Ministry of Education and Science of Ukraine
V. N. Karazin Kharkiv National University

ANATOMICAL AND PHYSIOLOGICAL ASPECTS OF THE CENTRAL AND PERIPHERAL NERVOUS SYSTEM

Methodical recommendations
for self-preparation of 2nd year students of the School of medicine
in the discipline «Anatomical and physiological aspects
of the central and peripheral nervous system»

Kharkiv – 2023

UDK 616.8 (072)
A 53

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Approved for publication by the decision of the Scientific and Methodical Council of V. N. Karazin Kharkiv National University (Protocol № 7 of April 19, 2023)

A 53 **Anatomical** and physiological aspects of the central and peripheral nervous system : methodical recommendations for self-preparation of 2nd year students of the School of medicine in the discipline «Anatomical and physiological aspects of the central and peripheral nervous system» / compilers S. Scherstiuk, K. Gaft, R. Sydorenko, A. Pogrebnyak. – Kharkiv : V. N. Karazin Kharkiv National University, 2023. – 72 p.

Methodical recommendations for students in course «Anatomical and physiological aspects of the central and peripheral nervous system» are developed in accordance with the current programs in physiology for students of medical faculties of universities. The manual is designed for students in preparation for the course «Anatomical and physiological aspects of the central and peripheral nervous system». Each topic contains a list of practical skills and control questions. The topics are illustrated with drawings and diagrams that facilitate the perception of the material and promote its better assimilation. The materials allow students to form a correct understanding of the laws of the human body. For medical students.

UDK 616.8(072)

CONTENT

INTRODUCTION

Human anatomy and Physiology is the science of structure of biological organisms and life processes, the activity of individual organs and a living organism. The subject of these two sciences are the parameters of the living organism, for physiology, these are the functions of the body, their relationships, regulation and adaptation to the environment, for anatomy, these are the morphological features of the individual as a whole and in the process of evolution during individual development. This discipline is designed to combine the existing knowledge of human anatomy and physiology, to give the highest understanding of the existence of biological matter, to form the foundation for medical tactics in the medical practice of a future doctor.

Specific goals for students:

- Analyze information about the main indicators characterizing the normal functional state of the organism as a whole;
- Determine the relationship between the mechanisms of functioning of organs and the relationship of their structural components;
- Explain the mechanisms of functioning of organs and draw conclusions about the norm and pathology;
- Assess the state of health of people of different ages and in different conditions;
- Apply laboratory and instrumental research methods to assess the state of health;
- Anticipate changes in the activities of organs and systems under the influence of various environmental factors;
- To identify the leading mechanisms for ensuring the integrative activity of the organism;
- Demonstrate mastery of the moral and ethical principles of attitude towards a living person and the body as an object of study.

Topics of practical classes

№	Topic of practical lesson	Hours
1	Introduction to the anatomical and physiological aspects of the central nervous system. Physiological anatomy of synapses of the central nervous system. Excitation and inhibition in the central nervous system. Anatomical and physiological features of the reflex arc. Conduction of excitation through nerve fibers and through the neuromuscular synapse. General characteristics of biological regulation.	5
2	Anatomical and physiological aspects of the nervous system in the regulation of motor functions. Anatomical organization of motor functions of the spinal cord. Anatomy of sensory and motor functions of spinal centers. Anatomical and physiological aspects of motor spinal reflexes. Anatomical and physiological aspects of tendon reflexes.	5
3	Anatomical and physiological aspects of the importance of the brain in the regulation of movements and posture. The role of the brainstem in the regulation of body functions. Tonic reflexes and coordination of movements. The role of the cerebellum in the regulation of motor functions and reticular formation. Integrative functions of the diencephalon and forebrain. The role of the forebrain and cerebellum in the regulation of motor functions of the body. Regulation of system activity.	5
4	Anatomical and physiological aspects of the somato-sensory system. Anatomical and physiological bases of pain and anesthesia. Peripheral receivers, conductors and cortical centers of analyzers, their functional unity. Anatomical and physiological aspects of the visual, auditory, vestibular, olfactory and gustatory sensory systems. The sense of smell. Olfactory part of the nasal mucosa. Leading ways of the olfactory analyzer. The organ of taste. Taste papillae of the tongue, their topography. Leading ways of the taste analyzer. General cover. Skin: functions. Varieties of skin sensitivity.	5
5	Anatomical and physiological aspects of the autonomic nervous system (ANS). Anatomical and physiological organization of the autonomic nervous system. Sympathetic, parasympathetic and metasympathetic divisions, aspects in the regulation of visceral functions. Mechanisms of excitation transmission in ganglionic and neuro-organ synapses of sympathetic and parasympathetic systems.	5
6	Anatomical and physiological aspects of the peripheral nervous system (PNS). Spinal nerves: structure, formation, functions and areas of their innervation. Cervical, humeral, lumbar, sacral, genital and coccygeal plexus: formation, topography, branches, areas of innervation. Functional features of peripheral nerves. Phases of regeneration in case of damage. Cranial nerves. Localization of nuclei, names of nerves and their functions. Sensitive nodes and their localization. Vegetative (parasympathetic) cranial ganglia. Afferent and efferent components reflex arc.	5

	Total	30

Tasks for independent work

№	Topic of independent work	Hours
1.	Preparation for passing test tasks as components of USQE and USMLE RX on the topic: "Introduction to the physiological anatomy of the central nervous system. Physiological anatomy of synapses of the central nervous system. Excitation and inhibition in the central nervous system. Anatomical and physiological features of the reflex arc. Conduction of excitation through nerve fibers and through the neuromuscular synapse. General characteristics of biological regulation. ".	15
2.	Preparation for passing test tasks as components of USQE and USMLE RX on the topic: "Anatomical and physiological aspects of the nervous system in the regulation of motor functions. Anatomical organization of motor functions of the spinal cord. Anatomy of sensory and motor functions of spinal centers. Anatomical and physiological aspects of motor spinal reflexes. Anatomical and physiological aspects of tendon reflexes. ".	15
3.	Preparation for passing test tasks as components of USQE and USMLE RX on the topic: "Anatomical and physiological aspects of the importance of the brain in the regulation of movements and posture. The role of the brainstem in the regulation of body functions. Tonic reflexes and coordination of movements. The role of the cerebellum in the regulation of motor functions and reticular formation. Integrative functions of the diencephalon and forebrain. The role of the forebrain and cerebellum in the regulation of motor functions of the body. Regulation of system activity ".	15
4.	Preparation for passing test tasks as components of USQE and USMLE RX on the topic: "Anatomical and physiological aspects of blood vessels and their role in blood circulation. Basic patterns of blood flow. Vascular tone. The movement of blood in the vessels. Blood pressure in systemic vessels. Blood pressure measurement ".	15
5.	Preparation for passing test tasks as components of USQE and USMLE RX on the topic: "Anatomical and physiological aspects of the autonomic nervous system (ANS). Anatomical and physiological organization of the autonomic nervous system. Sympathetic, parasympathetic and metasympathetic divisions, aspects in the regulation of visceral functions. Mechanisms of excitation transmission in ganglionic and neuro-organ synapses of sympathetic and parasympathetic systems.	15
6.	Preparation for passing test tasks as components of USQE and USMLE RX on the topic: "Anatomical and physiological aspects of the peripheral nervous system (PNS). Cranial nerves. ".	15
	Total:	90

Lesson 1. Introduction to the anatomical and physiological aspects of the central nervous system. Physiological anatomy of synapses of the central nervous system.

Functions of the Nervous System

The nervous system is involved in some way in every body function. Some of the major functions of the nervous system are:

1. *Sensory input.* Sensory receptors monitor numerous external and internal stimuli, such as touch, temperature, taste, smell, sound, blood pressure, and body position. Action potentials from the sensory receptors travel along nerves to the spinal cord and brain, where they are interpreted.

2. *Integration.* The brain and spinal cord are the major organs for processing sensory input and initiating responses. The input may produce an immediate response, may be stored as memory, or may be ignored.

3. *Homeostasis.* The nervous system plays an important role in the maintenance of homeostasis. This function depends on the ability of the nervous system to detect, interpret, and respond to changes in internal and external conditions. The nervous system can stimulate or inhibit the activities of other systems to help maintain homeostasis.

4. *Mental activity.* The brain is the center of mental activity, including consciousness, memory, and thinking.

5. *Control of skeletal muscles.* Skeletal muscles normally contract only when stimulated by the nervous system. Thus, through the control of skeletal muscle, the nervous system controls the major movements of the body.

Divisions of the Nervous System

The nervous system can be divided into the central and the peripheral nervous systems .The central nervous system (CNS) consists of the brain and spinal cord. The peripheral nervous system (PNS) consists of nerves and ganglia, which lie outside the CNS. The PNS has two subdivisions: The afferent division conducts action potentials from sensory receptors to the CNS . The neurons that transmit action potentials from the periphery to the CNS are afferent neurons. The efferent division conducts action potentials from the CNS to effector organs such as muscles and glands. The neurons that transmit action potentials from the CNS toward the periphery are efferent neurons. The efferent division can be further subdivided into the somatic motor nervous system, which transmits action potentials from the CNS to skeletal muscles, and the autonomic nervous system (ANS), which transmits action potentials from the CNS to cardiac muscle, smooth muscle, and glands. The autonomic nervous system, in turn, is divided into sympathetic and parasympathetic portions. The sympathetic

division prepares the person for physical activity, whereas the parasympathetic division activates functions such as digestion that are normally associated with the body at rest.

Central Nervous System

The central nervous system (CNS) consists of the brain and spinal cord. The brain is that part of the CNS housed within the cranial vault. The major regions of the brain are the brainstem, the diencephalon, the cerebrum, and the cerebellum.

Spinal Cord

The spinal cord extends from the foramen magnum at the base of the skull to the second lumbar vertebra. The cord consists of a central gray part and a peripheral white part (Fig.1). The gray matter, seen in cross section, is shaped like the letter H, with posterior (dorsal) horns containing association neurons and cell processes of sensory neurons and anterior (ventral) horns containing motor neurons. In the thoracic and upper lumbar regions, an additional gray horn, the lateral horn, contains sympathetic autonomic motor neurons. Ascending axons carrying action potentials to the brain or descending axons carrying action potentials from the brain are grouped by function as nerve pathways, or nerve tracts, within the white matter of the spinal cord.

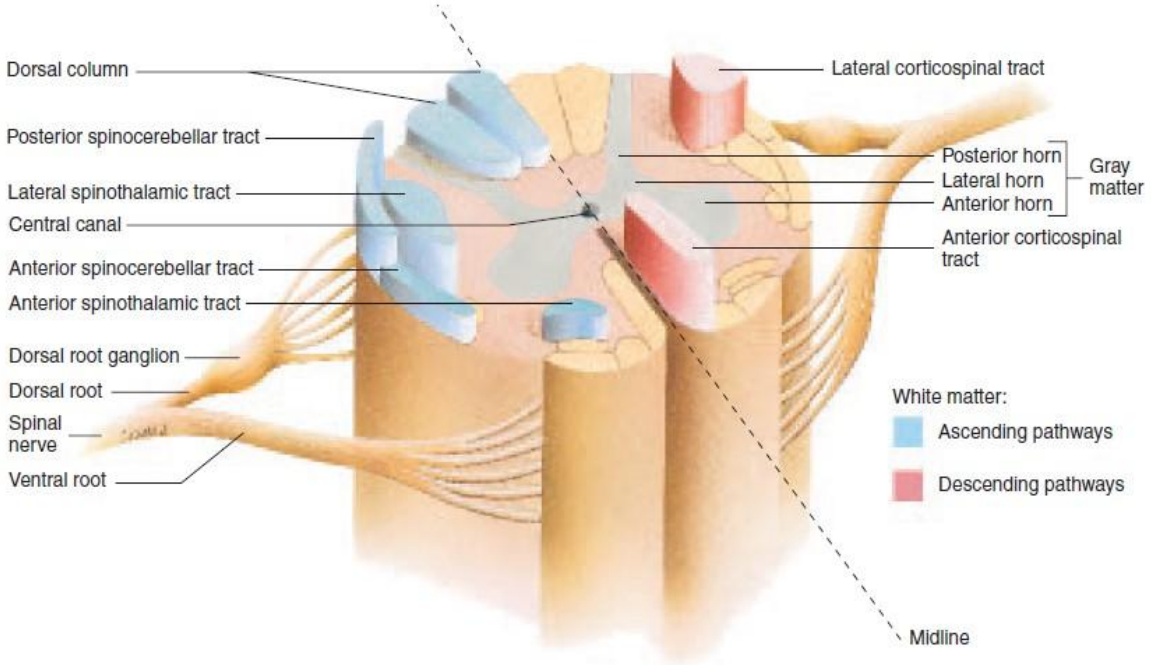


Fig.1 The Spinal Cord.

Cross section of the spinal cord showing the horns, pathways (nerve tracts), and roots.

Dorsal (posterior) roots enter and ventral (anterior) roots exit the spinal cord. The dorsal root consists of afferent axons that carry action potentials to the spinal cord, and the ventral root consists of efferent axons that carry action potentials away from the spinal cord. The dorsal and ventral roots unite to form spinal nerves. The dorsal roots have dorsal root ganglia, or spinal ganglia, which contain the cell bodies of the afferent neurons. The axons of these neurons project into the posterior horn, where they synapse with other neurons or ascend or descend in the spinal cord.

The Synapse

A synapse is a junction where the axon of one neuron interacts with another neuron or an effector organ such as a muscle or gland (fig.2). The end of the axon forms a presynaptic terminal. The membrane of the dendrite or effector cell is the postsynaptic membrane, and the space separating the presynaptic and postsynaptic membranes is the synaptic cleft. Chemical substances called neurotransmitters are stored in synaptic vesicles in the presynaptic terminal. Those neurotransmitters are released by exocytosis from the presynaptic terminal in response to each action potential.

The neurotransmitters diffuse across the synaptic cleft and bind to receptor molecules on the postsynaptic membrane. The binding of neurotransmitters to their receptors causes channels for sodium, potassium, or chloride ions to open or close in the postsynaptic membrane, depending on the type of neurotransmitter in the presynaptic terminal and the type of receptors on the postsynaptic membrane. The response may be either a stimulation or an inhibition of an action potential in the postsynaptic cell.

For example, if sodium ion channels open, the postsynaptic cell becomes depolarized, and an action potential will occur if threshold is reached. If potassium or chloride ion channels open, the inside of the postsynaptic cell tends to become more negative, or hyperpolarized, and an action potential is inhibited from occurring.

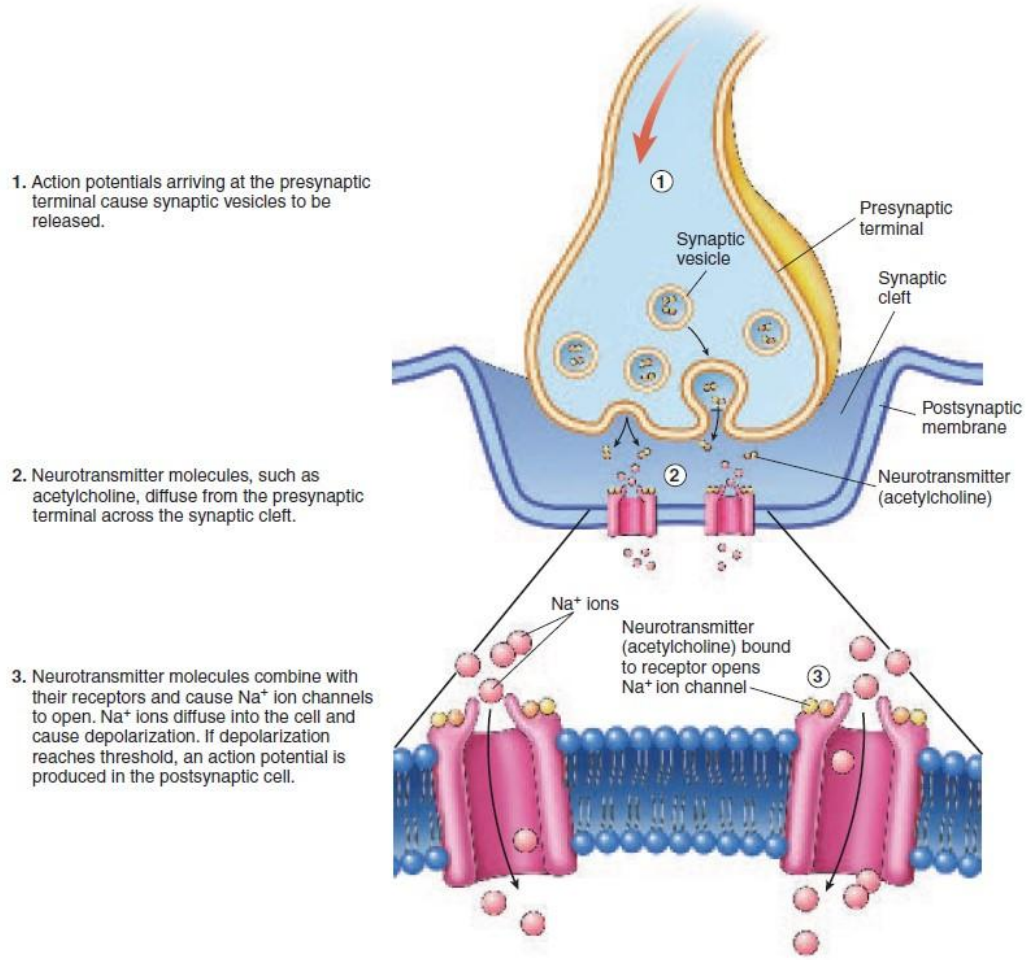


Fig.2 The Synapse.

Neurotransmitters are released from synaptic vesicles in the presynaptic terminal in response to an action potential. The neurotransmitters diffuse across the synaptic cleft and bind to receptors on the postsynaptic cell membrane, causing a stimulation or inhibition of action potentials in the postsynaptic cell.

Of the many neurotransmitter substances or suspected neurotransmitter substances, the best known are norepinephrine and acetylcholine. Other neurotransmitters include serotonin, dopamine, (gamma)-aminobutyric acid (GABA), glycine, and endorphins. Neurotransmitter substances are rapidly broken down by enzymes or are transported back into the presynaptic terminal. Consequently, they are removed from the synaptic cleft so their effects on the postsynaptic membrane are very short term. In synapses where acetylcholine is the neurotransmitter, such as in the neuromuscular junction, an enzyme called acetylcholinesterase breaks down the acetylcholine soon after it is released. No acetylcholine therefore remains in the cleft to stimulate the postsynaptic receptors and produce a second action potential, unless more acetylcholine is released from the presynaptic terminal. Norepinephrine is actively transported back into the presynaptic terminal or is broken down by other enzymes. The breakdown products are then returned to the presynaptic terminal for reuse or diffuse into the circulatory

system and are carried away from the area. The release and breakdown of neurotransmitters occurs so rapidly that a neuron can be stimulated by presynaptic action potentials many times a second.

CLASSIFICATION OF SYNAPSE

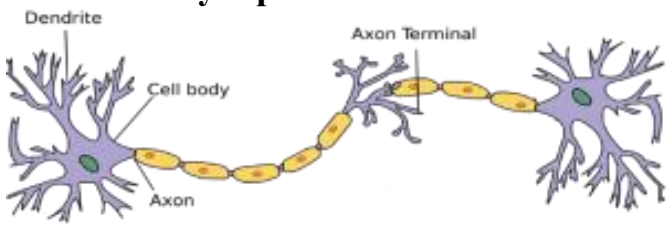
It is classified by two methods:

1. **Anatomical classification** 2. **Functional classification**

ANATOMICAL CLASSIFICATION

There are three

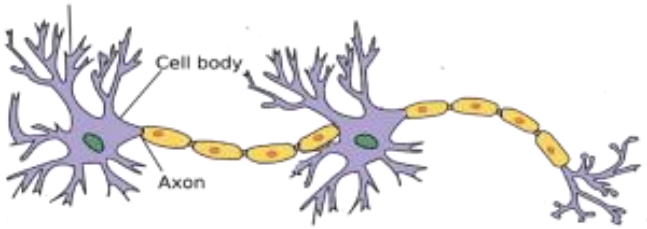
1. **Axoaxonic synapse**



(axon + axon) Axoaxonic synapse

In which axon of the one neuron terminates on axon of another neuron.

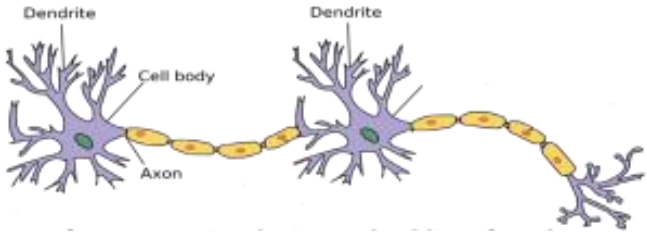
2. **Axosomatic synapse**



(axon + soma) Axosomatic synaps

In this synapse, axon of one neuron ends on soma (body) of another neuron.

3. **Axodendric synapse**



(axon + dendrites) Axodendric synapse

In which one neuron's axon attach to dendrites of other neuron.

FUNCTIONAL CLASSIFICATION

Functional classification of synapse, is on the basis of mode of impulse transmission. According to that synapse is classified into two categories:

- **Electrical synapse**
- **Chemical synapse**

ELECTRICAL SYNAPSE

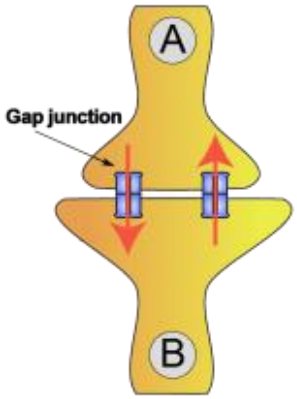
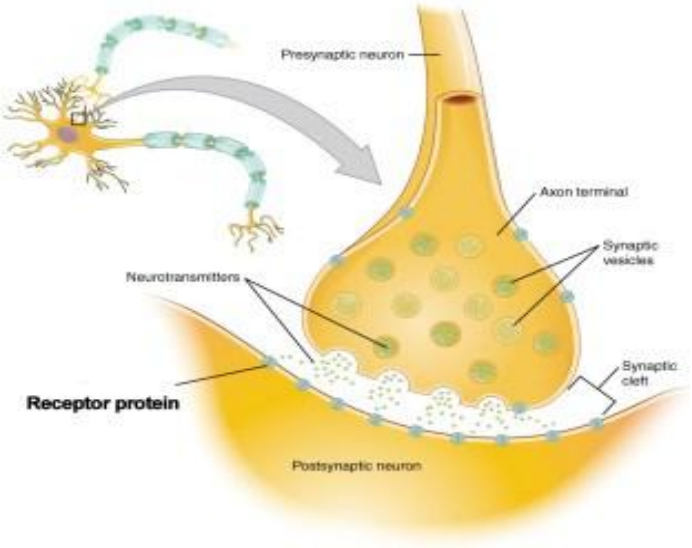


Fig.3 Gap junction.

It is very simple, as you can see in image that two neuron are connected by gap junction(Fig.3). There is direct exchange of ions between the two neuron through the gap junction. Because of this reason, the action potential reaches to end part of presynaptic neuron directly enters into postsynaptic neuron.

Due to direct flow of current, synaptic delay is very less. Moreover, the impulse is transmitted in either direction through electrical synapse.

This type of impulse transmission occurs in some tissues like the cardiac muscle fibers, smooth muscle fibers of intestine and the epithelial cells of lens in the eye.



CHEMICAL SYNAPSE

Fig.4 Chemical synapse.

Chemical synapse is the junction between two nerve fiber or between nerve fiber and muscle fiber.

In this synapse, there is no continuity between two neurons. There is space between two neurons is known as synaptic cleft. Before this synaptic cleft, neuron is known as presynaptic neuron. In same way, after synapse neuron is known as postsynaptic neuron (Fig.4).

You can see that there are synaptic vesicles in presynaptic neuron. When action potential reaches to the presynaptic terminal, neurotransmitter substance release from this vesicles. When this chemical named neurotransmitter releases, it has ability to tear the presynaptic membrane and reaches to the postsynaptic membrane. In simple language message reaches from one neuron to other neuron, although there is space.

Now, neurotransmitter and receptor protein make complex. This causes potential changes in neuron, this way message passes from one neuron to other neuron.

Excitation and Inhibition in the Central Nervous System

To make a working nervous system, only two forces are necessary: excitation and inhibition. Excitatory signaling from one cell to the next makes the latter cell more likely to fire. Inhibitory signaling makes the latter cell less likely to fire. At chemical synapses in the brain, glutamate and GABA (gamma-aminobutyric acid) are transmitters for excitation and inhibition, respectively. Dopamine, serotonin, norepinephrine, and other more celebrated brain chemicals have earned their fame as transmitters with much more specialized effects. But the bread and butter of the brain are unquestionably glutamate and GABA. In principle, a nervous system of only a handful of neurons and two transmitters—excitatory and inhibitory—is possible.

The balance between neural excitation and neural inhibition is crucial to healthy cognition and behavior. A brain dominated by glutamate would only be capable of exciting itself in repeated bursts of activity, similar to an epileptic seizure. Conversely, a brain dominated by GABA would only be capable of quiet whispers of activity, with little synchronization necessary for meaningful communication between brain areas. Healthy brain activity thrives in the middle area between these two extremes, where a balance between excitation and inhibition generates complex patterns of activity.

CLASSIFICATIONS OF INHIBITION

Direct (postsynaptic)
Indirect (presynaptic)

Lateral, reciprocal, renshaw, inhibition following excitation, pessimal.

Unconditioned and conditioned.

MECHANISM OF PRESYNAPTIC (INDIRECT) INHIBITION

- occurs at presynaptic terminal before the signals reach the synapse
- the inhibitory transmitter is GABA (gama-amino butyric acid) → opening of Cl- channel allowing large Cl ions to diffuse into terminals
- the negative charge of these ions cancels excitatory effect of positive charge Na+ ions that enter terminals when action potential arrival – the positivity in postsynaptic neuron is reduced thus reducing excitation of synapse
- it occurs in many sensory pathway in nervous system
- terminal nerve fiber inhibits one another, minimizes the sideway spread of signal in sensory tract

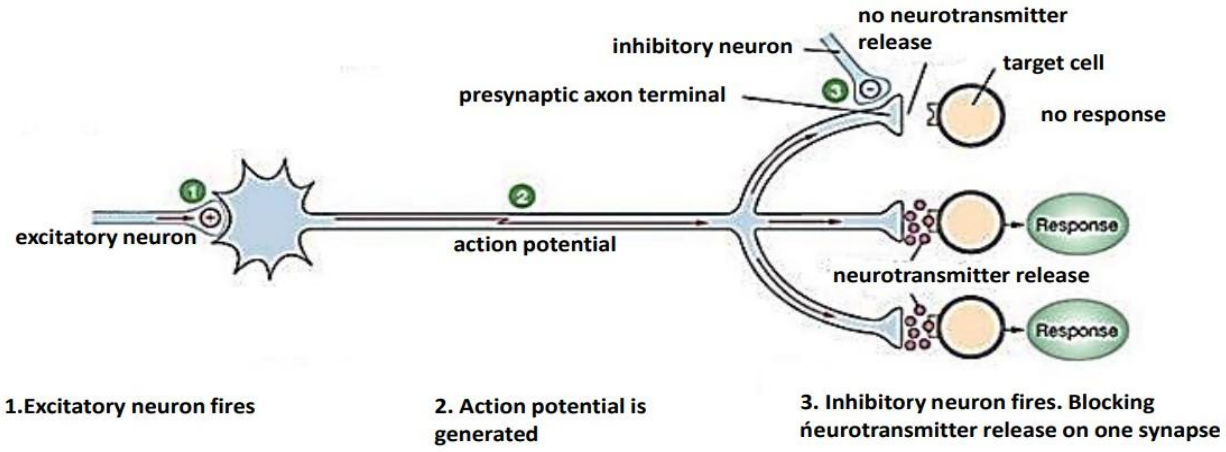


Fig.5 (Presynaptic inhibition).

MECHANISM OF THE POSTSYNAPTIC (DIRECT) IHIBITION

- increases (more negative) normal resting membrane potential
- opens Cl channel and allows Cl ions to move from ectracellular space into cells → more negative potential than normal
- opens K channel and allows K + ions to move from cells into extracellular space → more negative potential than normal
- both Cl influx and K+ exflux increase (more negative) intracellular negativity → hyperpolarization
- it inhibits neuron because membrane potential is away from threshold for excitation (- 45mV)
- IPSP → - 5mV

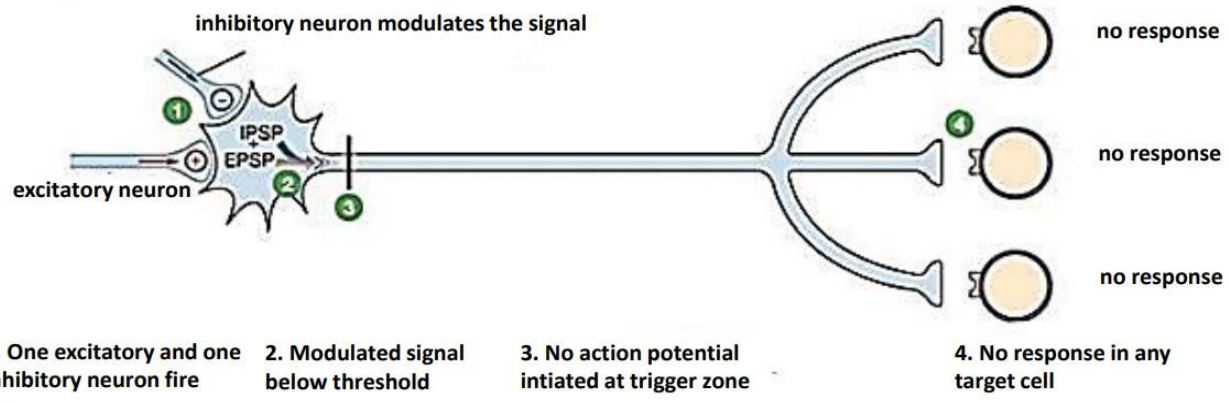


Fig.6 (Postsynaptic inhibition).

Reflexes

A reflex is an involuntary reaction in response to a stimulus applied to the periphery and transmitted to the CNS. Reflexes allow a person to react to a stimulus more quickly than is possible if conscious thought is involved. A reflex arc is the neuronal pathway by which a reflex occurs. The reflex arc (fig.7)is the basic functional unit of the nervous system and is thesmallest, simplest pathway capable of receiving a stimulus and yielding a response. A reflex arc has five basic components: (1) a sensory receptor; (2) an afferent, or sensory, neuron;(3) association neurons, which are neurons located between and communicating with two other neurons; (4) an efferent, or motor, neuron; and (5) an effector organ. Most reflexes involve the spinal cord or brainstem and not the higher brain centers.

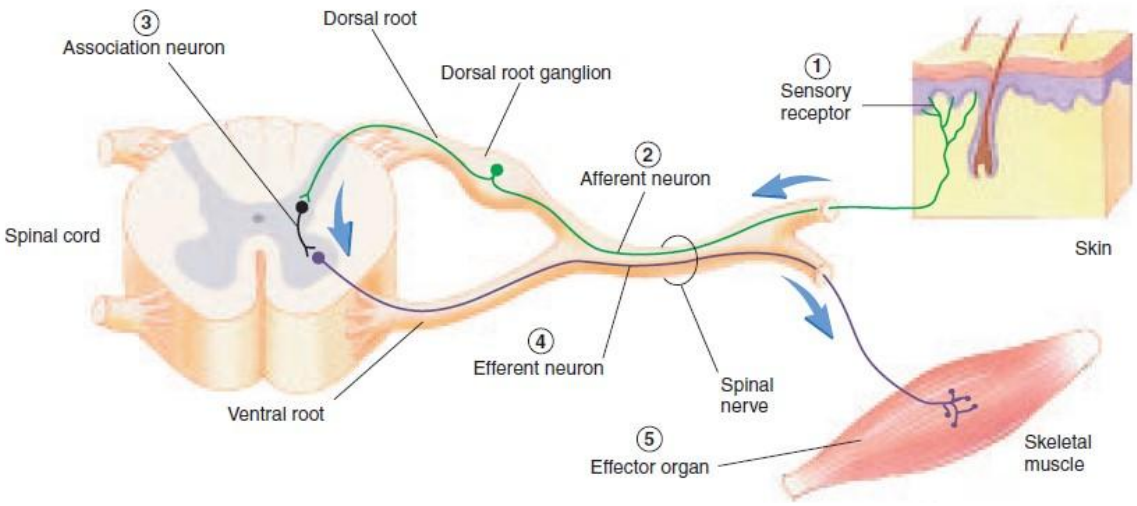


Fig.7 Reflex Arc.

A reflex arc includes a sensory receptor (1), an afferent neuron (2), an association neuron (3), an efferent neuron (4), and an effector organ (5).

The result of a reflex can be seen when a persons fingertouches a hot stove. Pain receptors in the skin are stimulated by the hot stove, and action potentials are produced. Afferent neurons conduct the action potentials to the spinal cord, where they synapse with association neurons. The association neurons, in turn, synapse with efferent neurons in the spinal cord that conduct action potentials along their axons to flexor muscles in the upper limb. These muscles contract and pull the finger away from the stove. No conscious thought is required for this reflex, and withdrawal of the finger from the stimulus begins before the person is consciously aware of any pain.

Classification of reflexes:

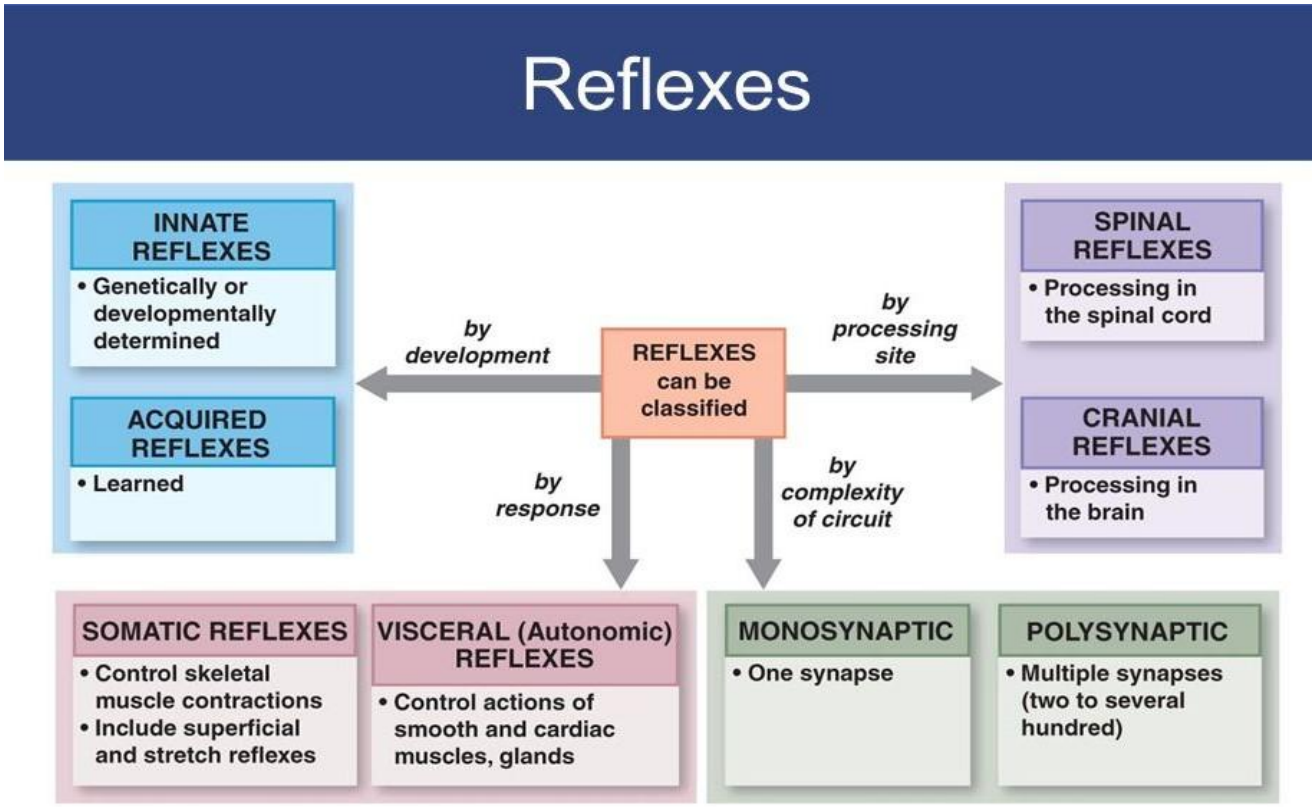


Fig.8 The classification of reflexes.

Biological regulation

Biological regulation is what allows an organism to handle the effects of a perturbation, modulating its own constitutive dynamics in response to particular changes in internal and external conditions. Biological systems exhibit a wide range of mechanisms and strategies to ensure theirsurvival under variable conditions. In some cases, they compensate for internal or external perturbationsbymaintainingthe conditions under which their constitutive processes remain viable (through physical buffering, relative damping of the changes in concentration, temperature, pH...);

in other cases, to achieve a similar outcome, they switchbetween differentavailable metabolic regimes. Allthese mechanisms,usuallyassociated with the concepts of „homeostasis“ and „adaptation“ respectively, tend to bebroadly interpreted as regulatory, insofar asthey contribute to maintain the system“s viability against perturbations by functionally modulating its own dynamic behaviour.

Lesson 2. Anatomical and physiological aspects of the nervous system in the regulation of motor functions. Anatomical organization of motor functions of the spinal cord.

Spinal neurons are organized into nuclei and laminae.

Nuclei

The prominent nuclear groups of cell columns within the spinal cord from dorsal to ventral are the marginal zone, substantia gelatinosa, nucleus proprius, dorsal nucleus of Clarke, intermediolateral nucleus and the lower motor neuron nuclei.(fig.9)

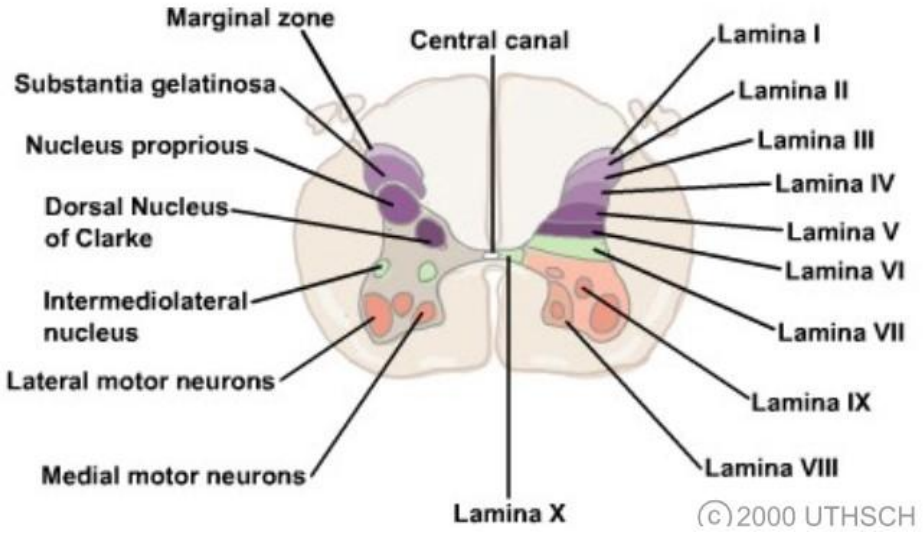


Fig.9

Marginal zone nucleus or posterior marginalis, is found at all spinal cord levels as a thin layer of column/tract cells (column cells) that caps the tip of the dorsal horn. The axons of its neurons contribute to the lateral spinothalamic tract which relays pain and temperature information to the diencephalon (Fig.9).

Substantia gelatinosa is found at all levels of the spinal cord. Located in the dorsal cap-like portion of the head of the dorsal horn, it relays pain, temperature and mechanical (light touch) information and consists mainly of column cells (intersegmental column cells). These column cells synapse in cell at Rexed layers IV to VII, whose axons contribute to the ventral (anterior) and lateral spinal thalamic tracts. *The homologous substantia gelatinosa in the medulla is the* ***spinal trigeminal nucleus****.*

Nucleus proprius is located below the substantia gelatinosa in the head and neck of the dorsal horn. This cell group, sometimes called the chief sensory nucleus, is

associated with mechanical and temperature sensations. It is a poorly defined cell column which extends through all segments of the spinal cord and its neurons contribute to ventral and lateral spinal thalamic tracts, as well as to spinal cerebellar tracts. The axons originating in nucleus proprius project to the thalamus via the spinothalamic tract and to the cerebellum via the ventral spinocerebellar tract (VSCT).

Dorsal nucleus of Clarke is a cell column located in the mid-portion of the base form of the dorsal horn. The axons from these cells pass uncrossed to the lateral funiculus and form the dorsal (posterior) spinocerebellar tract (DSCT), which subserve unconscious proprioception from muscle spindles and Golgi tendon organs to the cerebellum, and some of them innervate spinal interneurons. The dorsal nucleus of Clarke is found only in segments C8 to L3 of the spinal cord and is most prominent in lower thoracic and upper lumbar segments.

The homologous dorsal nucleus of Clarke in the medulla is the accessory cuneate nucleus, which is the origin of the cuneocerebellar tract (CCT).

Intermediolateral nucleus is located in the intermediate zone between the dorsal and the ventral horns in the spinal cord levels. Extending from C8 to L3, it receives viscerosensory information and contains preganglionic sympathetic neurons, which form the lateral horn. A large proportion of its cells are root cells which send axons into the ventral spinal roots via the white rami to reach the sympathetic tract as preganglionic fibers. Similarly, cell columns in the intermediolateral nucleus located at the S2 to S4 levels contains preganglionic parasympathetic neurons (Figure 3.7).

Lower motor neuron nuclei are located in the ventral horn of the spinal cord. They contain predominantly motor nuclei consisting of α, β and γ motor neurons and are found at all levels of the spinal cord--they are root cells. The a motor neurons are the final common pathway of the motor system, and they innervate the visceral and skeletal muscles.

Rexed Laminae

The distribution of cells and fibers within the gray matter of the spinal cord exhibits a pattern of lamination. The cellular pattern of each lamina is composed of various sizes or shapes of neurons (cytoarchitecture) which led Rexed to propose a new classification based on 10 layers (laminae). This classification is useful since it is related more accurately to function than the previous classification scheme which was based on major nuclear groups (Fig.9).

Laminae I to IV, in general, are concerned with exteroceptive sensation and comprise the dorsal horn, whereas laminae V and VI are concerned primarily with proprioceptive sensations. Lamina VII is equivalent to the intermediate zone and acts

as a relay between muscle spindle to midbrain and cerebellum, and laminae VIII-IX comprise the ventral horn and contain mainly motor neurons. The axons of these neurons innervate mainly skeletal muscle. Lamina X surrounds the central canal and contains neuroglia.

Rexed lamina I – Consists of a thin layer of cells that cap the tip of the dorsal horn with small dendrites and a complex array of nonmyelinated axons. Cells in lamina I respond mainly to noxious and thermal stimuli. Lamina I cell axons join the contralateral spinothalamic tract; this layer corresponds to nucleus posteromarginalis.

Rexed lamina II – Composed of tightly packed interneurons. This layer corresponds to the substantia gelatinosa and responds to noxious stimuli while others respond to non-noxious stimuli. The majority of neurons in Rexed lamina II axons receive information from sensory dorsal root ganglion cells as well as descending dorsolateral fasciculus (DLF) fibers. They send axons to Rexed laminae III and IV (fasciculus proprius). High concentrations of substance P and opiate receptors have been identified in Rexed lamina II. The lamina is believed to be important for the modulation of sensory input, with the effect of determining which pattern of incoming information will produce sensations that will be interpreted by the brain as being painful.

Rexed lamina III – Composed of variable cell size, axons of these neurons bifurcate several times and form a dense plexus. Cells in this layer receive axodendritic synapses from Aβ fibers entering dorsal root fibers. It contains dendrites of cells from laminae IV, V and VI. Most of the neurons in lamina III function as propriospinal/interneuron cells.

Rexed lamina IV – The thickest of the first four laminae. Cells in this layer receive Aß axons which carry predominantly non-noxious information. In addition, dendrites of neurons in lamina IV radiate to lamina II, and respond to stimuli such as light touch.

The ill-defined nucleus proprius is located in the head of this layer. Some of the cells project to the thalamus via the contralateral and ipsilateral spinothalamic tract.

Rexed lamina V – Composed neurons with their dendrites in lamina II. The neurons in this lamina receive monosynaptic information from Aß, Ad and C axons which also carry nociceptive information from visceral organs. This lamina covers a broad zone extending across the neck of the dorsal horn and is divided into medial and lateral parts. Many of the Rexed lamina V cells project to the brain stem and the thalamus via the contralateral and ipsilateral spinothalamic tract. Moreover, descending corticospinal and rubrospinal fibers synapse upon its cells.

Rexed lamina VI – Is a broad layer which is best developed in the cervical and lumbar enlargements. Lamina VI divides also into medial and lateral parts. Group Ia afferent axons from muscle spindles terminate in the medial part at the C8 to L3 segmental levels and are the source of the ipsilateral spinocerebellar pathways. Many of the small neurons are interneurons participating in spinal reflexes, while descending brainstem pathways project to the lateral zone of Rexed layer VI.

Rexed lamina VII – This lamina occupies a large heterogeneous region. This region is also known as the zona intermedia (or intermediolateral nucleus). Its shape and boundaries vary along the length of the cord. Lamina VII neurons receive information from Rexed lamina II to VI as well as visceral afferent fibers, and they serve as an intermediary relay in transmission of visceral motor neurons impulses. The dorsal nucleus of Clarke forms a prominent round oval cell column from C8 to L3. The large cells give rise to uncrossed nerve fibers of the dorsal spinocerebellar tract (DSCT). Cells in laminae V to VII, which do not form a discrete nucleus, give rise to uncrossed fibers that form the ventral spinocerebellar tract (VSCT). Cells in the lateral horn of the cord in segments T1 and L3 give rise to preganglionic sympathetic fibers to innervate postganglionic cells located in the sympathetic ganglia outside the cord. Lateral horn neurons at segments S2 to S4 give rise to preganglionic neurons of the sacral parasympathetic fibers to innervate postganglionic cells located in peripheral ganglia.

Rexed lamina VIII – Includes an area at the base of the ventral horn, but its shape differs at various cord levels. In the cord enlargements, the lamina occupies only the medial part of the ventral horn, where descending vestibulospinal and reticulospinal fibers terminate. The neurons of lamina VIII modulate motor activity, most probably via g motor neurons which innervate the intrafusal muscle fibers.

Rexed lamina IX – Composed of several distinct groups of large a motor neurons and small γ and β motor neurons embedded within this layer. Its size and shape differ at various cord levels. In the cord enlargements the number of α motor neurons increase and they form numerous groups. The α motor neurons are large and multipolar cells and give rise to ventral root fibers to supply extrafusal skeletal muscle fibers, while the small γ motor neurons give rise to the intrafusal muscle fibers. The α motor neurons are somatotopically organized.

Rexed lamina X – Neurons in Rexed lamina X surround the central canal and occupy the commissural lateral area of the gray commissure, which also contains decussating axons.

In summary, laminae I-IV are concerned with exteroceptive sensations, whereas laminae V and VI are concerned primarily with proprioceptive sensation and act as a relay between the periphery to the midbrain and the cerebellum. Laminae VIII and IX form the final motor pathway to initiate and modulate motor activity

via α, β and γ motor neurons, which innervate striated muscle. All visceral motor neurons are located in lamina VII and innervate neurons in autonomic ganglia.

Spinal Nerves

The spinal nerves arise along the spinal cord from the union of the dorsal roots and ventral roots. All the spinal nerves are mixed nerves because they contain both sensory and somatic motor neuron cell processes. Some spinal nerves are also parasympathetic or sympathetic. Most of the spinal nerves exit the vertebral column between adjacent vertebrae. Spinal nerves are categorized by the region of the vertebral column from which they emerge—cervical (C), thoracic (T), lumbar (L), sacral (S), and coccygeal (Cx)(fig.10). The spinal nerves are also numbered (starting superiorly) according to their order within that region. The 31 pairs of spinal nerves are therefore C1 through C8, T1 through T12, L1 through L5, S1 through S5, and Cx. Most of the spinal nerves are organized into three plexuses where nerves come together and then separate: the cervical plexus, the brachial plexus, and the lumbosacral plexus. The major nerves of the neck and limbs are branches of these plexuses. Spinal nerves T2 through T11 do not join a plexus. Instead, these nerves extend around the thorax between the ribs, giving off branches to muscles and skin. Efferent nerve fibers derived from plexuses innervate groups of skeletal muscles, and afferent nerve fibers supply sensory innervation to the skin overlying those muscles.

Cervical Plexus

The cervical plexus originates from spinal nerves C1 to C4. Branches from this plexus innervate several of the muscles attached to the hyoid bone, as well as the skin of the neck and posterior portion of the head. One of the most important branches of the cervical plexus is the phrenic nerve, which innervates the diaphragm. Contraction of the diaphragm is largely responsible for the ability to breathe.

Brachial Plexus

The brachial plexus originates from spinal nerves C5 to T1.Five major nerves emerge from the brachial plexus to supply the upper limb and shoulder. The axillary nerve innervates two shoulder muscles and the skin over part of the shoulder. The radial nerve innervates all the muscles located in the posterior arm and forearm. It innervates the skin over the posterior surface of the arm, forearm, and hand. The musculocutaneous nerve innervates the anterior muscles of the arm and the skin over part of the forearm. The ulnar nerve innervates two anterior forearm muscles and most of the intrinsic hand muscles. It also innervates the skin over the ulnar side of the hand. The ulnar nerve can be easily damaged where it passes posterior to the medial side of the elbow. The median nerve innervates most of the anterior forearm

muscles and some of the intrinsic hand muscles. It also innervates the skin over the radial side of the hand.

Lumbosacral Plexus

The lumbosacral plexus originates from spinal nerves L1 to S4. Four major nerves exit the plexus to supply the lower limb. The obturator nerve innervates the muscles of the medial thigh and the skin over the same region. The femoral nerve innervates the anterior thigh muscles and the skin over the anterior thigh and medial side of the leg. The tibial nerve innervates the posterior thigh muscles, the anterior and posterior leg muscles, and most of the intrinsic foot muscles. It also innervates the skin over the sole of the foot. The common fibular nerve innervates the muscles of the lateral thigh and leg and some intrinsic foot muscles. It innervates the skin over the anterior and lateral leg and the dorsal surface of the foot. The tibial and common peroneal nerves are bound together within a connective tissue sheath and together are called the ischiadic nerve.

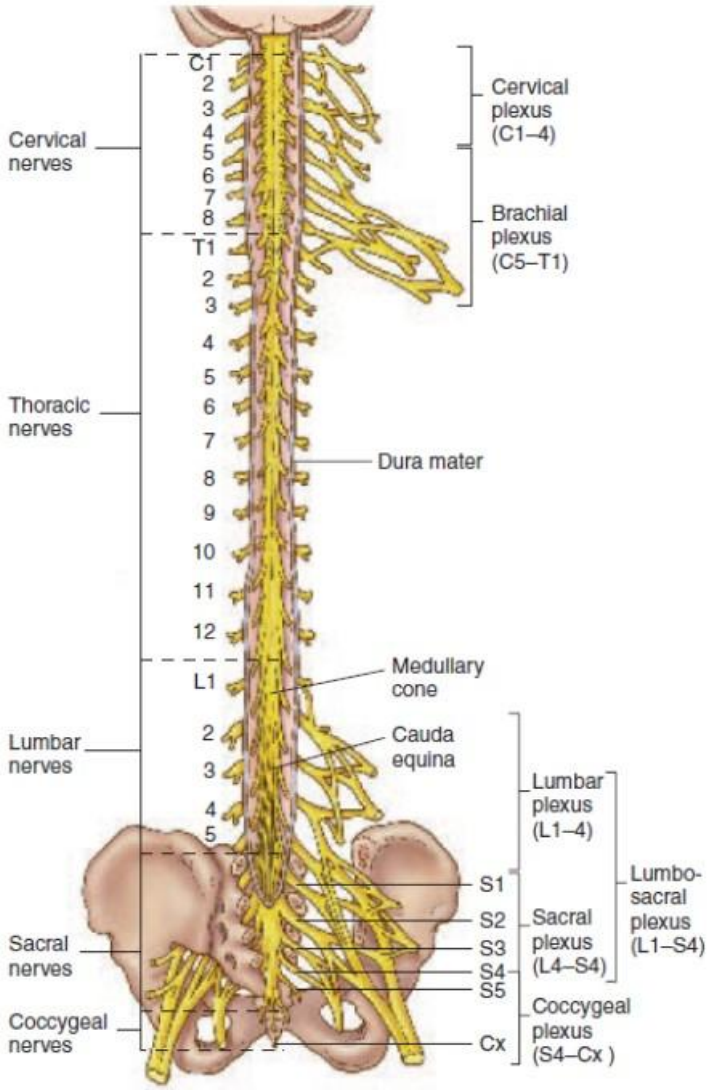


Fig.10 Spinal Nerves

Spinal cord, the spinal nerves, their plexuses, and their branches.

Anatomical and physiological properties of peripheral nerves and myoneural synapses.

MACROSCOPIC STRUCTURE OF PERIPHERAL NERVES

The central nervous system includes the brain and spinal cord, while the peripheral nervous system is composed of peripheral nerves and their spinal nerve derivatives, cranial nerves, and the peripheral autonomic nervous system. Peripheral nerves consist of motor, sensory, and postganglionic autonomic nerve fibers that serve to communicate between the spinal cord and the rest of the body. Motor axons that exit the ventral horn and sensory axons that enter the dorsal horn of the spinal cord distally form the ventral and dorsal rootlets, respectively; these combine to form mixed spinal nerves as they pass through the spinal foramen.

Spinal nerves then split into dorsal and ventral rami, which contribute to plexuses and peripheral nerves that supply different areas of the body . For example, the ventral rami of C5 through T1 form the brachial plexus, while the dorsal rami at these levels supply the posterior neck and trunk. The motor neuron cell bodies of peripheral nerves are located in the ventral horn of the spinal cord, and the sensory neuron cell bodies are located in the dorsal root ganglia just outside of the spinal cord in the intervertebral foramina. Understanding the distinct locations of motor versus sensory cell bodies is critical to accurately diagnose and localize conditions such as a brachial plexus injury. For example, nerve avulsion from the spinal cord constitutes a postganglionic injury to the motor nerve fibers, but a preganglionic injury to the sensory nerve fibers since the connections between the sensory cell bodies in the dorsal root ganglion and the axons are not severed.

Peripheral nerves are composed of organized groups of nerve fascicles that form nerve branches to innervate end organs. Fascicles within a nerve are larger and fewer in number in more proximal locations and smaller and greater in number distally. In the proximal extremity, the nerve fibers that supply the proximal limb tend to be more superficially located within the nerve to facilitate branching to their target, compared with more distally directed fibers that are distributed over multiple fascicles. As the nerve reorganizes distally, nerve fibers with the same distal target join the same fascicles. Fascicles become superficially positioned before branching, and terminal branches are often monofascicular. Distally, fascicles are cable-like and can be followed proximally for a considerable distance with consistent somatic organization. Eventually, fascicles will begin to intermingle with other fascicles proximally and will become less discrete. The ability to follow well-defined fascicles for a substantial distance proximally is the basis for nerve transfer surgery. Historically, it was thought that fascicles frequently redistribute by branching and uniting with other fascicle branches, resulting in a constantly changing plexiform

architecture. Sunderland believed that any given fascicular pattern would not persist for more than 1.5 cm.

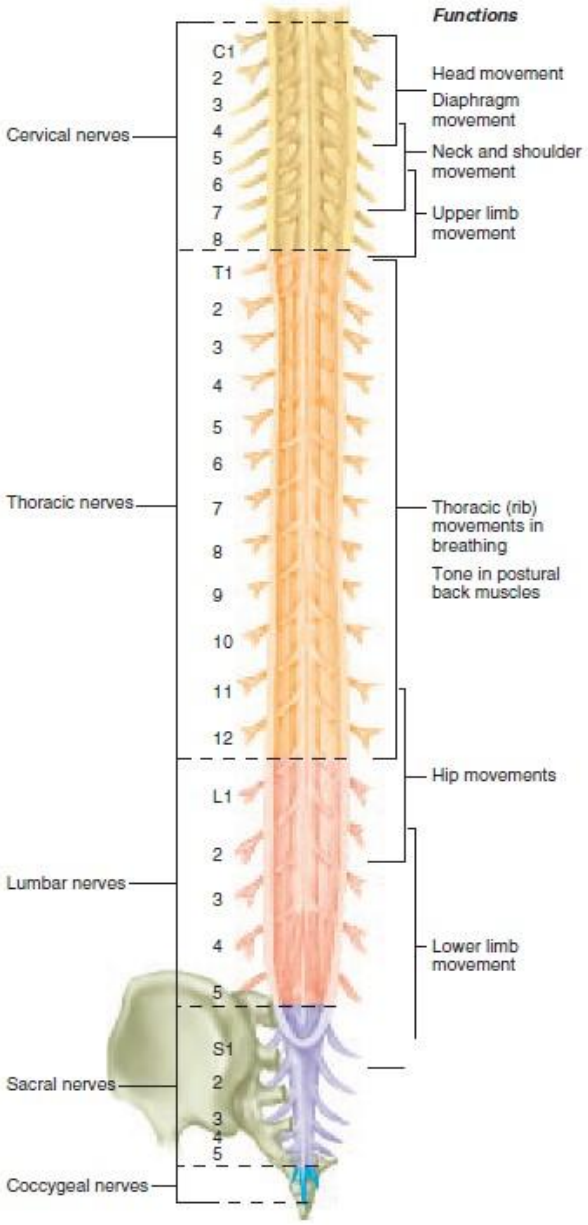


Fig.11 Functional Regions of the Spinal Cord.

Regions of the spinal cord supplying muscles and receiving sensory input from specific regions of the body.

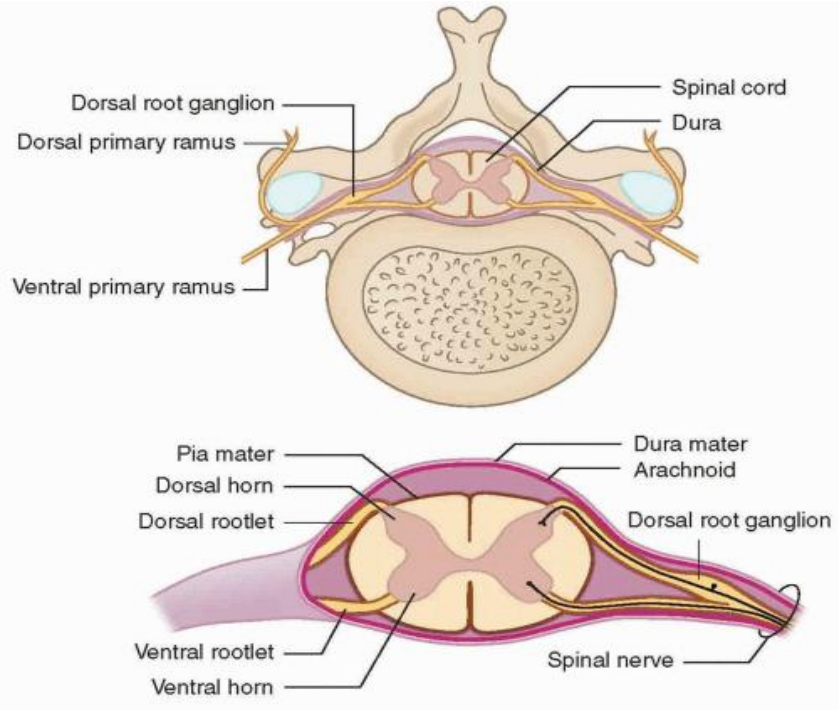
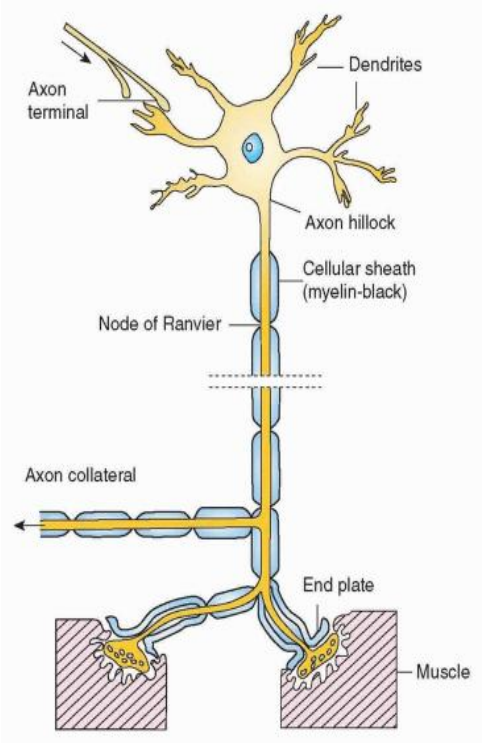


Fig.12
Illustration showing that motor axons that exit the ventral horn of the spinal cord form ventral rootlets, and sensory axons that enter the dorsal root ganglia form dorsal rootlets. Ventral and dorsal rootlets combine to form mixed spinal nerves, which then split into ventral and dorsal rami.

MICROSCOPIC STRUCTURE OF PERIPHERAL NERVES

The neuron is the smallest functional unit of nerves and is composed of a cell body with cytoplasmic extensions, including multiple dendritic processes to receive information (afferent) and a single axonal process to transmit information (efferent) (Fig.13). Inside of the cell body, otherwise known as the soma, is the nucleus, neurofilaments, mitochondria, lysosomes, and Nissl bodies surrounded by cytoplasm. The cell bodies of peripheral nerves are sometimes located within the central nervous system. The axon originates from the soma at a site called the axon hillock and travels distally as a peripheral extension.

Each axon has a thin outer layer called the axolemma, which is the cell membrane that encloses the axoplasm and extends from the



cell body along the entire length of the axon. The axoplasm acts as a conduit for transport of substances from the cell body to the distal nerve terminals, and vice versa. Within the axon there are many structures supporting its function, including mitochondria, endoplasmic reticulum, lysosomes, vesicles, microtubules, and neurofilaments. Schwann cells wrap around the axons and lay down myelin along the axolemma.

Fig.13

Diagram of a neuron, which is the smallest functional unit of peripheral nerves. The dendrites receive information (afferent) and the axon transmits information (efferent) to other neurons or to end organs such as motor end plates. The axon hillock is the site where the axon originates from the cell body. Each axon is covered by a cellular sheath, otherwise known as the axolemma. Myelinated nerve fibers have axons that are surrounded by a series of Schwann cells, each wrapped around the axon many times to form the myelin sheath. The segments of axon between Schwann cells are called nodes of Ranvier. Axons can form branches at the nodes of Ranvier, allowing a single cell body to innervate multiple end organs.

Axons with their associated Schwann cells form nerve fibers. Myelinated nerve fibers are composed of a series of adjacent Schwann cells that surround and wrap around a single axon, covering it with multiple compact layers of plasma membrane to form a myelin sheath. The segments of axon covered by Schwann cells and myelin are called internodes, whereas the small segments of axon between Schwann cells are called nodes of Ranvie.

Neuromuscular junction, also called **myoneural junction**, site of chemical communication between a nerve fibre and a muscle cell. The neuromuscular junction is analogous to the synapse between two neurons. A nerve fibre divides into many terminal branches; each terminal ends on a region of muscle fibre called the end plate. Embedded in the end plate are thousands of receptors, which are long protein molecules that form channels through the membrane. Upon stimulation by a nerve impulse, the terminal releases the chemical neurotransmitter acetylcholine from synaptic vesicles. Acetylcholine then binds to the receptors, the channels open, and sodium ions flow into the end plate. This initiates the end-plate potential, the electrical event that leads to contraction of the muscle fibre.

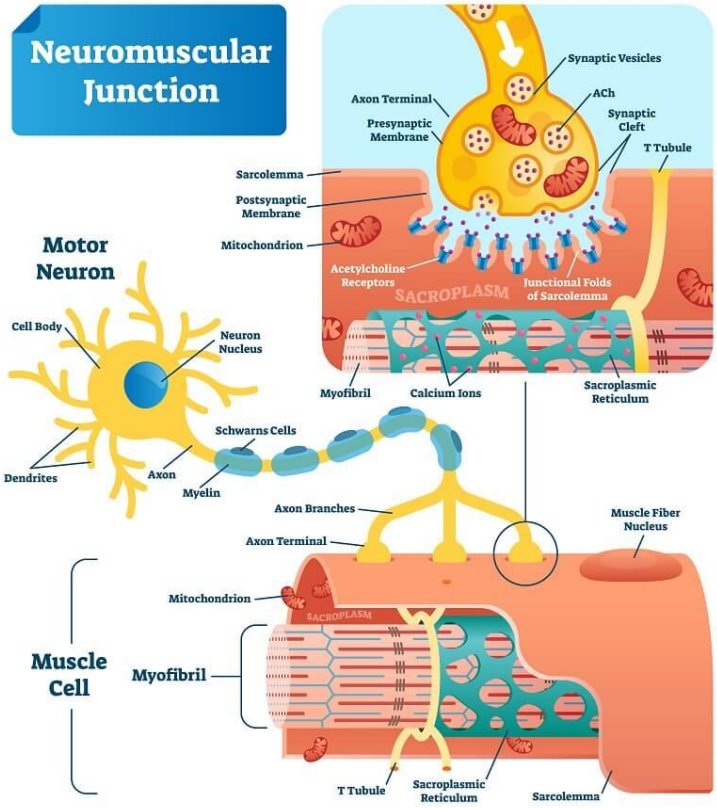


Fig.14 Neuromuscular junction

Spinal Reflexes

As noted in the previous chapter, a sense of body position is necessary for adaptive motor control. In order to move a limb toward a particular location, it is imperative to know the initial starting position of the limb, as well as any force applied to the limb. Muscle spindles and Golgi tendon organs provide this type of information. In addition, these receptors are components of certain spinal reflexes that are important for both clinical diagnosis as well as for a basic understanding of the principles of motor control.

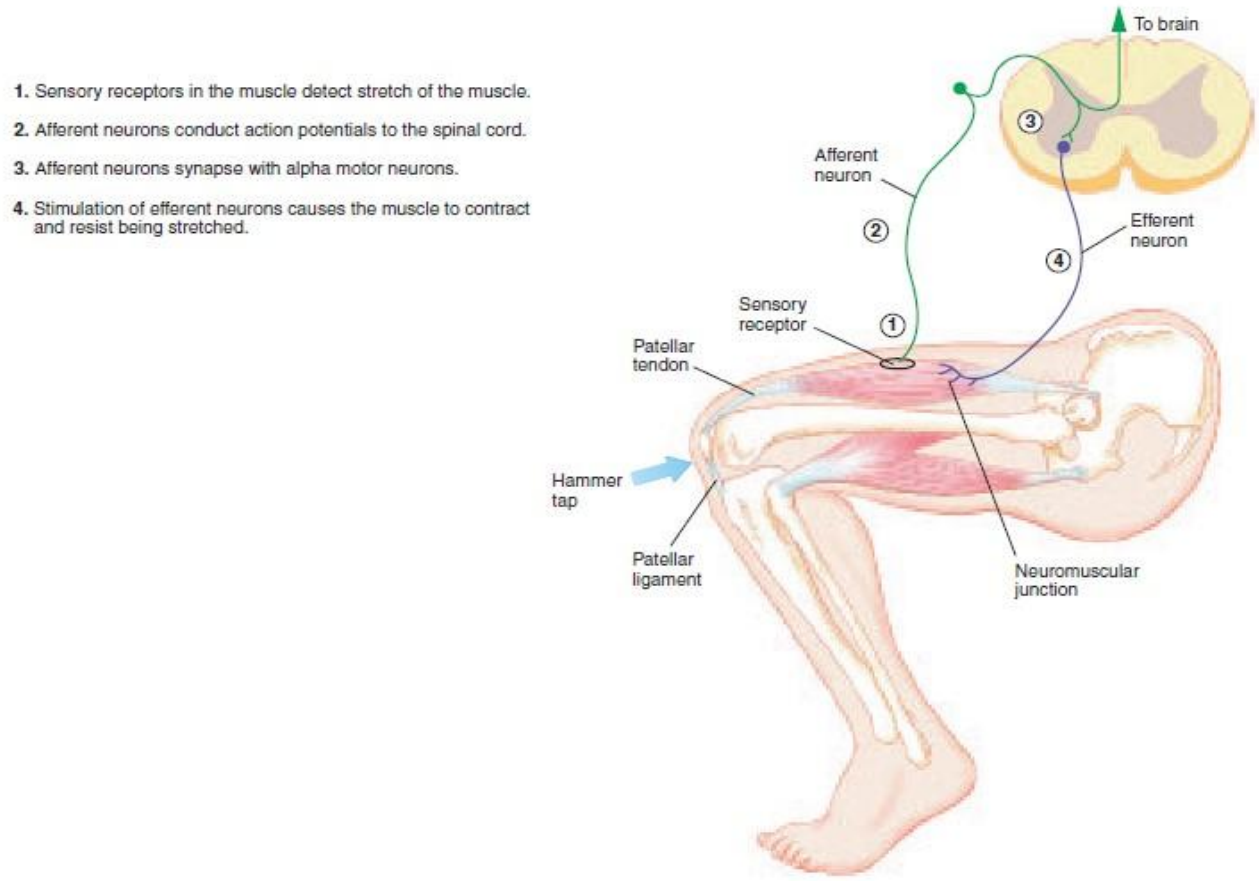
Knee-Jerk Reflex

The simplest reflex is the stretch reflex, a reflex in which muscles contract in response to a stretching force applied to them. Descending neurons within the spinal cord synapse with the neurons of the stretch reflex and modulate their activity. This activity is important in maintaining posture and in coordinating muscular activity. The knee-jerk reflex, or patellar reflex (figure 15), is a classic example of the stretch reflex and is used by clinicians to determine if the higher CNS centers that normally influence this reflex are functional. When the patellar ligament is tapped, the

quadriceps femoris muscle tendon and the muscles themselves are stretched. Sensory receptors within these muscles are also stretched, and the stretch reflex is activated.

Consequently, contraction of the muscles extends the leg, producing the characteristic knee-jerk response. All spinal reflexes are lost for a few weeks after a severe spinal cord injury. By about 2 weeks after injury the knee-jerk reflex returns, but it is often exaggerated. When the stretch reflex is greatly exaggerated, it indicates that the neurons within the brain or spinal cord that normally modify this reflex have been damaged.

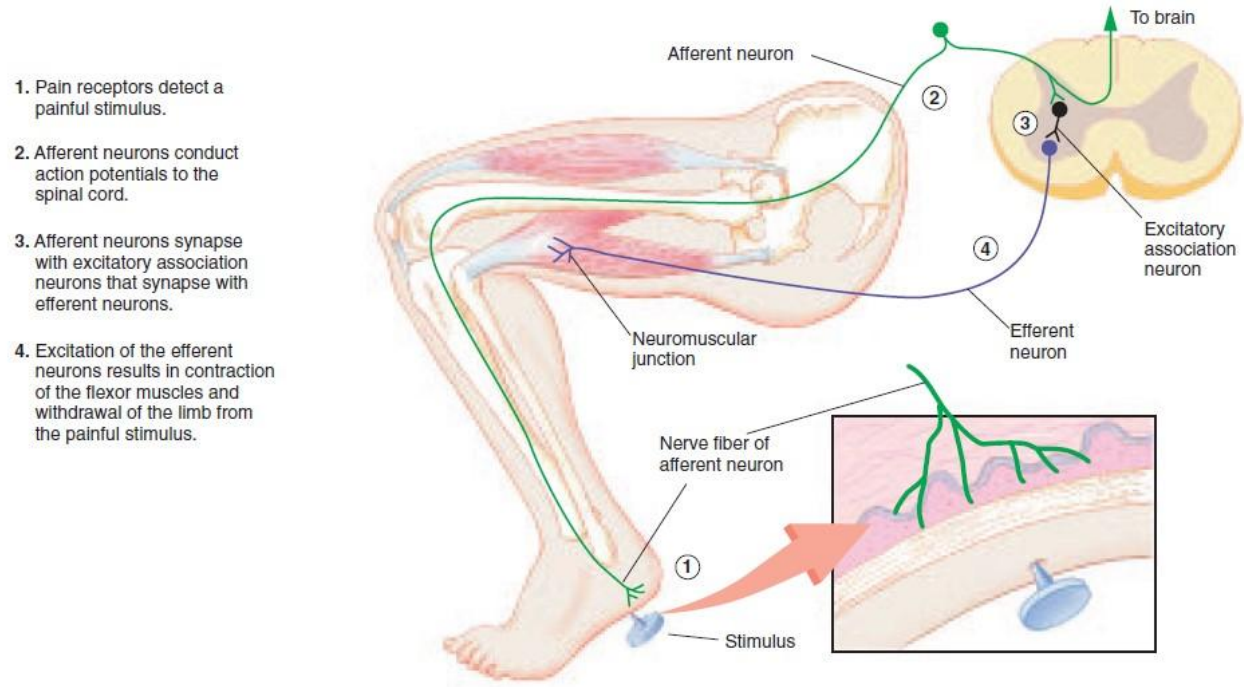
Fig.15 (knee-jerk reflex)



Withdrawal Reflex

The function of the withdrawal, or flexor reflex, is to remove a limb or other body part from a painful stimulus (fig 16). The sensory receptors are pain receptors. Action potentials from painful stimuli are conducted by afferent neurons through the dorsal root to the spinal cord, where they synapse with excitatory association neurons, which in turn synapse with efferent neurons. These neurons stimulate muscles, usually flexor muscles, that remove the limb from the source of the painful stimulus.

Fig.16. (Withdrawal Reflex)



A comprehensive examination of the neurological patient should include testing a series of reflexes:

- brachioradialis reflex
- finger flexors reflex
- Hoffman reflex
- Tromner reflex
- Pectoral reflex
- Supra-patellar reflex
- Cross-adductors reflex
- knee reflex
- patellar reflex
- ancle reflex
- plantar reflex

The main reflexes of a newborn:

Spinal motor automatisms can be checked by:

Protective reflex of the newborn, Support reflex and automatic gait in newborns, Crawling reflex (Bauer) and spontaneous crawling, Grasp reflex, Reflex Galant, Perez reflex , Moro reflex.

Oral segmental automatisms can be checked by:

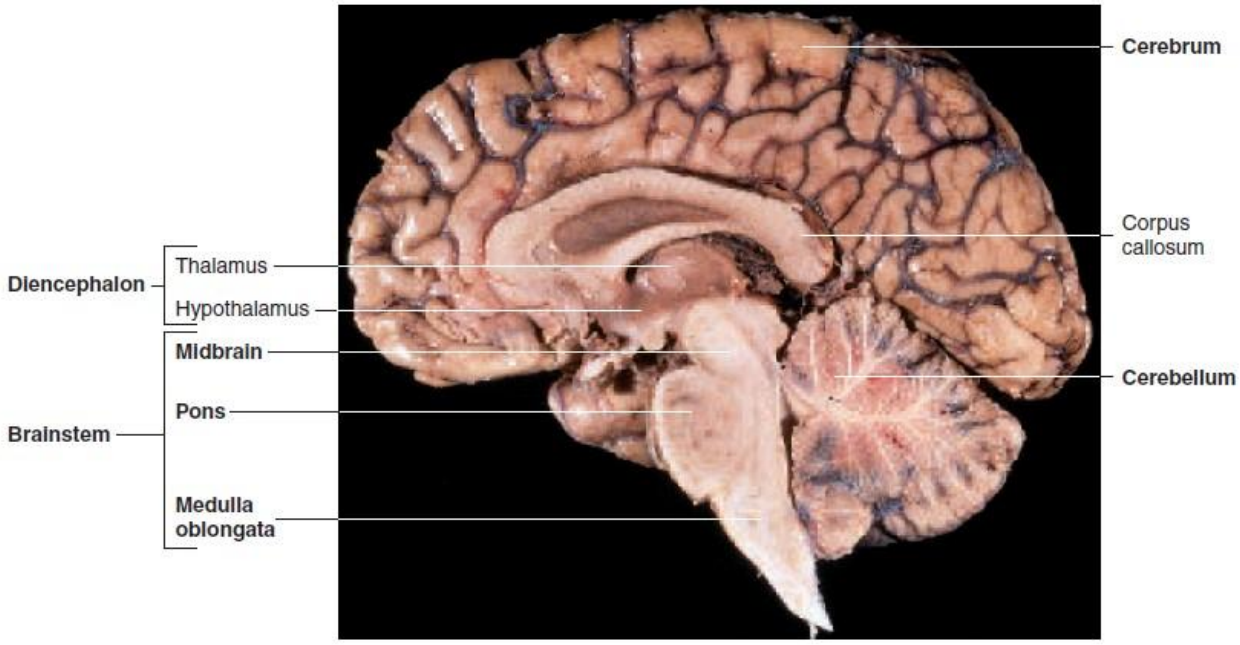
Sucking reflex, Search reflex (Kussmaul reflex), Proboscis reflex, Palmar-mouth reflex (Babkin reflex).

Lesson 3. Anatomical and physiological aspects of the importance of the brain in the regulation of movements and posture. The role of the brainstem in the regulation of body functions.

Central Nervous System

The central nervous system (CNS) consists of the brain and spinal cord. The brain is that part of the CNS housed within the cranial vault. The major regions of the brain are the brainstem, the diencephalon, the cerebrum, and the cerebellum (fig.19).

Fig.19 (CNS)



Brainstem

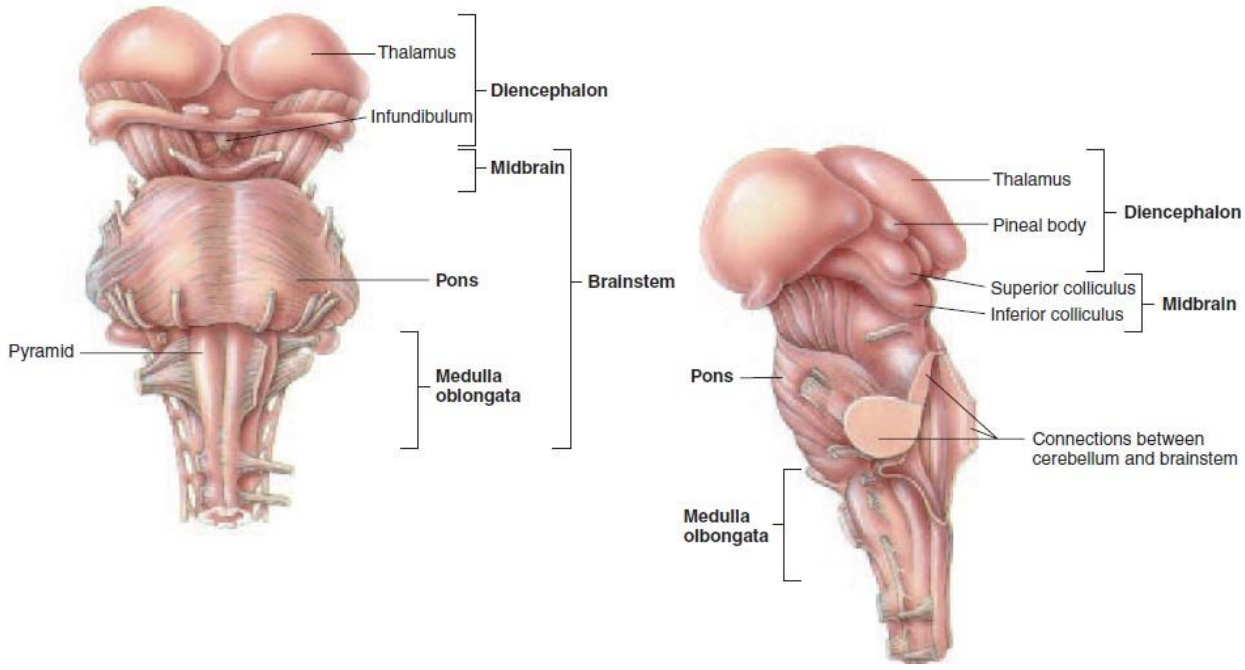
The medulla oblongata, pons, and midbrain constitute the brainstem (fig. 20). The brainstem connects the spinal cord to the remainder of the brain and contains several nuclei involved in vital body functions such as the control of heart rate and breathing. Damage to small areas of the brainstem can cause death, whereas damage to relatively large areas of the cerebrum or cerebellum often do not cause death.

Medulla Oblongata

The medulla oblongata is the most inferior portion of the brainstem (see figure 20) and is continuous with the spinal cord. In addition to ascending and descending nerve tracts, the medulla oblongata contains discrete nuclei with specific functions such as regulation of heart rate and blood vessel diameter, breathing, swallowing, vomiting,

coughing, sneezing, balance, and coordination. On the anterior surface, two prominent enlargements called pyramids extend the length of the medulla oblongata. The pyramids consist of descending nerve tracts, which transmit action potentials from the brain to motor neurons of the spinal cord and are involved in the conscious control of skeletal muscles.

Fig.20 (Brainstem)



Pons

Immediately superior to the medulla oblongata is the pons. It contains ascending and descending nerve tracts, as well as several nuclei. Some of the nuclei in the pons relay information between the cerebrum and the cerebellum. The term pons means bridge, and it describes both the structure and function of the pons. Not only is the pons a functional bridge between the cerebrum and cerebellum, but on the anterior surface, it resembles an arched footbridge. Several nuclei of the medulla oblongata, described above, also extend into the lower part of the pons, so that functions such as breathing, swallowing, and balance are controlled in the lower pons, as well as in the medulla oblongata. Other nuclei in the pons control functions such as chewing and salivation.

Midbrain

The midbrain, just superior to the pons, is the smallest region of the brainstem (see figure 20). The superior part of the midbrain consists of four mounds called the colliculi. The two inferior colliculi are major relay centers for the auditory nerve

pathways in the CNS. The two superior colliculi are involved in visual reflexes. Turning the head toward a tap on the shoulder, a sudden loud noise, or a bright flash of light are reflexes controlled in the superior colliculi. The midbrain contains nuclei involved in the coordination of eye movements and in the control of pupil diameter and lens shape. The midbrain also contains a black nuclear mass, called the substantia nigra, which is part of the basal nucle and is involved in the regulation of general body movements. The rest of the midbrain consists largely of ascending pathways from the spinal cord to the cerebrum and descending motor pathways from the cerebrum to the spinal cord.

Reticular Formation

Scattered throughout the brainstem is a group of nuclei collectively called the reticular formation (fig 20.1). The reticular formation is made up of a net-like structure of various brainstem nuclei and neurons and covers an expansive portion of the brainstem, beginning in the mesencephalon, extending caudally through the medulla oblongata, and projecting into the superior cervical spinal cord segments. The reticular formation does not have any distinct cytoarchitectural boundaries and is dispersed throughout the brainstem as a network of interconnected neurons with many projections rostrally to subcortical and cortical brain structures as well as caudally to the spinal cord. Despite having non-distinct borders, the reticular formation contains over 100 individual brainstem nuclei.The reticular formation is a major component of the reticular activating system, which plays an important role in arousing and maintaining consciousness and in regulating the sleep–wake cycle. Stimuli such as an alarm clock ringing, sudden bright lights, smelling salts, or cold water being splashed on the face canarouse consciousness. Conversely, removal of visual or auditory stimuli may lead to drowsiness or sleep. General anesthetics function by suppressing the reticular activating system. Damage to cells of the reticular formation can result in coma.

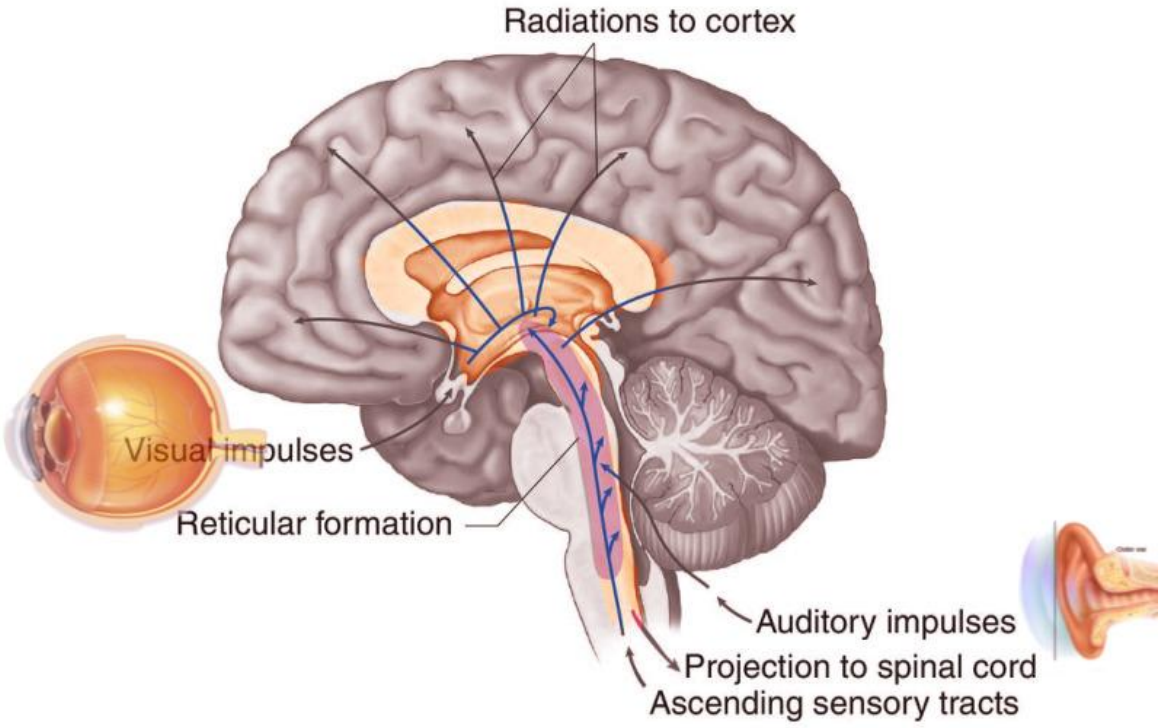
Diencephalon

The diencephalon (figure 21.2) is the part of the brain between the brainstem and the cerebrum. Its main components are the thalamus, epithalamus, and hypothalamus.

Thalamus

The thalamus is by far the largest part of the diencephalon. It consists of a cluster of nuclei and is shaped somewhat like a yo-yo, with two large, lateral parts connected in the center by a small intermediate . Most sensory input that ascends through the spinal cord and brainstem projects to the thalamus, where afferent neurons synapse with thalamic neurons. Thalamic neurons, in turn, send their axons to the cerebral cortex. The thalamus also has other functions, such as influencing mood and registering an unlocalized, uncomfortable perception of pain.

Fig.20.1 Reticular activating system



Epithalamus

The epithalamus is a small area superior and posterior to the thalamus. It consists of a few small nuclei that are involved in the emotional and visceral response to odors, and the pineal body. The pineal body is an endocrine gland that may influence the onset of puberty. It also may play a role in controlling some long-term cycles that are influenced by the light–dark cycle.

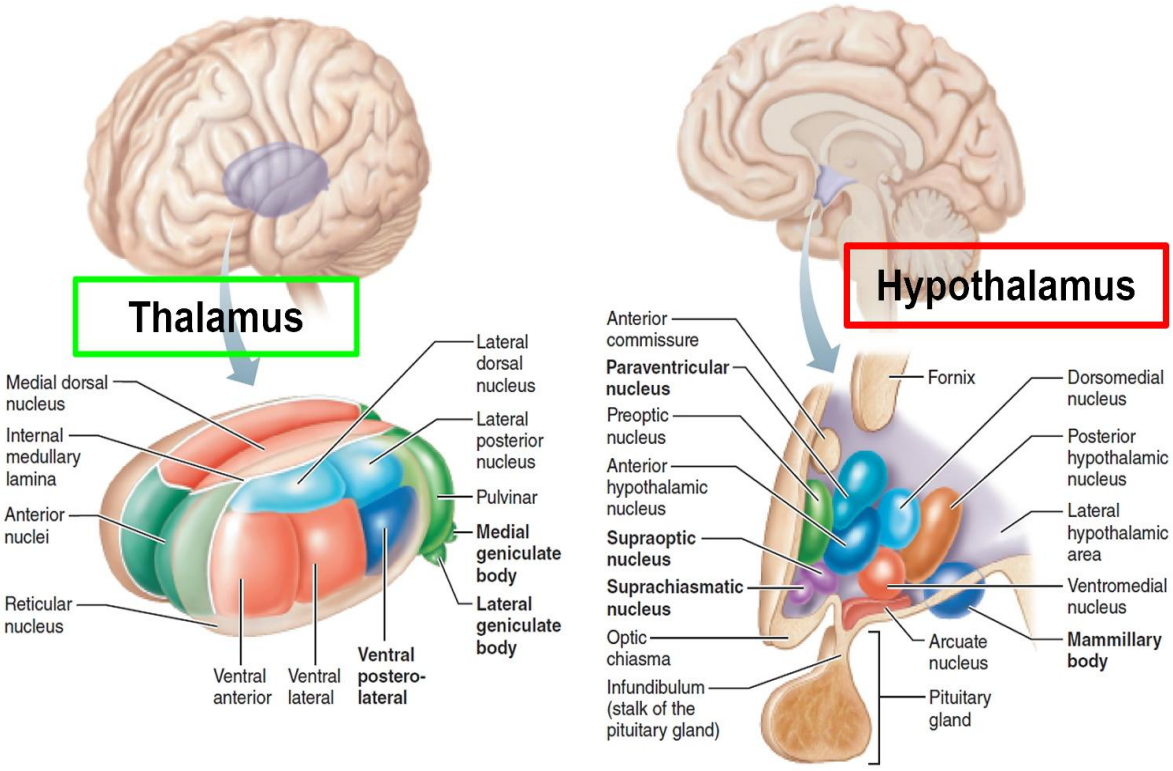
Hypothalamus

The hypothalamus is the most inferior part of the diencephalon and contains several small nuclei which are very important in maintaining homeostasis. The hypothalamus plays a central role in the control of body temperature, hunger, and thirst. Sensations such as sexual pleasure, feeling relaxed and "good" after a meal, rage, and fear are related to hypothalamic functions. Emotional responses, which seem to be inappropriate to the circumstances, such as "nervous perspiration" in response to stress or feeling hungry as a result of depression, also involve the hypothalamus.

A funnel-shaped stalk, the, extends from the floor of the hypothalamus to the pituitary gland. The hypothalamus plays a major role in controlling the secretion of hormones from the pituitary gland. The mamillary bodies form externally visible

swellings on the posterior portion of the hypothalamus and are involved in emotional responses to odors and in memory.

Fig 21.1 (Nucleus of Thalamus and Hypothalamus)



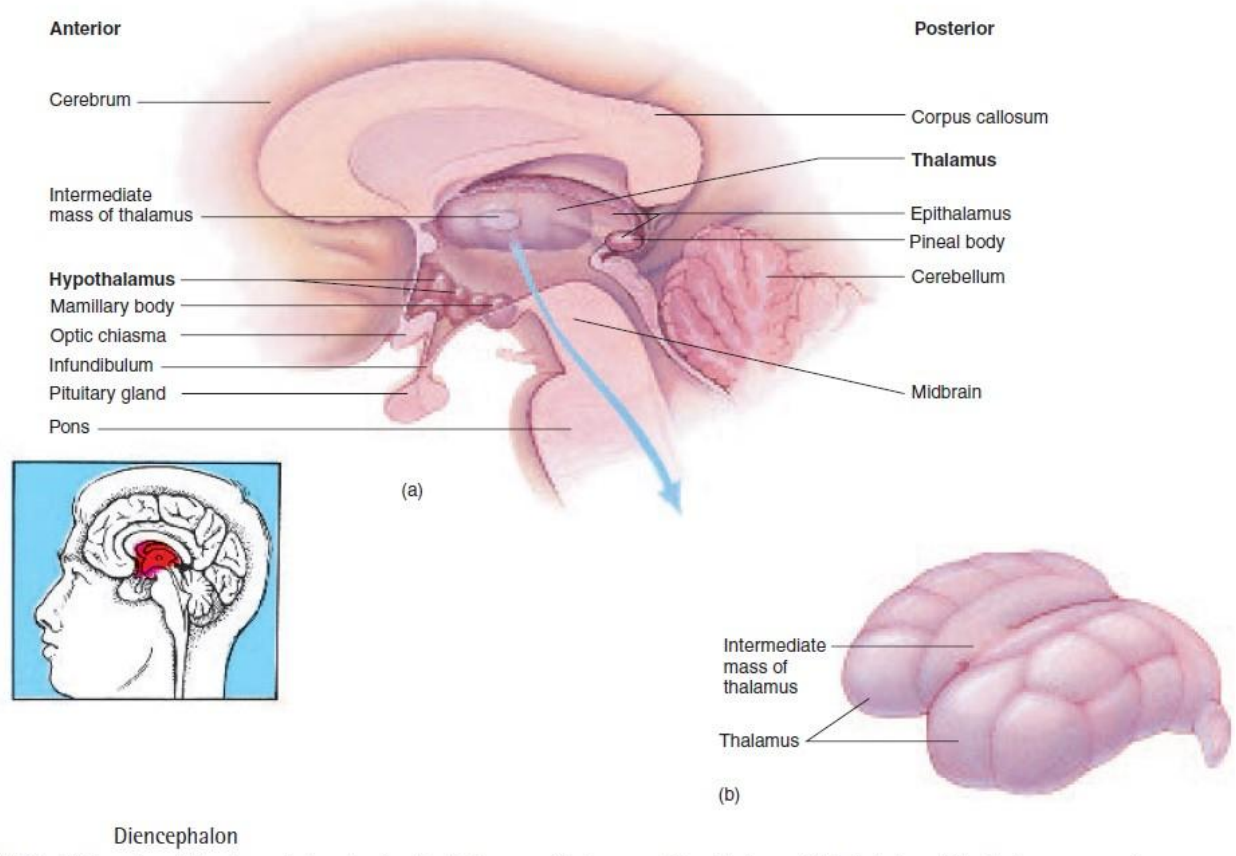
Cerebrum

The cerebrum is the largest part of the brain (figure 22). It is divided into left and right hemispheres by a longitudinal fissure. The most conspicuous features on the surface of each hemisphere are numerous folds called gyri, which greatly increase the surface area of the cortex, and intervening grooves called sulci.

Each cerebral hemisphere is divided into lobes, named for the skull bones overlying them. The frontal lobe is important in voluntary motor functions, motivation, aggression, mood, and olfactory (smell) reception. The parietal lobe is the principal center for the reception and evaluation of most sensory information, such as touch, pain, temperature, balance, and taste. The frontal and parietal lobes are separated by a prominent sulcus called the central sulcus. The occipital lobe functions in the reception and integration of visual input and is not distinctly separate from the other lobes. The temporal lobe evaluates olfactory (smell) and auditory (hearing) input and plays an important role in memory. Its anterior and inferior portions are referred to as the “psychic cortex,” and they are associated with functions such as abstract thought

and judgment. Most of the temporal lobe is separated from the rest of the cerebrum by a lateral fissure.

Fig 21.2(Diencephalon)

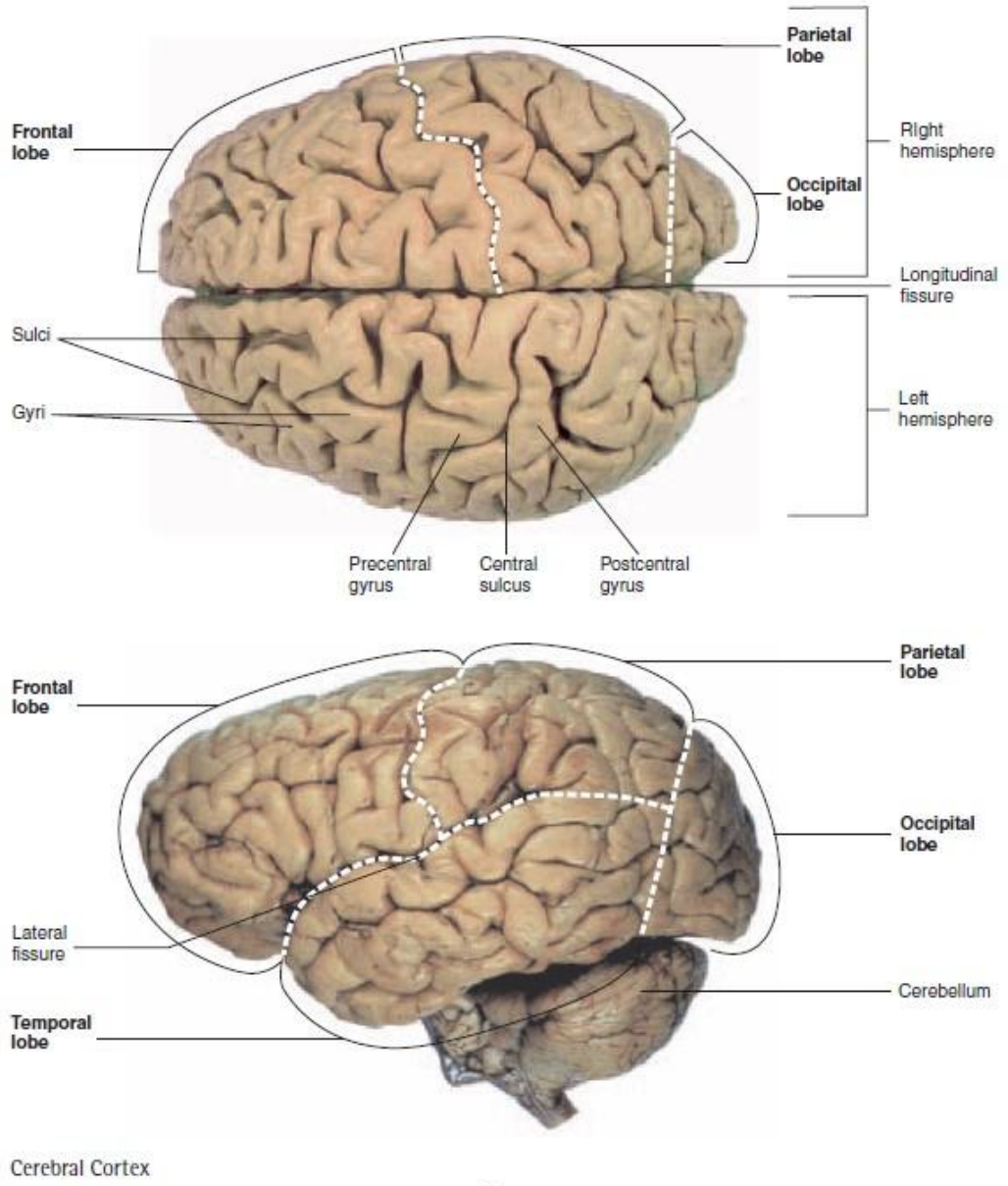


Diencephalon

(*a*) Midsagittal section of the diencephalon showing the thalamus, epithalamus, and hypothalamus. (*b*) Both halves of the thalamus as seen from a dorsolateral view with the separations between nuclei depicted by indentations on the surface.

Basal Nuclei

The basal nuclei are a group of functionally related nuclei (figure 23). Two primary nuclei are the corpus striatum, located deep within the cerebrum, and the substantia nigra, a group of darkly pigmented cells located in the midbrain. The basal nuclei play an important role in posture and in planning and coordinating motor movements. Complex neural connections link the basal nuclei with the cerebral cortex. Dopamine is a neurotransmitter produced in the substantia nigra, which exerts an inhibitory influence on the corpus striatum. The major effect of the basal nuclei is to decrease muscle tone and inhibit muscular activity. Disorders of the basal nuclei, such as Parkinson's disease and cerebral palsy, result in increased muscle tone and in exaggerated, uncontrolled movements, occurring mainly when the person is trying to hold still, because of decreased basal nuclei function.



(*a*) Superior view of both cerebral hemispheres showing the gyri and lobes. (*b*) Lateral view of the left cerebral hemisphere showing the gyri and lobes.

Fig.22 (Cerebral cortex)

Cerebellum

The cerebellar cortex is composed of gray matter and has gyri and sulci, but the gyri are much smaller than those of the cerebrum (fig.24.1). Internally, the cerebellum consists of nuclei (fig. 24.2) and nerve tracts. The cerebellum is involved in balance, maintenance of muscle tone, and coordination of fine motor movement. If the cerebellum is damaged, muscle tone decreases, and fine motor movements become very clumsy. A major function of the cerebellum is that of a comparator. Action potentials from the cerebral motor cortex descend into the spinal cord to initiate voluntary movements. Collateral branches are also sent from the motor cortex to the cerebellum, giving information representing the intended movement. Simultaneously, action potentials from proprioceptive neurons reach the cerebellum.

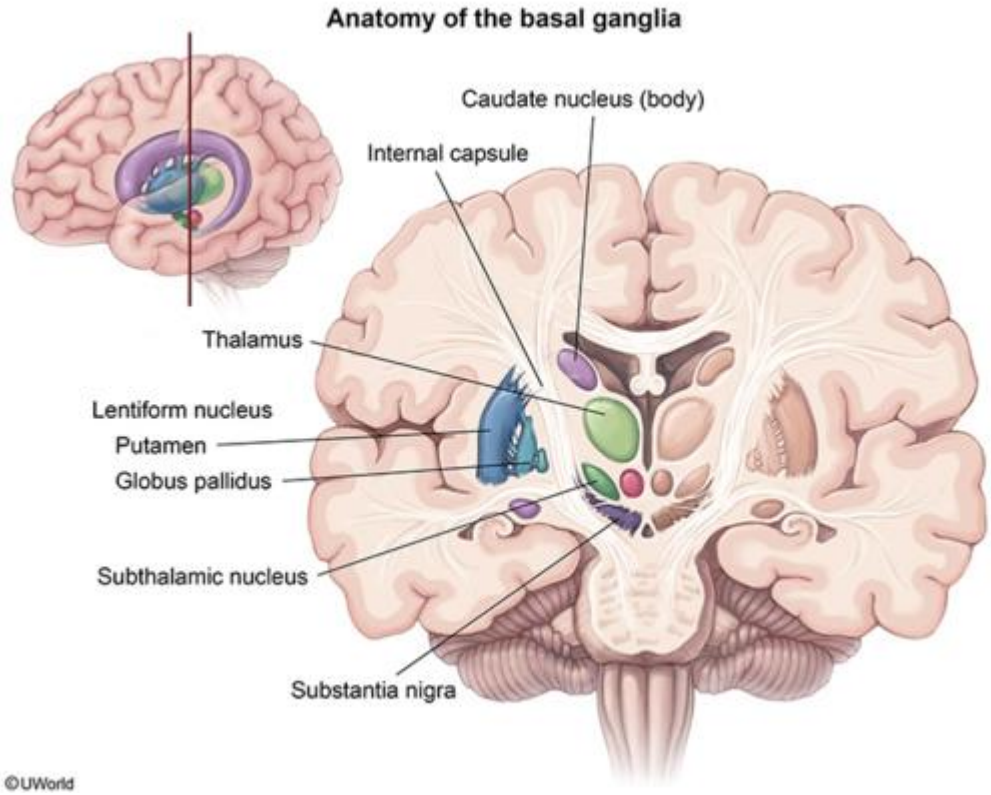
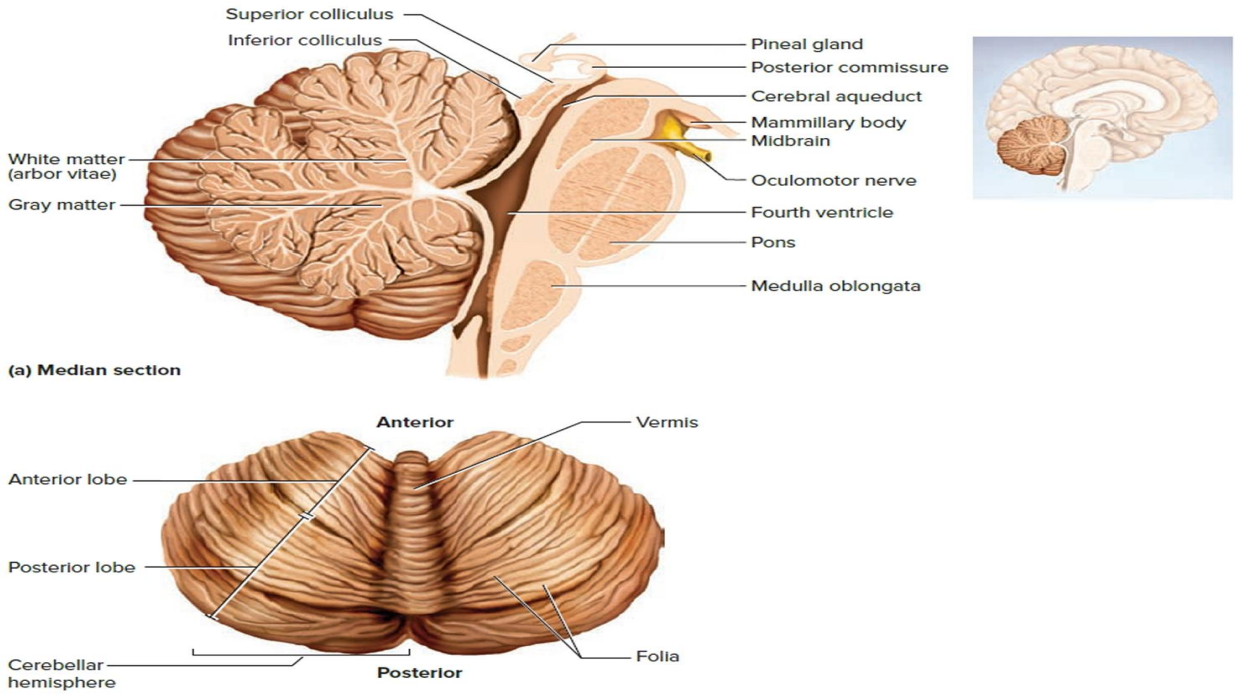


Fig.23 (Basal ganglia)

Proprioceptive neurons innervate joints and tendons, providing information about the position of body parts. The cerebellum compares information about the intended movement from the motor cortex with sensory information from the moving structures. If a difference is detected, the cerebellum sends action potentials to motor neurons in the motor cortex and the spinal cord to correct the discrepancy. The result is smooth and coordinated movements. For example, if you close your eyes, the cerebellar comparator function allows you to touch your nose smoothly and easily with your finger. If the cerebellum is not functioning, your finger tends to overshoot the target. One effect of alcohol is to inhibit the function of the cerebellum. Dysfunction of the cerebellar comparator can be understood by observing the actions of someone who is drunk. Another function of the cerebellum involves learning a motor skill such as playing the piano or riding a bicycle. When such a skill is being learned, the cerebrum is directly involved in initiating the various movements. Once the cerebellum "learns" these skills, much of the movement can be accomplished automatically by the cerebellum.

Fig 24.1(Cerebellum)



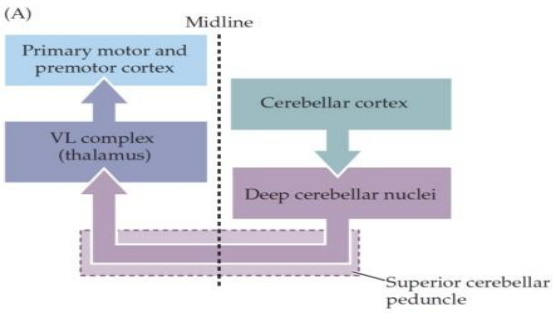
At the center of the cerebellum is a collection of nuclei – the cerebellar deep nuclei (DCN). The deep cerebellar nuclei are the output areas of the cerebellum, receiving inputs from the cortex and projecting out to the thalamus, red nucleus and brainstem. From medial to lateral the cerebellar nuclei are the fastigial, interpositus (in man, this is subdivided into the globose and emboliform nuclei) and dentate nuclei.

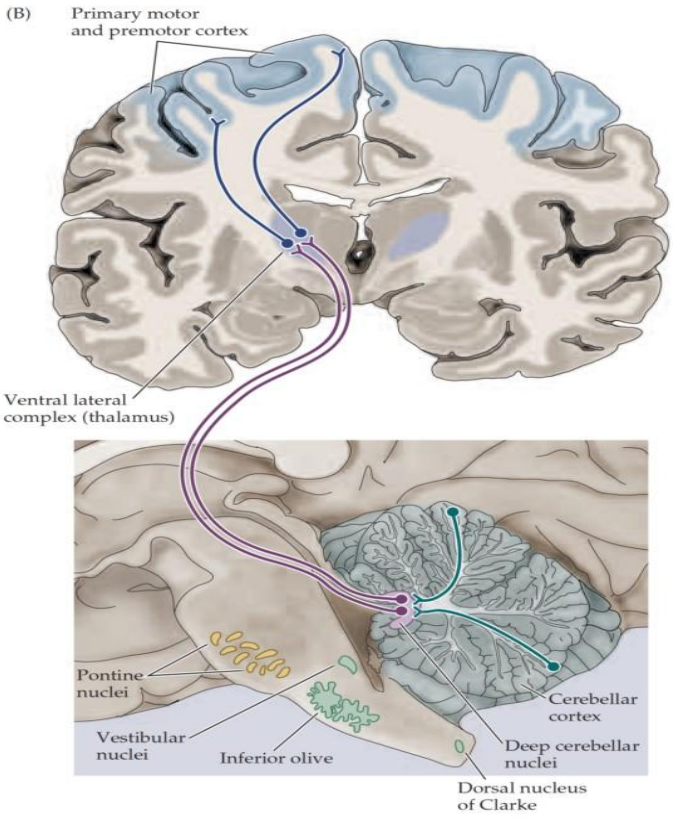
Fig.24.2.

Symptoms of damage to the cerebellum:

Ataxia is a disorder of movement coordination.

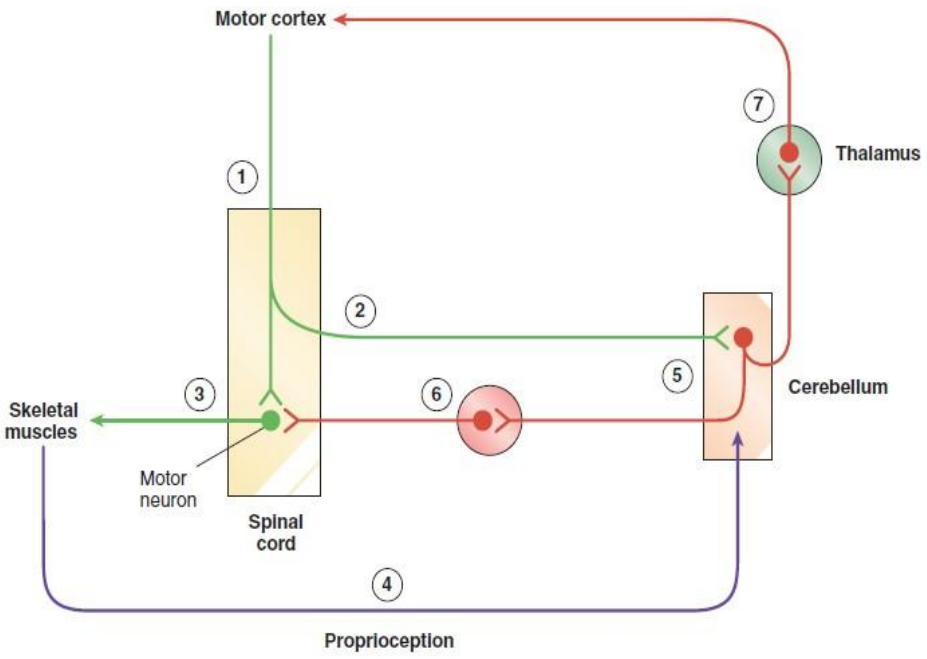
- Hypermetria is an exaggeration of the range of motion, when the limb misses when reaching the desired goal. Hypometria is a deficiency of the limit of movements, when during movements the limb stops before reaching the goal.
- Asynergy. It consists in a violation of coordination between synergistic muscles, it can be:
- Asynergy: when bending the body back, the patient does not have joint bending of the legs at the knees;
- Asynergy: when trying to sit down from a lying position, the patient does not have joint fixation of the legs in a horizontal position;
- Adiadochokinesis. When the cerebellum is damaged, the replacement of any movement with the opposite occurs slowly.
- Astasia is violation of static reflexes: establishing, posture.
- Atony is a significant decrease in muscle tone.
- Asthenia is muscle weakness.





Functional organization of the outputs from the cerebellum to the cerebral cortex. (A) Targets of the cerebellum. The axons of the deep cerebellar nuclei cross in the midbrain in the decussation of the superior cerebellar peduncle before reaching the thalamus. (B) Idealized coronal and sagittal sections through the human brainstem and cerebrum, showing the location of the structures and pathways diagrammed in (A).

1. The motor cortex sends action potentials to motor neurons in the spinal cord.
2. Action potentials from the motor cortex inform the cerebellum of the intended movement.
3. Motor neurons in the spinal cord send action potentials to skeletal muscles, causing them to contract.
4. Proprioceptive signals from the skeletal muscles and joints to the cerebellum convey information concerning the status of the muscles and the structures being moved during contraction.
5. The cerebellum compares the information from the motor cortex to the proprioceptive information from the skeletal muscles and joints.
6. Action potentials from the cerebellum to the spinal cord modify the stimulation from the motor cortex to the motor neurons.
7. Action potentials from the cerebellum are sent to the motor cortex, which modifies its motor activity.



Cerebellar Comparator Function

Fig 24.3 Cerebellar comparator function

Lesson 4. Anatomical and physiological aspects of the somato-sensory system. Anatomical and physiological bases of pain and anesthesia.

The somatosensory systems inform us about objects in our external environment through touch (i.e., physical contact with skin) and about the position and movement of our body parts (proprioception) through the stimulation of muscle and joints. The somatosensory systems also monitor the temperature of the body, external objects and environment, and provide information about painful, itchy and tickling stimuli. The sensory information processed by the somatosensory systems travels along different anatomical pathways depending on the information carried. For example, the posterior column-medial lemniscal pathway carries discriminative touch and proprioceptive information from the body, and the main sensory trigeminal pathway carries this information from the face. Whereas, the spinothalamic pathways carry crude touch, pain and temperature information from the body, and the spinal trigeminal pathway carries this information from the face.

Pain is a sensation characterized by a group of unpleasant perceptual and emotional experiences. There are two types of pain sensation: (1) sharp, well-localized, pricking, or cutting pain resulting from rapidly conducted action potentials and (2) diffuse, burning, or aching pain resulting from action potentials that are propagated more slowly.

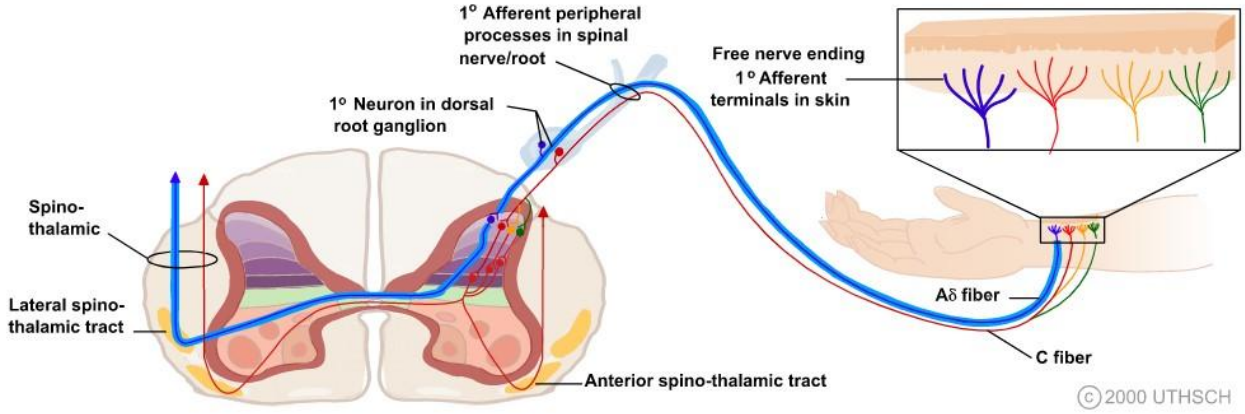
Superficial pain sensations in the skin are highly localized as a result of the simultaneous stimulation of pain receptors and tactile receptors, which help to localize the source of the pain stimuli. Deep or visceral pain sensations are not highly localized because of the absence of tactile receptors in the deeper structures. Visceral pain stimuli are normally perceived as diffuse pain. Action potentials from pain receptors in local areas of the body can be suppressed by chemical anesthetics injected near a sensory nerve and result in reduced pain sensation. This treatment is called local anesthesia. Pain sensations can also be suppressed if consciousness is inhibited by chemical anesthetics that affect the reticular formation. This treatment is called general anesthesia.

Pain sensations can also be influenced by inherent control systems. Afferent axons from tactile receptors in the skin have collateral branches that synapse with neurons in the dorsal horn of the spinal cord. Those neurons, in turn, synapse with and inhibit the neurons in the dorsal horn that give rise to the lateral spinothalamic tract. Rubbing the skin in the area of an injury stimulates the tactile receptors, which send action potentials along the afferent axons to the spinal cord. According to the gate control theory, these action potentials“close the gate” and inhibit action potentials carried to the brain by the lateral spinothalamic tract. Action potentials carried by the lateral spinothalamic tract can also be inhibited by action potentials carried by descending neurons of the dorsal column system. These neurons are stimulated by mental or

physical activity, especially involving movement of the limbs. The descending neurons synapse with and inhibit neurons in the dorsal horn that give rise to the lateral spinothalamic tract. Vigorous mental or physical activity increases the rate of action potentials in neurons of the dorsal column and can reduce the sensation of pain.

Nociceptors are sensory receptors that detect signals from damaged tissue or the threat of damage and indirectly also respond to chemicals released from the damaged tissue. Nociceptors are free (bare) nerve endings found in the skin (Fig.25), muscle, joints, bone and viscera. Recently, it was found that nerve endings contain transient receptor potential (TRP) channels that sense and detect damage. The TRP channels are similar to voltage-gated potassium channels or nucleotide-gated channels, having 6 transmembrane domains with a pore between domains 5 and 6. They transduce a variety of noxious stimuli into receptor potentials, which in turn initiate action potential in the pain nerve fibers. This action potential is transmitted to the spinal cord and makes a synaptic connection in lamina I and/or II. The cell bodies of nociceptors are mainly in the dorsal root and trigeminal ganglia. No nociceptors are found inside the CNS.

Fig.25. Different nociceptors/free nerve endings, and the fibers carrying pain sensation from the nociceptors to the spinal cord



Nociceptors are not uniformly sensitive. They fall into several categories, depending on their responses to mechanical, thermal, and/or chemical stimulation liberated by the damage, tumor, and/or inflammation.

General Senses

Receptors are sensory nerve endings in the skin and other tissues capable of responding to stimuli by developing action potentials. There are several types of receptors, each responding to a different type of stimulus. Mechanoreceptors respond to mechanical stimuli such as the bending or stretching of receptors, chemoreceptors respond to chemicals such as odor molecules, photoreceptors respond to light, thermoreceptors respond to temperature changes, and nociceptors respond to stimuli that result in the sensation of pain. Many of the receptors for the general senses are associated with the skin; others are associated with deeper structures, such as tendons, ligaments, and muscles. Receptors consist of several types of nerve endings that respond to a wide range of stimuli. Structurally the simplest and most common sensory nerve endings are free nerve endings, which are relatively unspecialized neuronal branches similar to dendrites. Free nerve endings are distributed throughout almost all parts of the body. Some free nerve endings respond to painful stimuli, some to temperature, some to itch, and some to movement. Temperature sensations are detected by specialized free nerve endings called cold receptors and warm receptors. Cold receptors respond to decreasing temperatures and warm receptors respond to increasing temperatures. When cold or hot temperatures become excessive, however, below 12°C (54°F) or above 47°C (117°F), respectively, neither the cold nor warm receptors function, and pain receptors are stimulated. That is why it is sometimes difficult to distinguish very cold from very warm objects touching the skin. The remaining nerve endings are structurally more complex than free nerve endings, and many ofthem are enclosed by capsules. Merkel's disks are small, superficial nerve endings involved in detecting light touch and superficial pressure. Hair follicle receptors, associated with hairs, are also involved in detecting light touch. Light touch receptors are very sensitive but are not very discriminative, meaning that the point being touched cannot be precisely located. Receptors for fine, discriminative touch, called Meissner's corpuscles, are located just deep to the epidermis. These receptors are very specific in localizing tactile sensations. Deeper tactile receptors, called Ruffini's end organs, play an important role in detecting continuous pressure in the skin. The deepest receptors are the receptors associated with tendons and joints and are called pacinian corpuscles. These receptors relay information concerning deep pressure, vibration, and position (proprioception).

Vision

The visual system includes the eyes, the accessory structures, and the afferent neurons that project to the cerebral cortex where action potentials conveying visual information are interpreted. Much of the information we obtain about the worldaround us is detected by the visual system. Our education is largely based on visual input and depends on our ability to read words and numbers. Visual input includes information about light and dark, movement, color, and hue.

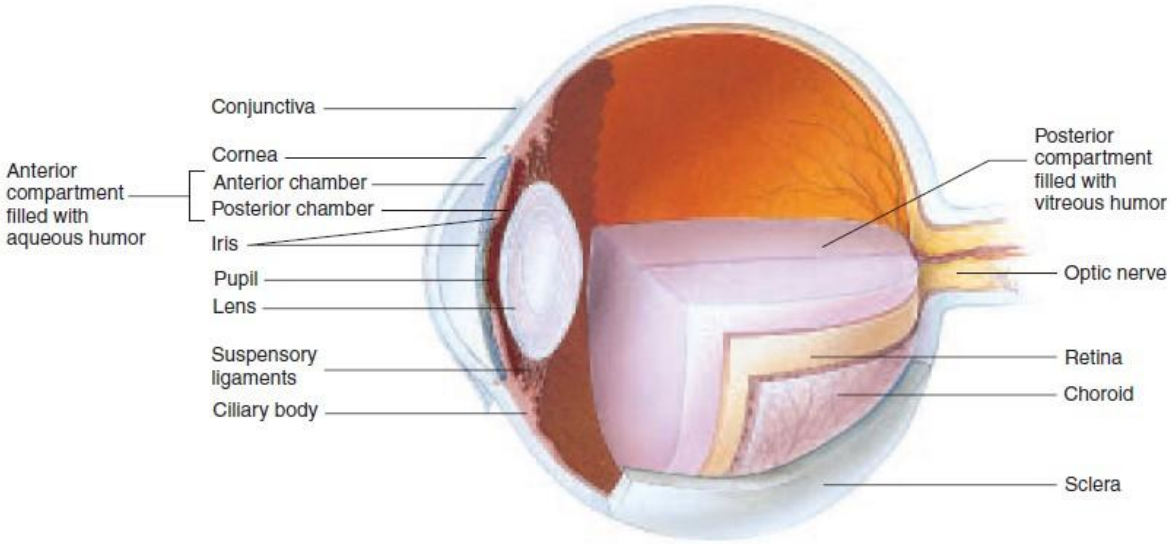
Anatomy of the Eye

The eyeball is a hollow, fluid-filled sphere. The sphere has a larger, posterior compartment, which makes up about fivesixths of the eye, and a much smaller anterior compartment, which makes up about one-sixth of the eye. The wall of the eye consists of three layers, or tunics (figure 26). The outer, or fibrous, tunic consists of the sclera and cornea. The middle, or vascular, tunic consists of the choroid, ciliary body, and iris. The inner, or nervous, tunicconsists of the retina.

Fibrous Tunic

The sclera is the firm, white, outer connective tissue layer of the posterior five-sixths of the eye. The sclera helps maintain the shape of the eye, protects the internal structure, and provides attachment sites for the extrinsic eye muscles. A small portion of the sclera can be seen as the “white of the eye.”The cornea is the transparent, anterior sixth of the eye that permits light to enter the eye. As part of the focusing system of the eye, it also bends, or refracts, the entering light.

Fig.26.



Layers and Compartments of the Eye

Vascular Tunic

The middle tunic of the eye is called the vascular tunic because it is the layer containing most of the blood vessels of the eye. The posterior portion of the vascular tunic, associated with thesclera, is the choroid. This is a very thin structure consisting of a vascular network and many melanin-containing pigment cells, so that it appears black in color. The black color absorbs light so that it is not reflected inside the eye. If light was reflected inside the eye, the reflection would interfere with vision. The interiors of cameras are black for the same reason. Anteriorly the vascular tunic consists of the ciliary body and iris. The ciliary body is continuous with the anterior margin of the choroid. The ciliary body contains smooth muscles called ciliary muscles, which attach to the perimeter of the lens by suspensory ligaments. The lens is a flexible, biconvex, transparent disc. The iris is the colored part of the eye. It is attached to the anterior margin of the ciliary body, anterior to the lens. The iris is a contractile structure consisting mainly of smooth muscle that surrounds an opening called the pupil. Light passes through the pupil, and the iris regulates the diameter of the pupil, which controls the amount of light entering the eye. Parasympathetic stimulation from the oculomotor nerve (cranial nerve III) causes the circular smooth muscles of the iris to contract, resulting in pupillary constriction, whereas sympathetic stimulation causes radial smooth muscles of the iris to contract, resulting in pupillary dilation. As light intensity increases, the pupil constricts; as light intensity decreases, the pupil dilates.

Nervous Tunic

The retina, or nervous tunic, is the innermost tunic and it covers only the posterior five-sixths of the eye. It consists of an outer pigmented retina and an inner sensory retina (fig.27) . The pigmented retina, with the choroid, keeps light from reflecting back into the eye. The sensory retina contains photoreceptor cells, called rods and cones, which respond to light. Over most of the retina, rods are 20 times more common than cones, with the concentration of rods increasing anteriorly. Rods are very sensitive to light and can function in very dim light, but they do not provide color vision. Cones require much more light, and they do provide color vision. There are three types of cones, each sensitive to a different color: blue, green, or red. The many colors that we can see result from various functional combinations of these three types of cones. The outer segments of rod and cone cells are modified by numerous foldings of the cell membrane to form discs. Rod cells contain a photosensitive pigment called rhodopsin, which is made up of the protein opsin in loose chemical combination with a pigment calledretinal. Cone cells contain a slightly different photosensitive pigment. When light strikes a rod cell, retinal changes shape and loses its attachment to the opsin molecule. As a result, opsin “opens up” with a release of energy(fig 28). This reaction is somewhat like a spring (opsin) being held by a trigger (retinal). This change in rhodopsin stimulates a

response in the rod cell. Retinal then completely detaches from rhodopsin. Energy (ATP) is required to reattach retinal to rhodopsin and, at the same time, to return rhodopsin to the shape that it had before being stimulated by light.

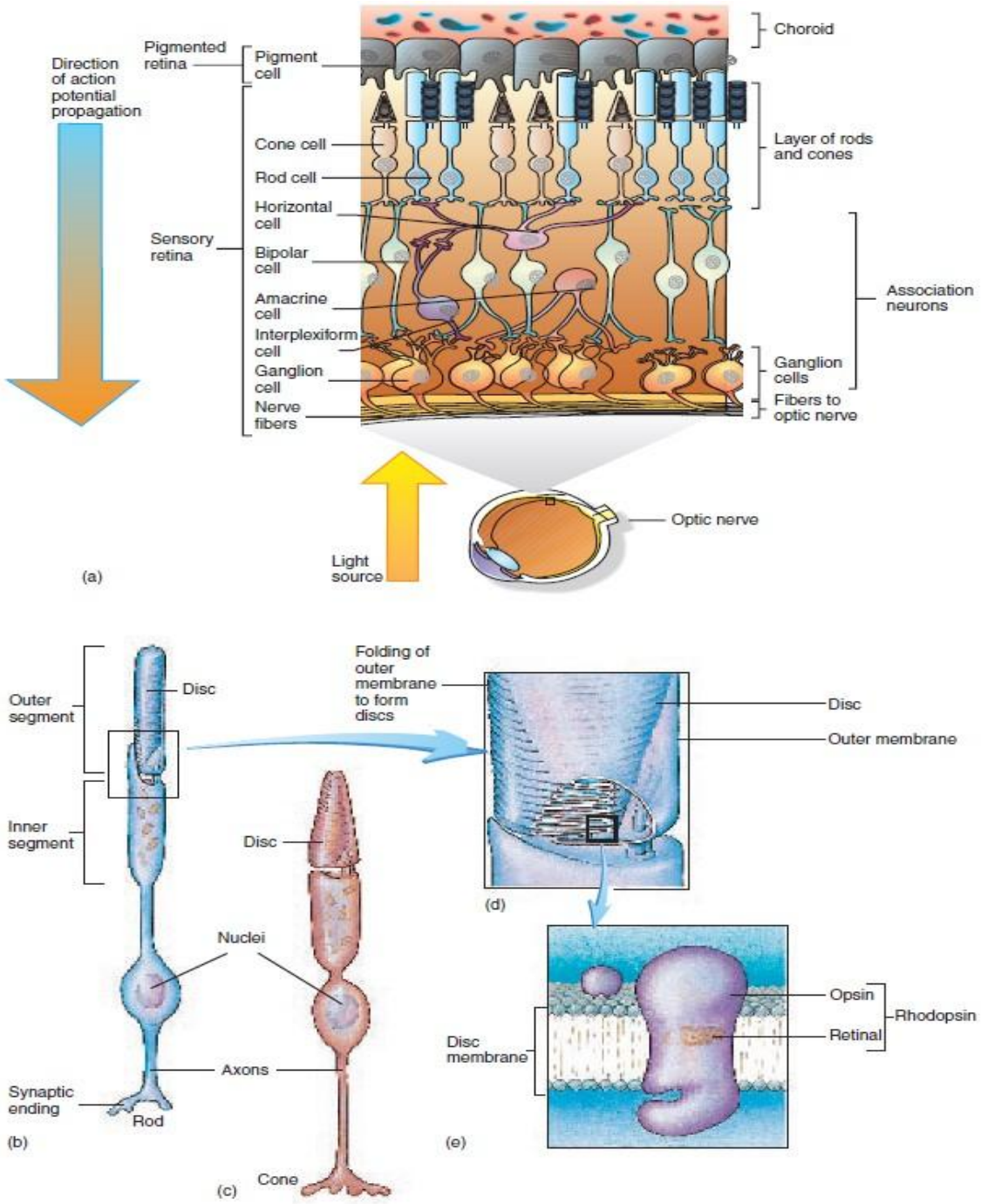
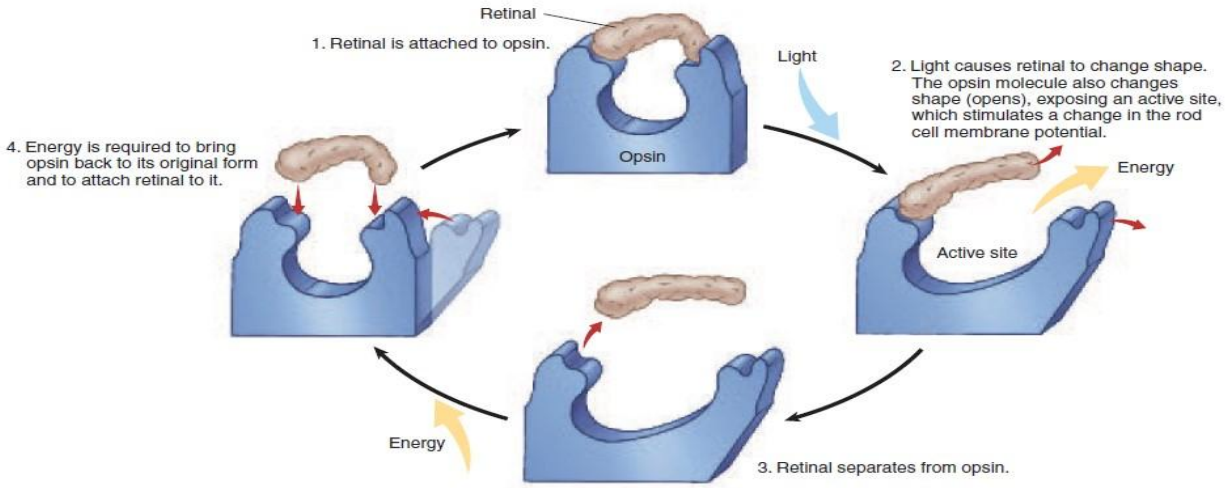


Fig. 27. The Retina.

(*a*) Enlarged section of the retina showing its structure. (*b*) Greatly enlarged view of a rod cell. (*c*) Greatly enlarged view of a cone cell. (*d*) Enlargement of a part of the rod cell to show the discs. (*e*) Enlargement of a disc membrane showing the position of rhodopsin.

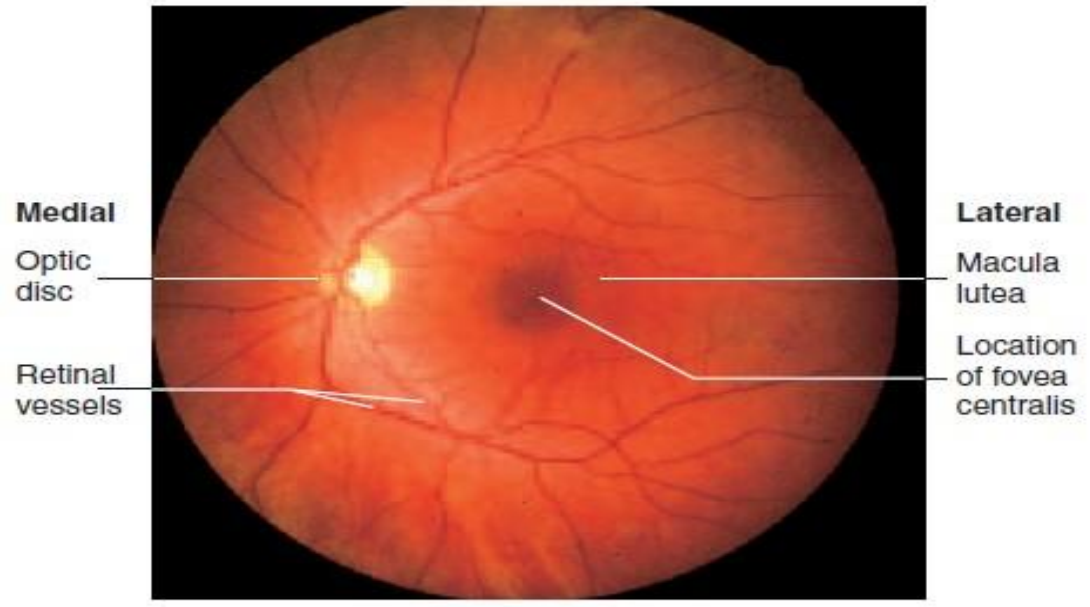
The rod and cone cells synapse with bipolar cells of the sensory retina (see figure 27). These and the horizontal cells of the retina modify the output of the rod and cone cells. For example, this modification is involved in the sharpening of borders between objects of contrasting brightness. The bipolar and horizontal cells synapse with ganglion cells, whose axons converge at the posterior of the eye to form the optic nerve When the posterior region of the retina is examined with an ophthalmoscope, two major features can be observed: the macula lutea and the optic disc (figure 29). Near the center of the posterior retina is a small yellow spot called the macula lutea. In the center of the macula lutea is a small pit, the fovea centralis. The fovea centralis is the part of the retina where light is normally focused when the eye is looking directly at an object. The photoreceptor cells are more densely packed in this part of the retina than in any other. When images are focused onto the retina, the fovea centralis is able to detect those images most clearly because of this higher concentration of photoreceptors. The fovea centralis is also the part of the retina with the highest concentration of cones. Just medial to the macula lutea is a white spot, the optic disc, through which a number of fairly large blood vessels enter the eye and spread over the surface of the retina. This is also the spot at which axons from the retina meet, pass through the outer two tunics, and exit the eye as the optic nerve. The optic disc contains no photoreceptor cells and does not respond to light; it is therefore called the blind spot of the eye. A small image projected onto the blind spot cannot be seen. You can demonstrate this by drawing two small dots about 2 inches apart on a card, closing one eye, and holding the card about 1 foot in front of your open eye. As you move the card toward you, focusing on one dot, the other dot seems to disappear.

Fig. 28.



Rhodopsin Cycle

Fig. 29.



Ophthalmoscopic View of the Retina

This view shows the posterior wall of the left eye as seen through the pupil. Notice the vessels entering the eye through the optic disc. The macula lutea, with the fovea centralis in the center, is located lateral to the optic disc.

The main causes of visual impairment.

Causes of visual impairment can be congenital or acquired.

Congenital causes of poor vision are associated with improper fetal development, complications during pregnancy and childbirth.
Acquired vision problems are those acquired during life. Most of these pathologies occur when age-related changes in the visual apparatus begin (at 40-45 years).
It is impossible to completely avoid the causes that cause vision impairment. However, there are a number of preventive measures that will partially help to avoid vision problems:

1. Proper organization of the workplace.
2. Complete diet. You should regularly consume products with substances useful for the eyes (blueberries, citrus fruits, eggs, nuts, honey, pumpkin).
3. Take vitamins and minerals to improve vision.
4. Gymnastics for the eyes - do the exercises in the morning and in the evening, and during the working day, rest the eyes every 40 minutes.
5. Regularly visit an ophthalmologist in order to detect visual disturbances in time.

Hearing and Balance

The organs of hearing and balance are divided into three parts: external, middle, and inner ear (figure 30). The external ear is the part extending from the outside of the head to the eardrum. The middle ear is an air-filled chamber medial to the eardrum. The inner ear is a set of fluid-filled chambers medial to the middle ear. The external and middle ears are involved in hearing only, whereas the inner ear functions in both hearing and balance.

The Ear and Its Functions

External Ear

The auricle is the fleshy part of the external ear on the outside of the head. The auricle opens into the external auditory meatus, a passageway that leads to the eardrum. The auricle directs sound waves toward the external auditory meatus. The meatus is lined with hairs and ceruminous glands, which produce cerumen, a modified sebum commonly called earwax. The hairs and cerumen help prevent foreign objects from reaching the delicate eardrum. The tympanic membrane, or eardrum, is a thin membrane that separates the external ear from the middle ear. Sound waves reaching the tympanic membrane through the external auditory meatus cause it to vibrate.

Middle Ear

Medial to the tympanic membrane is the air-filled cavity of the middle ear. Two openings, the oval window and the round window on the medial side of the middle ear, connect the middle ear with the inner ear. The middle ear contains three auditory ossicles : the malleus, incus, and stapes, which transmit vibrations from the tympanic membrane to the oval window. The malleus is attached to the medial surface of the tympanic membrane, the incus connects the malleus to the stapes, and the base of the stapes is seated in the oval window. As the vibrations are transmitted from the malleus to the stapes, the force of the vibrations is amplified about 20-fold. There are two unblocked openings into the middle ear. One opens into the mastoid air cells in the mastoid process of the temporal bone. The other, called the auditory tube, or eustachian tube, opens into the pharynx and enables air pressure to be equalized between the outside air and the middle ear cavity. Unequal pressure between the middle ear and the outside environment can distort the tympanic membrane, dampen its vibrations, and make hearing difficult. Distortion of the tympanic membrane also stimulates pain fibers associated with that structure. That distortion is why, as a person changes altitude, sounds seem muffled and the tympanic membrane may become painful. These symptoms can be relieved by opening the auditory tube, allowing air to enter or exit the middle ear. Swallowing, yawning, chewing, and

holding the nose and mouth shut while gently trying to force air out of the lungs are methods that can be used to open the auditory tube.

Inner Ear

The inner ear consists of interconnecting tunnels and chambers within the temporal bone, called the bony labyrinth. Inside the bony labyrinth is a similarly shaped but smaller set of membranous tunnels and chambers called the membranous labyrinth(fig.31). The membranous labyrinth is filled with a clear fluid called endolymph, and the space between the membranous and bony labyrinth is filled with a fluid called perilymph. The bony labyrinth can be divided into three regions: the cochlea, vestibule, and semicircular canals. The cochlea is involved in hearing, and the vestibule and semicircular canals are involved primarily in balance.

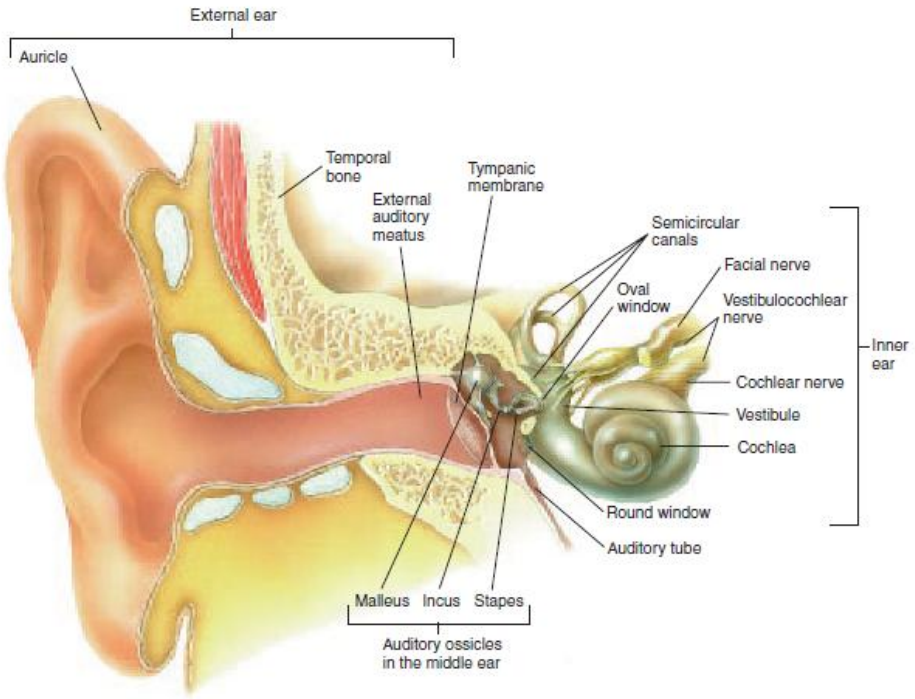


Fig.30. Anatomy of the ear.

Hearing

The cochlea is shaped like a snail shell and contains a bony core shaped like a screw. The threads of this screw are called the spiral lamina. A Y-shaped membranous complex divides the cochlea into three portions. The base of the Y is the spiral lamina. One branch of the Y is the vestibular membrane, and the other branch is the basilar membrane. The space between these membranes is called the cochlear duct. This complex is the membranous labyrinth, and it is filled with endolymph. If the Y is viewed lying on its right side, the space above the Y is called the scala vestibuli, and the space below the Y is called the scala tympani . These two spaces are filled with perilymph. The scala vestibuli extends from the oval window to the apex of the

cochlea, and the scala tympani extends from the apex to the round window. The two scalae are continuous with each other at the apex of the cochlea. Inside the cochlear duct is a specialized structure called the spiral organ, or organ of Corti. Thespiral organ contains specialized sensory cells called hair cells, which have hairlike microvilli on their surfaces. The hair tips are embedded within an acellular gelatinous shelf called the tectorial membrane, which is attached to the spiral lamina.

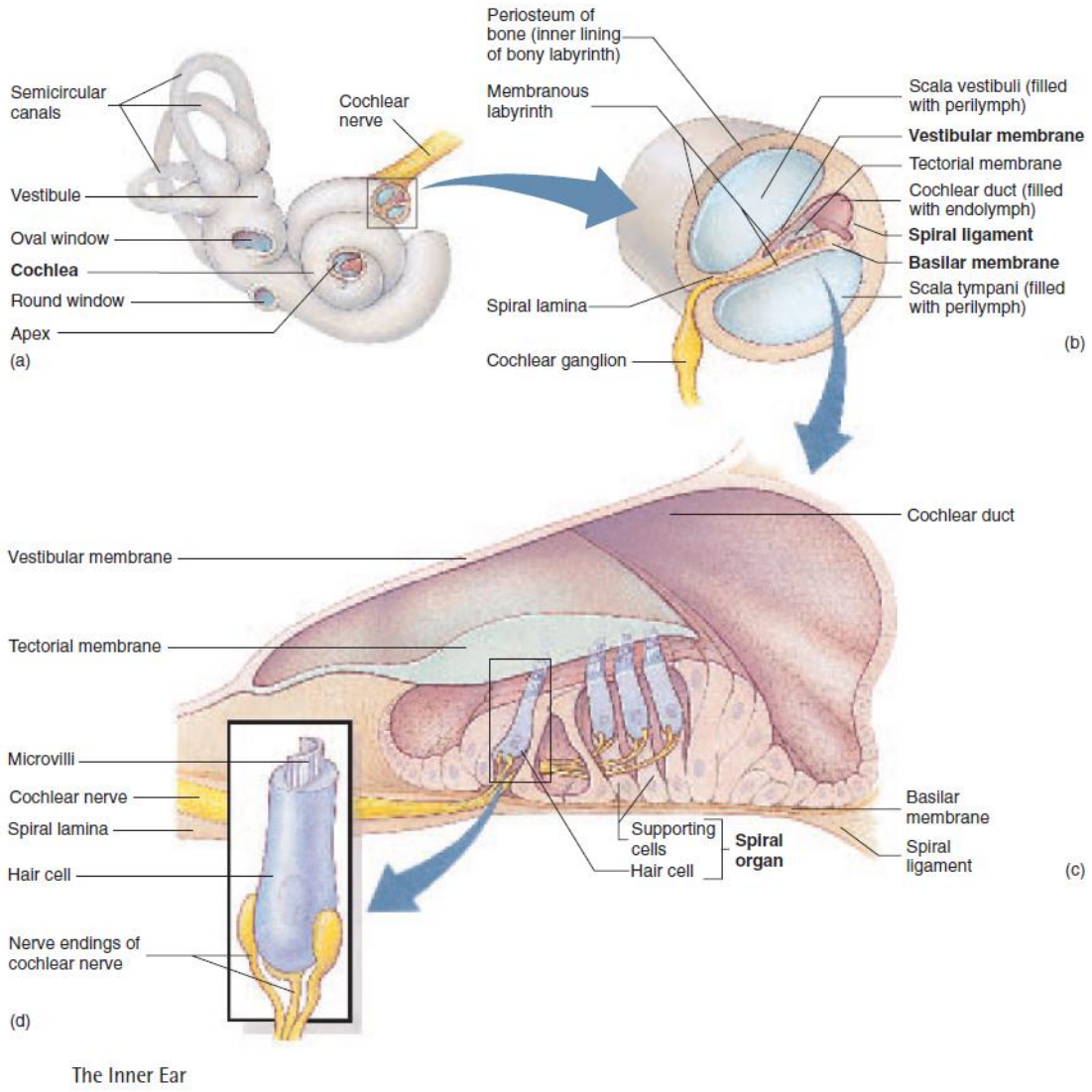


Fig.31. The inner ear

Hair cells have no axons of their own, but each hair cell is associated with terminals of sensory neurons, the cell bodies of which are located within the spiral ganglion. Afferent fibers of the sensory neurons join to form the cochlear nerve. This nerve joins the vestibular nerve to become the vestibule cochlear nerve (cranial nerve VIII), which carries action potentials to the brain. Sound waves are collected by the auricle and are conducted through the external auditory meatus toward the tympanic membrane. Sound waves strike the tympanic membrane and cause it to vibrate. This

vibration causes vibration of the three ossicles of the middle ear, and by this mechanical linkage the force of vibration is amplified and transferred to the oval window.

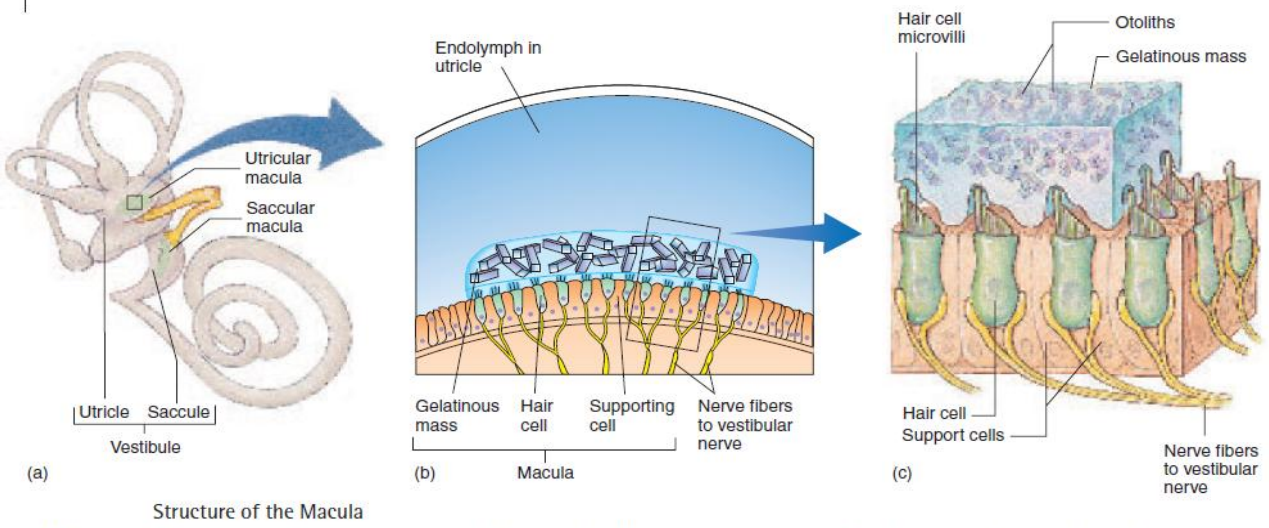
Vibrations of the base of the stapes, seated in the oval window, produce waves in the perilymph of the cochlea. The two scalae can be thought of as a continuous U-shaped tube, with the oval window at one end and the round window at the other. The vibrations of the stapes in the oval window cause movement of the perilymph, which pushes against the membrane covering the round window. This phenomenon is similar to pushing against a rubber diaphragm on one end of a fluid-filled glass tube. If the tube has a rubber diaphragm on each end, the fluid can move.

If one end of the glass tube or of the cochlear tubes were solid, no fluid movement would occur. The waves produced in the perilymph cause displacement of the vestibular membrane. This displacement creates waves in the endolymph, within the cochlear duct, and displacement of the basilar membrane. As the basilar membrane is displaced, the hair cells, seated on the basilar membrane, move with the movements of the membrane. The microvilli of the hair cells are embedded into the tectorial membrane, which is a rigid shelf that does not move. Because one end of the microvilli move with the hair cells and their other ends are embedded into the nonmoving tectorial membrane, the microvilli bend. The bending of the microvilli causes stimulation of the hair cells, which induces action potentials in the cochlear nerves. The basilar membrane is not uniform throughout its length. The membrane is narrower and denser near the oval window and wider and less dense near the tip of the cochlea. The various regions of the membrane can be compared to the strings in a piano (i.e., some are short and thick, and others are longer and thinner). As a result of this organization, sounds with higher pitches cause the basilar membrane nearer the oval window to maximally distort, whereas sounds with lower pitches cause the basilar membrane nearer theapex of the cochlea to distort maximally. Different hair cells are stimulated in each case, and, because of the differences in which hair cells are maximally stimulated, a person is able to detect variations in pitch. Sound volume is a function of sound wave amplitude, which causes the basilar membrane to distort more intensely and the hair cells to be stimulated more strongly. The cochlear nerves, whose cell bodies are located in the cochlear ganglion, send axons to the cochlear nucleus in the brainstem. Neurons in the cochlear nucleus project to other areas of the brainstem and to the inferior colliculus in the midbrain. From the inferior colliculus, fibers project to the thalamus, and from there to the auditory cortex of the cerebrum.

Equilibrium

The sense of equilibrium, or balance, has two components: static equilibrium and kinetic equilibrium. Static equilibrium is associated with the vestibule and is involved in evaluating the position of the head relative to gravity. Kinetic equilibrium is

associated with the semicircular canals and is involved in evaluating the change in rate of head movements. The vestibule can be divided into two chambers: the utricle and the saccule(figure 31). Each chamber contains specialized patches of epithelium called the maculae, which are surrounded by endolymph (figure 31). The maculae, like the spiral organ, contain hair cells. The tips of the microvilli of these cells are embedded in a gelatinous mass weighted by otoliths, particles composed of protein and calcium carbonate (figure 32). The mass moves in response to gravity, bending the hair cell microvilli and initiating action potentials in the associated neurons. The action potentials from these neurons are relayed by way of the vestibulocochlear nerve (cranial nerve VIII) to the brain, where they are interpreted as a change in position of the head. For example, when a person bends over, the maculae are displaced by gravity, and the resultant action potentials provide information to the brain concerning the position of the head relative to gravity (figure 31). Three semicircular canals are involved in kinetic equilibrium and placed at nearly right angles to one another. The placement of the semicircular canals enables a person to detect movements in essentially any direction. The base of each semicircular canal is expanded into an ampulla . Within each ampulla the epithelium is specialized to form a crista ampullaris (figure 31). Each crista consists of a ridge of epithelium with a curved gelatinous mass, the cupula , suspended over the crest (figure 31). The cupula is structurally and functionally very similar to the maculae, except that no otoliths occur in the cupula. The hairlike processes of the crista hair cells (figure 31) are embedded in the cupula. The cupula is a float that is displaced by endolymph movement within the semicircular canals (figure 31). As the head begins to move in a given direction, the endolymph tends to remain stationary. This difference causes the cupula to be displaced in a directionopposite to that of the movement of the head. As movement continues, the fluid “catches up.” When movement ofthe head stops, the fluid tends to continue to move, displacing the cupula in the direction of the movement. Movement of the cupula causes the hair cell microvilli to bend, which initiates depolarization in the hair cells. This depolarization initiates action potentials in the vestibular nerves, which join the cochlear nerves and relay the information to the brain.



Structure of the Macula

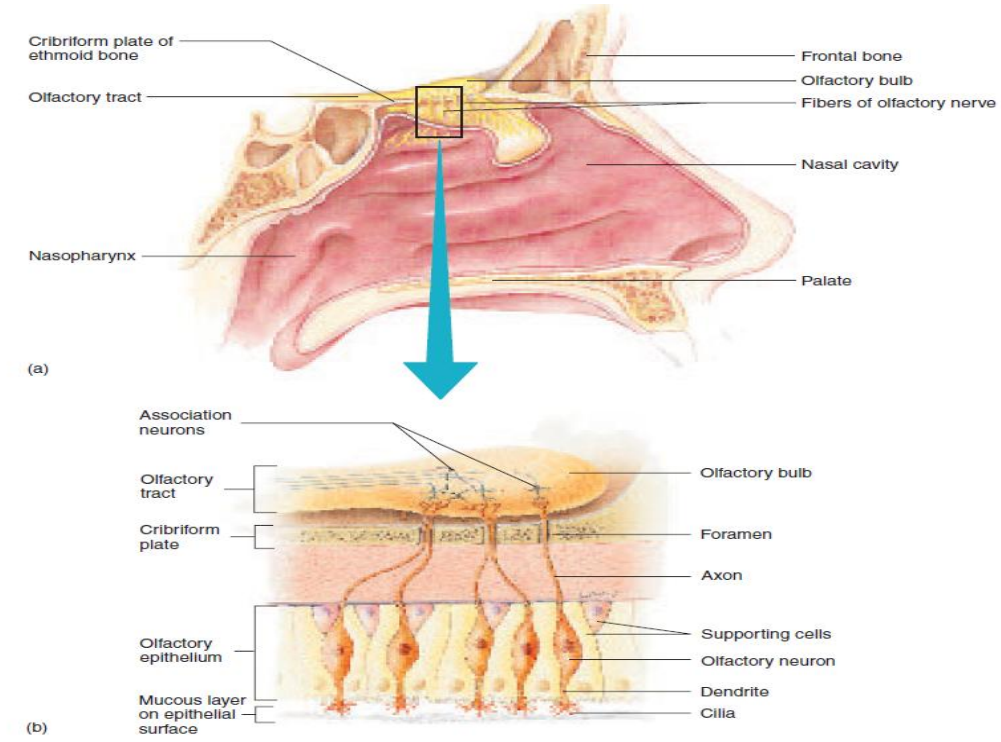
(*a*) The location of the utricular and saccular maculae within the vestibule. (*b*) Enlarged view of a section through the utricular macula showing the otoliths. (*c*) Enlargement of that portion of part (*b*) indicated by the box. The relation between the hair cell microvilli and the gelatinous mass can be seen.

Fig. 32. The Macula.

Olfaction

The sense of smell, called olfaction, occurs in response to airborne molecules called odors that enter the nasal cavity (figure 33). Olfactory neurons are bipolar neurons within the olfactory epithelium lining the superior part of the nasal cavity. The dendrites of the olfactory neurons extend to the epithelial surface of the nasal cavity, and their ends are modified into bulbous enlargements. These enlargements possess long specialized cilia, which lie in a thin mucous film on the epithelial surface. Airborne molecules become dissolved in the mucus on the surface of the epithelium and bind to receptor molecules on the membranes of the specialized cilia. The moleculesmust first be dissolved in fluid in order to reach the olfactory receptors. The exact nature and site of the interaction is not fully understood, but in some way the combination of airborne molecules with receptors causes the olfactory neurons to depolarize. The threshold for the detection of odors is very low, so very few molecules bound to an olfactory neuron can initiate an action potential. Once an odor molecule has become bound to a receptor, however, that receptor does not respond to another odor molecule for some time. It is unlikely that there is a different type of receptor for each of the thousands of detectable odors. It has been proposed that a wide variety of detectable odors are actually combinations of a smaller number of (perhaps as few as seven) primary odors interacting with a limited number of receptor types. Axons from olfactory neurons form the olfactory nerves (cranial nerve I), which pass through foramina of the cribriform plate and enter the olfactory bulb. There they synapse with association neurons that relay action potentials to the brain through the olfactory tracts. Each olfactory tract terminates in an area of the brain called the olfactory cortex, located within the temporal and frontal lobes. Within the olfactory bulb and olfactory cortex, feedback loops occur that tend to inhibit

transmission of additional action potentials stimulated by a prolonged exposure to the same odor. This feedback, plus the temporary decreased sensitivity at the level of the receptors, results in adaptation to a given odor. For example, if you enter a room that has an odor, you are aware of the odor, but you adapt to the odor and cannot smell it as well after the first few minutes. If you leave the room for some time and then reenter the room, the odor again seems more intense.



Nasal Cavity and Olfactory Structures

(*a*) Sagittal view of the lateral wall of the nasal cavity, showing the location of the olfactory bulb and nerve. (*b*) Olfactory bulb and olfactory epithelium enlarged to show the olfactory neurons.

Fig.33

Taste

The sensory structures that detect taste stimuli are the taste buds (figure 34). Taste buds are oval structures located on the surface of certain papillae, which are enlargements on the surface of the tongue. Taste buds are also distributed throughout other areas of the mouth and pharynx, such as on the palate, root of the tongue, and epiglottis. Each taste bud consists of two types of cells. Specialized epithelial cells form the exterior supporting capsule of the taste bud, and the interior of each bud consists of about 40 taste cells. Each taste cell contains hairlike processes, called taste hairs, that extend into a tiny opening in the epithelium, called a taste pore. Dissolved substances bind to receptors on the hairs and initiate action potentials that are carried by afferent neurons to the parietal lobe of the cerebral cortex.Taste sensations from the anterior two-thirds of the tongue are carried by the facial nerve (cranial nerve VII). Taste sensations from the posterior third of the tongue are carried by the glossopharyngeal nerve (cranial nerve IX). In addition, the vagus nerve (cranial nerve X) carries some taste sensations from the root of the tongue. Taste sensations can be

divided into four basic types: sour, salty, bitter, and sweet. Even though there are only four primary taste sensations, a fairly large number of different tastes can be perceived, presumably by combining the four basic taste sensations. Many taste sensations, however, are strongly influenced by olfactory sensations. This influence can be demonstrated by comparing the taste of some food before and after pinching your nose. It is easy to detect that the sense of taste is reduced while the nose is pinched. Although all taste buds are able to detect all four of the basic taste sensations, each taste bud is usually most sensitive to one class of taste stimuli. The stimulus type to which eachtaste bud responds most strongly is related to its position on the tongue. Taste buds at the tip of the tongue react more strongly to sweet and salty taste stimuli, taste buds at the back of the tongue react more strongly to bitter taste stimuli, and taste buds on the side of the tongue react most strongly to sour taste stimuli.

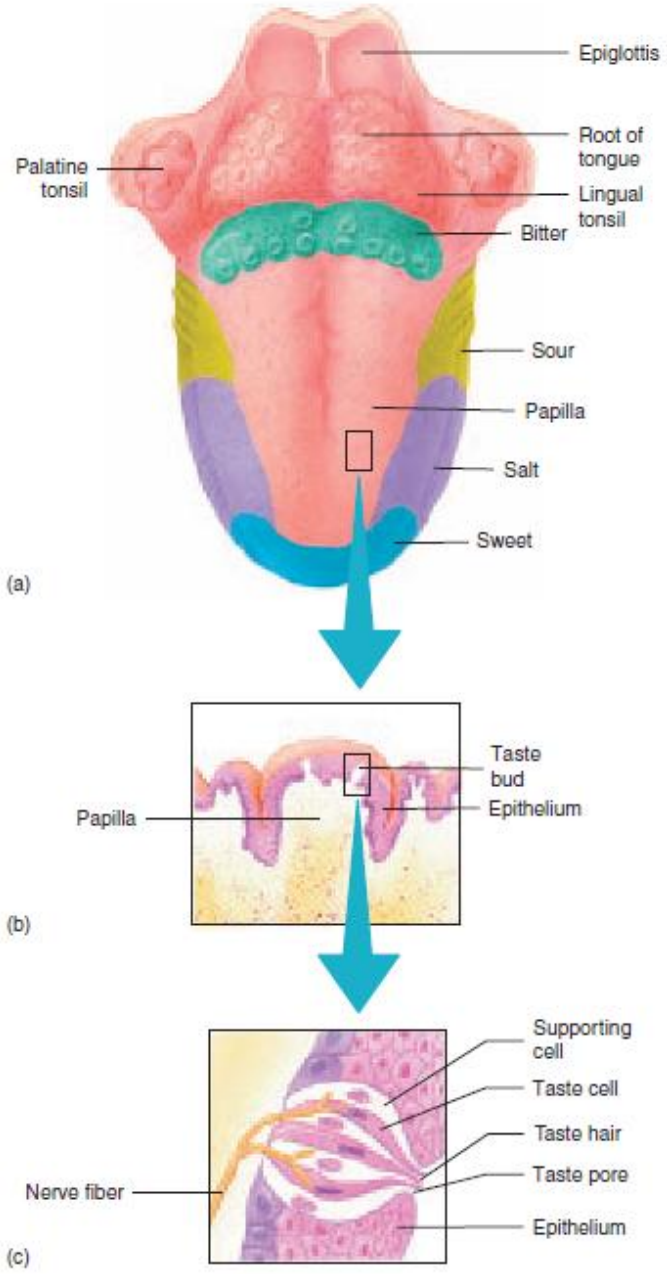
Loss of smell and taste:

The inability to detect certain odors, such as gas or smoke, may be dangerous, and several systemic and intracranial disorders should be excluded before dismissing symptoms as harmless. Whether brain stem disease (involvement of the nucleus solitarius) can cause disorders of smell and taste is uncertain, because other neurologic manifestations usually take precedence.

Anosmia (complete loss of the sense of smell) is probably the most common abnormality. Hyperosmia (increased sensitivity to odors) usually reflects a neurotic or histrionic personality but can occur intermittently with seizure disorders. **Dysosmia** (disagreeable or distorted sense of smell) may occur with infection of the nasal sinuses, partial damage to the olfactory bulbs, or mental depression. Some cases, accompanied by a disagreeable taste, result from poor dental hygiene. Uncinate epilepsy can produce brief, vivid, unpleasant olfactory hallucinations. **Hyposmia** (partial loss of smell) and hypogeusia (diminished sense of taste) can follow acute influenza, usually temporarily. Sudden loss of smell also may be an early symptom of COVID-19.

Although abnormal taste sensations may be due to mental disorders, local causes should always be sought. Glossopharyngeal and facial nerve integrity can be determined by testing taste on both sides of the dorsum of the tongue with sugar, salt, vinegar (acid), and quinine (bitter).

Drying of the oral mucosa caused by heavy smoking, Sjögren syndrome, radiation therapy of the head and neck, or desquamation of the tongue can impair taste, and various drugs (eg, those with anticholinergic properties and vincristine) alter taste. In all instances, the gustatory receptors are diffusely involved. When limited to one side of the tongue (eg, in Bell palsy), ageusia (loss of the sense of taste) is rarely noticed. Sudden loss of taste may be an early symptom of coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).



The Tongue

(*a*) Dorsal surface of the tongue and regions of the tongue sensitive to various tastes. (*b*) Section through a papilla showing the location of taste buds. (*c*) Enlarged view of a section through a taste bud.

Fig. 34.

Lesson 5. Anatomical and physiological aspects of the autonomic nervous system.

Autonomic Nervous System

Somatic motor neuron cell bodies are located in the CNS, and their axons extend from there to skeletal muscles. Axons from autonomic motor neurons, on the other hand, do not extend all the way from the CNS to target tissues. Instead, two neurons in series extend from the CNS to the target organs. The first is called the preganglionic neuron, and the second is called the postganglionic neuron. The neurons are so named because preganglionic neurons synapse with postganglionic neurons in autonomic ganglia outside the CNS. Autonomic motor neurons innervate smooth muscle, cardiac muscle, and glands. Autonomic functions are controlled unconsciously. The autonomic nervous system is composed of sympathetic and parasympathetic divisions. Increased activity in sympathetic neurons generally prepares the individual for physical activity, whereas parasympathetic stimulation generally activates "vegetative" functions, such as digestion, normally associated with the body at rest.

Most organs that receive autonomic motor neurons are innervated by both the parasympathetic and sympathetic divisions. Sweat glands and blood vessels, however, are innervated by sympathetic neurons almost exclusively, whereas the smooth muscles associated with the lens of the eye are innervated primarily by parasympathetic neurons. In most cases, the influence of the two autonomic divisions is opposite on structures that receive dual innervation. For example, sympathetic stimulation of the heart causes an increase in heart rate, whereas parasympathetic stimulation causes a decrease in heart rate.

Sympathetic Division

The sympathetic division of the autonomic nervous system prepares a person for physical activity by increasing heart rate and blood pressure, by dilating respiratory passageways, and by stimulating perspiration. The sympathetic division also stimulates the release of glucose from the liver for energy. At the same time, it inhibits digestive activities. The sympathetic division is sometimes referred to as the "fight-or-flight" system because, as it prepares the body for physical activity, it prepares the person to either stand and face a threat or leave as quickly as possible.

Cell bodies of sympathetic preganglionic neurons are in the lateral horn of the spinal cord gray matter (see figure 35) between the first thoracic (T1) and the second lumbar (L2) segments. The axons of the preganglionic neurons exit through ventral roots and project to either sympathetic chain ganglia or collateral ganglia. The sympathetic chain ganglia are connected to one another and form a chain along both sides of the spinal cord. Collateral ganglia are located nearer target organs and consist of the celiac, superior mesenteric, and inferior mesenteric ganglia. Some preganglionic

neurons synapse in the sympathetic chain ganglia, but others pass through these ganglia and synapse in the collateral ganglia. Postganglionic neurons arise in the sympathetic chain ganglia or in the collateral ganglia and project to target tissues.

Parasympathetic Division

The parasympathetic division of the autonomic nervous system stimulates vegetative activities, such as digestion, defecation, and urination. At the same time, it slows the heart rate and respiration. It also causes the pupil of the eye to constrict and the lens to thicken. Preganglionic cell bodies of the parasympathetic division are located either within brainstem nuclei of the oculomotor nerve (III), facial nerve (VII), glossopharyngeal nerve (IX), or vagus nerve (X), or within the lateral part of the central gray matter of the spinal cord in the regions giving rise to spinal nerves S2 through S4.

Axons of the preganglionic neurons extend through spinal nerves or cranial nerves to terminal ganglia located either near target organs in the head or embedded in the walls of target organs in the thorax, abdomen, and pelvis. The axons of the postganglionic neurons extend a relatively short distance from the terminal ganglia to the target organ.

Autonomic Neurotransmitter Substances

All preganglionic neurons of both the sympathetic and parasympathetic divisions and all postganglionic neurons of the parasympathetic division secrete acetylcholine as a neurotransmitter. Most postganglionic neurons of the sympathetic division secrete norepinephrine, but some secrete acetylcholine. Many body functions can be stimulated or inhibited by drugs that either mimic these neurotransmitters or prevent the neurotransmitters from activating their target tissues.

The ANS exerts its control through chemical messengers known as neurotransmitters. The neurotransmitters involved in the ANS are acetylcholine, norepinephrine, and epinephrine. Preganglionic neurons of the sympathetic and parasympathetic divisions and postganglionic neurons of the parasympathetic nervous system utilize acetylcholine (ACh). Postganglionic neurons of the sympathetic nervous system use norepinephrine and epinephrine.

ACh is released by all preganglionic neurons, regardless of their involvement in the parasympathetic or sympathetic nervous system. ACh binds to nicotinic acetylcholine receptors, a ligand-gated ion channel, on postganglionic neurons. Once ACh binds, the ion channel is open to allow the flow of ions, specifically sodium and calcium, which induces an excitatory postsynaptic potential, and results in the propagation of a neuronal signal down the axon. ACh also gets released by postganglionic neurons of the parasympathetic nervous system. Here, ACh binds to muscarinic acetylcholine receptors on the target site, which are G-protein-coupled receptors. These act to

perform the functions of the parasympathetic nervous system listed above. It is important to note that ACh also gets released by postganglionic neurons of sweat glands, and binds to and activates muscarinic receptors. This activity is an exception to the sympathetic nervous system, which normally involves norepinephrine as its chemical messenger released from postganglionic neurons.

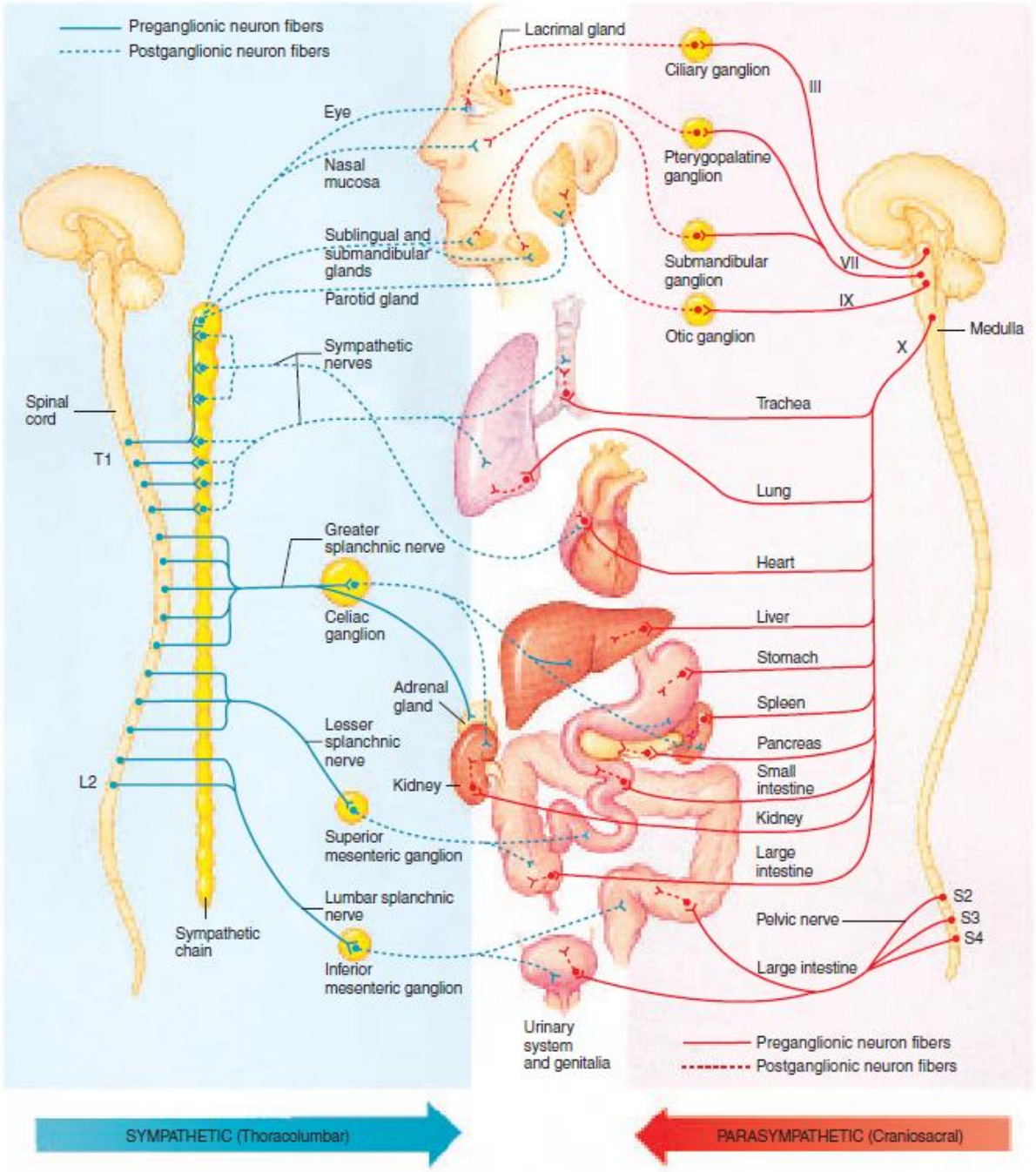
Norepinephrine gets released by postganglionic neurons of the sympathetic nervous system, which binds to and activates adrenergic receptors. These receptors further divide into alpha11 (G coupled receptor), alpha-2 (G coupled receptor), beta-1 (G coupled receptor), and beta-2 and beta-3 (G and G coupled receptor).

Epinephrine is released into systemic circulation by chromaffin cells within the adrenal gland, specifically the adrenal medulla. The sympathetic nervous system splanchnic nerves synapse on chromaffin cells and stimulate them to release epinephrine using the signal messenger acetylcholine. This feature of the adrenal gland is an important component of the sympathetic nervous system as it allows systemic effects to occur on major organ systems.

The metasympathetic nervous system belongs to the third division of the ANS and is a basic, independent and independent integrative system. All links of its reflex arc are localized only in the intramural ganglia of the walls of hollow organs, which provide local regulation of functions thanks to local reflexes. The number of neurons in the metasympathetic nervous system is 108, almost as many as in the spinal cord.

The metasympathetic nervous system has many characteristics that distinguish it from other parts of the autonomic nervous system:

1. Innervates only internal organs that have their own spontaneous activity, that is, automaticity. In the sphere of its innervation are smooth muscles, absorbent and secreting epithelium, local blood circulation, local endocrine elements.
2. Along with the common visceral pathways, it has its own sensory circuit.
3. The metasympathetic nervous system has its own mediator chain.
4. Organs with damaged or disabled metasympathetic pathways, with the help of specific ganglioblockers, lose their inherent ability to coordinate rhythmic effector functions.
5. It is not in antagonistic relations with other parts of the nervous system, but, being a truly basic innervation, it has much greater independence from the central nervous system than the sympathetic and parasympathetic nervous systems.
6. It has a direct and feedback connection with the sympathetic and parasympathetic systems, and does not have direct synaptic contacts with the efferent part of the somatic reflex arc.



Innervation of the Major Target Organs by the Autonomic Nervous System

Preganglionic fibers are indicated by solid lines, and postganglionic fibers are indicated by broken lines. The parasympathetic fibers are red, and the sympathetic fibers are blue.

Fig. 35.

Table 1. Physiological effects of the sympathetic and parasympathetic nervous systems

Organ/system	Sympathetic effects	Parasympathetic effects
Cell metabolism	Increases metabolic rate, stimulates fat breakdown and increases blood sugar levels	No effect
Blood vessels	Constrict blood vessels in viscera and skin. Dilate blood vessels in the heart and skeletal muscle	No effect
Eye	Dilates pupils	Constricts the pupils
Heart	Increases rate and force of contraction	Decreases heart rate
Lungs	Dilate the bronchioles	Constrict the bronchioles
Kidneys	Decrease urine output	No effect
Liver	Causes the release of glucose	No effect
Digestive system	Decreases peristalsis and constricts digestive system sphincters	Increases peristalsis, dilates digestive system sphincters
Adrenal medulla	Stimulates cells to secrete epinephrine and norepinephrine	No effect
Lacrimal glands	Inhibit production of tears	Increase production of tears
Salivary glands	Inhibit saliva production	Increase saliva production
Sweat glands	Stimulated to produce perspiration	No effect

(Source: adapted McErlean and Migliozzi, 2017).

Fig. 36.

Diseases of the autonomic nervous system are caused by damage or irritation of any of its departments: central or peripheral.

Vegetative dysfunction (vegetative dystonia) can be considered as a violation of the normal functioning of the autonomic nervous system. It is based on a congenital defect of hypothalamic regulation, which, in turn, is directly dependent on external stress factors, injuries, infections. In addition, hypothalamic dyscoordination often occurs against the background of hormonal imbalance in the pubertal and climacteric periods, during pregnancy, it can be a consequence of physical exertion, craniocerebral injuries, neuroinfections, and cerebrovascular pathology.

Vegetative dysfunction is manifested by a spectrum of clinical manifestations that characterize a violation of the regulatory activity of the nervous system. A person with autonomic dysfunction is characterized by weather lability (dependence on fluctuations in atmospheric pressure, humidity, and air temperature). Such people do not tolerate physical, emotional and mental stress.

Symptoms of autonomic dysfunction:

- general weakness;
- increased fatigue;
- poor reaction of the body to weather changes;
- decrease in working capacity;
- dizziness;
- interruptions in the work of the heart;
- feeling of lack of air;
- pains in the heart;
- stomach pains;
- constipation, flatulence;
- sleep disturbance, insomnia;
- emotional disorders (panic attacks, anxiety, fear).

A panic attack is a paroxysmal vegetative crisis characterized by symptoms of increased anxiety, a feeling of fear, death, lack of air, difficulty breathing, dizziness, chills, increased sweating, nausea, preconscious state, accelerated urination. This condition is associated with the sudden release of a large amount of biologically active substances (adrenaline, dopamine, etc.) into the blood, under the influence of which all the above symptoms occur. This leads to an increase in heart rate, intensive breathing, increased sweating. The condition is accompanied by significant psychological discomfort and unpleasant experiences.
Most often, the panic attacks develop in people with high intelligence, developed willpower, prone to introspection and self-control, with a heightened sense of responsibility, with psychological trauma suffered in childhood.

A combination of vegetative-vascular, neuroendocrine, metabolic and trophic disorders caused by damage to the hypothalamus is called hypothalamic syndrome.
Causes of hypothalamic syndrome:

- acute and chronic neuroinfection;
- brain injury;
- acute and chronic intoxication;
- brain tumors;
- insufficiency of cerebral circulation;
- mental injuries;
- endocrine disorders;
- chronic diseases of internal organs.

Diseases of the autonomic nervous system in most cases are chronic with periodic attacks. Treatment of such disorders is always long and complex.

Lesson 6. Anatomical and physiological aspects of the peripheral nervous system. Cranial nerves.

The peripheral nervous system is the part of the nervous system that is outside the brain and spinal cord and consists of cranial, spinal nerves and nerve plexuses. Its main purpose is to ensure the arrival of impulses from the central nervous system (CNS) to the working organs - muscles and vice versa.

The peripheral nervous system, unlike the central nervous system, does not have such protection, so it is at risk of mechanical damage and negative effects of toxins. The causes of damage to the peripheral nervous system can be infectious diseases, vitamin deficiency, intoxication, injuries, circulatory disorders, etc.
Diseases of the peripheral nervous system (neuritis, neuropathy, neuralgia) can have different localization, causes and manifestations.

These ailments cause sensitivity disorders (numbness, burning, etc.), pain, muscle weakness. Without timely treatment of diseases of the peripheral nervous system, movement restrictions, coordination disorders, instability when walking, and a change in quality of life may occur.

Methods of diagnosing diseases of the peripheral nervous system are aimed at identifying and correcting the underlying disease (for example, peripheral nerve damage in diabetes, alcoholism, etc.).
Treatment of diseases of the peripheral nervous system is complex and may consist of:

drug therapy (aimed at correcting the underlying disease, relieving pain and restoring nerve function);
non-drug therapy (physiotherapeutic procedures);
surgical intervention (in the case of a long-term persistent neurological defect and the ineffectiveness of conservative therapy, in acute conditions and the presence of absolute indications for the surgical treatment of diseases of the peripheral nervous system).
Treatment of diseases of the peripheral nervous system, as well as therapy of diseases of the central nervous system, must be carried out immediately.

Any damage to the nerves and their branches, including minor ones, has a significant impact on the motor and sensory function of a certain point or on the entire area.

After damage, nerves and their branches can restore their function - this is possible with minor damage, in other cases, neurosurgical intervention aimed at comprehensive restoration of function is necessary.

Damage to peripheral nerves in any of their localization (place) is accompanied by a number of symptomatic manifestations, which are divided into groups, depending on the nature of the damage: vegetative, sensory, motor and trophic.

Vegetative (sectoral and vasomotor)
They are accompanied by anhidrosis (disruption of sweating) of the skin, redness of the skin appears in the area of damage and local temperature increases. After 2-3 weeks, the previously reddened area takes on a pale appearance, and the elevated temperature decreases;

Sensory (sensitivity)
They are divided into two main categories: withdrawal symptoms (anesthesia/hypesthesia) and pain symptoms (paresthesia and hyperpathy). As a rule, the symptoms are combined, but with partial damage to the nerve trunk, they are accompanied by paresthesias and pain. Soreness can increase when pressing on the nerve trunk below the injured area.

Motor (motor)
They appear immediately after an injury, are accompanied by muscle paresis - this eventually leads to muscle atrophy. With severe damage to the nerves of the limbs, the patient loses motor function (he cannot move his arms or legs);

Trophic (exhaustion)
Accompanied by thinning and decreased sweating, increased vulnerability of the skin. A change in the color of the nails (clouding) is possible, and in severe cases, osteoporosis may develop.

Cranial nerves.

Cranial nerves, cranial nerves - nerves that begin directly in the brain. All cranial nerves, except the vagus, innervate the head and neck. The vagus nerve also innervates the organs of the thoracic and abdominal cavities. When cranial nerves are damaged, the functions they provide deteriorate or disappear.

Pathsways:

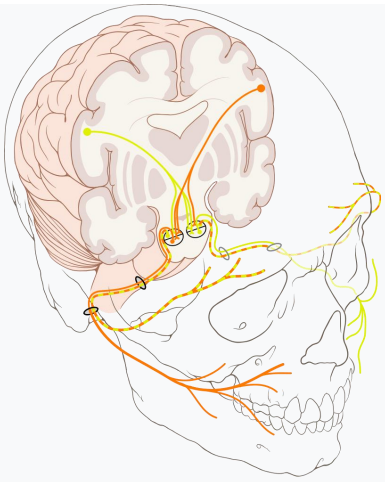


Fig.37.

Cortical-nuclear (cortical-bulbar) path on the example of the facial nerve.
The general scheme of the structure of pathways for cranial nerves is as follows:
for sensory nerves (or mixed nerves containing sensory fibers):

The first neuron is located in the sensitive node (except for the proprioceptive fibers of the trigeminal nerve, which go directly to the CNS);
The second neuron is located in the brain stem;
The third neuron is located in the anterior nucleus of the anteroparietal group of the thalamus.
Neurons in the thalamus mainly send their axons to the central gyrus of the hindbrain.

For the somatomotor component (the name of the path is cortico-nuclear:
the first neuron is located in the motor areas of the cerebral cortex;
the second neuron is a neuron of one of the motor nuclei.

The visceromotor component is characterized by the following path:
the first neuron is a neuron of the hypothalamus or another higher autonomic center;
the first neuron is a neuron of the autonomic nucleus of the brainstem;
the second neuron is a neuron of the vegetative node.

Nuclei of cranial nerves are a collection of neurons that are compactly located among the white matter in the central nervous system. Each such structure performs certain functions, that is, there are motor nuclei (consisting of motor neurons that innervate muscles) and sensitive nuclei (mainly the second neurons of the sensitive nerve pathway). Vegetative nuclei (parasympathetic nuclei in the context of cranial nerves) are often listed separately, but they are also motor (visceromotor), which cause contraction of smooth muscles or the secretion of glands, or sensitive (viscerosensory), which ensure the sensitivity of internal organs. With the exception of the optic, olfactory, and terminal nerves, each nerve has one or more nuclei.
The fibers of the cranial nerves can direct impulses both in the direction of the CNS (afferent, or sensitive fibers) and in the direction from the CNS to the periphery

(efferent, or motor fibers). Accordingly, innervation by a nerve can be either sensitive, or motor, or mixed, if the nerve consists of fibers of both types. Not all fibers of each nerve have separate nuclei. For example, VII, IX and X pairs of cranial nerves carry sensitive taste fibers, but they end in one place - in the nucleus of the solitary tract. It is the same with the trigeminal nuclei, to which all superficial and deep sensory information goes, and the double nucleus, which is common to the three nerves.

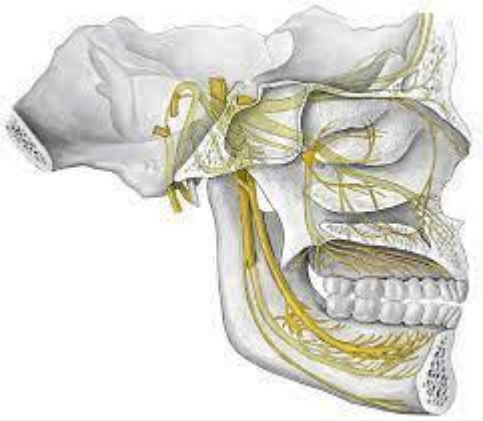


Fig.38. Cranial nerves.

Topically, the motor nuclei are located longitudinally above each other, in the direction from the top of the head, and in a somewhat straight line, as if forming "pillars". The same applies to sensitive cores. These "pillars" are similar in organization to the horns of the spinal cord and indicate the embryonic development of nerve components (the sensory "pillars" are located dorsally and arise from the pterygoid plate of the neural tube, and the motor ones are located ventrally and develop from the plate of the same name. However, it should be remembered that that such an organization is more theoretical, because a number of nuclei are located in unexpected places from the point of view of embryology, which is connected with the migration of some groups of neurons from their original area of origin and formation.

Depending on the innervation, there are seven nuclei that correspond to seven main types of innervation: four sensitive (afferent) and three motor (efferent).

Sensitive innervation can be:

general somatic — formed by trigeminal nuclei and perceives tactile, pain and temperature information from the skin and mucous membranes and proprioceptive information from muscles and ligaments (fibers of V, VII, IX and X pairs of nerves go to these nuclei);

general visceral — formed by the nucleus of the single pathway, receives sensitive information from the organs of the neck, chest cavity, abdomen, as well as the parotid gland (fibers of the IX and X pairs of nerves).

In addition to these two main types of information, which are also characteristic of spinal nerves, two more special sensitive types of innervation are distinguished for cranial nerves, which, accordingly, have their anatomical substrates:

a special visceral part of the core of the lonely path that perceives taste; fibers go from VII, IX and X pairs of nerves;
special somatic - formed by the vestibular and convolutional nuclei, connected to the VIII pair.

Motor innervation can be:
general visceromotor — formed by all parasympathetic visceromotor nuclei (III, VII, IX and X pairs of nerves) and innervates the organs of the head, neck, chest, abdominal cavity (secretion of saliva, slowing of heartbeat, spasm of bronchi, etc.);
general somatomotor — which innervates muscles formed from somites; consists of the nuclei of the cranial nerves of the oculomotor group and the nucleus of the hypoglossal nerve.
special visceromotor (branchiomotor) — provides innervation of the muscles formed from the pharyngeal arches (chewing, facial muscles, throat muscles); the nerves that carry such information are V, VII, IX and X.

Nodes
A node is a collection of compactly located neurons that are outside the central nervous system, in fact it is the same nucleus, only on the periphery.

Cranial nerves are connected with nodes of two types - sensitive and vegetative. The first are present only when the nerve includes fibers of general or special sensitivity, the second — when there are parasympathetic fibers:

Sensitive nodes contain neurons, the processes of which actually form the nerve on the periphery.
The terminal node belongs to the nerve of the same name.
Trigeminal node - contains primary sensory neurons that form the trigeminal nerve.
The convoluted node is connected with the convoluted (hearing) part of the convoluted-parietal nerve.
The perineal node is connected with the perineal (equilibrium) part of the gyrus-parietal nerve.
The geniculate node is connected with the facial (more precisely, the intermediate) nerve.
Upper (jugular) and lower (stony) nodes of the hyoid nerve.
Upper (jugular) and lower (nodular) nodes of the vagus nerve.

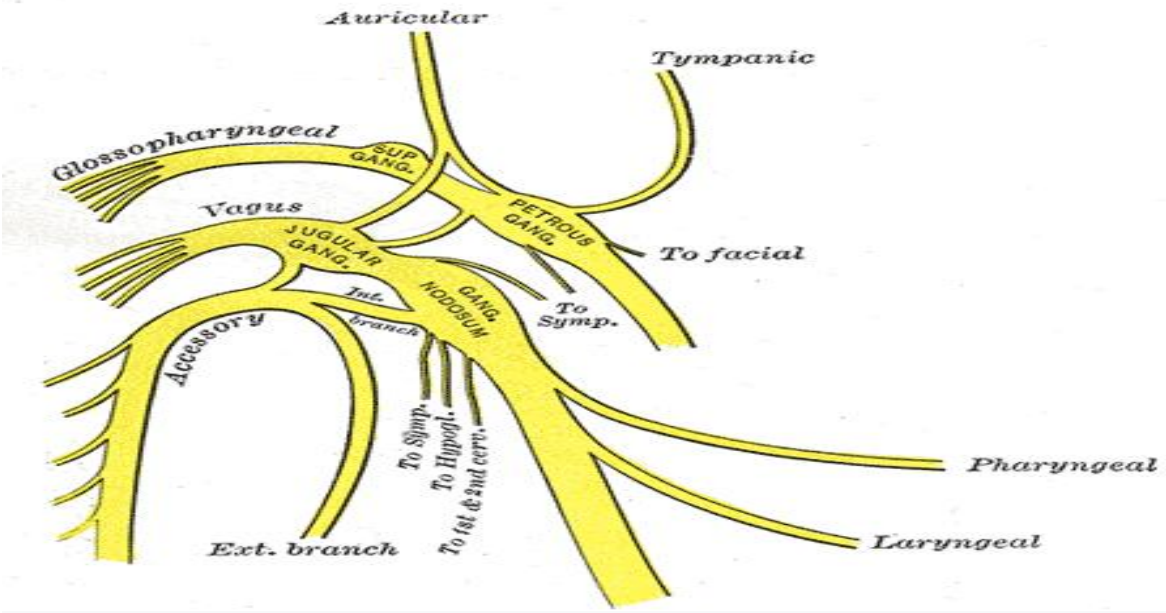


Fig.39. 4 nodes on the example of the IX and X cranial nerves, the jugular and petrous relate to the IX nerve, and the jugular and nodular to the X.

Cranial nerves are connected with five large vegetative nodes of the head. Nerves carry prenodal branches that transmit information to neurons in the node, from which postnodal fibers depart that directly innervate the target organ.

The pterygoid node is connected with the facial nerve, whose fibers form the parasympathetic root of this node. The axons of the maxillary nerve (branch of the trigeminal nerve), which form the sensitive root of this node, pass through it.

The ear node is connected with the glossopharyngeal nerve, which approaches the node in the form of a parasympathetic root. The sensitive branch is formed by the sensitive fibers of the mandibular nerve (branch of the trigeminal nerve), which pass through it in transit.

The submandibular node is a parasympathetic root formed by the facial nerve, sensitive by the trigeminal nerve.

The hypoglossal node is the parasympathetic root formed by the facial nerve, and the sensitive root by the trigeminal nerve.

The ciliary node - the parasympathetic root is formed by the oculomotor nerve, and the sensitive root is formed by the nasopharyngeal nerve, one of the small branches of the trigeminal nerve.

Oculomotor, facial and glossopharyngeal nerves, in addition to the above-mentioned large vegetative nodes, are connected with a large number of small nerve nodes, which consist of several dozen or several hundred neurons.

The vagus nerve is connected to a large number of parasympathetic nodes in the abdominal and thoracic cavities, which are located inside the organs (so-called intramural nodes).

Coming out of the skull

Cranial nerves leave the skull (although it is more correct to say "enter" about sensitive fibers) through the following openings:
the terminal (0) and olfactory (I) nerves exit through the openings of the ethmoid plate of the ethmoid bone;
the optic nerve (II) exits the optic canal of the sphenoid bone;
oculomotor (III), block (IV), branches of the eye (V1) and abductor (VI) nerves leave the skull cavity through the upper orbital fissure formed between the wings of the sphenoid bone;
the maxillary nerve (V2) exits the skull through the round foramen of the sphenoid bone
the mandibular nerve (V3) exits through the oval opening of the sphenoid bone;
the facial (VII) and parenchymal nerves (VIII) leave the skull through the internal auditory opening of the temporal bone;
the glossopharyngeal (IX), vagus (X) and the descending part of the additional (XI) nerve exit the skull through the jugular foramen formed by the temporal and occipital bones;
the hyoid nerve (XII) exits through the canal of the hyoid nerve in the occipital bone;
the ascending part of the accessory nerve (the one that starts in the spinal cord) enters the skull through a large foramen.

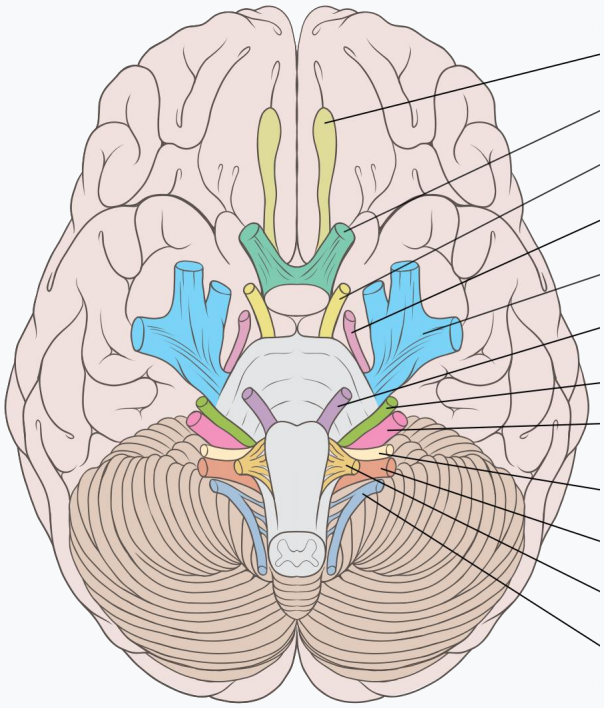


Fig.40. Coming out of cranial nerves from the skull.

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Навчальне видання

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АНАТОМО-ФІЗІОЛОГІЧНІ АСПЕКТИ ЦЕНТРАЛЬНОЇ ТА ПЕРИФЕРИЧНОЇ НЕРВОВОЇ СИСТЕМИ

Методичні рекомендації для самостійної роботи студентів 2-го курсу навчання медичного факультету з дисципліни «Анатомо-фізіологічні аспекти центральної та периферичної нервової системи»

(Англ. мовою)

В авторській редакції

Формат 60х84/16. Ум. друк. арк. 4,25. Наклад 50 пр. Зам. № 54/2023.

Харківський національний університет імені В. Н. Каразіна,
61022, м. Харків, майдан Свободи, 4.
Свідоцтво суб'єкта видавничої справи ДК № 3367 від 13.01.2009