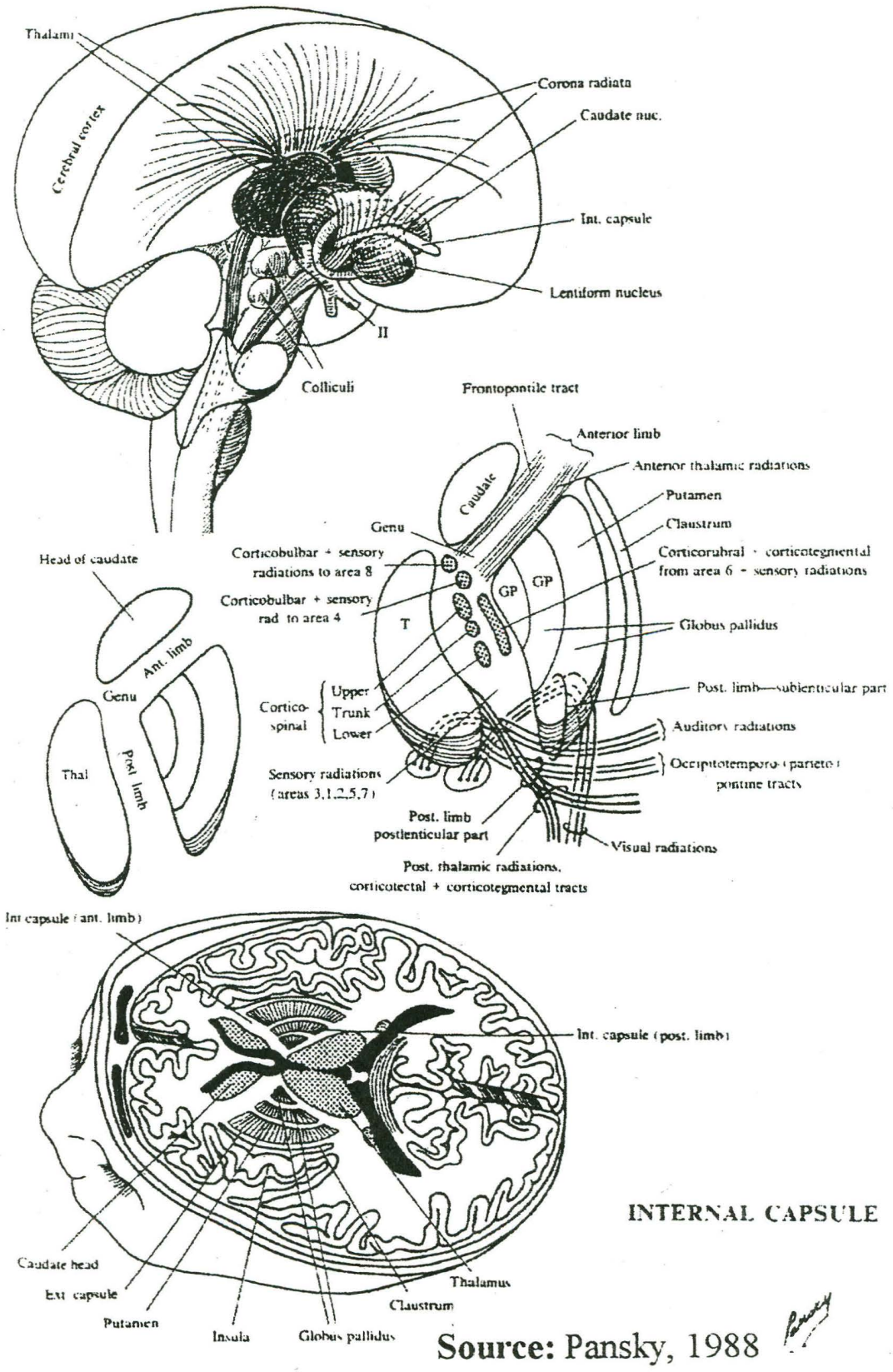
2-Middle peduncle: Carries connections for impulses to the cerebellum from the pons. pons → cerebellum

3-Superior peduncle: Carries impulses from the dentate nucleus to the midbrain. dentate nucleus → midbrain

c. Functions

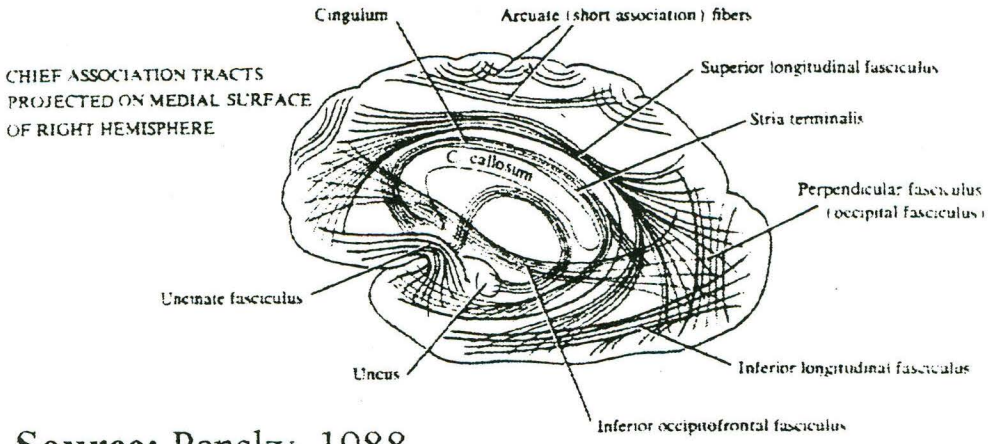
The cerebellum is concerned with the coordination of somatic motor activity, the regulation of muscle tone and mechanisms that influence and maintain equilibrium. It functions mainly as a reflex center. No sensory information transmitted to the cerebellum enters the conscious sphere. The cerebellum is utilized primarily in the autonomic regulation and control of motor functions. Sensory impulses involved in these reflexes come from receptors called proprioceptors.

- somatic motor activity
- muscle tone regulation
- equilibrium
- reflex center
- autonomic regulation
- control of motor



INTERNAL CAPSULE

Source: Pansky, 1988



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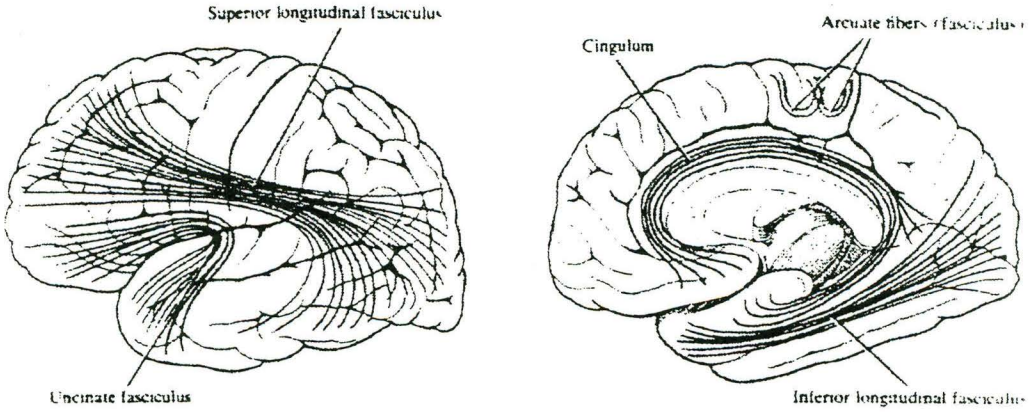
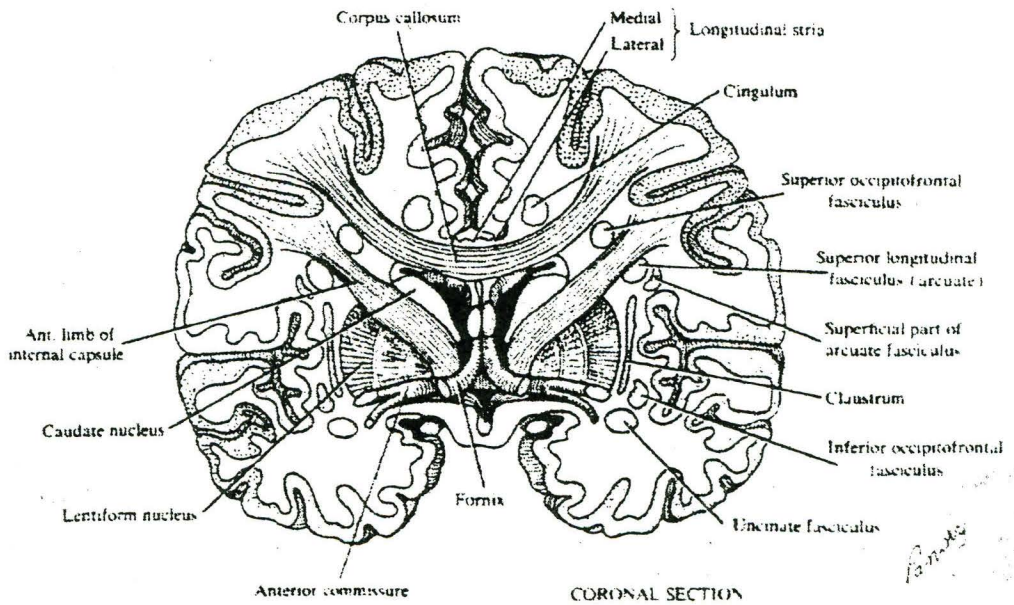
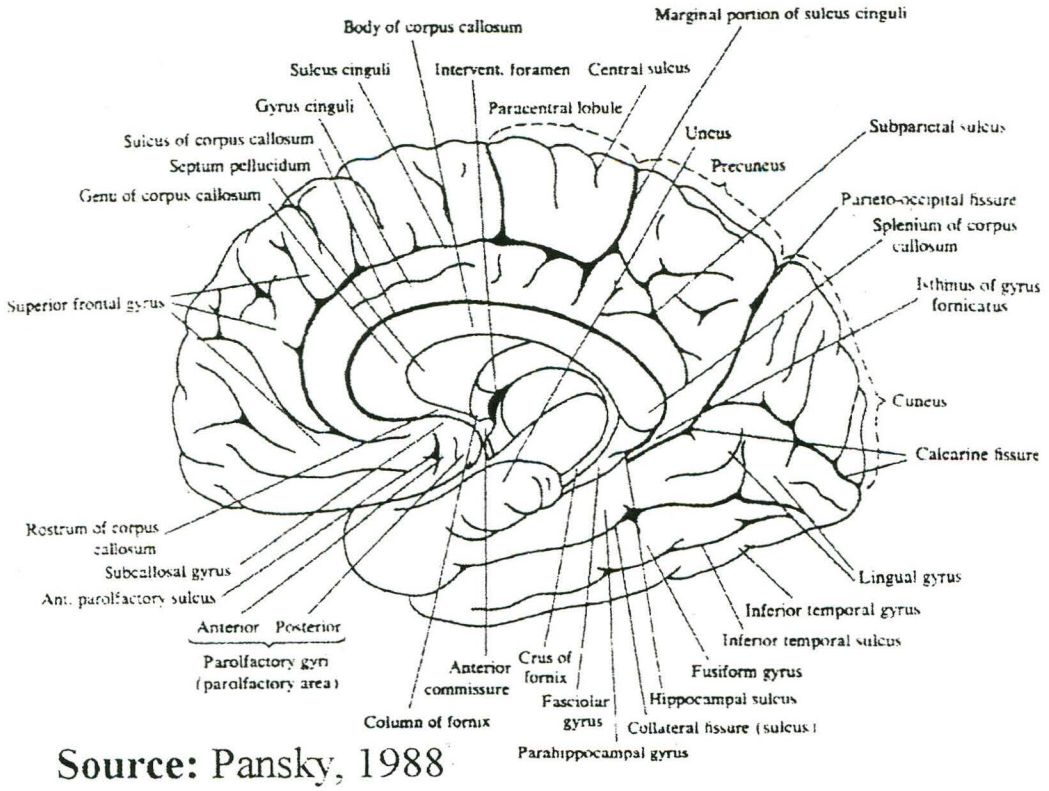


MAJOR ASSOCIATION FIBERS





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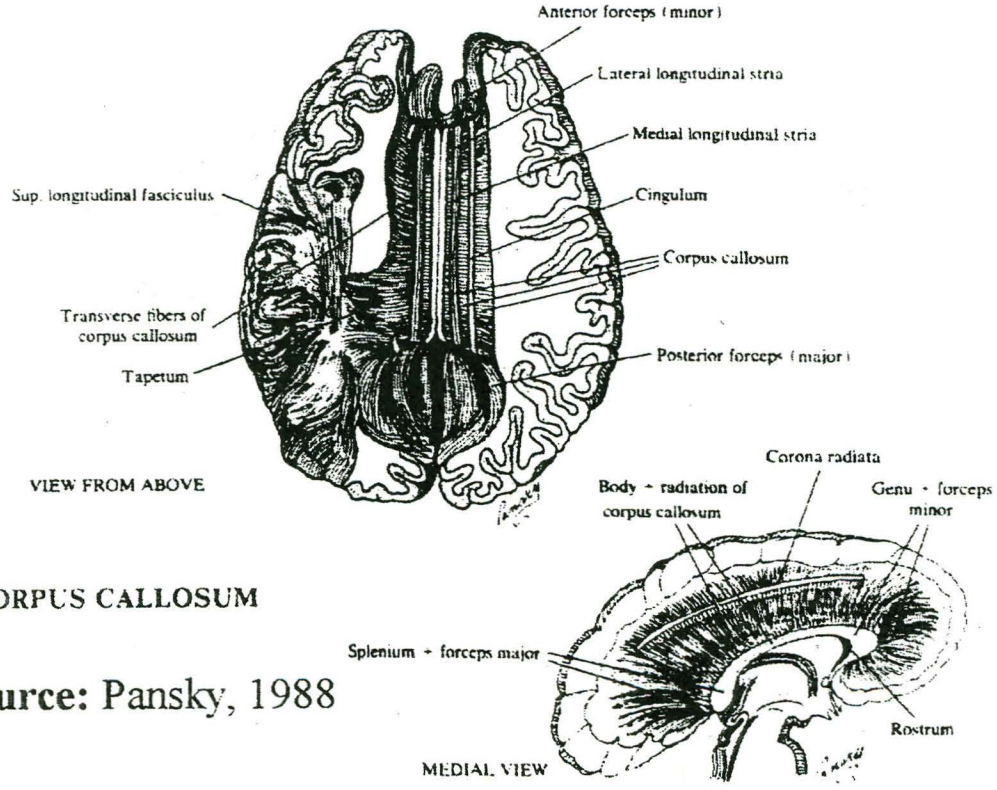

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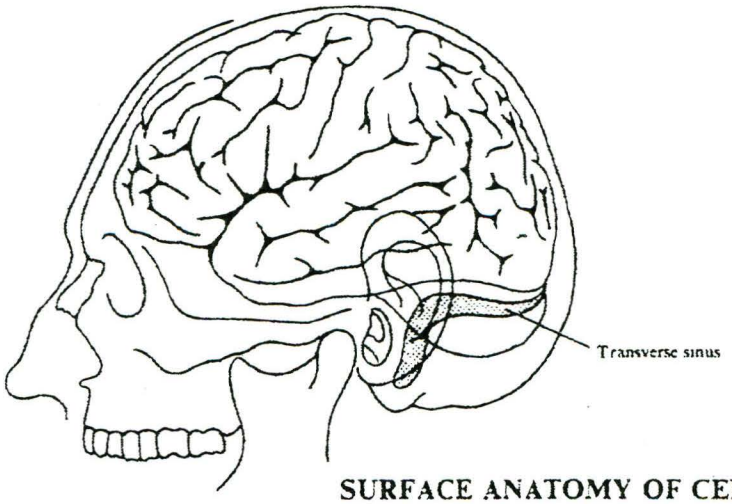
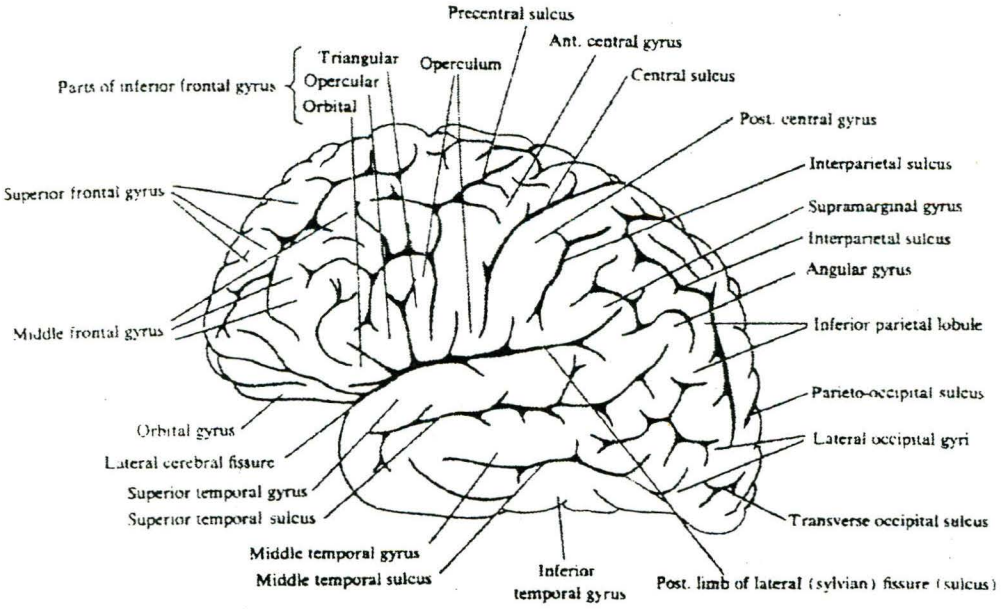
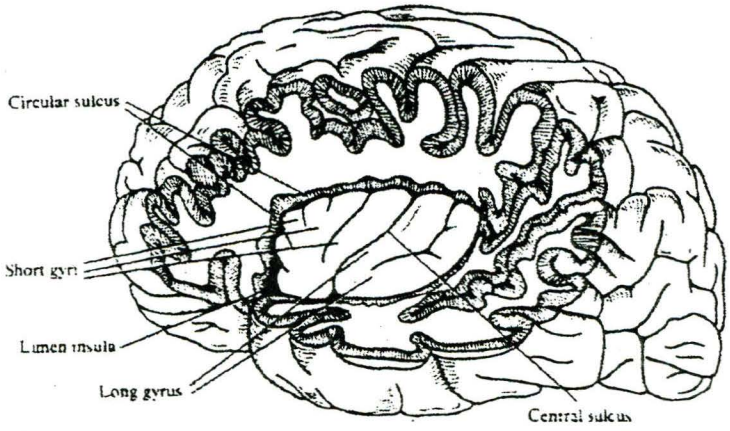


SURFACE ANATOMY OF CEREBRUM





CENTRAL (INSULAR) LOBE

Source: Pansky, 1988

- **Fine coordination of muscle movements** - three main functions:

1. Muscle coordination:
The cerebellum acts to make muscular movements smooth, instead of jerky and trembling. When the cerebellum is damaged, movements essential in running, walking, writing and other activities become uncoordinated.

2. Posture and equilibrium:
Impulses from the vestibular apparatus, in the inner ear, are continuously delivered to the flocculonodular lobe of the cerebellum, which uses that information to help maintain equilibrium. In addition, efferent fibers travel in the vestibulospinal tract to facilitate flexors and extensors to maintain posture.

3. Muscle tone:
The cerebellum receives major input from stretch receptors (muscle spindles and Golgi tendon organs), which provide the means for unconscious neural control of muscle tonus and the gradual alteration of muscle tensions for maintenance of equilibrium and posture.

- **Blood Supply**
The blood supply to the brain comes from two pairs of arteries: The right and left internal carotids and the right and left vertebrals. These four vessels eventually unite on the inferior aspect of the brain surrounding the pituitary gland. The importance of having 4 separate vessels that anastomose at one location is to ensure an adequate blood supply to the brain by the alternate routes should one vessel become occluded.

a. Derivation of surface arteries

Internal Carotid Artery: The common carotids (right and left) bifurcate into the external and internal carotids at the superior border of the thyroid cartilage. The internal carotid then passes upward, in front of the transverse processes of the upper three cervical vertebrae and enters the cranial cavity through the carotid canal in the petrous portion of the temporal bone. It forms an S curve around the body of the sphenoid bone and below the brain, giving off posterior communicating and ophthalmic arteries (going to orbit and eye). At its terminus the internal carotid divides into anterior and middle cerebral arteries (both contribute to Circle of Willis and provide blood to the cerebrum).

Vertebral Artery: The vertebral arteries (right and left) are the first branches off of the subclavian arteries (right and left). They pass upward through the transverse foramina of the upper six cervical vertebrae and enter the cranium through the foramen magnum. They then give off spinal branches to supply the spinal cord and some of the cerebellum. The two vertebral arteries then join at the posterior rim of the pons to form the basilar artery. The basilar artery continues forward to the anterior rim of the pons and divides onto the posterior cerebral arteries.

b. Circle of Willis
The posterior cerebral arteries join the posterior communicating arteries, derived from the internal carotids, and with the anterior cerebrals and the anterior communicating arteries they complete an arterial ring beneath the brain called the Circle of Willis. Branches of this circle are distributed to various parts of the brain.

- Functions of the Cerebellum
Refer to fig. N for localization of some of the functional systems in the cerebral cortex.

a. Visual system
(see the section in this study guide under Ocular/Visual biology; Anatomy of the Eye; U: 1-5).

b. Auditory and Vestibular systems
(see section Human Biology; Gross anatomy; A-10 for anatomy of the ear and section Human Biology; Neuroscience; D-4 for auditory mechanisms). The nerve fibers of the auditory and vestibular systems arise in the 8th cranial nerve (vestibulocochlear nerve). This nerve has two well-defined parts: the cochlear nerve for hearing and the vestibular nerve for equilibrium.

Auditory System:

Afferent system: The cochlear nerve originates in the spiral organ of Corti, in the cochlea in the inner ear. Its cell bodies lie in the spiral ganglion from which its central fibers pass through the internal acoustic meatus to terminate in the dorsal and ventral cochlear nuclei in the medulla. The secondary auditory fibers arising from the cochlear nuclei form three acoustic striae:

-The dorsal and intermediate acoustic striae ascend as the lateral lemniscus to synapse in the contralateral nucleus of the inferior colliculus. From the inferior colliculus tertiary auditory fibers arise and travel to the medial geniculate nucleus of the thalamus. These fibers are then sent laterally to the hearing center in the temporal cortex.

-Part of the auditory relay in the medulla is uncrossed and terminates in the reticular formation, the superior olivary nuclei and others.

-The ventral acoustic striae synapse in the ipsilateral nucleus of the superior colliculus.

Efferent system: There is an efferent cochlear bundle which projects from the olivocochlear bundle in the brain stem back to the cochlea. This is a pathway by which the central nervous system may influence itself and represents an inhibitory feedback system.

Vestibular system: The primary vestibular fibers arise from the superior and inferior vestibular ganglia with peripheral receptors in the semicircular canals of the inner ear. The secondary vestibular fibers arise from the vestibular nuclei in the medulla and send axons to many structures such as:

-Nuclei of the extraocular muscles- via the vestibuloencephalic pathway for coordination of eye movements.

-Spinal cord- via crossed and uncrossed fibers that descend in the medial longitudinal fasciculus in a pathway called the vestibulospinal tract for coordination of head and body movements.

-Thalamus- send fibers to cortex area 2.

-Cerebellum and reticular formation- to facilitate posture and equilibrium. Fibers from the vestibular nuclei pass through the puxtarestiform body (medial portion of the inferior cerebellar peduncle) and terminate in the archicerebellum (flocculonodular lobe) and in the fastigial nuclei of the cerebellum. The fastigial nuclei project efferent fibers to the vestibular nuclei, which passes through the vestibular nerve and terminate on the hair cells of the membranous labyrinth. These efferent neurons probably exert inhibitory effects to ameliorate the effects of motion sickness and nystagmus.

c. Somasthetic system

This is the system concerned with bodily sensations. The "somasthetic area" in the brain is a region in the postcentral gyrus of each parietal lobe that receives nerve impulses carrying somasthetic information. The ascending sensory pathways to the cortex are covered in earlier sections of the Neuroanatomy section of this study guide.

d. limbic system

The limbic system is a group of subcortical structures (as the hypothalamus, the hippocampus and the amygdala) of the brain that are concerned with emotion, autonomic activity, and motivation. The "limbic lobe" is considered to be the marginal medial portion of the cortex of each cerebral hemisphere.

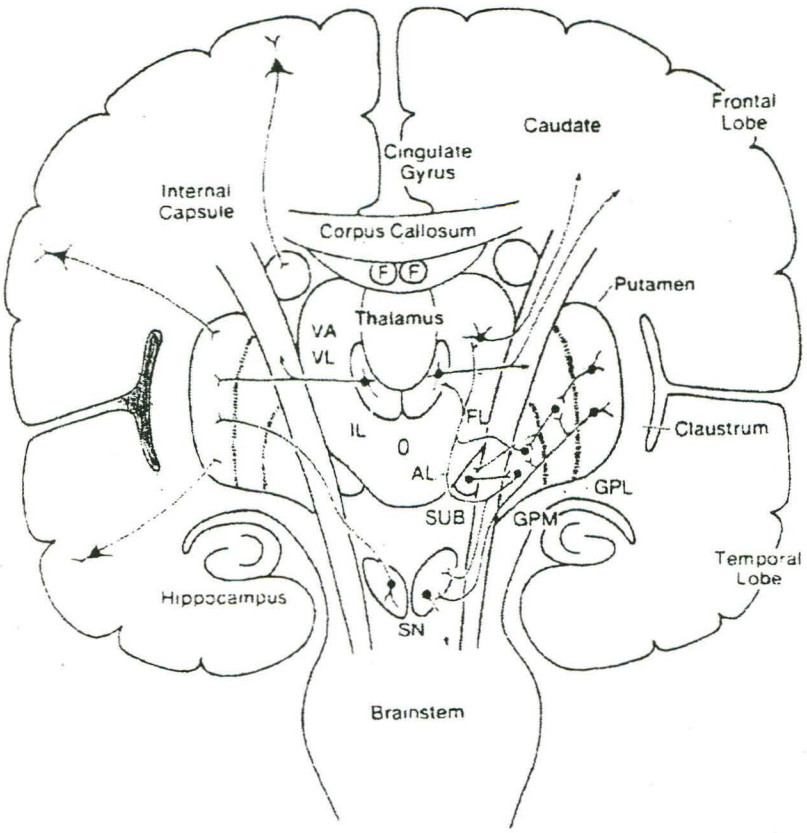
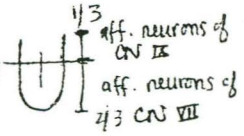


Fig. 21.16 Schematic frontal section of human brain, showing main connections and relations of the basal ganglia (shaded). Globus pallidus, lateral segment (GPL); medial segment (GPM). SUB, subthalamic nucleus; SN, substantia nigra; AL, ansa lenticularis; FL, fasciculus lenticularis. Thalamic nuclei: VA, ventral anterior; VL, ventral lateral; IL, intralaminar nucleus; F, fornix; O, cerebral aqueduct. Connections of caudate are similar to those shown for putamen. (Modified from Shepherd, 1979)

Source: Shepherd, 1994

e. Olfactory system
The sensory cells for the sense of smell are bipolar neuroepithelial cells whose cell bodies are located in the olfactory mucosa of the nose. Their dendrites pick up stimuli and pass them on to axons, which pass in bundles, as the olfactory here, through the cribiform plate of the ethmoid bone. They synapse with second order neurons (mitrial nerve cells) in the olfactory bulbs (rhinencephalon). From here fibers run in the olfactory tract to reach the areas of olfactory sense of the brain located in the frontal (gyrus cinguli: smell association) and temporal lobes (the uncus: smell appreciation) and the amygdaloid nucleus of the cerebrum. The amygdaloid nucleus enables olfactory stimuli to influence food seeking and sexual behavior.

f. Gustation system
The taste buds on the posterior third of the tongue are supplied by afferent neurons of the glossopharyngeal (9th) nerve, while the anterior two thirds of the tongue are supplied by afferent neurons of the facial (7th) nerve. The vagus (10th) nerve also supplies afferent neurons to the taste receptors in the epiglottis. The lingual branches of these nerves form the first order neurons which pass through the solitary tract and terminate in the solitary nucleus. Second order neurons cross over and ascend in the medial lemniscus and terminate in the ventral posteromedial nucleus of the



1st order → terminate in Solitary nucleus

2nd order → thalamus termination

thalamus. Third order (thoracocortical) neurons project to the inferior aspect of the postcentral gyrus (parietal lobe).

D. NEUROPHYSIOLOGY

Integration of Nerve Signals

- Synaptic processes

There are two types of synapses in the nervous system, electrical synapses and chemical synapses. Electrical synapses consist of gap junctions that permit the direct passage of ions and other small molecules from one cell to another. Electrical synapses transmit information in both directions. In chemical synapses, on the other hand, there is a space, called a synaptic cleft, between one cell and the other that prevents the direct passage of ions. In order for ions to flow into the second cell, chemical transmitters must be released from the first cell into the synaptic cleft, where they bind with chemically activated ion channels in the second cell.

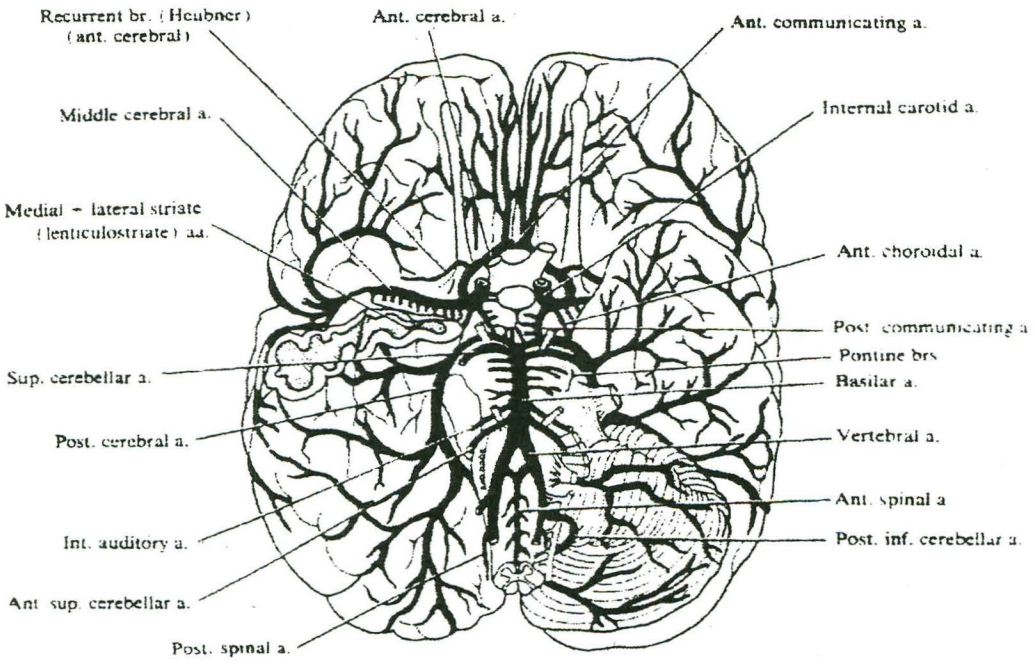
The structure of the electrical synapse is similar to the gap junctions seen in other cells. Studies have shown that the pre- and postsynaptic cells are connected by a protein channel called a connexon that spans the gap between them. The connexon is made of six protein subunits called connexin that are arranged into a hexagonal assembly. Electrical synapses are found between axons and soma, axons and dendrites, dendrites and dendrites, and soma and soma. These "electrical" synapses serve as channels for both electrical and metabolic communication. These synapses synchronize the activity of many adjoining cells as well as provide a pathway for a rapid communication between cells.

Although electrical synapses are found in many areas of the nervous system, the predominant type of synapse is the chemical synapse. In chemical synapses at least two cells participate: the cell producing the chemical signal, called the presynaptic neuron, and the target cell that receives the signal, called the postsynaptic neuron. The terminal ending is part of the presynaptic neuron, and it contains vesicles. These vesicles, filled with chemicals referred to as neurotransmitters, fuse with the presynaptic membrane. The fusion of the vesicle with the presynaptic cell membrane causes the release of the chemical neurotransmitters into the synaptic cleft. The transmitters in turn act upon the receptors located on postsynaptic cell membranes. When transmitters bind the receptors, one of two things can happen, there is either depolarization of the membrane or hyperpolarization of the membrane occurs. Finally, the termination of synaptic transmission occurs when the transmitter is removed from the synaptic cleft. This process is accomplished in most neurotransmitter systems by the transport of the transmitters back into the presynaptic terminal. Other transmitters are removed from the synaptic cleft by degrading enzymes, and the metabolic products are then transported back into the presynaptic terminal movements, are controlled solely by the spinal cord and have no control from higher structures. Spinal cord reflexes represent the most basic of motor responses. These reflexes are carried out entirely within the spinal cord and are modified by inputs from higher centers to generate complex movements. They are also used to help diagnose disorders of the motor system. The following is a list of spinal reflexes that are explained in further detail under the heading

Reflexes- automatic body movements, called reflex

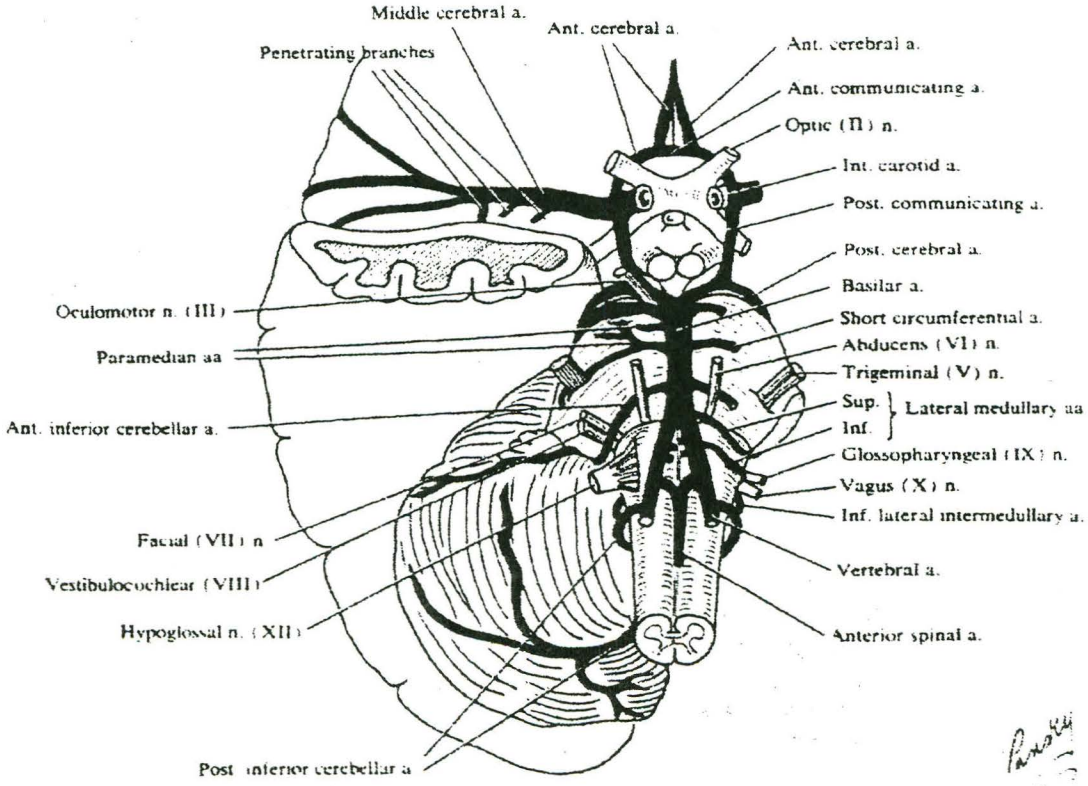
Motor pathways.

a. stretch reflex: commonly called the knee jerk reflex.
b. inverse myotic reflex: involves the Golgi tendon organ.
c. flexor withdrawal reflex: involves cutaneous receptors.



Source: Pansky, 1988

ARTERIES AT BASE OF BRAIN



Source: Pansky, 1988

- Feedback

Feedback is the return of some of the output of a system as input so as to exert some control in the process. Feedback controls are a type of self-regulating mechanism by which certain activities are sustained within prescribed ranges. There are two types of feedback, one is positive and the other is negative. In a positive feedback system there tends to be an increase of activity or product to get back to the normal set point. It reinforces and accelerates certain factors within a given system. In negative feedback, the controlling mechanism responds in a manner that decreases activity or product to get back to the normal set point level. It is, therefore, a corrective action that returns a factor within the specific system to a normal range.

- Adaptation

Often, when a stimulus is continuously applied, the brain at some point no longer consciously perceives it. This adjustment happens, for example, with background noise such as the ticking of a clock. After a period of time it is unnoticed. This phenomenon is called sensory adaptation. The adaptation to a sensory stimulus can be caused by mechanisms either within the brain or at the receptor site. Adaptation mechanisms that work at receptor sites are the most clearly understood and best illustrated by the Pacinian corpuscle.

When pressure applied to the Pacinian corpuscle is continuously maintained, the free nerve ending eventually reverts back to its original shape even though the layers of connective tissue remained deformed. Since the Na+ channels embedded within the nerve membrane are opened only when the nerve fiber is deformed, they close only when the form of the nerve fiber is again circular. Consequently, even though pressure on the Pacinian corpuscle is still maintained, it ceases to produce a generator potential when it resumes its normal shape and thus no longer transmits information about the pressure of the stimulus.

Mechanisms of adaptation are also found at the molecular level. Chemical receptors on membranes, for example, are internalized and removed from the surface of the membrane after continued exposure to drugs. With the removal of these chemical receptors, higher levels of the drug are necessary to achieve the same effect. This may be why, after repeated use, the body develops a tolerance to drugs.

- Habituation

Habituation, or the decrease in a behavioral response to a repeated stimulus, can be explained at the cellular level in terms of a decrease in synaptic transmission, as a result of the inactivation of Ca^{2+} channels in the presynaptic terminal. The reduction of Ca^{2+} influx in turn decreases the amount of neurotransmitter that is released into the synaptic cleft. In addition, the number of synapses that contain active zones for the release of vesicles decreases, as does the area of the active zones. Together, these mechanisms diminish the functional capacity of the synapse.

Habituation
Ca^{2+} ↓
↓ neurotransmitter
↓ # of synapses
↓ area of active zones

1. Sensory coding

- Sensory organs are highly specialized extensions of the nervous system in that they contain sensory neurons adapted to respond to specific stimuli and conduct nerve impulses to the brain for interpretation. A sensation is the arrival of a sensory impulse to the brain. The interpretation of a sensation is referred to as perception. In order to perceive a sensation, the following four conditions are necessary:

a. a stimulus sufficient enough to initiate a response in the nervous system must be present.

b. a receptor must convert the stimulus to a nerve impulse. A receptor is a specialized, peripheral dendritic ending of a sensory fiber or the specialized receptor cell associated with it.

c. The conduction of the nerve impulse must occur from the receptor to the brain along a nervous pathway.

d. The interpretation of the impulse in the form of a perception must occur within a specific portion of the brain. Only impulses reaching the cerebral cortex are consciously interpreted as sensation. If impulses reach the spinal cord or brain stem, they initiate a reflex motor response rather than a conscious sensation.

- Receptor potentials

Sensory receptors are activated when they detect a specific stimulus. This specific stimulus is called an adequate stimulus and is unique to each type of sensory receptor. In the visual system, for example, the photoreceptors detect light but are insensitive to frequencies of sound. Likewise, the auditory receptors of the ear respond only to sound and are insensitive to light.

An adequate stimulus will produce a change in the membrane potential of the sensory receptor cell. This change in the membrane potential is called a generator potential. In some sensory receptors, such as somatic sensory receptors, the generator potential is a depolarization of the membrane. In others, such as the photoreceptors of the eye, it is a hyperpolarization of the membrane. The generator potential, in turn, produces an action potential or a series of action potentials. The action potentials can be generated by the receptor cell itself or by a neuron connected to the receptor cell. These action potentials transmit information about the nature of the stimulus to the central nervous system.

- Unimodal and multimodal units

- Receptive field concept

For any neuron in a sensory pathway, the receptive field consists of all the sensory receptors that can influence its activity. Thus, cell A in the figure below has a receptive field consisting of the two receptors (2 and 3) which connect to it. Cell B, at the second level in this system, has a receptive field consisting of receptors 1, 2, and 3. The connections to a cell may be excitatory or inhibitory, and they may be mediated by interneurons at a given level as well as relay neurons between connecting levels. The properties of receptive fields generally reflect the increasing degree of information processing and feature extraction that occurs in neurons at successively higher levels in sensory pathways.

2. Somatosensory system

- Transmission of tactile, proprioceptive, temperature, and pain sensations

a. Tactile: The receptors that respond to touch, or tactile, stimuli are called Pacinain corpuscles. This type of receptor is located beneath the skin and consists of a free nerve ending that is encapsulated by layers of connective tissue. The nerve ending is wrapped with myelin along the length of the fiber. The fiber itself extends into the spinal cord, where it forms synapses with other nerve cells. The adequate stimulus for the Pacinian corpuscle is pressure applied to the skin. This pressure causes the layers of connective tissue and free nerve ending to compress. The compression of the free nerve ending causes an opening of Na+ channels in the nerve membrane. The resulting influx of Na+ ions depolarizes the membrane and produces a generator potential. If the generator potential is of sufficient amplitude, it will then depolarize the membrane in the region of the first node of Ranvier to threshold and initiate an action potential.