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CENTRAL NERVOUS SYSTEM

ЦЕНТРАЛЬНАЯ НЕРВНАЯ СИСТЕМА

The manual for medical students

*Учебное пособие для медицинских вузов
(специальность «Лечебное дело»)*

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LIST OF ABBREVIATIONS

Art., art., — articulatio
Artt., artt., — articulationes
For., for. — foramen
Lig., lig. — ligamentum
Ligg., ligg. — ligamenta
M., m. — musculus
Mm., mm. — muscoli
N., n. — nervus
Nn., nn. — nervi
R., r. — ramus
Rr., rr. — rami
S., s. — sulcus

PREFACE

The creation of the manual “Central Nervous System” in English meets the requirement of modern Russian medicine and education. Nowadays many English-speaking oversea students study in Medical Universities of Russia. Besides, many Russian school leavers have a good command of the English language so they will be able to use this manual taking into consideration the fact that many Russian specialists in medicine work abroad after graduating from the universities or take part in different international conferences and symposiums.

The English version of the manual is based on the Russian manual by professor I. V. Gayvoronskiy “Normal Human Anatomy” which has been published in Russia 9 times and is approved by the Ministry of education of Russia.

This manual introduces the main principles of Russian Anatomy School such as: detailed study of the general aspects and items of Anatomy including the development of organs and anomalies of the development. If we compare theoretical approaches to Anatomy in Russia and in other countries we`ll see that our approach is based on the system descriptions of organs, i.e. we describe separately Skeletal system, Articulations, Muscular system etc. Moreover, we use Latin terminology while describing the organs and discuss clinicoanatomical and functional problems. As for the manuals in other countries many of them describe Anatomical systems in accordance with the regional and topographical principles.

The structure of our manual meets the requirements of modern standards of medical education in Russia which in their turn correspond to the major European standards. After each chapter we give test questions and clinicoanatomical problems. The English and Latin terminology is given in accordance with International Anatomical Nomenclature.

The authors strongly believe that the manual will allow future doctors to form the morphological foundation for the further study of theoretical and clinical disciplines. We also hope that it will be of great help to Anatomy teachers.

ПРЕДИСЛОВИЕ

Создание учебного пособия «Центральная нервная система» на английском языке является требованием современной системы медицинского образования в России. В настоящее время в медицинских университетах нашей страны обучаются студенты из различных регионов дальнего зарубежья. Кроме того, многие выпускники российских школ хорошо владеют английским языком, поэтому они также смогут пользоваться данным пособием, принимая во внимание, что зачастую русские специалисты в медицине после окончания университета уезжают работать за рубеж или принимают участие в различных международных конференциях и симпозиумах.

Английская версия пособия базируется на русском учебнике профессора И. В. Гайворонского «Нормальная анатомия человека», который был издан в России 9 раз и одобрен Министерством образования Российской Федерации.

Данное пособие познакомит читателей с главными принципами Русской анатомической школы, которые заключаются в подробном изучении общих вопросов, в том числе развития органов и аномалий развития. В России преподавание анатомии ведется с функционально-клинических позиций и основано на описании органов по системам, т.е. отдельно изучается опорно-двигательная система, артросиндесмология, миология и другие системы. Также при описании строения органов акцентируется внимание на латинской терминологии. Что касается зарубежных руководств по анатомии человека, многие из них основываются на регионально-топографическом принципе без использования латинской терминологии.

Структура данного пособия соответствует современным стандартам медицинского образования в России, которые, в свою очередь, соответствуют важнейшим европейским стандартам. После каждой главы мы приводим контрольные вопросы и ситуационные клинические задачи. Английская и латинская терминология приведена в соответствии с Международной анатомической номенклатурой.

Авторы выражают уверенность, что данное пособие позволит будущим докторам сформировать морфологический фундамент для последующего изучения теоретических и клинических дисциплин. Мы также надеемся, что оно принесет определенную пользу и преподавателям анатомии человека.

1. GENERAL DATA OF CENTRAL NERVOUS SYSTEM

The nervous system, *systema nervosum*, is a collection of anatomically and functionally interrelated structures which regulate and coordinate the activity of the body as a single whole, and the interaction of the organism with the external environment. It works as an apparatus which perceives the stimuli, analyze them and provides the body's response.

The nervous system appeared during evolution as an integrative system, i.e. the system which coordinates the functions of all organs and provides the adaptation of the organism to environmental changes. Unlike the activity of the other integrative systems (cardio-vascular system provides the humoral integration and the endocrine system provides the hormonal integration), the activity of the nervous system is very rapid, aiming and momentary (hundredths of a second pass from the moment of the stimulus appearance to the feeling of the stimulus). Usually, a certain organ reacts to the stimulus, or the group of the organs. When the action of the stimulus ceases, the response momentarily stops.

1.1. Classification of Nervous System

According to the topographical and anatomical principles, the nervous system is divided into central and peripheral. The central nervous system consists of the brain and the spinal cord; the peripheral nervous system comprises all the nervous structures lying outside the brain and the spinal cord. The structures associated with the spinal cord form the spinal part of the peripheral nervous system. Here belong the sensory ganglia of the spinal nerves, the roots of the spinal nerves, the trunks and the branches of the spinal nerves, the plexuses of the spinal nerves, the ganglia of the sympathetic nervous system and nerve endings. The spinal part provides the innervation of the trunk, limbs, partially of the neck and internal organs.

The structures associated with the brain constitute the cranial part of the peripheral nervous system. Here belong the sensory ganglia of the cranial nerves, the cranial nerves, the branches of the cranial nerves, the ganglia of the parasympathetic nervous system and nerve endings. The cranial part provides the innervation of the head, partially of the neck and internal organs. It should be noted that the division of the central nervous system into central and peripheral is arbitrary because these parts are closely interrelated, anatomically and functionally.

According to the function, the nervous system is divided into somatic (animal) and autonomic (vegetative). The somatic nervous system is respon-

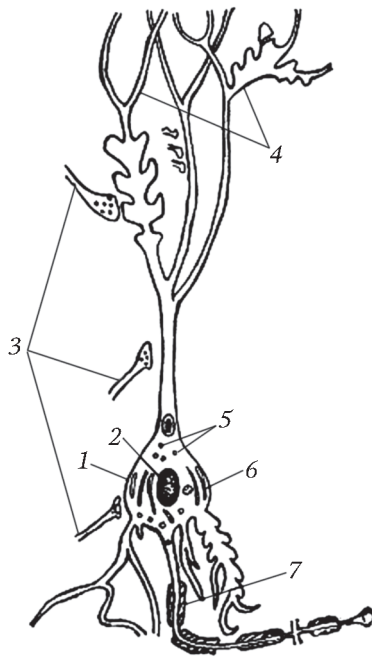


Fig. 1.1. Scheme of the structure of neuron:

1 — cell body; 2 — nucleus; 3 — endings of other neurons; 4 — dendrites; 5 — secretory granules; 6 — neurofibrillar apparatus; 7 — axon

sible for the innervation of the *soma* (skin, skeletal muscles). The autonomic nervous system provides the innervation of the internal organs, glands and vessels. In its turn, it comprises the sympathetic and parasympathetic parts.

The central nervous system includes billions of highly specialized cells, the neurons and glial cells; the glial cells provide the activity of the neurons (support, protect and perform the trophic function). The neurons are grouped according to their functions into the corresponding cerebral and spinal centres. These centres constantly receive the impulses from different sensory receptors of skin, muscles, internal organs, organs of vision, hearing, balance, taste and smell. This information is analyzed by the central nervous system in fractions of a second to give an appropriate response. When the central nervous system generates a response, it uses the ability of the brain to store and release the information which was received previously (memory) at a determined moment. The greatest achievement of the nervous system, developed during evolution, is the thinking ability. The thinking activity is the higher nervous activity of the human body; it is performed as a result of analysis and synthesis of the nerve impulses in the higher cerebral centers.

The central nervous system also has an own initiative. It actively influences the vessels, muscles and glands, stimulating their work, and it also effects on the sensory organs, regulating their functioning.

Peripheral nervous system connects the spinal cord and brain with the receptors (sensory apparatuses of the organs) and with the effectors (the apparatuses transmitting the nerve impulses to the effector organs). In the response to the internal or external stimuli, the effector organs give the adaptive reactions of the organism, such as contraction of muscles or discharge of the secretions by the glands.

Somatic nervous system innervates skin, muscles, skeleton, some internal organs (tongue, pharynx, larynx etc.). It communicates the body as an integrated system with the external environment. It accepts the stimuli from outside, analyzes them and provides the response reaction to the external stimuli, controlling the skeletal (striated) muscles.

Autonomic nervous system innervates the internal organs and blood vessels, controls the action of smooth musculature and the work of the glands. It unites the different parts of the body into the integrated system and carries adaptive and trophic functions in the body.

1.2. Neurons

The neuron, or neurocyte, is a structural unit of the nervous system (fig. 1.1).

The neuron consists of a cell body (*soma*), processes and their endings. There are two types of the processes: dendrites and axon (neuritis).

The cell body is a mass of cytoplasm (neuroplasm) with a large round nucleus. The neurons of the autonomic nervous system may have 2–3 nuclei. The number of nucleoli in the nucleus is 1–3. The increase of the number and size of the nucleoli indicates the increase of the functional activity of the neuron. The nucleus carries the genetic information which determines the properties of the neuron and regulates the synthesis of proteins. The cytoplasm of the neuron contains the organelles of general purpose (mitochondria, ribosomes, endoplasmic reticulum, lysosomes, Golgi complex etc.) and specialized structures (neurofibrils, chromatophilic substance and synaptic vesicles). There are two types of neurofibrils: neurofilaments and neurotubules. In the cell body the neurofilaments form the network of thin white protein filaments, 6–10 nanometers

in diameter. In the neuron's processes the filaments are arranged longitudinally. They perform a support function, giving a certain form to the cell.

The neurotubules are also formed by the protein filaments having a spiral orientation. The diameter of the tubules is 20–30 nm, the thickness of the wall is 10 nm. The neurotubules transport the substances within the neuron.

The chromatophilic substance (Nissl substance) is the condensation of protein (ribonucleoproteins). This substance is found in the cytoplasm of the cell body and dendrites; it is not observed in the axons.

The synaptic vesicles are situated mainly in the cytoplasm of the axon terminal, but may be located in the neuronal soma. They contain the mediators (acetylcholine, nor-adrenaline, gamma aminobutyric acid etc.), which provide the chemical transmission of the nerve impulse from one neuron to another, or from the neuron to the effector organ.

Externally, the neuron has a membrane, called cytolemma, which determine the limits of the cell and provides the contact of the cell with surrounding environment. Besides, the cytolemma contains much of protein structures that carry out chemoreceptor function. The cytolemma is able to conduct the nervous excitation (nerve impulse).

There are two types of the neuron processes: dendrites and axon (neuritis); they are the cytoplasmic extensions. The dendrites conduct the nerve impulse only towards the cell body. They start to branch near the cell body, then gradually become thinner and end in the surrounding tissues. The dendrites greatly increase the receptive surface of a neuron. The number of the dendrites varies from 1 to 10. Rarely, the neurons without dendrites are observed. Such cells perceive the impulses by the cell body.

Apart from the dendrites, the neuron always has only one axon (neuritis). This process is always larger, longer and less branched. It has sparse collateral branches just near the terminal. There is a correlation between the size of the cell body and length of the axon: the larger cell body, the longer and larger the axon. The axon conducts the nerve impulse only away from the cell body. Thus, the neuron with its processes is strictly dynamically polarized: the nerve impulse passes towards the cell body via the dendrites and away from it via the axon.

The neurons differ from each other in shape, size, number of processes and function.

According to the shape of the cell body, the neurons are described as: pyramidal, piriform, fusiform, polygonal, oval, stellate, round etc.

According to the size of the cell body, three groups of the neurons are distinguished: small (4–20 mcm); middle (20–60 mcm) and large (60–130 mcm).

According to the number of the processes, the neurons are classified as (fig. 1.2): unipolar, bipolar, pseudounipolar and multipolar. In the human nervous system the bipolar, pseudounipolar and multipolar neurons are observed most commonly.

According to the function, three groups of the neurons are distinguished in the reflex arch:

- 1) receptor (sensory, afferent), having the sensory nerve endings (receptors), which are able to perceive the stimuli from the internal or external environment;
- 2) effector (motor, efferent), whose axon terminals have the effectors, which transmit the nerve impulse to the effector organ;
- 3) association (intermediate), which have the intermediate position in the reflex arch and transmit the information from the afferent neuron to the efferent one. The complex reflex arches may have several association neurons.

The structure and the function of the neurons are interrelated.

For example, the pseudounipolar neurons are receptor (sensory). They perceive such excitations as pain, temperature changes and tactile stimuli. The bipolar neurons

are the cells of special senses. They perceive the light, olfactory, auditory and vestibular stimuli. The small multipolar neurons are association; middle and large neurons, multipolar and pyramidal, are motor.

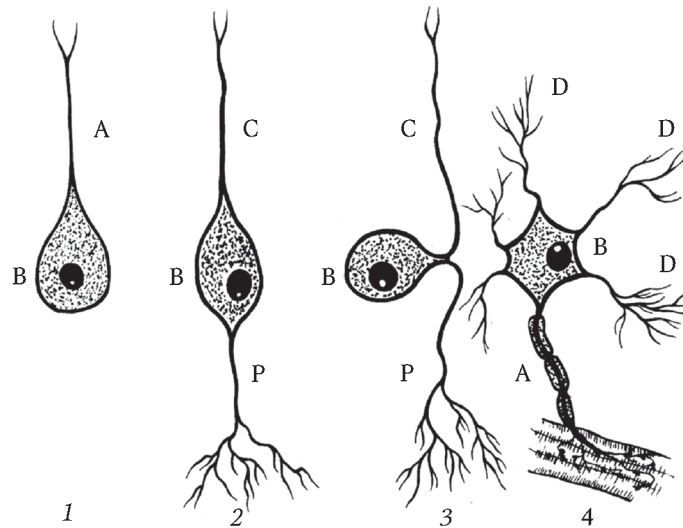


Fig. 1.2. Main types of the neurons:

1 – unipolar neuron; 2 – bipolar neuron; 3 – pseudounipolar; 4 – multipolar neuron; A – axon; B – body; C – central process; D – dendrite; P – peripheral process

It should be noted that the processes of the receptor neurons (bipolar and pseudounipolar) are not called a dendrite or axon but peripheral and central processes respectively. They have such names due to the position of the processes relatively to the central nervous system and to the cell body. The peripheral process passes from the cell body to the periphery, while the central process runs from the cell body to the spinal cord or the brain.

1.3. Nerve Fibres

The nerve fibres are the neuronal processes ensheathed by a glial membrane, which conduct the nerve impulses.

The neuronal process situated in the center of the nervous fibre is called the axial cylinder. The axial cylinder is a neuroplasmic extension with contained organelles, surrounded by a membrane called axolemma.

Depending on the presence of the myelin in the glial cell membrane, two types of the nerve fibres are distinguished: myelinated and non-myelinated. In the myelinated fibres the glial cell membrane is thicker (forms $\frac{1}{2}$ – $\frac{2}{3}$ of the diameter of the whole nerve fibre); these fibres have white colour due to contained myelin.

The myelinated fibres are divided into three groups according to the diameter: thick (12–20 mcm), middle (6–12 mcm) and thin (1–6 mcm). The nerve fibre narrows at

regular intervals, 1–3 mm long, to form the nodes of Ranvier, 1 mm thick, where the myelinated layer is absent and short gaps exist between adjacent glial (Schwann) cells.

The conduction speed depends on the nerve fibre diameter. In thick myelinated fibres the speed of conduction is 80–120 m/s, in the middle fibres it is 30–80 m/s, in thin fibres it is 10–30 m/s. The nerve conduction velocity in a certain group of fibres does not depend on the excitation power.

Today it is known that thick myelinated fibres mainly conduct motor impulses; the middle fibres conduct the temperature and tactile impulses; the thin fibres conduct pain impulses. Thus, knowing the fibre composition, it is possible to give the functional characteristic of the nerve (motor, sensory, mixed).

The myelin sheath prevents the propagation of the nerve impulses, passing through the nerve fibre, to the surrounding tissues, i.e. plays the role of dielectric (insulator). The myelination of the nerve fibres starts during the 4–5th months of the fetal development and has unequal length in different parts of the nervous system. During development, the glial cell membrane (mesaxon of Schwann cell) wraps the axial cylinder many times in a tight spiral membrane. The inner layers of the membrane contain mainly myelin (proteins and lipids); the outer layers contain cytoplasm and membranes of Schwann cells (lemmocytes). The completion of the myelination indicates the maturity of the nervous structures. For example, the nerve fibres of the cerebral hemispheres, responsible for emotional and mental functions, myelinate only by the age of 12–13 years.

The non-myelinated fibres have a small diameter (1–4 mcm); the conduction speed of the nerve impulses in these fibres is 1–2 m/s. Unlike the saltatory conduction of the nerve impulses in myelinated fibres, the passage of impulses in non-myelinated fibres is uninterrupted. Non-myelinated fibres are efferent fibres of the autonomic nervous system. They supply the viscera, glands and vessels.

Each non-myelinated fibre contains not one axial cylinder but several (up to 20). They are enveloped by the sheath consisting of lemmocytes (fig. 1.3).

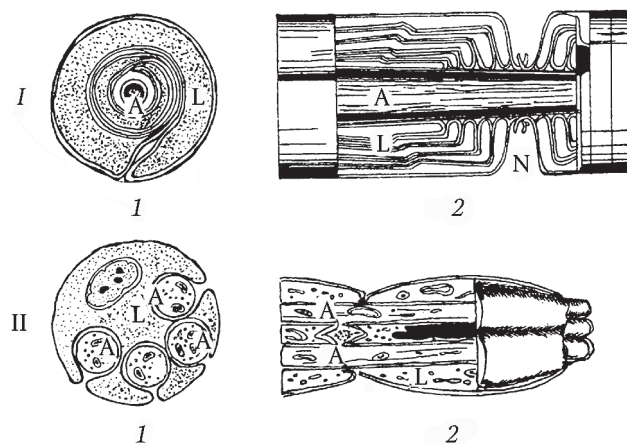


Fig. 1.3. Scheme of the nerve fibre structure:

I — somatic nervous system; *II* — vegetative nervous system; *1* — transverse section; *2* — longitudinal section; A — axon; L — lemmocyte; N — node of Ranvier

Depending on the direction of the nerve impulse relatively to the central nervous system, there are 2 groups of the fibres: centripetal and centrifugal. The centripetal fibres are afferent (ascending) and pass towards the spinal cord or brain. The centrifugal fibres run from the brain or spinal cord to the effector organs (muscles, vessels, glands) and are called efferent (descending) fibres.

The nerve fibres situated within the central nervous system constitute white matter of the spinal cord and brain.

1.4. Nerve Endings

Nerve endings are the terminal parts of the nerve fibres. According to the function, three types of the endings are recognized: receptors, effectors and interneuronal synapses.

Receptors are the nerve endings of the sensory (receptor) neurons' peripheral processes, which perceive the specific stimuli from the external or internal environment and transform the energy of excitation into the nerve impulse.

According to localization, the receptors are divided into exteroceptors, proprioceptors and interoceptors (fig. 1.4).

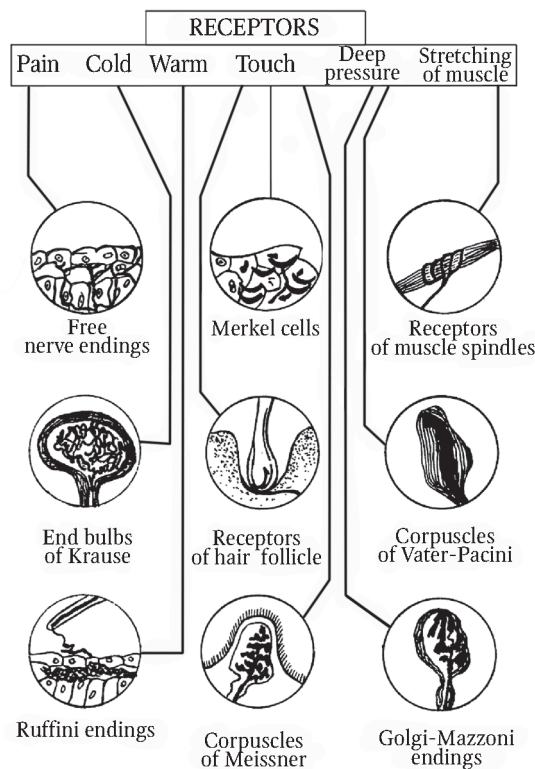


Fig. 1.4. Main types of the receptors of somatic nervous system

Exteroceptors are situated in the skin and mucous membranes of the oral and nasal cavities and eyeball's conjunctiva. They respond to external stimuli such as tactile, temperature and pain.

Interoceptors lie in the walls of the viscera, in the glands and vessels. They react to the chemical and mechanical stimuli. Interoceptors perceive the chemical composition of certain substances (taste, smell etc), degree of filling of the organs or pain.

Proprioceptors, or deep receptors, are located in muscles, tendons, fasciae, periosteum, ligaments and joint capsules. They respond to the tactile stimuli, pressure, vibration, position of the body parts and degree of the muscle tension.

Extero-, intero- and proprioceptors are mainly receptors of general sensation.

Receptors of special sense organs (organs of vision, hearing, balance, smell and taste) have the special sensory receptors. They respond to visual (light and colour), acoustic (sound and noise), vestibular (angular and vertical accelerations), olfactory (smell) and gustatory stimuli.

The receptors which perceive the stimuli by an immediate contact with them are called the contact receptors. The receptors for the stimuli produced by distant objects are called the distant receptors.

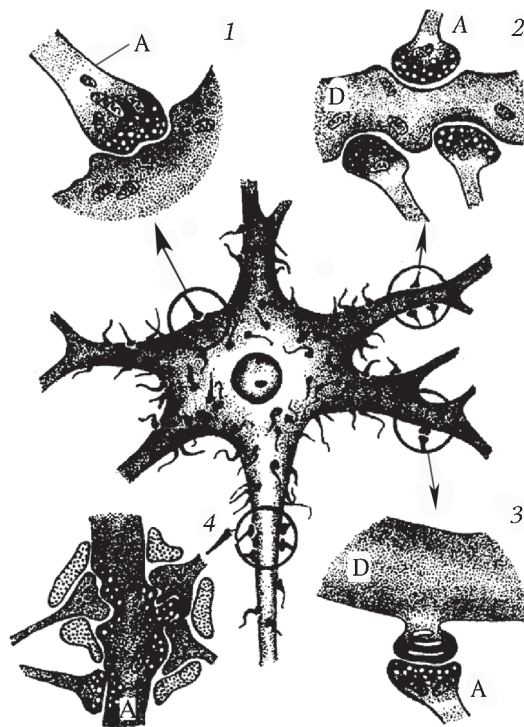


Fig. 1.5. Interneuronal synapses:

1 — axosomatic synapses; 2 — axodendritic synapses; 3 — pin-shaped axodendritic synapses; 4 — dendroaxonic synapses of divergent type; A — axon; D — dendrite

According to the structure, the receptors are divisible into three categories: free nerve endings, encapsulated nerve endings and primary sensory cells. Free nerve endings respond to pain stimuli; encapsulated endings respond to tactile, temperature and proprioceptive stimuli; primary sensory cells respond to visual, acoustic, vestibular and gustatory stimuli.

Synapsis is a specialized morpho-functional structure, intended for the contact transmission of the nerve impulse from one neuron to another, or from the neuron to the effector organ.

According to localization, the synapses may be interneuronal and situated between the neuron and tissue. The interneuronal synapses can be classified by the type of neuronal part participating in the contact: axo-somatic (axon — cell body), axodendritic (axon-dendrite), axoaxonic (axon-axon). The most common interneuronal synapses (fig. 1.5) are axo-somatic (axon terminals of one neuron contact with the cell body of another neuron) and axodendritic (axon terminals of one neuron contact with the dendrites of another neuron). One neuron may have up to 10 000 synaptic contacts. Most syn-

apses involve the dendrites (approximately $\frac{4}{5}$ of the total number), and just $\frac{1}{5}$ is on the cell body. Axoaxonic synapses provide the inhibition of impulses passing from one neuron to another through axodendritic and axosomatic synapses.

Less frequently the dendrodendritic, dendrosomatic and somatosomatic synapses are observed.

The synapses between neuron and tissue are classified according to the localization into neuromuscular and neurosecretory.

According to the mechanism of the nerve impulse transmission, the synaptic structures are divided as follows:

- 1) synapses with chemical (neurotransmitter) transmission of the nerve impulse;
- 2) synapses with electrical transmission of the nerve impulse;
- 3) synapses with mixed transmission of the nerve impulse.

Morphologically, the synapses represent the thickenings having different forms (boutons, bulbs or threads). Ultrastructurally, the following parts of synapsis are distinguished: presynaptic part, synaptic cleft and postsynaptic part (fig. 1.6). Presynaptic part for the chemical synapses is usually formed by the axon terminal and contains numerous presynaptic vesicles and mitochondria. Presynaptic vesicles are filled with a neuromediator. The neuromediators are acetylcholine, noradrenaline, gamma aminobutyric acid (GABA), histamine, dopamine, glycine, prostaglandins etc (more than 30 substances). The size of presynaptic vesicle shows the type of a neuromediator: acetylcholine is in the small vesicles (the diameter is 30–50 nm); noradrenaline is in the middle vesicles (50–90 nm); GABA in the large vesicles (100–120 nm). One neuron may synthesize and release several mediators (3–5). As a nerve impulse approaches the presynaptic membrane, it causes the release of the vesicles with a neurochemical transmitter which rapidly diffuses into the synaptic cleft. One vesicle may contain up to 10 000 molecules of a mediator.

The synaptic cleft is 10–200 mcm in width; it is filled with intercellular matrix. The synaptic cleft of the chemical synapses is wider than that of the electrical synapses.

As a mediator passes through the synaptic cleft, it reacts with chemoreceptor on the postsynaptic membrane. According to the chemical nature of a mediator, the following main types of the chemoreceptors are distinguished: α -, β -adrenoreceptors; M, N-cholinoreceptors; purinoreceptors, GABA-receptors etc. α -, β -adrenoreceptors react with such mediators as adrenaline, noradrenaline, dopamine, i. e. catecholamines; M, N-cholinoreceptors react with acetylcholine; purinoreceptors react with purine bases; and GABA-receptors with gamma aminobutyric acid.

After reaction, the mediator is broken down (inactivated) by a specific substance contained in the chemoreceptor (acetylcholine is inactivated by acetylcholinesterase, noradrenaline by monoamine oxidase etc.).

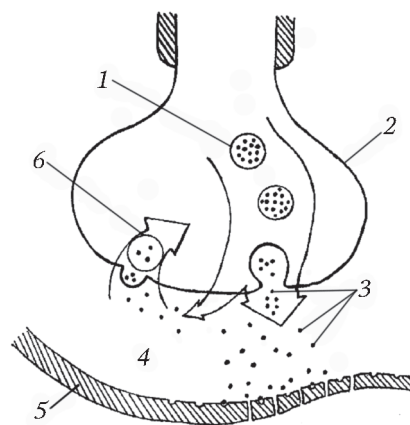


Fig. 1.6. Ultrastructure of synapsis:

1 – synaptic vesicles; 2 – presynaptic membrane; 3 – molecules of the mediator, which diffuses by exocytosis into the synaptic cleft; 4 – synaptic cleft; 5 – postsynaptic membrane with protein chemoreceptors; 6 – molecules of inactivated mediator, which returns into the axon terminal by pinocytosis

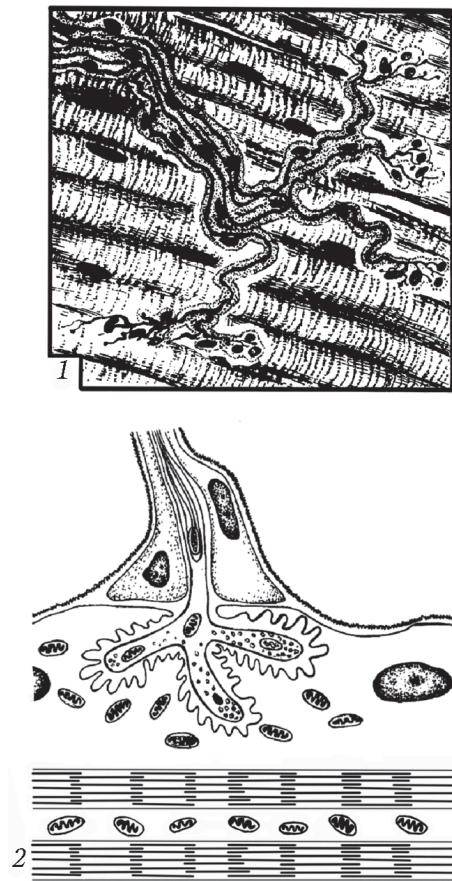


Fig. 1.7. Effectors in the striated muscle:
1 – nerve fibres and nerve endings (motor plaques), visible by light-optical microscope; 2 – ultrastructure of neuromuscular synapsis

synapses conduct only excitatory impulses.

Effectors are the synapses (junctions) between the axons of the somatic or vegetative efferent neurons and tissues, conducting the nerve impulse from the neurons to the effector organ.

The effectors in the striated muscles are represented by the motor plaques (endplates) (fig. 1.7). Near the motor plaque the myelinated nerve fibre loses the myelin layer and divides into terminal branches. These branches immerse into the folds of sarcolemma of the muscle fibre. The neuromuscular synapsis has a synaptic cleft, 10–20 nm in width, between the axon terminal and sarcolemma of the muscle fibre.

As usual, the mediator in these synapses is acetylcholine which acts as an excitatory mediator. The synapses with a narrow cleft are electrical. The synapses between neuron and tissue in the autonomic nervous system have such mediators as acetylcholine, noradrenaline, adenosine triphosphate etc. Exactly the mediators determine a certain reaction to the stimulus and the length of the reaction.

Inactivated molecules of the mediator are reabsorbed through the presynaptic membrane where they are restored.

Thus, the chemical transmission of the nerve impulses includes 4 stages: the synthesis of a mediator, the diffusion of a mediator through the synaptic cleft, the reaction with chemoreceptors of the postsynaptic membrane and inactivation.

Ultrastructural features of the synapsis determine the features of its functioning:

1) the transmission of the nerve impulse is unidirectional (the law of dynamic polarization of the synapsis) due to features of the synthesis, diffusion and reaction of a mediator;

2) the synaptic delay is a small delay (0,08 seconds) associated with the diffusion of a mediator and its reaction with chemoreceptor;

3) high selective sensitivity of the chemoreceptors (they react only with specific mediator);

4) the fatigue, caused by the consumption of the mediator

The electrical synapses do not have vesicles and are characterized by a narrow synaptic cleft and by the absence of specific chemoreceptors. They provide the transmission of the nerve impulses without synaptic delay in both directions.

According to the function, the synapses are divided into excitatory and inhibitory. The chemical synapses conduct both excitatory and inhibitory impulses. The electrical

1.5. General Concept of Reflex Activity

The activity of the nervous system is based on the reflexes (reflex acts).

The reflex is a response reaction of the body to an external or internal stimulus. The numerous reflex acts are divided into unconditioned and conditioned.

Unconditioned reflexes are congenital (genetic) reactions of the body to the stimuli, produced with participation of the spinal cord or brain stem. These reflexes comprise the lower nervous activity.

Conditioned reflexes are developed on the basis of the unconditioned reflexes; they are produced only with participation of the cerebral cortex and form the higher nervous activity. The higher nervous activity is characterized by the complexity of the reflex actions. They are not just reactions to a certain stimulus; they are based on the analysis of numerous afferent signals from the external and internal environment, which pass to the brain via different sensory pathways (proprioceptive, pain, tactile, visual, auditory, olfactory etc), and on the analysis of the signals from memory which stores the information about past experience.

It should be noted that a human, performing a specific action, usually predicts its results, i.e. primarily the afferent idea appears and then the action is performed. The coincidence or the discrepancy between the predicted and actual results influences the kind of the accompanying emotional reactions. In the first case they are positive, otherwise (in the second case) – negative.

The morphological base of the reflex is a **reflex arch** which is a chain of the neurons providing the reception of stimulus, conversion of the stimulus energy into the nerve impulse, the conduction of the nerve impulse towards the nerve centres, analysis of the received information and the response reaction.

Depending on the complexity, the reflex arches can be simple or complex. As a rule, the unconditioned reflexes are performed using the simple reflex arches. As for the conditioned reflexes, they are realized by means of the complex reflex arches.

The simple reflex arch consists of 3 parts: afferent, intermediate (association) and efferent.

Let's consider the main parts of the somatic reflex arch, formed with participation of the spinal cord's structures (fig. 1.8).

The afferent part (limb) is represented by a sensory (receptor) neuron which is situated in the sensory ganglion of the spinal nerve (posterior root ganglion); this neuron is pseudounipolar. From its cell body one process arises; it soon divides into peripheral and central processes. The peripheral process starts by receptor in the periphery (in the skin, muscles, tendons, joint capsules). The area containing the receptors the stimulation of which causes a definite reflex is called the reflexogenic zone. The nerve impulses caused by the stimulation of the reflexogenic zone pass centripetally towards the sensory neuron's soma and then via its central process into the spinal cord. The central process of the receptor neuron forms a synaptic contact with the dendrites of the intermediate (association) neuron.

Association neuron is a small multipolar neuron with short axon, forming the intermediate part of the reflex arch. It receives the nerve impulse via its dendrites, conducts the impulse through the axon and forms the synaptic contact with the efferent neuron.

Efferent neuron is the large multipolar neuron, whose axon leaves the central nervous system and ends by the effector in the tissue of the effector organ (striated musculature).

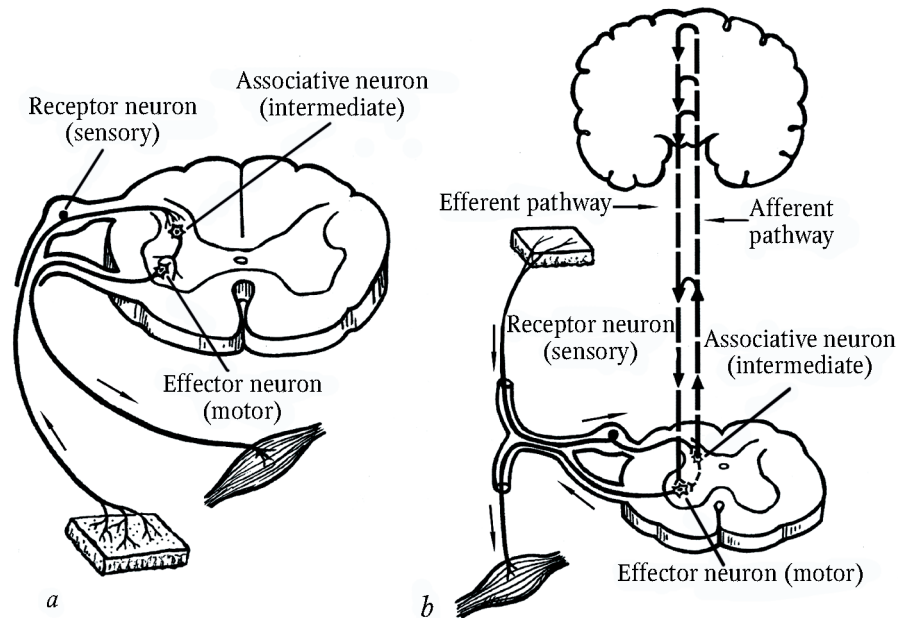


Fig. 1.8. Reflex arches of somatic nervous system:
a – simple reflex arch; *b* – complex reflex arch

The complication of the reflex arches occurs due to the intermediate part. The association neurons form numerous nuclei (nerve centres) in the spinal cord and brain. The nerve centres are the groups of the neurons, united on the base of the morphofunctional characteristics, which conduct the nervous impulses from one neuron to another and perform a certain processing of the nervous impulses. According to I.P. Pavlov, the nerve centre is an accumulation and cohesion of the neurons.

Between the nerve centre and effector organ there is a two-way communication. Reaching the effectors, situated in the muscle or gland, the nerve impulses cause the response reaction to the stimulus. This is accompanied by the excitation of the effector organ's receptors, resulting in the generation of new impulses which pass towards the nerve centre. The existence of a feedback allows the nerve centres to control the correctness of the performing commands running from the nerve centres, and to correct timely the body responses.

TEST QUESTIONS

1. Classify the nervous system according to the topographical and anatomical principles, and according to the function.
2. Describe the structure of neuron. Classify the neurons.
3. What types of neurons, according to the number of processes, do you know?
4. What types of neurons, according to the function, do you know?

5. Give the characteristic of myelinated fibers.
6. Give the characteristic of non-myelinated fibers.
7. What is the receptor? Give the classification of receptors.
8. What is the synapsis? Describe its structure and the laws of its functioning.
9. Give the classifications of the synapses.
10. What is the reflex? Classify the reflexes.
11. What parts does the reflex arch have? Describe them. Describe the differences between the simple and complex reflex arches. Give the definition of the nerve centre.

2. SPINAL CORD

2.1. External Structure of Spinal Cord

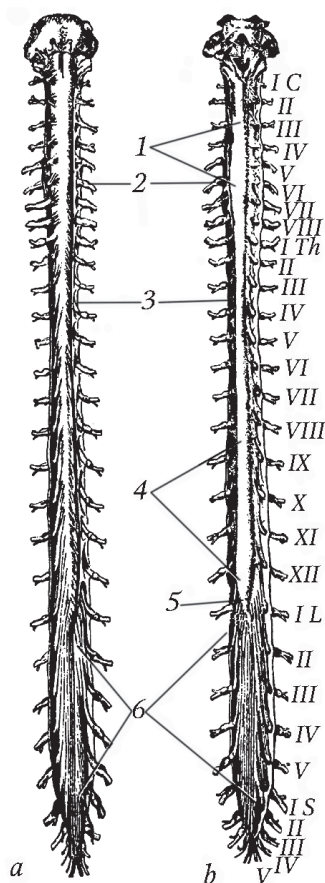


Fig. 2.1. Spinal cord:

a — anterior aspect (anterior surface); *b* — posterior aspect (posterior surface);

1 — cervical enlargement (*intumescentia cervicalis*); 2 — spinal ganglion (*ganglion sensorium spinalis*); 3 — dura mater of spinal cord (*dura mater spinalis*); 4 — lumbosacral enlargement (*intumescentia lumbosacralis*); 5 — medullary cone (*conus medullaris*); 6 — cauda equina (*cauda equina*); C_{I-VIII} — the roots of the cervical spinal nerves; Th_{I-XII} — the roots of the thoracic spinal nerves; L_{I-V} — the roots of the lumbar spinal nerves; S_{I-IV} — the roots of the sacral spinal nerves

The spinal cord, *medulla spinalis*, is shaped as a thick-walled tube, slightly flattened from front to back. Its average length is 42–45 cm; the largest transverse diameter is 12 mm; the weight is about 35 g.

The spinal cord is inside the vertebral canal. Above, at the level of the atlantal arch, it is continuous with the medulla oblongata. Below, at the level of the I lumbar vertebra in males and the II lumbar vertebra in females it ends by the medullary cone, *conus medullaris*, from whose apex the *filum terminale* descends to be attached to the periosteum of II coccygeal vertebral body.

The spinal cord is constructed symmetrically. Its anterior surface is traversed by a deep anterior median fissure, *fissura mediana anterior*. Its depth reaches $\frac{1}{3}$ of spinal cord's anteroposterior size. On the posterior median surface of the spinal cord there is a posterior median sulcus, *sulcus medianus posterior*, to which a glial septum, dividing the posterior part of the spinal cord into two halves, adjoins. Each lateral surface carries the anterolateral sulcus, *sulcus anterolateralis*, situated 2–3 mm lateral to each side of the anterior median fissure, and the posterolateral sulcus, *sulcus posterolateralis*, situated 4–5 mm lateral to each side of the posterior median sulcus.

Through the anterolateral and posterolateral sulci of the spinal cord, the anterior (ventral) and posterior (dorsal) roots of the spinal nerves pass. The posterior root has an enlargement representing the sensory ganglion of the spinal nerve, *ganglion sensorium nervi spinalis* (posterior root ganglion, or spinal ganglion, *ganglion spinale*). The anterior and posterior roots of one side, situated at the same level in the horizontal plane, converge near the intervertebral foramen. The anterior root and the peripheral processes of the pseudounipolar neuron of the spinal ganglion join immediately after the ganglion to form the trunk of the spinal nerve, *truncus nervi spinalis*. There are 124 roots along the spinal cord: 62 posterior and 62 anterior roots (fig. 2.1). All the roots form 31 pairs of the spinal nerves.

A part of the spinal cord, corresponding to the four roots of the spinal nerves, or to the pair

of the spinal nerves, situated at the same level in the horizontal plane, is called **the segment of the spinal cord** (fig. 2.2).

There are 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal segments in the spinal cord. Each segment innervates the certain body part called the metamer. The latter includes the area of the skin (dermatom) and the skeletal muscles which develop from a single myotom.

The spinal cord segments provide the segmental innervation of the trunk and limbs. The segmental innervation is characterized by a striped distribution: on the trunk these stripes encompass the body like rings, while on the limbs they pass longitudinally (fig. 2.3).

The segments are denoted by the initial letters which show the part of the spinal cord, and by the digits, corresponding to the number of the segment: cervical segments, *segmenta cervicalia*, – C₁–C₈; thoracic segments, *segmenta thoracica*, – Th₁–Th₁₂; lumbar segments, *segmenta lumbalia*, – L₁–L₅; sacral segments, *segmenta sacralia*, – S₁–S₅; coccygeal segment, *segmentum coccygeum*, – Co₁.

During the first months of prenatal development, the vertebral column and the spinal cord grow in length equally (the spinal cord occupies the whole length of the vertebral and sacral canals). The roots of all the spinal nerves arise from the spinal cord at a right angle to pass through the corresponding intervertebral foramina. Hence in this period all the spinal segments are situated at the level of the corresponding vertebrae. Beginning from the fourth month of prenatal life, the spinal cord starts to lag behind in growth. The spinal cord's

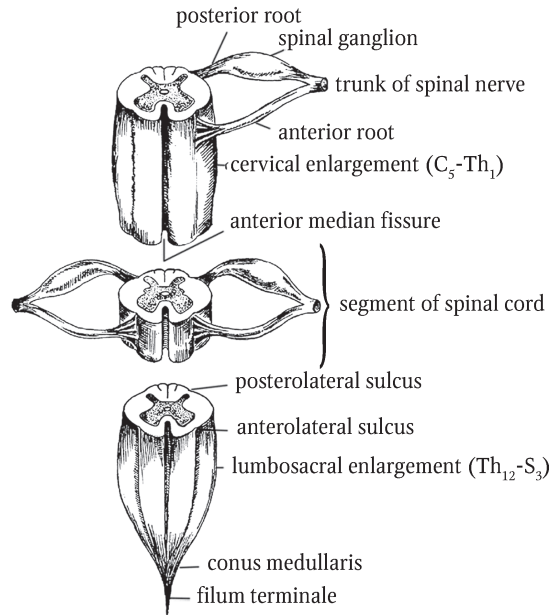


Fig. 2.2. External view of the spinal cord

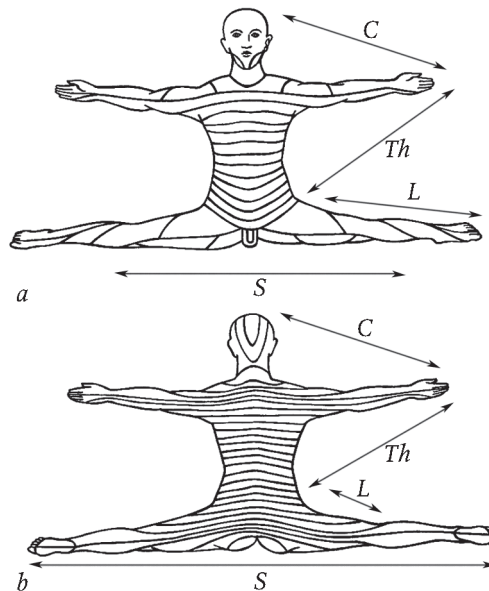


Fig. 2.3. Segmental distribution of the cutaneous sensitivity:

a – anterior view; *b* – posterior view.

Zones of the segmental innervation: C – cervical; Th – thoracic; L – lumbar; S – sacral

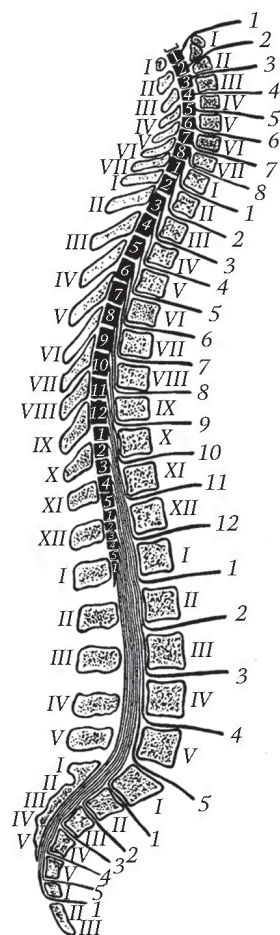


Fig. 2.4. Topography of the spinal cord segments: the vertebrae are denoted by Roman numerals; the segments and the spinal nerve roots are denoted by Arabic numerals

cranial end is continuous with the brain hence is fixed therefore, the topical relations between the spinal cord's upper parts and vertebral column are changed insignificantly. The caudal end of the spinal cord gradually lags behind in growth in comparison to the vertebral canal, and in a newborn the lower end of the spinal cord is already at the level of the III lumbar vertebra; in an adult it is at the level of the I lumbar vertebra.

The skeletotopy of the spinal segments is of great importance for the topical diagnosis of the nervous system diseases. Let's consider the skeletotopy of the segments in males. The upper cervical segments (C_1-C_4) are situated at the level of the corresponding cervical vertebrae. The lower cervical segments (C_5-C_8) and upper thoracic segments (Th_1-Th_4) have smaller height in comparison to the height of the vertebral bodies and lie one vertebra higher. The middle thoracic segments (Th_5-Th_8) are situated already 2 vertebrae higher; the lower thoracic segments (Th_9-Th_{12}) are 3 vertebrae higher. All the lumbar segments (L_1-L_5) are at the level of the X–XI and upper half of the XII thoracic vertebrae. All the sacral (S_1-S_5) and coccygeal (Co_1) segments are level with the lower half of the XII thoracic and I lumbar vertebrae (these segments comprise the conus medullaris).

The skeletotopy of the spinal cord segments is shown in the table 1 and fig. 2.4.

The skeletotopy of the segments is important in the diagnostics of the segmental disorders: knowing a damaged vertebra, it is easy to determine an injured spinal cord segment; and conversely, according to the segmental disorders of the sensitivity or motor actions, it is possible to find a damaged vertebra. For example, to determine the vertebra, at the level of which a certain segment is located, we should subtract from the number of the segment: 1 (if these are lower cervical or upper thoracic segments); 2 (if these are middle thoracic segments); and 3 (if these are lower thoracic segments (IX, X, XI, XII)).

Table 1

Skeletotopy of the spinal cord segments

Segments	Relation to the vertebral bodies
C_1-C_4	C_1-C_{IV}
C_5-Th_1	C_{V-VII}, Th_{I-III}
Th_5-Th_8	Th_{IV-VI}
Th_9-Th_{12}	Th_{VII-IX}
L_1-L_5	Th_{X-XII}
$S_1-S_5-Co_1$	$Th_{XII}-L_I (L_{II})$

The spinal cord is not straight. It is curved in the sagittal plane that is caused by the cervical lordosis and thoracic kyphosis of the vertebral column. The spinal cord has two enlargements which correspond to the segments innervating the upper and lower limbs. The cervical enlargement, *intumescentia cervicalis*, extends from the V cervical to the I thoracic segments; the lumbosacral enlargement, *intumescentia lumbosacralis*, extends throughout the XII thoracic and upper three sacral segments. Level with the I lumbar vertebra's upper border, the lumbosacral enlargement is continuous immediately with the conus medullaris.

The delay of the spinal cord growth compared to the growth of the vertebral column causes the change of the spinal roots's direction. In the cervical part they are oriented horizontally, in the middle part they have oblique direction, and from the caudal segments they pass almost vertically. The length of the roots (from their emergence to the formation of the spinal nerve trunks in the intervertebral foramina) increases in the caudal direction. In the cervical part the spinal nerve roots are 1–1,5 cm long, while in the lumbar and sacral parts they reach 3–12 cm. The roots of the lower four lumbar, five sacral and coccygeal spinal nerves together with the filum terminale form so called *cauda equina* situated in the dural sac (fig. 2.1). Thus, the cauda equina consists of 40 roots: 20 anterior and 20 posterior, corresponding to 10 lower segments of the spinal cord (L_{2-5} , S_{1-5} , Co_1).

2.2. Internal Structure of Spinal Cord

The internal structure of the spinal cord can be studied by dissection and macroscopic inspections of the transverse section or by examination of the histotopograms at low magnification. In the center of the spinal cord there is a central canal, *canalis centralis*, (fig. 2.5). It extends throughout the spinal cord and ends in the conus medul-

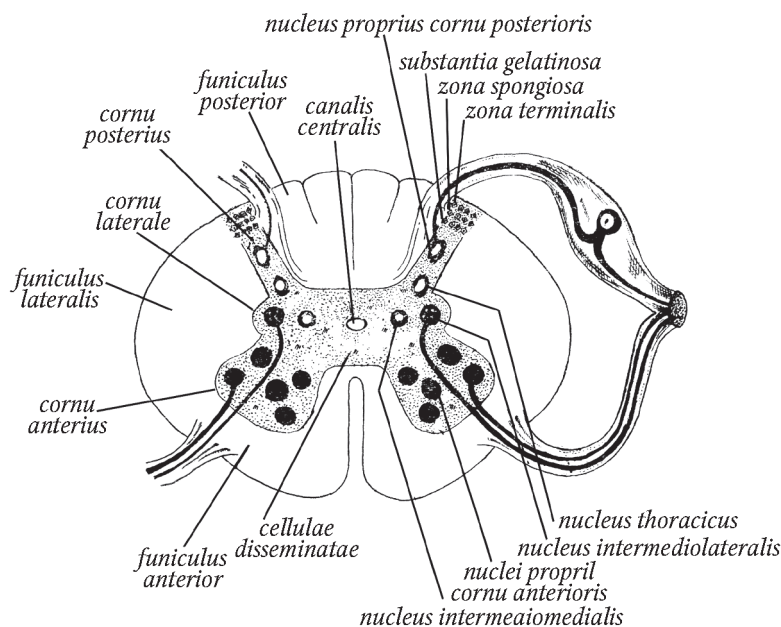


Fig. 2.5. Internal structure of the spinal cord. Transverse section at a mid-thoracic level

laris by a small expansion called the terminal ventricle, *ventriculus terminalis*. Around the central canal grey matter, *substantia grisea*, is arranged. Grey matter resembles a butterfly in shape; in the fresh spinal cord preparations it has light-grey color. In the transverse sections at the different levels of the spinal cord, the area of grey matter is unequal: in the enlargements and conus medullaris, the area of grey matter is larger. Grey matter is mainly formed by the cell bodies.

Each half of grey matter (on the right and on the left) has an anterior expanded part called the anterior horn, *cornu anterius*, and posterior, more narrow, part known as the posterior horn, *cornu posterius*. The part situated between the anterior and posterior horns is described as the central intermediate substance, *substantia intermedia centralis*. In the segments C₈–L₃ there is a projection of grey matter, called the lateral horn, *cornu laterale*. The posterior, lateral and anterior horns form the grey columns, *columnae griseae*: posterior columns, *columnae posteriores*; lateral columns, *columnae laterales*; anterior columns, *columnae anteriores*, respectively.

On the lateral surface of the posterior horn (or lateral horn, where it is present) there is no distinct boundary between white and grey matter. Here are small areas of grey matter, separated by the white matter fascicles and collectively called the spinal reticular formation, *formatio reticularis medullae spinalis*. It is well-defined near the medulla oblongata in the cervical level of the spinal cord; in the thoracic level it gradually decreases, and in the lumbar level it disappears.

Apart from the cell bodies, grey matter contains the neuronal processes and endings, glial elements and microvessels. Some neurons are grouped into the nuclei. The neurons of each group (nucleus) have the same form and size. Within the nucleus the signals from one neuron to another are transmitted by means of synaptic contacts. Centrally in the posterior horn there are the middle multipolar neurons which form the nucleus proprius of the posterior horn, *nucleus proprius cornu posterioris*. At the posterior horn's base, in the central intermediate substance, there is a thoracic nucleus, *nucleus thoracicus* (of Clarke). This nucleus is fusiform; it is the large and well-defined in the thoracic segments hence the name. The nucleus corresponding to the it in the cervical level is called Stilling's nucleus. The central intermediate substance also contains the intermediomedial nucleus, *nucleus intermediomedialis*. In the lateral horn, situated only in the C₈–L₃ segments, there is a sympathetic intermediolateral nucleus, *nucleus intermediolateralis*.

The anterior horn contains six nuclei proprii, *nuclei proprii cornu anterioris*: antero-medial, posteromedial, anterior, anterolateral, posterolateral and central nuclei.

In the tip of the posterior horn there is an area described as gelatinous substance, *substantia gelatinosa* (of Rolando). Dorsal to the gelatinous substance is a spongy zone, *zona spongiosa*. The most external layer of the posterior horn is the terminal (marginal) zone, *zona terminalis*. All these areas contain small multipolar neurons.

Grey matter between the nuclei is mainly formed by separate small multipolar neurons, the disseminated cells, *cellulae disseminatae*, which whole are considered to be a nucleus because though they are not arranged compactly but have the same form, size and function.

The central intermediate substance of the 2–4 sacral segments contains the neurons that form the sacral parasympathetic nuclei, *nuclei parasympathici sacrales*.

Besides, some authors have described the parasympathetic centers in the thoracic and lumbar spinal segments. Some modern authors confirm the existence of so called grey commissure situated medial to the sympathetic nucleus in the lateral horn and containing the cells, antagonistic to the sympathetic.

Throughout 5–6 upper cervical segments, between the anterior and posterior horns is the spinal nucleus of the accessory nerve (XI cranial nerve). The axons of its neurons

pass through the lateral funiculus and leave the spinal cord between the anterior and posterior roots.

The gelatinous substance at the level of C₁–C₄ contains the spinal nucleus of the trigeminal nerve (V cranial nerve).

Grey matter is surrounded by white matter which consists mainly of the processes (myelinated fibres) of the neurons. Most of nerve fibres pass longitudinally (parallel or at a very acute angle to each other). Only in the certain limited areas, the fibres have another direction. These fibres pass almost horizontally and form a *zona radicularis* situated medial to the posterior horn. The same direction is also typical of the fibres arising from the the anterior horns` s nuclei proprii. These fibres pass through the anterolateral sulcus, forming the anterior spinal roots. The nerve fibres situated behind the anterior median fissure have an oblique direction and form the anterior white commissure, *comissura alba anterior*. Within the latter some nerve fascicles cross from one half of the spinal cord to the other, i.e. the anterior white commissure is a decussation of the nerve fibres.

Each half of the spinal cord consists of three white funiculi: anterior, lateral and posterior. The anterior funiculus, *funiculus anterior*, is between the anterior median fissure and medial surface of the anterior horn. The lateral funiculus, *funiculus lateralis*, is between the lateral surfaces of the anterior and posterior horns. The posterior funiculus, *funiculus posterior*, occupies the place between the posterior median septum and medial surface of the posterior horn. On the spinal cord` s surface the anterolateral and posterolateral sulci indicate the boundaries between the funiculi.

Each funiculus consists of the nerve fascicles (axons) which are united according to the same origin, direction and functional purpose. The collection of the axons transmitting the nerve impulses of the same function and direction and situated in the strictly determined places of the central nervous system is called the nerve tract.

2.3. Segmental Apparatus and Conduction Apparatus of the Spinal Cord

Segmental apparatus of the spinal cord is a collection of the functionally inter-related nerve structures providing the performance of the unconditioned (congenital) reflexes which are based on the simple reflex arches.

The segmental apparatus comprises the following structures (fig. 2.6).

1. The fibres of the posterior spinal roots (the central processes of the pseudounipolar neurons in the spinal ganglia), situated in the *zona radicularis* and ending by synaptic contacts with the intermediate neurons.

2. The intermediate neurons, the role of which is performed by the disseminated cells, the neurons of the gelatinous substance, spongy and terminal zones. The disseminated cells transmit the nerve impulse in the same segment to the neurons of the anterior horns` s nuclei proprii on the same side. The cells in the terminal and spongy zones transmit the information to the disseminated cells of 1–2 overlying and underlying segments. The cells in the gelatinous substance transmit the impulses to the disseminated cells in 3–4 overlying and underlying segments. Thus, during strong stimulation, the information is distributed over 6–7 segments (fig. 2.7).

3. Posterior, lateral and anterior fasciculi proprii of the spinal cord formed by the axons of the intermediate neurons situated at the tip of the posterior horn (neurons of the gelatinous substance, spongy and terminal zones) and dividing into ascending and descending branches which distribute to overlying and underlying segments. On

the transverse section of the spinal cord, the fasciculi proprii look like a narrow rim, immediately adjoining grey matter. The axons of the intermediate neurons have the numerous collaterals which form the synapses with the neurons of the anterior horns's nuclei proprii in the overlying and underlying segments.

4. The large multipolar neurons in the anterior horns's nuclei proprii and the commencements of their axons constituting the anterior spinal root fibres before their exit from the spinal cord.

Other elements of the reflex arches of unconditioned reflexes belong to the peripheral nervous system (anterior and posterior spinal roots, spinal ganglia, spinal nerves and their branches).

Most intermediate neurons of the segmental apparatus give their axons to the efferent neurons of the same side, but there are the neurons, whose axons travel to the opposite side of the spinal cord and cause the muscle contraction in the opposite body half. Minor part of the axons divides into two branches ending on the efferent neurons in the same and opposite sides. They may cause the muscle contraction of either one or both body sides simultaneously (for example, during an unconditioned reaction to the strong stimulus).

During the appearance of the nerve impulse even in one receptor, dozens (or hundreds) of the association neurons are involved in the nervous process; each neuron may cause the excitation of hundreds or thousands of efferent neurons in the anterior horns's nuclei proprii. The axons of each neuron cause the contraction of more than 100 muscle fibres. Thus, the stimulation of only one receptor causes the contraction of not only individual muscles but several muscle groups. This occurs due to avalanche increase of the nerve impulses in the spinal segmental apparatus.

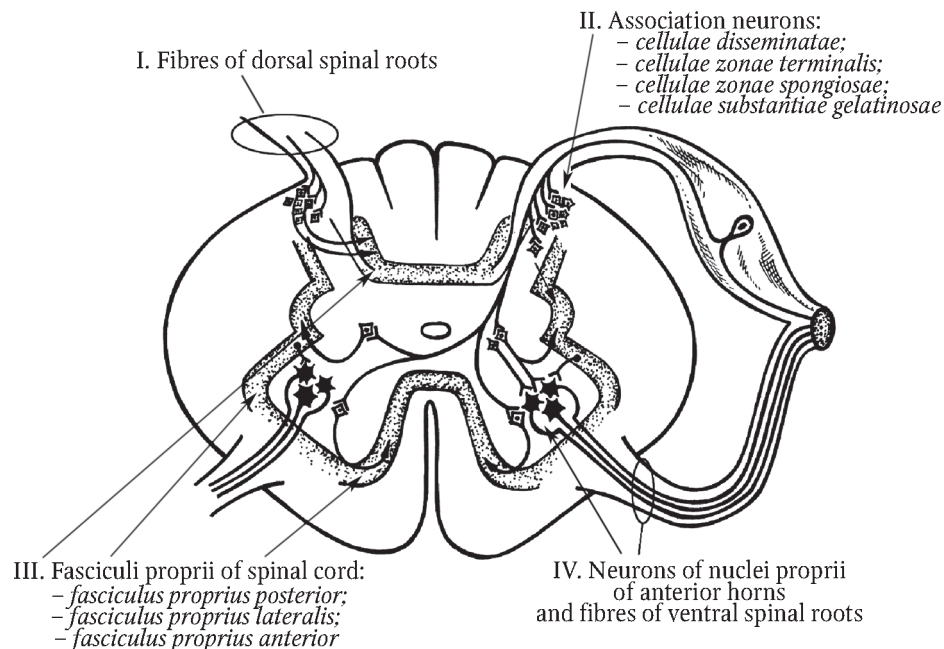


Fig. 2.6. Structures of the spinal cord constituting its segmental apparatus

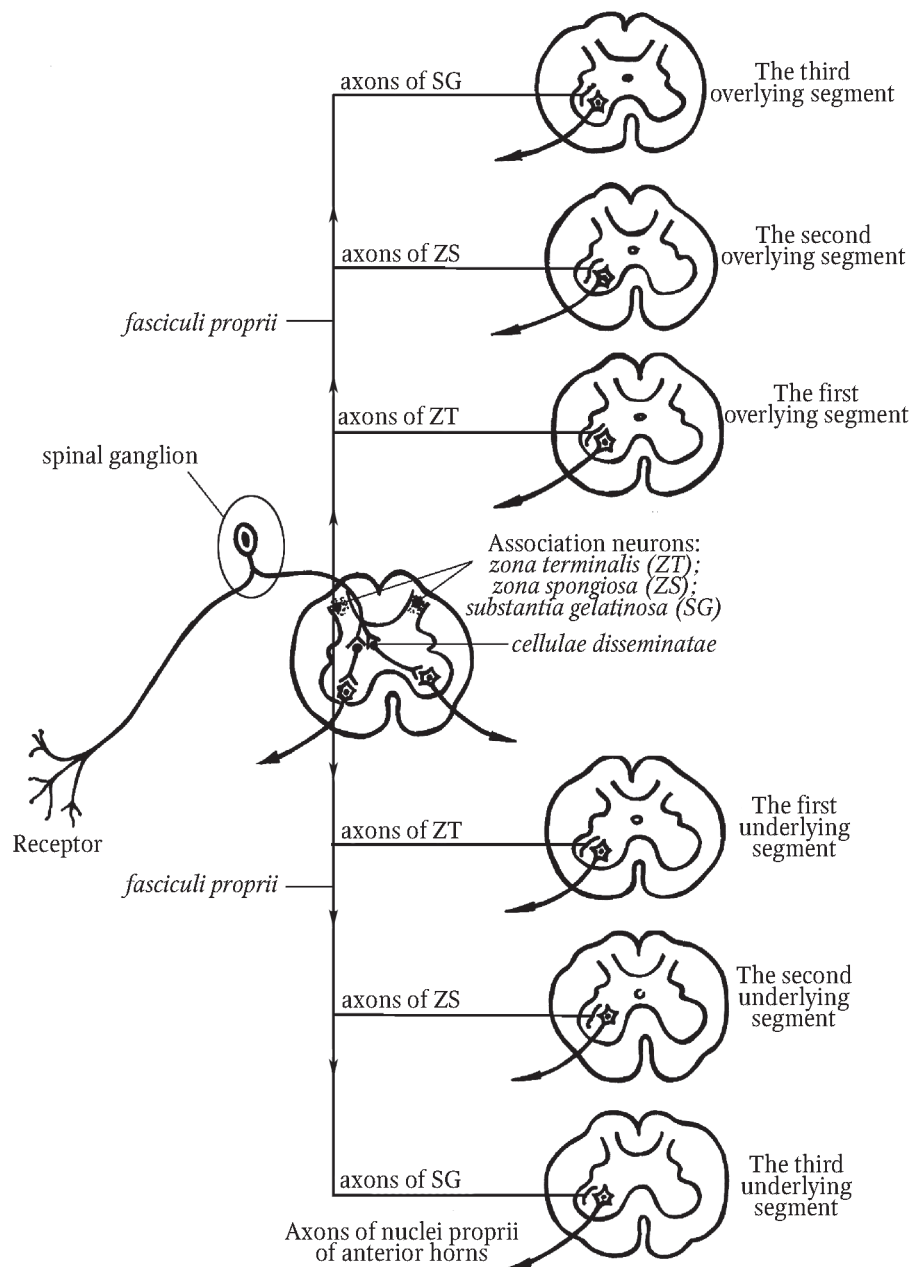


Fig. 2.7. The distribution of the nervous impulses in the spinal segmental apparatus to overlying and underlying segments (schematically). The formation of the polysegmental response to the stimulus:

SG – substantia gelatinosa; ZS – zona spongiosa; ZT – zona terminalis

Thus, the spinal segmental apparatus includes all grey matter structures (except for the nuclei comprising association neurons, which belong to the conduction apparatus), and the structures, anatomically and functionally interrelated with them: the fasciculi proprii of the spinal cord and the parts of the anterior and posterior spinal roots, corresponding to the certain segments.

Conduction apparatus of the spinal cord is included into the integration apparatus. It provides two-way communication with the integration cerebral centres (fig. 2.8) situated in the cerebellar cortex, midbrain superior colliculi and in the cerebral cortex. The integration centre of the autonomic nervous system is in the diencephalon.

The spinal conduction apparatus consists of the afferent (ascending) and efferent (descending) tracts. The afferent tracts start from the neurons located in the spinal ganglia and conduct the nerve impulses towards the integration cerebral centres. Along the afferent tract there are association neurons that collectively form the communication nerve centres. The efferent tracts are formed by the axons from the cerebral nuclei. They end on the neurons of the anterior horns's nuclei proprii in the spinal cord.

Thus, the integration apparatus situated in the spinal cord includes the afferent and efferent tracts and the communication centres located along the afferent tracts (nucleus proprius, thoracic nucleus, intermediomedial nucleus).

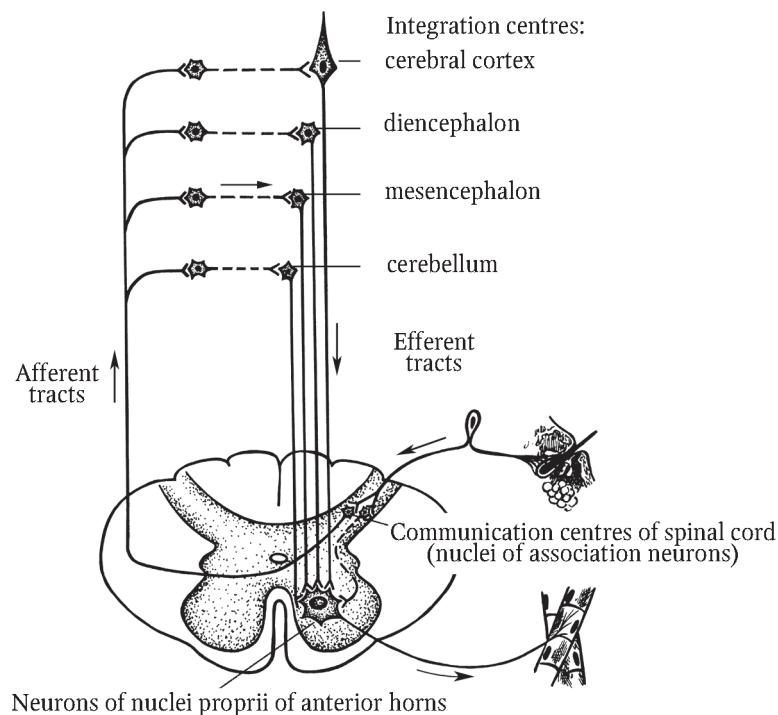


Fig. 2.8. The structures composing the integration (suprasegmental) apparatus of the nervous system

2.4. Composition of the Spinal Cord Funiculi. Brief Review of the Conduction Tracts contained in the Funiculi

The positions of the most important conduction tracts, the functions of which have been currently studied fairly completely, are shown in the figure 2.9; the relative area of each tract has been noted.

The posterior funiculus contains the following conduction tracts:

- 1) gracile fasciculus, *fasciculus gracilis* (of Goll);
- 2) cuneate fasciculus, *fasciculus cuneatus* (of Burdach);
- 3) posterior fasciculus proprius, *fasciculus proprius posterior*;
- 4) zona radicularis, *zona radicularis*.

Fasciculus gracilis is located in the medially in the posterior funiculus. It is formed by the central processes of the pseudounipolar neurons situated in lower 19 spinal ganglia (Co_1 , S_{1-5} , L_{1-5} , Th_{5-12}). These fibres enter the spinal cord, being a part of the posterior spinal roots; they bypass grey matter and travel immediately into the posterior funiculus where take ascending direction. The fasciculus gracilis nerve fibres conduct the impulses of conscious proprioceptive and partially tactile sensations from the lower body. The proprioceptive (deep) sensation is the information from the muscles, fasciae, tendons and joint capsules about the spatial position of the body parts, the muscle tone, the sense of weight, pressure and vibration.

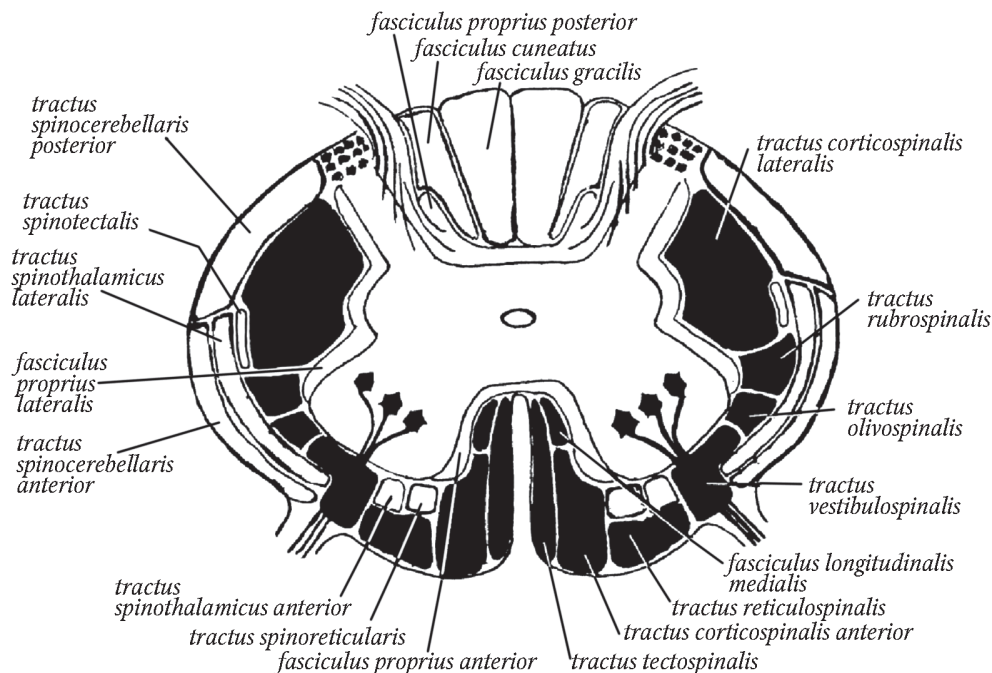


Fig. 2.9. The position of the conduction tracts shown on the transverse section of the spinal cord through upper cervical segment (schematically)

Fasciculus cuneatus is lateral to the fasciculus gracilis. It is formed by the central processes of the pseudounipolar neurons situated in upper 12 spinal ganglia (Th₁₋₄, C₁₋₈). The fasciculus cuneatus is formed like the fasciculus gracilis; it conducts the nerve impulses from the muscle receptors of the upper limb, neck and upper part of the trunk.

Posterior fasciculus proprius is formed by the axons of the association neurons which belong to the segmental apparatus. They lie close to the posterior horn, medial to it, and are oriented in the cranio-caudal direction.

Zona radicularis is formed by the nerve fibres of the posterior spinal root (the central processes of the pseudounipolar neurons located in the spinal ganglia). They are oriented horizontally and situated posterolaterally in the posterior funiculus.

Thus, the posterior funiculus is composed of the sensory fibres (the two afferent nerve fibres tracts, fibres of the posterior spinal root and posterior fasciculus proprius).

The lateral funiculus contains the following tracts:

- 1) posterior spinocerebellar tract, *tractus spinocerebellaris posterior* (of Flechsig);
- 2) anterior spinocerebellar tract, *tractus spinocerebellaris anterior* (of Gowers);
- 3) lateral spinothalamic tract, *tractus spinothalamicus lateralis*;
- 4) lateral corticospinal tract, *tractus corticospinalis lateralis*;
- 5) rubrospinal tract, *tractus rubrospinalis* (of Monakow);
- 6) olivospinal tract, *tractus olivospinalis*; spino-olivary tract, *tractus spinoolivarius*;
- 7) spinotectal tract, *tractus spinotectalis*.
- 8) lateral fasciculus proprius, *fasciculus proprius lateralis*;

Posterior spinocerebellar tract occupies the posterolateral part of the lateral funiculus. It is formed by the axons from the thoracic nucleus of the same side. This tract fibres conduct the impulses of unconscious proprioceptive sensation from the trunk, limbs and neck.

Anterior spinocerebellar tract is situated in the anterolateral part of the lateral funiculus. It is formed partially by the axons from the intermediomedial nucleus of the same side, and partially by those of the opposite side. The nerve fibres pass to the opposite side via the anterior white commissure. This tract carries out the same function as the posterior spinocerebellar tract.

Lateral spinothalamic tract is medial to the anterior spinocerebellar tract. It is formed by the axons from the posterior horn's nucleus proprius. They pass to the opposite side via the anterior white commissure and then ascend obliquely throughout 2-3 segments. This tract conducts the impulses of the pain and temperature sensation from the trunk, limbs and neck.

Lateral corticospinal tract lies in the posteromedial part of the lateral funiculus. It occupies near 40 % of the whole square of the lateral funiculus. The tract fibres are the axons of the pyramidal cells situated in the cerebral cortex therefore, this pathway is also called the pyramidal tract. In the spinal cord the tract's fibres end in each segment on the motor cells of the anterior horns's nuclei proprii. This tract conducts impulses providing conscious (voluntary) movements and the inhibitory effect on the neurons of the anterior horns's nuclei proprii.

Rubrospinal tract is placed in the middle of the lateral funiculus's anterior part. It is formed by the axons of the red nucleus cells, passing to the opposite side in the midbrain. The tract fibres end in the spinal cord on the neurons of the anterior horns's nuclei proprii. The function of this tract is to support the skeletal muscle tone for a long time (in the comfortable pose) and to perform the complex automatic unconditioned movements (walking, running).

Olivospinal and spino-olivary tracts are situated in the anteromedial part of the lateral funiculus. The olivospinal tract is formed by the axons from the olivary nucleus (located

in the medulla oblongata) of the same side. The nerve fibres end on the motor cells of the anterior horns` s nuclei proprii. The spino-olivary tract is formed by the part of the axons from the thoracic and intermediomedial nuclei; they end in the olivary nuclei. The function of these tracts is to provide the unconditioned regulation of the muscle tone and unconditioned movements during the changes of the body position in the space (in vestibular loads).

Spinotectal tract, *tractus spinotectalis*, is medial to the lateral spinothalamic tract. It is formed by the axons from the posterior horn` s nucleus proprius and end on the cells of the superior colliculus nuclei in the midbrain. The tract conducts the impulses of the unconscious pain, temperature and tactile sensation from the trunk, neck and limbs.

Lateral fasciculus proprius is a thin bundle, formed by the axons of the association neurons which belong to the segmental apparatus. The fasciculus lies in immediate vicinity to grey matter. These fibres transmit the nerve impulses to the neurons of the anterior horns` s nuclei proprii in the overlying and underlying segments.

Thus, the lateral funiculus contains the ascending (afferent), descending (efferent) tracts and fasciculi, i.e. according to the fibre composition it is mixed. Hence, the damages to the lateral funiculus manifest in both sensory and motor disorders.

Anterior funiculus contains the following tracts:

- 1) tectospinal tract, *tractus tectospinalis*;
- 2) anterior corticospinal tract, *tractus corticospinalis anterior*;
- 3) reticulospinal tract, *tractus reticulospinalis*, and spinoreticular tract, *tractus spino-reticularis*;
- 4) anterior spinothalamic tract, *tractus spinothalamicus anterior*;
- 5) medial longitudinal fasciculus, *fasciculus longitudinalis medialis*;
- 6) vestibulospinal tract, *tractus vestibulospinalis*;
- 7) anterior fasciculus proprius, *fasciculus proprius anterior*.

Tectospinal tract lies medially in the anterior funiculus, adjoining the anterior median fissure. It is formed by the axon from the midbrain superior colliculi of the opposite side. The fibres decussate in the midbrain. They end in the spinal cord on the motor cells of the anterior horns` s nuclei proprii. The function of this tract is to perform the unconditioned movements in response to the strong light, sound, olfactory and tactile stimuli (protective reflexes).

Anterior corticospinal tract is placed in the anterior part of the anterior funiculus, lateral to the tectospinal tract. The pathway is formed by the axons of the pyramidal cells situated in the cerebral cortex therefore, like the lateral corticospinal tract it is also called the pyramidal tract. Its fibres end in the spinal cord on the neurons of the anterior horns` s nuclei proprii. To innervate the limb musculature, the fibres gradually cross to the opposite side. To innervate the musculature of the trunk, the fibres pass both to the same and opposite sides. The tract carries out the same function as the lateral corticospinal tract.

Reticulospinal and spinoreticular tracts are situated lateral to the anterior corticospinal tract. These tracts are formed by the axons from the reticular formation (descending fibres) of the brain and of the spinal cord (ascending fibres). The reticular formation tracts play the important role in the support of the muscle tone; besides, they provide the differentiation of the impulses passing through the other tracts.

Anterior spinothalamic tract is lateral to the spinoreticular tract. Like the lateral spinothalamic tract, it is formed by the axons from the posterior horn` s nucleus proprius of the opposite side. It conducts the tactile impulses.

Medial longitudinal fasciculus lies in the posterior part of the anterior funiculus. It is constituted by the axons from the Cajal` s and Darkshevich` s nuclei situated in the

midbrain. They end in the cervical spinal segments on the motor cells of the anterior horns` s nuclei proprii. This fascicle provides the coordinated turns of the head and eyes.

Vestibulospinal tract is at the boundary between the anterior and lateral funiculi. It is formed by the axons from the vestibular nuclei (situated in the pons) of the same side. It ends on the motor cells of the anterior horns` s nuclei proprii. The tract provides the unconditioned regulation of the muscle tone and unconditioned movements during the changes of the body position in the space (during the vestibular loads).

Anterior fasciculus proprius lies in the anterior funiculus, medial to the anterior horn. This fascicle is formed by the axons of the association neurons which belong to the segmental apparatus. It provides the transmission of the nerve impulses to the neurons of the anterior horns` s nuclei proprii in the overlying and underlying segments.

Thus, the anterior funiculus contains mainly efferent fibres. The afferent tracts are represented here by thin bundles hence, the damage to the anterior funiculus manifests in the motor disorders.

To summarize everything described above, we emphasize some common patterns of the afferent and efferent tracts:

1) the afferent nerve tracts are formed in the spinal cord` s funiculi either by central processes of the pseudounipolar neurons of the spinal ganglia or the axons of the association neurons comprising the communication nuclei;

2) the afferent nerve tracts include not less than three neurons: I — receptor; II — association neuron of the communication nucleus (there may be several association neurons); III — the last association neuron which is situated in the integration cerebral centre;

3) the efferent nerve tracts always consist of two neurons: I neuron lies in the integration cerebral centre (it is association neuron relatively to the reflex arch); II neuron (effector) is represented by a motor cell of the anterior horns` s nuclei proprii;

4) the motor cells of the anterior horns` s nuclei proprii are heterogenous in their structure and function. They are classified as large motoneurons, small motoneurons and gamma motoneurons. The descending tracts passing from the cells of the cerebral cortex (pyramidal tracts) end on the large motoneurons. Thus, they provide the performance of the voluntary movements. The extrapyramidal tracts and axons of the association neurons situated belonging to the spinal segmental apparatus, which provide the performance of the unconditioned motor acts, end on the small motoneurons. The reticulospinal tract fibres which conduct the impulses supporting the muscle tone end on gamma motoneurons.

2.5. Meninges and Intermeningeal Spaces of the Spinal Cord

The spinal cord lies in the vertebral canal. However, between the canal` s walls and the surface of the spinal cord there is a space, 3–6 mm in width, which contains the spinal meninges and the content of the intermeningeal spaces (fig. 2.10).

The spinal cord is surrounded by three meninges: pia mater, arachnoid mater and dura mater. The pia mater, *pia mater spinalis*, immediately adjoins the spinal cord` s surface. It is rich in vessels which supply the spinal cord. Above, the spinal pia is continuous with the cerebral pia. Below, it envelops the spinal part of the filum terminale, *pars spinalis fili terminalis*, and, joining the other meninges, continues as a component of the dural part of the filum terminale, *pars duralis fili terminalis*.

The pia mater is dense and quite elastic. It closely envelops the spinal cord. It is pinkish-white, about 0,15 mm thick.

The numerous connective-tissue septa extend from the external surface of the pia mater to the arachnoid mater. From the lateral surface of the pia mater, closer to the anterior

spinal roots, the denticulate ligaments, *ligamenta denticulata*, arise. They lie in the frontal plane and look like a series of triangular processes. The apices of these processes are enveloped by the processes of the arachnoid mater and are fixed to the inner surface of the dura mater in the middle between two neighboring spinal nerves. The duplication of the pia mater enters the anterior median fissure already during the development of the spinal cord, and in adult it becomes a septum.

External to the spinal pia mater is the arachnoid mater, *arachnoidea mater spinalis*. It is a thin transparent membrane, 0,01–0,03 mm thick. The arachnoid is not entire, has slit-like openings and does not have vessels. At the foramen magnum it is continuous with the cerebral arachnoid; below, level with the II sacral vertebra, it blends with the spinal pia mater. From the lateral surface of the arachnoid the processes extend; they form the sheaths enveloping the ligamenta denticulata and spinal roots, penetrating the arachnoid.

The most external of the meninges is the dura mater, *dura mater spinalis*. This is a long connective tissue tube, separated from the vertebral periosteum (*endorachis*) by the epidural space, *spatium peridurale* (fig. 2.11). Above, at the foramen magnum, it is

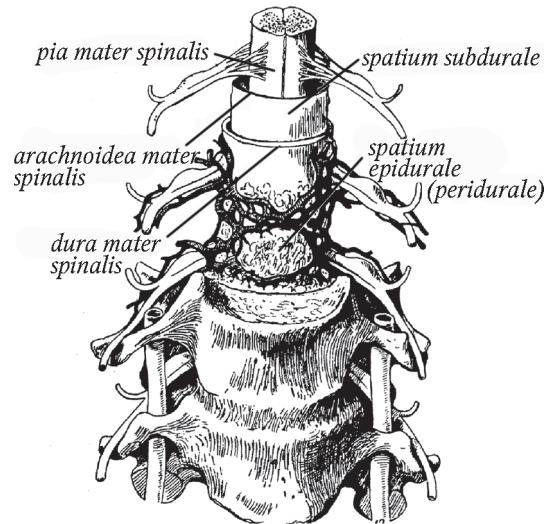


Fig. 2.10. The meninges and intermeningeal spaces of the spinal cord (anterior aspect)

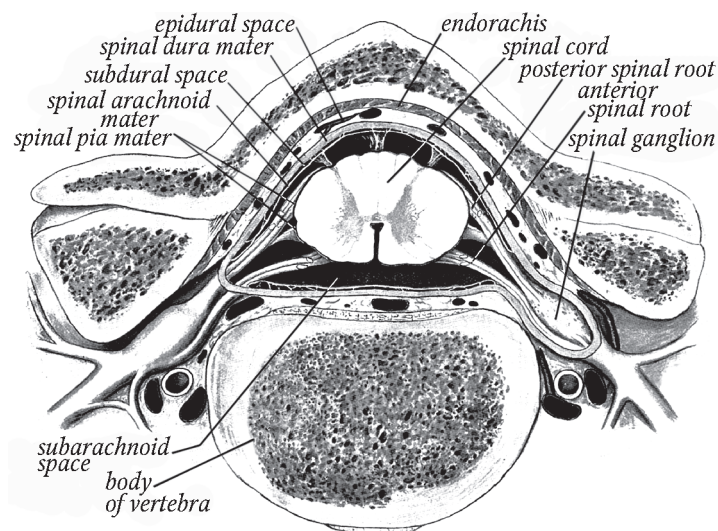


Fig. 2.11. The meninges and intermeningeal spaces of the spinal cord (transverse section)

continuous into the cerebral dura. Below, the dura mater ends in the cone, the apex of which is opposite the II sacral vertebra. Below this level the dura mater blends with the other spinal meninges into a common sheath enveloping the filum terminale. The thickness of the spinal dura mater ranges from 0,5 to 1,0 mm. The dura mater and *endorachis* are connected by the numerous connective tissue cords which are the most numerous in the cervical region.

The spinal dura mater gives the tubular prolongations surrounding the spinal nerve roots and spinal nerves as they traverse the intervertebral foramina; these prolongations are continuous into the spinal nerve sheaths.

Between the inner surface of the vertebral canal and dura mater there is a space called epidural (extradural), *spatium epidurale seu peridurale*. It contains fat and internal vertebral venous plexuses, *plexus venosi vertebrales interni*. Between the dura mater and arachnoid there is a slit-like space termed subdural, *spatium subdurale*, containing a little of cerebrospinal fluid. Between the arachnoid and pia mater there is a subarachnoid space, *spatium subarachnoideum*, containing the cerebrospinal fluid, *liquor cerebrospinalis*.

TEST QUESTIONS

1. Where is the spinal cord located? At the level of which vertebrae does it end?
2. Describe the spinal cord: its beginning, end and enlargements. Describe the composition of the cauda equina and its location. How is the cauda equina formed?
3. What parts of the spinal cord are distinguished? How many segments does each part include?
4. Give the definition of the spinal cord segment. How many segments are in the spinal cord?
5. Explain what the segmental body innervation means.
6. How is it accepted to denote the segments of the spinal cord?
7. Describe the relations (skeletonotopy) of the spinal segments to the vertebrae.
8. Describe the external structure of the spinal cord: its grooves, funiculi. Describe the structure of the funiculus.
9. Describe the structure of white and grey matter.
10. Describe the relations between white and grey matter in the spinal cord.
11. Explain what the anterior white commissure consists of.
12. Describe the central canal of the spinal cord. How does it end below and continue above?
13. Describe grey matter of the spinal cord. What is the horn? What segments of the spinal cord have the lateral horns? What are the columns of the spinal cord?
14. Explain, what is the nucleus?
15. Name and describe the nuclei of the posterior horns, lateral horns and anterior horns.
16. Describe the localization of the sympathetic and parasympathetic nuclei in the spinal cord.
17. The nuclei of which cranial nerves are located in the grey matter of the spinal cord?
18. Give the definition of the spinal ganglion. Describe its localization. How many spinal ganglia exist?
19. Describe the localization of the sensory, intermediate and motor neurons of the simple (spinal) reflex arch.

20. Describe the formation of the spinal nerves: the roots, the trunks. Through which sulci of the spinal cord do the spinal nerve roots pass? Through which openings do the spinal nerves leave the vertebral canal? How many pairs of the spinal nerves exist?
21. Give the definition of the segmental spinal cord's apparatus (its components and function)?
22. Give the definition of the conduction spinal cord's apparatus (its components and function)?
23. Name and describe the composition (conduction tracts) of the anterior funiculi, lateral funiculi and posterior funiculi.
24. List the meninges of the spinal cord in sequence. Describe their features.
25. Where are the denticulate ligaments located?
26. Describe the location and content of the epidural, subdural and subarachnoid spaces.
27. Where is cerebrospinal fluid situated in the spinal cord?

CLINICOANATOMICAL PROBLEMS

1. During the examination of a patient with trauma of the back, a doctor found the segmental disorders due to the damage to the XI-XII thoracic segments. At the level of which vertebrae, should the doctor do the radiography?
2. A patient has a compression of the spinal cord's ventral surface at the level of the VIII cervical segment. What types of the neurologic disorders (sensory or motor) are observed?
3. A patient has a tumor in the area of the anterior white commissure. What conduction tracts are damaged?
4. A patient has the paralysis of a body half. What tracts at the level of the spinal cord are damaged?
5. At what level should a doctor do the lumbar puncture without affecting the spinal cord?
6. A doctor is performing the lumbar puncture. List in sequence the structures, through which the needle passes during insertion.

3. BRAIN

3.1. General Data of the Brain

The brain, *encephalon*, is the part of the central nervous system that includes all the higher nervous centres. It is divided into the brain stem, *truncus encephali*, cerebellum, *cerebellum*, and cerebrum, *cerebrum*. In early stages of the development (the third week of prenatal life), the brain comprises three cerebral vesicles: rhombencephalon (or hind-brain), mesencephalon (or midbrain) and prosencephalon (or forebrain) (table 2). Further, the rhombencephalon develops into the myelencephalon (or medulla oblongata) and metencephalon. The metencephalon includes the pons, cerebellum and isthmus rhombencephali. The prosencephalon develops into the diencephalon and telencephalon during the 5th week of the embryonic life.

The brain stem is phylogenetically ancient part; it contains the structures which belong to the segmental apparatus of the brain and the subcortical centres of the hearing, vision, smell and tactile sensation. The brain stem consists of the medulla oblongata, pons and mesencephalon. The 10 pairs of the cranial nerves (III–XII) are associated with them. The II cranial nerve, the optic nerve, is associated with the diencephalon, the I cranial nerve, the olfactory nerve, is associated with telencephalon. The spatial position of the cerebral parts is shown in the figure 3.1.

The structures within the brain stem can be conventionally divided into three zones:

Table 2

Classification of the brain's parts

Tree-vesicle stage	Five-vesicle stage	Cavity of cerebral vesicle	Parts of the brain
I. Rhombencephalon	I. Myelencephalon (medulla oblongata) II. Metencephalon	The fourth ventricle	Medulla oblongata 1. Pons 2. Cerebellum 3. Isthmus rhombencephali
II. Mesencephalon	III. Mesencephalon	Aqueduct of mesencephalon	Mesencephalon: a) Cerebral peduncles; b) Tectal plate (quadrigeminal plate)
III. Prosencephalon	IV. Diencephalon V. Telencephalon	The third ventricle Lateral ventricles	Diencephalon: a) hypothalamus; b) thalamencephalon 1. Cerebral hemispheres; 2. Basal nuclei; 3. Rhinencephalon

I – the base of the brain stem (corresponds to the ventral surface). Here the descending (efferent) pyramidal tracts arising from the cerebral cortex pass (the corticospinal and corticonuclear tracts). They provide the performance of the precise, purposeful, conscious movements and inhibit the segmental apparatus. If the ventral surface of the brain stem is damaged, the central paralysis (paresis) occurs; it is characterized by the

increase of the muscle tone, increase of the muscle contractile activity (hyper-reflexia) and appearance of excessive abnormal movements (hyperkynesia).

II — tegmentum of the brain stem (corresponds to the brain-stem middle area). It contains the afferent (ascending) tracts and efferent extrapyramidal tracts arising from the motor subcortical centres. Besides, the tegmentum contains the reticular formation cells and nuclei, the cranial nerve nuclei and subcortical centres of the extrapyramidal system, which regulate the muscle tone and provide involuntary movements. The damage to the brain-stem tegmentum results in the sensory disorders, cranial nerve disorders, the disorders of the muscle tone and vital functions (respiration, vascular tone, heart activity).

III — tectum of the brain stem, situated dorsal to the cavity of the neural tube. It is represented by the subcortical integration centre of the midbrain, the quadrigeminal plate. The latter provides the unconditioned reflexes in response to the strong and sudden stimuli. The cerebellum is an integration centre of the rhombencephalon; it controls the coordination of movements.

The diencephalon, which develops from the posterior part of the anterior cerebral vesicle (III), is functionally and morphologically associated with the organ of vision. It contains the communication centres of all types of sensitive information and the integration centre of the vegetative functions. The telencephalon, which also develops from the anterior cerebral vesicle, comprises the phylogenetically newest part of the brain, where the higher integration centres are located. These centres produce conscious analysis of the received information and response voluntary movements.

It should be noted that from the spinal cord and cranial nerve sensory nuclei to the subcortical integration centres (cerebellum, mesencephalon and diencephalon) the unconscious afferent tracts pass, while to the integration centres of the cerebral cortex the conscious afferent tracts ascend. From the subcortical integration centres to the cranial nerve motor nuclei and to the motor nuclei of the spinal cord's anterior horns (the nuclei proprii), the extrapyramidal efferent tracts run (they provide unconscious movements); from the cerebral cortex the pyramidal efferent tracts pass (they provide conscious voluntary movements). The spatial relationship between the brain stem and telencephalon is shown in the figure 3.1.

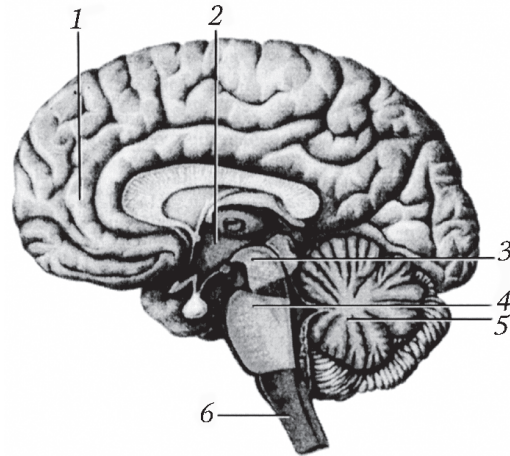


Fig. 3.1. Spatial relationship between the brain stem and telencephalon:

1 — telencephalon; 2 — diencephalon; 3 — mesencephalon; 4 — pons; 5 — cerebellum; 6 — myelencephalon

3.2. Medulla Oblongata

3.2.1. External Structure of Medulla Oblongata

The medulla oblongata, *myelencephalon*, (*bulbus cerebri*, *medulla oblongata*), is an immediate prolongation of the spinal cord. It is shaped like a truncated cone with the base directed up. Its average length is 25 mm, the largest width at the base is 22 mm,

thickness is 14 mm; the average weight is 6 g. Its ventral surface adjoins the lower part of the occipital bone's clivus and the dens of the axis. To understand the structure of the medulla oblongata, it should be recalled that, according to the development, it represents the segment of the neural tube. But during development, the lateral walls of the primary neural tube become considerably thicker, while the dorsal wall becomes thinner and remains only as a thin plate. This plate is formed by ependymal epithelium, to which pia mater adjoins from outside. During the making of the anatomical preparation, this part of the dorsal wall is usually destroyed.

The medulla oblongata has ventral, dorsal and lateral surfaces.

On the ventral medullary surface there is an anterior median fissure (fig. 3.2) which is continuous below with the spinal anterior median fissure.

On either side of the anterior median fissure there is a longitudinal elevation called the pyramid, *pyramis medullae oblongatae*, formed by the descending nerve fibres. At the boundary between the medulla oblongata and spinal cord, the most part of the fibres pass to opposite side forming the pyramidal decussation, *decussatio pyramidum*, which defines the lower border of the medulla oblongata. Lateral to each pyramid there is an anterolateral sulcus, *sulcus anterolateralis*, which is continuous below with the spinal anterolateral sulcus. It is well distinct in the upper part of the medulla oblongata where the roots of the hypoglossal nerve pass through it. In the lower part, the sulcus is interrupted by the external arcuate fibres, *fibrae arcuatae externae*, running transversely.

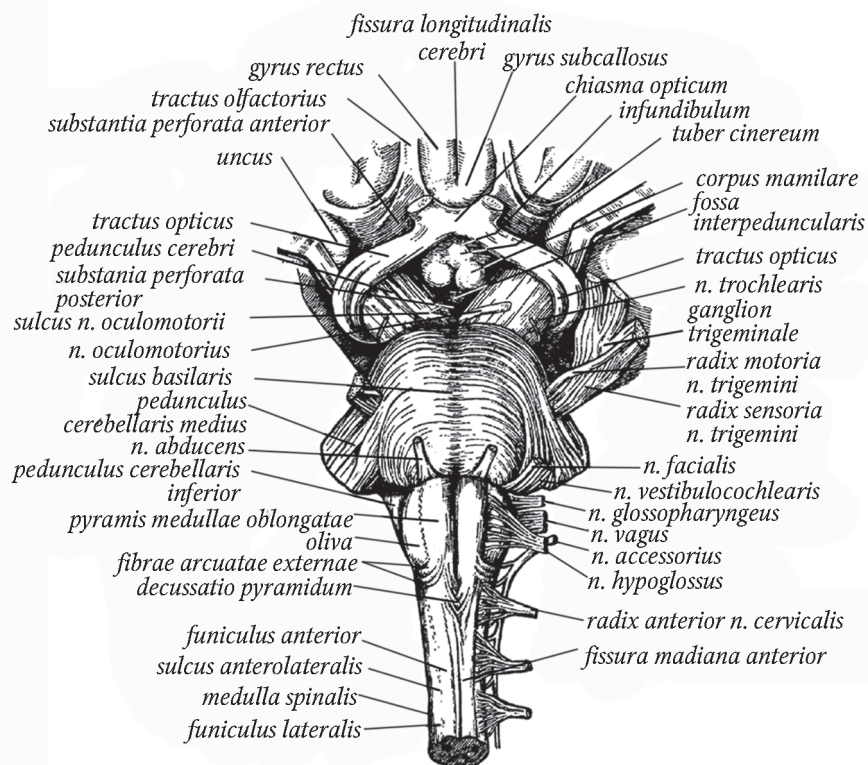


Fig. 3.2. Ventral surface of the brain stem

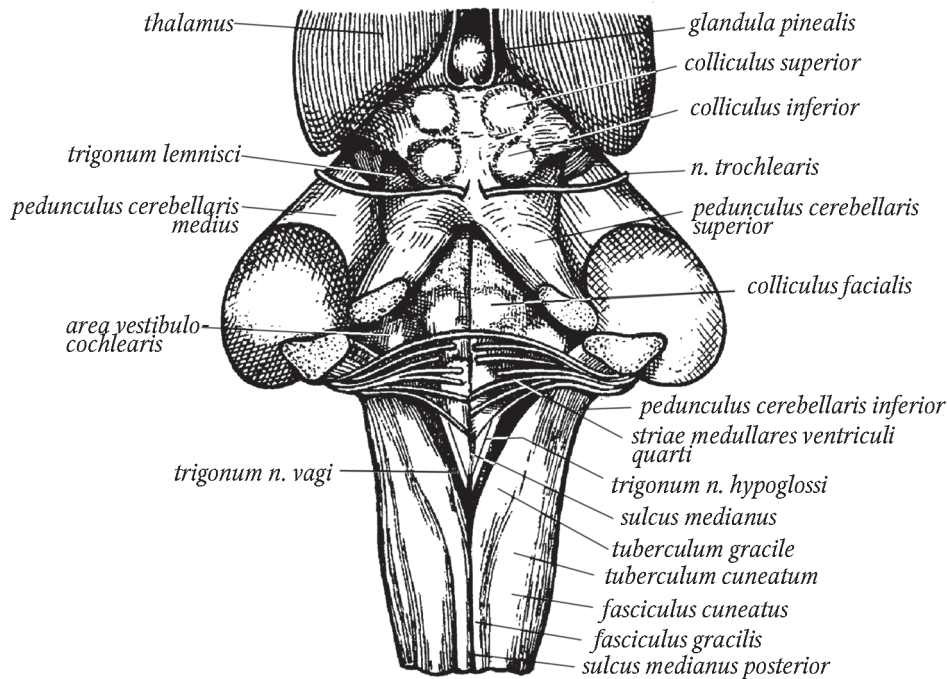


Fig. 3.3. Dorsal surface of the brain stem

At the upper part of the anterolateral sulcus, an oval elevation, called the olive, protrudes. Its length is about 14 mm and the width is about 5 mm. The upper end of the olive reaches the pons. Lateral to the olive is the posterolateral sulcus, *sulcus posterolateralis*, which does not correspond to the posterolateral sulcus of the spinal cord. The roots of the accessory, vagus and glossopharyngeal nerves pass through this sulcus.

The dorsal medullary surface can be divided into upper and lower levels (fig. 3.3). The basis of the upper level is formed by the lower half of the rhomboid fossa (this is a shallow triangular depression). The relief of the rhomboid fossa is described in the chapter «The IV ventricle».

In the lower level, the upward continuations of the gracile and cuneate fasciculi pass along the sides of the posterior median sulcus. At the lower angle of the rhomboid fossa they form elongated swellings called the gracile and cuneate tubercles, *tuberculum gracile et tuberculum cuneatum*. Approximately in the middle of the medulla oblongata, the fascicles diverge from their fellows laterally and up, and then continue as thick elevations called the inferior cerebellar peduncles, *pedunculi cerebellares inferiores*, which immerse into the cerebellum. The right and left inferior cerebellar peduncles limit a triangular area which represents the lower half of the rhomboid fossa.

3.2.2. Internal Structure of Medulla Oblongata

The medulla oblongata consists of grey and white matter.

Grey matter loses the shape of a butterfly (compared to the spinal cord), distributes irregularly and forms four nuclear groups (fig. 3.4).

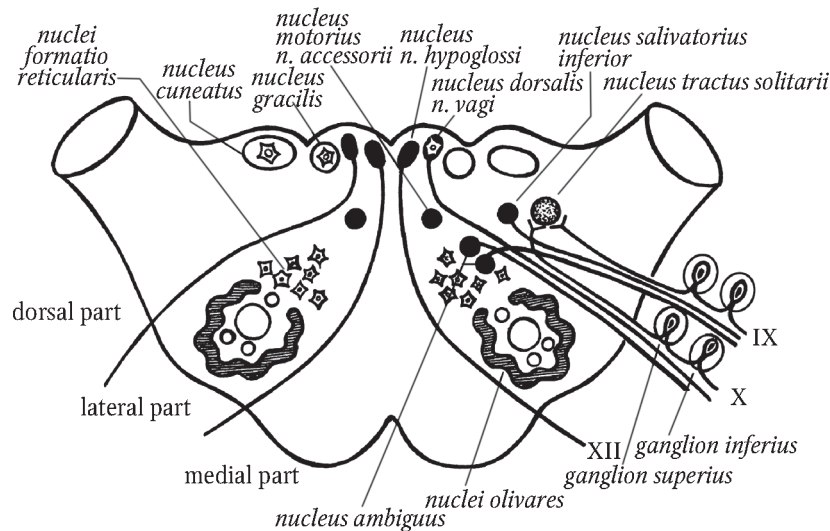


Fig. 3.4. Diagram of the position of the nuclei in the medulla oblongata

The first group: paired gracile and cuneate nuclei, *nucleus gracilis et nucleus cuneatus*, situated in the gracile and cuneate tubercles. The fibres comprising the gracile and cuneate fasciculi synapse with the neurons of these nuclei. Most axons of the gracile and cuneate nuclei (80 %) as internal arcuate fibres, *fibrae arcuate internae*, unite into a single bundle which at first passes ventrally, thereafter decussates at the midline and abruptly turns up as the medial lemniscus, *lemniscus medialis*. The decussation of these fibres is termed the lemniscal decussation, *decussatio lemniscorum medialis* (sensory decussation). The fibres comprising the medial lemniscus end in the thalamic nuclei. Therefore, the tract emerging from the neurons in the gracile and cuneate nuclei has the second name, the bulbothalamic tract, *tr. bulbothalamicus (lemniscus medialis)*. A smaller portion of the axons from the gracile and cuneate nuclei (20 %) as external arcuate fibres, *fibrae arcuatae externae*, passes forward to the ventral medullary surface in the area of the anterior median fissure. These fibres form the bulbocerebellar tract, *tr. bulbocerebellaris*; they curve around the pyramids and enter the cerebellum via the inferior cerebellar peduncles.

The second nuclear group includes the olivary nuclei. The fibres, emerging from the midbrain red nucleus and from the cerebral cortex, synapse with the neurons in the main olivary nucleus. Most axons of the olivary nuclei's neurons form the olivocerebellar tract, *tr. olivocerebellaris*, which decussate and enter the cerebellum via the inferior cerebellar peduncle. A smaller portion of the axons forms a descending olivospinal tract, *tr. olivospinalis*.

The third group is the nuclei of the reticular formation, *nuclei formatio reticularis*. They are scattered among the reticular formation nerve fibres, dorsal to the olivary nuclei. A part of the reticular formation cells and small nuclei (so called non-specific nuclei of the reticular formation) play the role of intermediate neurons in the brain-stem's seg-

mental apparatus. Other, larger, nuclei of the reticular formation function as the centres of such complex reflex acts as breathing (respiratory centre), heartbeat, tone of vessels (vasomotor centre) etc.

The fourth nuclear group is formed by the nuclei of the IX–XII cranial nerves. They are mainly placed in the triangular area on the dorsal medullary surface, facing the cavity of the IV ventricle. The nucleus of the XII, hypoglossal, nerve, *n. hypoglossus*, is in the area of the hypoglossal trigone, *trigonum n. hypoglossi*, which is situated medially in the rhomboid fossa's lower angle. Somewhat higher (rostrally) there is a nucleus of the XI, accessory, nerve, *n. accessorius*. This nucleus prolongates into the spinal cord to the level of C₅₋₆, occupying the area in the central intermediate substance, near the anterior horn.

In a small area on the dorsal medullary surface, known as the ala cinerea, a vegetative (parasympathetic) dorsal vagal nucleus, *nucleus dorsalis n. vagi*, is placed. This nucleus is within the vagal trigone, *trigonum nervi vagi*, lying dorsal to the hypoglossal nucleus. Rostral to the dorsal vagal nucleus is a vegetative (parasympathetic) nucleus of the IX, glossopharyngeal, nerve, called the inferior salivatory nucleus, *nucleus salivatorius inferior*. The X and IX cranial nerves have a common motor nucleus, the nucleus ambiguus, *nucleus ambiguus*. This nucleus projects near the posterior median sulcus, in the rhomboid fossa's lower part. The sensory nucleus of the X and IX cranial nerves is called the nucleus of solitary tract, *nucleus tractus solitarii*. This is an elongated nucleus, situated lateral to the vegetative nuclei.

The names of the nuclei and their functional purpose are summarized in table 3.

White matter of the medulla oblongata is represented by the nerve fibres having mainly longitudinal direction (fig. 3.5). Some of them are ascending (afferent), other are descending (efferent).

Most part of the ascending fibres is the continuation of those of the spinal cord. Along the posterior median sulcus there are gracile and cuneate fasciculi (of Goll and Burdach), the fibres of which synapse with the neurons of their respective nuclei (*nucleus gracilis et nucleus cuneatus*). The axons from these nuclei comprise the bulbothalamic and bulbocerebral tracts.

Close to the lateral medullary surface there are anterior and posterior spinocerebellar tracts (bundles of Gowers and Flechsig). The anterior spinocerebellar tract deviates laterally to enter the cerebellum via the inferior cerebellar peduncle. The posterior spinocerebellar tract is located more ventrally and continues into the pons.

Table 3

Cranial nerves, associated with the medulla oblongata, and their nuclei

The number and name of cranial nerve	The nuclei and their names		
	motor	sensory	parasympathetic
XII cranial nerve (hypoglossal)	Hypoglossal nucleus	—	—
XI cranial nerve (accessory)	Nucleus of accessory nerve	—	—
X cranial nerve (vagus)	Nucleus ambiguus	Nucleus of solitary tract	Dorsal vagal nucleus
IX cranial nerve (glossopharyngeal)	Nucleus ambiguus	Nucleus of solitary tract	Inferior salivatory nucleus

Medial to the anterior spinocerebellar tract, like in the lateral spinal funiculus, is the spinothalamic tract, *tr. spinothalamicus*, which unite the fibres of the anterior and lateral

spinothalamic tract ascending from the spinal cord. This tract keeps the same position (medial to the anterior spinocerebellar tract) throughout whole medulla oblongata.

The descending fibres of the medulla oblongata emerge from different motor nuclei located in the brain.

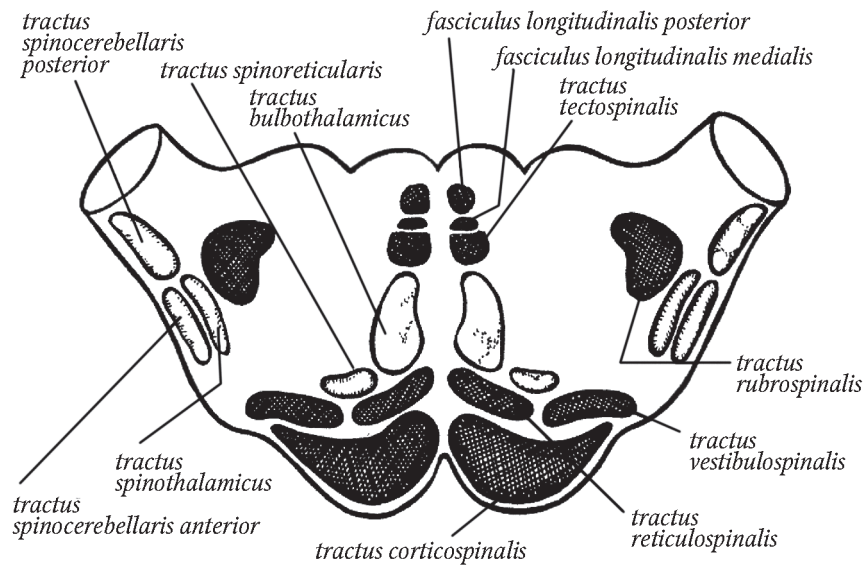


Fig. 3.5. Diagram showing the position of the conduction tracts in a transverse section of the medulla oblongata

The largest bundle of the efferent fibres, the corticospinal tract, *tr. corticospinalis*, is on the ventral side of the medulla oblongata; it forms the main mass of the pyramids. In the lower medulla major part of its fibres (70–80 %) pass to the opposite side to enter the spinal lateral funiculus as the lateral corticospinal tract, *tr. corticospinalis lateralis*. The rest of the fibres pass through the spinal anterior funiculus of the same side, forming the anterior corticospinal tract, *tr. corticospinalis anterior*.

Close to the dorsal medullary surface, flanking the median plane, is the dorsal longitudinal fasciculus, *fasciculus longitudinalis posterior*, which belongs to the conduction tracts of the autonomic nervous system. The medial longitudinal fasciculus, *fasciculus longitudinalis medialis*, is ventral to it. In front of the medial longitudinal fasciculus there is a tectospinal tract, *tr. tectospinalis*.

Medial to afferent spinothalamic tract is the rubrospinal tract. Dorsal to the pyramids is the reticulospinal tract, and lateral to it is the vestibulospinal tract.

Apart from the afferent and efferent tracts passing through the medulla oblongata, there are the tracts connecting the sensory nuclei of the IX and X cranial nerves with integration cerebral centres, the nucleothalamic and nucleocerebellar tracts, *tr. nucleothalamicus* et *tr. nucleocerebellaris*.

The nucleothalamic tract is a tract which transmits the general sensory impulses (superficial and deep) from the head region. Besides, it conducts the information from the interoceptors. The nucleocerebellar tract conducts unconscious proprioceptive impulses

from the head region. The corticonuclear tract fibres, *tr. corticonuclearis*, end in the motor nuclei of the IX, X, XI and XII cranial nerves. This tract is responsible for voluntary movements of the head, partially of the neck and several internal organs (the function is analogous to the corticospinal tract).

As shown in the figure 3.4, the fibres of the X and XII cranial nerves divide the cross section of the medulla oblongata into three parts on each side: medial, lateral and dorsal. The medial part is between the anterior median fissure and the hypoglossal nerve fibres. The lateral part is between the fibres of the hypoglossal and vagus nerves. The dorsal part is outward to the vagus nerve fibres.

The figures 3.4 and 3.5 show the position of the medulla oblongata's nuclei and tracts on the cross section. It is important to know the localization of the nuclei and tracts to understand the functional disorders in patients with neurological diseases.

3.3. Pons

3.3.1. External Structure of Pons

The pons, *pons*, is the anterior part of the rhombencephalon. It looks like a transverse bulge which narrows laterally. Its length along the midline is 2,5 cm, width is 3–3,5 cm, thickness is 2,5 cm, weight is 16–18 g. A pontine ventral surface is directed to the occipital bone's clivus; the dorsal surface is directed to the cerebellum. On the ventral surface there is a shallow basilar sulcus, *sulcus basilaris*, containing the basilar artery (fig. 3.6). The basilar sulcus is bounded by transversely striated prominences due to corticospinal fibres descending in the pons. The striation is caused by the nerve fibres converging on each side into the middle cerebral peduncles. An arbitrary lateral border of the pons is the line passing through the place where the trigeminal nerve emerges. This nerve is the largest of all the cranial nerves; the diameter of its trunk is 3–5 mm.

Apart from the trigeminal nerve roots, the roots of the abducens, facial and vestibulocochlear nerves emerge from the pons. The abducens nerve, *n. abducens*, VI cranial

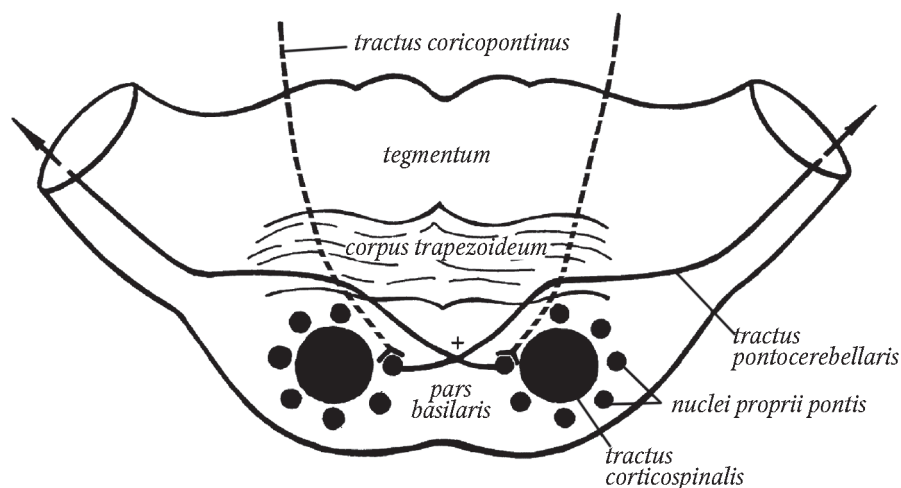


Fig. 3.6. Transverse section of the pons (schematically). Connections of the pontine nuclei

nerve, has one root, situated in a horizontal medullopontine sulcus, *sulcus bulbopontinus*, at the boundary between the pons and the medullary pyramid. The facial nerve, *n. facialis*, VII cranial nerve, and vestibulocochlear nerve, *n. vestibulocochlearis*, VIII cranial nerve, each has one root; the roots pass in the cerebellopontine angle, *angulus pontocerebellaris*. The dorsal pontine surface, triangular, is directed to the cavity of the IV ventricle and represents the rhomboid fossa's upper half (fig. 3.3). Laterally the triangle is bounded by the superior cerebellar peduncles, *pedunculi cerebellares superiores*; inferiorly it is bounded by the medullary striae of the IV ventricle, *striae medullares ventriculi quarti*. Along the midline there is a median sulcus, *sulcus medianus*, which is flanked by the medial eminence, *eminentia medialis*, bounded by the *sulcus limitans*. Above the medullary striae, within the medial eminence, there is a facial colliculus, *colliculus facialis*, formed by the facial nerve motor fibres which curve around the abducens nerve nucleus.

3.3.2. Internal Structure of Pons

A transverse section of the pons shows three parts: ventral, *pars ventralis*, or basilar part, *pars basilaris*; dorsal part, *pars dorsalis*, or tegmentum, *tegmentum pontis*; and the trapezoid body, *corpus trapezoideum*, located between these two parts (fig. 3.6).

The basilar part consists of white and grey matter. Grey matter forms numerous small pontine nuclei, *nuclei proprii pontis*. The nerve fibres from the neurons of the cerebral hemispheres form the corticopontine tract, synapsing with neurons in the pontine nuclei. The axons of these neurons run to the opposite side and reach the cortex of the cerebellar hemispheres via the middle cerebellar peduncles as the pontocerebellar tract, *tr. pontocerebellaris*.

White matter of the basilar pons is formed by the fibres running in longitudinal and transverse directions, *fibrae pontis longitudinales et fibrae pontis transversae*. The corticospinal tract, oriented longitudinally, passes through the basilar pons; within the pons it is represented by dispersed fibres. At the lower pontine edge these fibres converge into a compact bundle to form the medullary pyramids. The fibres comprising the corticonuclear tract also have a longitudinal direction; they partially end on the V, VI and VII cranial nerve motor nuclei and partially continue to the IX–XII cranial nerve motor nuclei located in the medulla oblongata.

The fibres comprising the corticopontine tract, which end in the pontine nuclei, also have a longitudinal direction. The axons from the pontine nuclei pass transversely, forming the pontocerebellar tract, *tr. pontocerebellaris*; they look like a transverse striation on the ventral pontine surface.

The dorsal part of the pons, *tegmentum*, also consists of white and grey matter. Grey matter forms the nuclei of the V, VI, VII and VIII cranial nerves, which are mainly located in the dorsolateral part of the tegmentum. Besides, here are the nuclei included in the reticular formation which is situated on each side of the midplane.

The trigeminal nerve nuclei (V cranial nerve) are located not only within the pons (fig. 3.7) but also in the midbrain and spinal cord. The pontine tegmentum contains a sensory pontine nucleus of the trigeminal nerve, *nucleus pontinus* (it is also called the principal nucleus of the trigeminal nerve, *nucleus principalis nervi trigemini*), and motor nucleus of the trigeminal nerve, *nucleus motorius n. trigemini*. The pontine nucleus is the communication centre of the tactile sense from the face. The posterior horns in the upper four cervical segments (C_1 – C_4) contain the spinal nucleus of the trigeminal nerve, *nucleus spinalis n. trigemini*. It is the communication centre of the pain and temperature senses from the face. The last sensory nucleus of the V cranial nerve, the mesencephalic

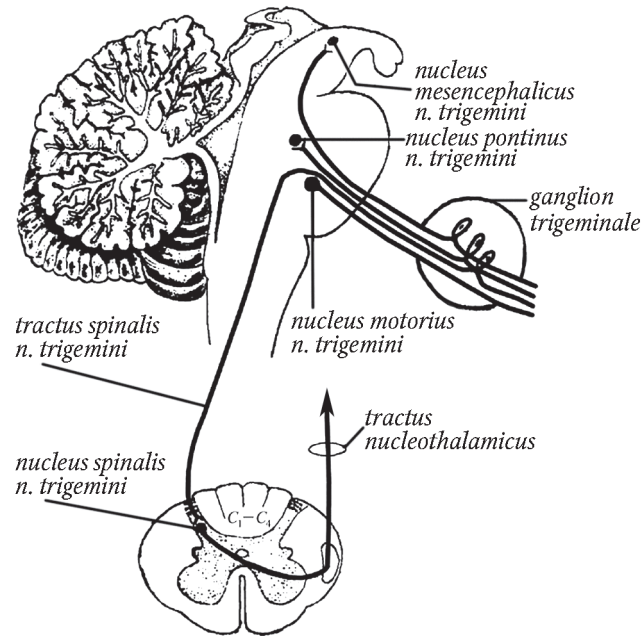


Fig. 3.7. Position of the trigeminal nerve nuclei (schematically)

nucleus of the trigeminal nerve, *nucleus mesencephalicus n. trigemini*, is in the central grey substance of the midbrain, lateral to the cerebral aqueduct. It is the communication centre of the proprioceptive sense from the musculature of the face, soft palate, suprahyoid muscles and tensor tympani.

The motor impulses to the noted muscles pass from the trigeminal nerve motor nucleus, situated in the pontine tegmentum. All the sensory trigeminal nerve nuclei represent the association neurons, whose axons pass into the integration cerebral centres via the nucleothalamic tract (the pathway conducting the conscious impulses of the general sensation from the head and neck) and nucleocerebellar tract (the pathway conducting the unconscious proprioceptive impulses from the head and neck).

The first neurons of the afferent tracts are in the trigeminal ganglion, *ganglion trigeminale*, lying in the trigeminal impression on the anterior surface of the temporal bone's pyramid in the splitting of the dura matter.

The abducens, VI cranial nerve, *n. abducens*, is a motor nerve (fig. 3.8). Its motor nucleus, *nucleus n. abducentis*, is located dorsally in the pontine tegmentum. The nucleus is surrounded by curved fibres of the facial nerve, which form the facial colliculus in the upper half of the rhomboid fossa. The root of the abducens nerve emerges in the medullopontine sulcus between the pons and medulla oblongata.

The facial, VII cranial nerve, *n. facialis*, is a mixed nerve: it has motor, sensory and parasympathetic nuclei. The axons from the motor nucleus, *nucleus nervi facialis*, at first pass dorsally, and then curve around the abducens nucleus and run ventrolaterally. The facial nerve root emerges in the cerebellopontine angle.

The parasympathetic nuclei of the facial nerve, the superior salivatory nucleus, *nucleus salivatorius superior*, and lacrimal nucleus, *nucleus lacrimalis*, lie laterally in the pon-

tine tegmentum. The axons from these nuclei emerge together with the motor nucleus fibres.

The sensory nucleus containing the intermediate neurons of the afferent tracts is called the nucleus of solitary tract, *nucleus tractus solitarii*. It is common for the X, IX and VII cranial nerves. The receptor neurons (pseudounipolar cells), linked with the facial nerve, lie in the geniculate ganglion, *ganglion geniculi*, which is placed in the facial canal of the pyramid. According to the modern nomenclature, the facial nerve sensory and parasympathetic elements refer to the intermediate nerve, *n. intermedius*.

The nuclei of the VIII, vestibulocochlear nerve, *n. vestibulocochlearis*, have complex architectonics and connections. They lie at the boundary between the medulla oblongata and pons, in the lateral part of the rhomboid fossa, which is called the vestibulocochlear area, *area vestibulocochlearis*.

Taking into account the complex structure of this nerve, it is appropriate to describe its cochlear and vestibular parts separately. The localization of the cochlear nuclei is shown in the figure 3.9. The vestibular nuclei and their connections are represented in the figure 3.10.

It should be noted that the cochlear nuclei lie in the most lateral part of the vestibulocochlear area; there are two cochlear nuclei: anterior (ventral) and posterior (dorsal), *nucleus cochlearis anterior et nucleus cochlearis posterior*. The central processes from the bipolar neurons of the cochlear ganglion situated in the bony part of the cochlea synapse in these nuclei. The central processes of the bipolar neurons collectively form the cochlear nerve (the lower, or cochlear, root of the vestibulocochlear nerve).

The axons of the cochlear nuclei neurons run to the nuclei of the trapezoid body. But the course of the axons from the ventral and dorsal nuclei differs considerably. The axons from the dorsal cochlear nucleus appear on the dorsal pontine surface, forming the medullary (acoustic) striae of the IV ventricle, *striae medullares ventriculi quarti*. Then they immerse in the median sulcus of the rhomboid fossa and synapse with the neurons of the trapezoid body's posterior nucleus. The axons from the ventral cochlear nucleus run to the opposite side, ending on the neurons of the trapezoid body's anterior nuclei. They pass in the ventral pons, forming the basis of the trapezoid body. On a transverse

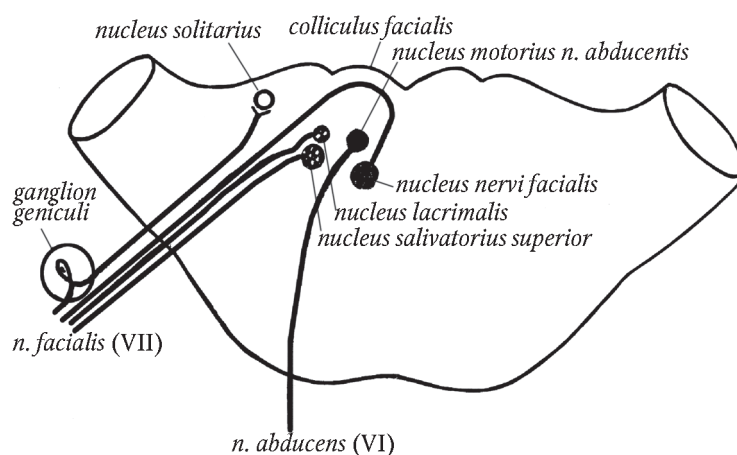


Fig. 3.8. The position of the vestibulocochlear and facial nerve nuclei (schematically)

section of the pons these fibres look like a transverse striation. The axons from the trapezoid body nuclei form a bundle called the lateral (acoustic) lemniscus, *lemniscus lateralis*. Its fibres run to the subcortical auditory centres (nucleus of the midbrain inferior colliculus, nuclei of the medial geniculate body and median thalamic nuclei). Along the lateral lemniscus within the pons the nuclei of the lateral lemniscus, *nuclei lemnisci lateralis*, are scattered; a part of the fibres from the cochlear nuclei, passing through the trapezoid body, is interrupted by the synapses with the neurons of these nuclei.

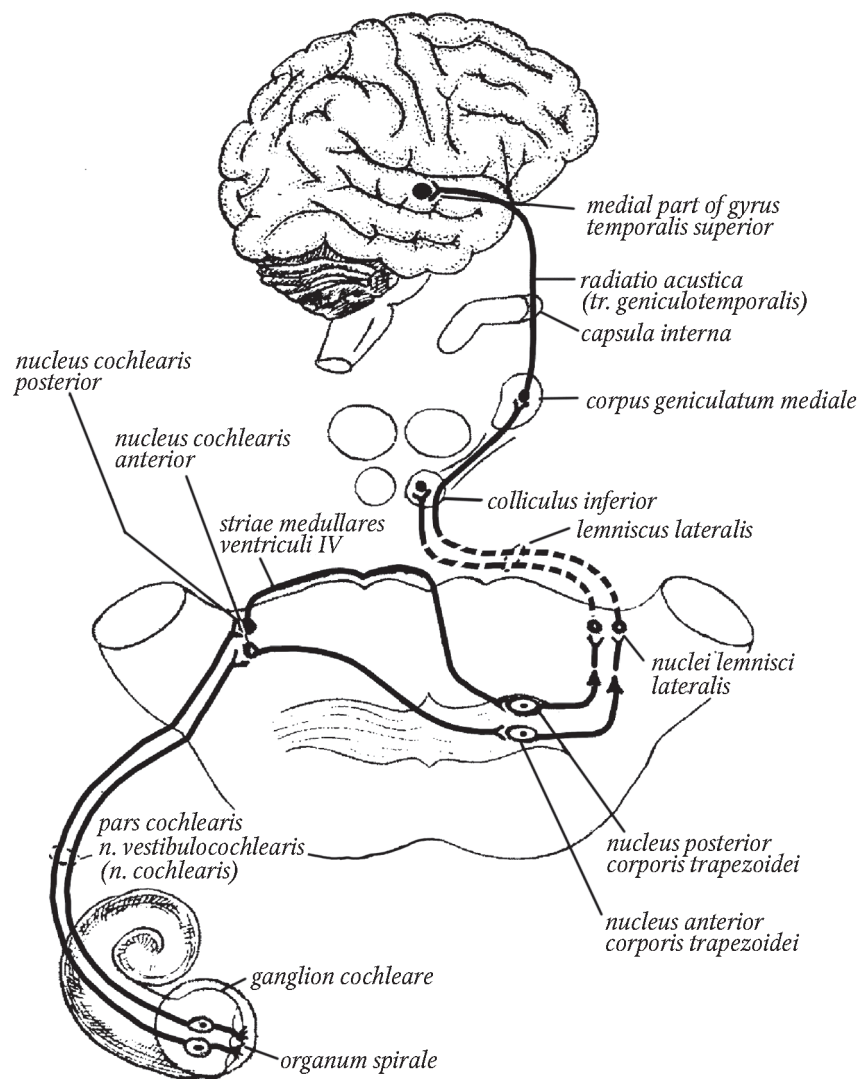


Fig. 3.9. The position of the cochlear nuclei in the pons (schematically). Auditory pathway

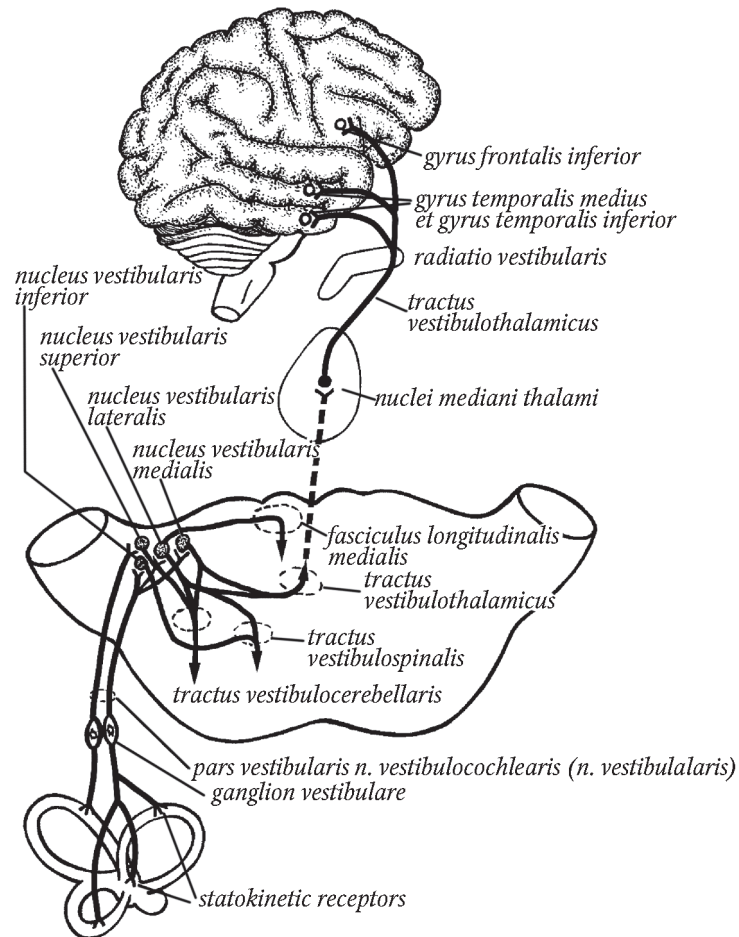


Fig. 3.10. The position of the vestibular nuclei in the pons (schematically). Vestibular pathway

The vestibular nuclei lie medial to the cochlear nuclei. On each side of the pons there are four nuclei: lateral vestibular nucleus (of Deiters), *nucleus vestibularis lateralis*; medial vestibular nucleus (of Schwalbe), *nucleus vestibularis medialis*; superior vestibular nucleus (of Bechterew), *nucleus vestibularis superior*, inferior vestibular nucleus (of Roller), *nucleus vestibularis inferior*. The central processes from the bipolar cells of the vestibular ganglion, located in the internal acoustic meatus, synapse with the neurons of the noted nuclei. The central processes of the vestibular ganglion neurons collectively form the vestibular nerve (upper, or vestibular, root of the vestibulocochlear nerve).

The axons of the vestibular nuclei neurons form several bundles running into the spinal cord, medial longitudinal fasciculus, cerebellum and to the median thalamic nuclei. The course of these fibres is described more detailed in the chapter «Conduction tracts of the central nervous system».

The names of the cranial nerve nuclei located in the pons are shown in table 4.

In conclusion, it should be noted that pontine grey matter is represented by four nuclear groups:

- 1) pontine nuclei, situated in the ventral pons;
- 2) nuclei of the V–VIII cranial nerves, located in the pontine tegmentum;
- 3) nuclei of the reticular formation, also located in the pontine tegmentum;
- 4) nuclei of the trapezoid body.

Table 4

Cranial nerves associated with the pons, and their nuclei

The number and name of cranial nerve	The nuclei and their names		
	motor	sensory	parasympathetic
VIII cranial nerve (vestibulocochlear)	—	Anterior cochlear nucleus; posterior cochlear nucleus; lateral vestibular nucleus (of Deiters); medial vestibular nucleus (of Schwalbe); superior vestibular nucleus (of Bechterew); inferior vestibular nucleus (of Roller)	—
VII cranial nerve (facial)	Nucleus of facial nerve	Nucleus of solitary tract	Superior salivatory nucleus; lacrimal nucleus
VI cranial nerve (abducens)	Abducens nucleus	—	—
V cranial nerve (trigeminal)	Motor nucleus of trigeminal nerve	Pontine nucleus of trigeminal nerve; spinal nucleus of trigeminal nerve; mesencephalic nucleus of trigeminal nerve	—

White matter of the pontine tegmentum is formed by the fibres of the longitudinal direction (fig. 3.11). Most of them are afferent and come to the pons from the spinal cord and medulla oblongata. Close to the lateral edge of the tegmentum there is a bundle of the anterior spinocerebellar tract. Medial to it (like in the medulla oblongata) is the spinothalamic tract (spinal lemniscus), which unites the fibres of the lateral and anterior spinothalamic tracts. More medial there are the fibres arising from the nuclei of the medulla oblongata: the nucleothalamic tract (trigeminal lemniscus) and bulbothalamic tract (medial lemniscus). In clinic literature the fibres of these three tracts (spinothalamic, nucleothalamic and bulbothalamic) are united by a common term, the medial lemniscus.

The most considerable efferent bundle in the pontine tegmentum is the rubrospinal tract which is situated in its lateral part. Close to it there is a vestibulospinal tract, whose fibres derive mainly from the lateral vestibular nucleus of the VIII cranial nerve.

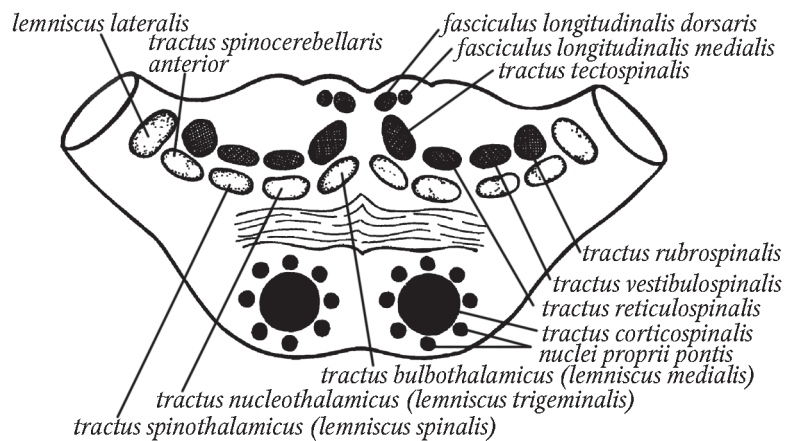


Fig. 3.11. The position of the conduction tracts on a transverse section of the pons (schematically)

From the nuclei of the pontine reticular formation a relatively small bundle arises; it joins the reticulospinal tract which starts from the reticular formation in the diencephalon and mesencephalon.

Dorsal to the midline, close to it, are the medial and dorsal longitudinal fasciculi. Anterior (ventral) to the medial longitudinal fasciculus is the tectospinal tract arising from the neurons of the mesencephalic superior colliculi.

3.4. Cerebellum

3.4.1. External Structure of Cerebellum

The cerebellum, *cerebellum*, develops from the dorsal wall of the metencephalon; it is the second largest part of the brain, after the cerebral hemispheres.

The cerebellum is placed in the posterior cranial fossa together with the medulla oblongata and pons.

The cerebellum has a rhomboid shape with prevalence of the transverse size. Its average sizes: the width is 10 cm; the length along the median line is 3–4 cm; the weight is 135 g.

The cerebellum consists of a middle part, *the vermis*, and two lateral voluminous parts, the hemispheres, *hemispheria*. Based on the development of the cerebellum in the phylogenesis, it should distinguish a small structure adjoining the ventral hemispheric surface, the flocculus. The vermis and cerebellar hemispheres have two surfaces: superior and inferior (fig. 3.12).

The superior surface of the cerebellum, *facies superior cerebelli*, is directed up and backwards. It is convex and has a median longitudinal ridge called the superior vermis, *vermis superior*. Laterally, the vermis is continuous with the hemispheres. The inferior cerebellar surface, *facies inferior cerebelli*, is directed down and forwards. It adjoins the occipital bone and has a longitudinal depression called the vallecule, *vallecule cerebelli*. The latter is adapted to the inferior vermis which is limited on each side by a vallecular sulcus.

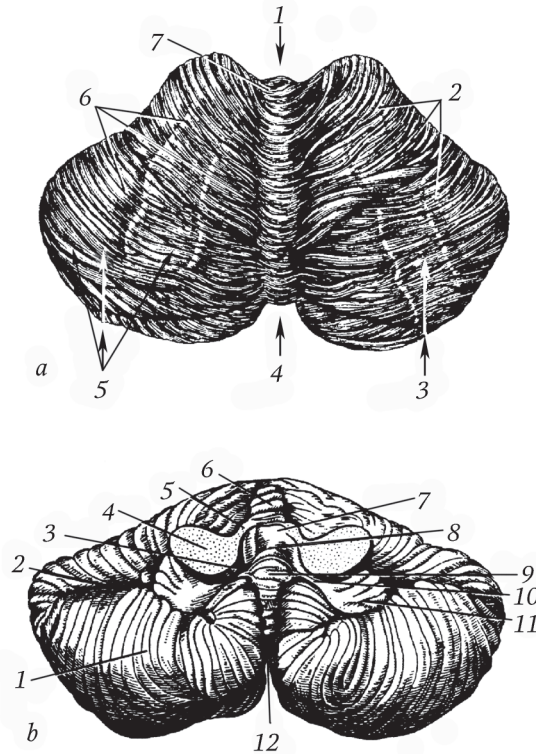


Fig. 3.12. Cerebellum:

a – superior aspect: 1 – anterior cerebellar notch; 2 – folia cerebelli; 3 – cerebellar hemispheres (superior surface); 4 – posterior cerebellar notch; 5 – cerebellar fissures; 6 – central lobule; 7 – vermis;
b – posterior aspect: 1 – cerebellar hemispheres (inferior surface); 2 – horizontal fissure; 3 – tela choroidea of IV ventricle; 4 – middle cerebellar peduncle; 5 – superior cerebellar peduncle; 6 – vermis; 7 – superior medullary velum; 8 – IV ventricle; 9 – nodulus; 10 – peduncle of flocculus; 11 – flocculus; 12 – posterior cerebellar notch

The cerebellar surface is wholly occupied by numerous parallel, transverse fissures of different depth, giving it a laminated appearance. Shallow fissures divide the cerebellar surface into *lamellae* (*gyri*); deeper fissures separate lamellar groups into *laminae* termed *folia cerebelli*. The deepest fissures divide the cerebellar surface into lobules, *lobuli*.

Of the fissures separating the cerebellar lobules, the horizontal fissure, *sulcus horizontalis*, is the deepest (up to 2 cm). It passes throughout cerebellar circumference and separates superior and inferior surfaces.

The cerebellar fissures continue without interruption from the vermis to the hemispheres. The flocculus also has a laminated structure but does not have lobules.

The vermis consists of eight lobules (four lobules are in the superior and four lobules are in the inferior vermis) (fig. 3.13). The most anterior lobule of the superior vermis is the lingula, *lingula cerebelli*; it is formed by several laminae. The next to the former is the central lobule, *lobulus centralis*, which corresponds to the upper, most prominent,

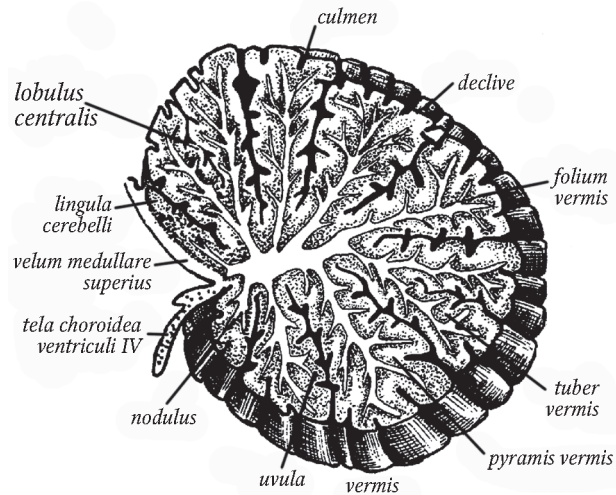


Fig. 3.13. The lobules of the vermis. Median section

portion of the vermis. Posterior to the central lobule is the *monticulus*, consisting of the *culmen* (anteriorly) and *declive* (posteriorly). The most posterior lobule of the superior vermis is *folium*, *folium cerebelli*, which limits the horizontal fissure superiorly.

In the inferior vermis, immediately below the *folium*, there is a *tuber vermis*. Anteriorly to it is the pyramid, *pyramis vermis*, which protrudes in the floor of the cerebellar vallecule. More anteriorly is the narrowest portion of the inferior vermis, the *uvula*, *uvula vermis*, which is as though compressed by the adjoining parts of the hemispheres. The most anterior lobule of the inferior vermis is the *nodulus*.

In front of and behind the vermis there are two depressions: the anterior and posterior cerebellar notches, *incisurae cerebelli anterior et posterior*, formed by the protruding edges of the right and left hemispheres.

In each hemisphere, the hemispheric lobules correspond to the vermian lobules. The superior hemispheric surface is divided into quadrangular lobule, *lobulus quadrangularis*, and superior semilunar lobule, *lobulus semilunaris superior*.

The inferior hemispheric surface is divided from front to back into the inferior semilunar lobule, *lobulus semilunaris inferior*, gracile lobule, *lobulus gracilis*, biventral lobule, *lobulus biventer*, and cerebellar tonsil, *tonsilla cerebelli* (fig. 3.14).

The flocculus is a small group of the cerebellar laminae adjoining the middle cerebellar peduncle.

Such a division of the cerebellum into the lobules was done based on the assumption about the existence of the connections between the certain hemispheric and vermian areas. The modern researches allow us to consider that it is more rational to distinguish the parts, the function of which developed during the phylogenesis and ontogenesis. Thus, the cerebellum can be divisible into *paleocerebellum*, which includes the flocculus and nodulus, *archicerebellum*, comprising the vermis, except for the nodulus, and *neocerebellum*, consisting of the cerebellar hemispheres which developed from the middle portion of the vermis.

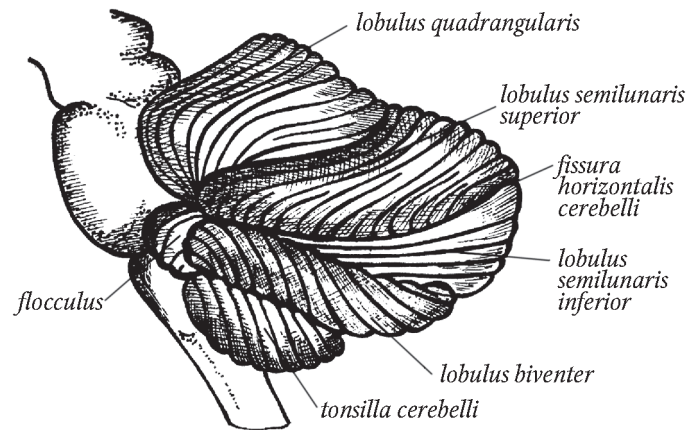


Fig. 3.14. The lobules of the cerebellar hemispheres. Lateral aspect

3.4.2. Internal Structure of Cerebellum

The sections of the cerebellum show grey matter, lying superficially and forming the cerebellar cortex, *cortex cerebelli*, and white matter, located under grey matter and forming the medullary body, *corpus medullare*, which is prolonged by laminae projecting towards the surface into the cerebellar lobules. On the median section of the cerebellum, white matter has a leaf shape, figuratively called «the tree of life», *arbor vitae*.

Within cerebellar white matter there are the cerebellar nuclei (fig. 3.15). In the vermis, on each side of the midline there is a *nucleus fastigii*. Lateral to this nucleus is the second small nucleus termed the *nucleus globosus*. More laterally there is a *nucleus emboliformis*. The largest nucleus, the *nucleus dentatus*, is situated in white matter of the cerebellar hemispheres.

The nucleus fastigii belongs to paleocerebellum; nucleus globosus and emboliformis were formed phylogenetically later (belong to archicerebellum); the nucleus dentatus belongs to neocerebellum.

Cerebellar white matter contains afferent and efferent fibres that connect the cerebellum to the brain stem and form the cerebellar peduncles. There are three pairs of the cerebellar peduncles: superior, middle and inferior. Superior cerebellar peduncles, *pedunculi cerebellares superiores*, connect the cerebellum to the midbrain; the middle cerebellar peduncles, *pedunculi cerebellares medii*, to the pons; inferior cerebellar peduncles, *pedunculi cerebellares inferiores*, to the medulla oblongata (fig. 3.16). The superior and inferior cerebellar peduncles can be seen from the dorsal surface of the brain stem, while the middle cerebellar peduncles from its ventral surface.

The cerebellum differs profoundly from the medulla oblongata and pons: a layer of grey matter, the cerebellar cortex, covers the whole cerebellar surface. The cerebellar cortex, *cortex cerebelli*, is a collection of the neurons, the arrangement of which is strictly subordinated to a certain pattern. The cortex consists of three layers: outer, the molecular layer; middle, the layer of Purkinje (piriform) neurons; inner, the granular layer. Such a layered neuronal arrangement is a distinct morphological feature of the integration cerebral centres thus the cerebellum is one of them. This explains numerous complex connections of the cerebellum with other parts of the central nervous system.

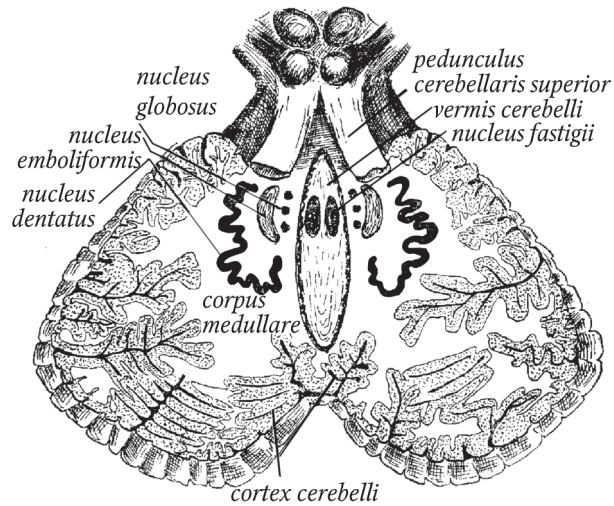


Fig. 3.15. The arrangement of white and grey matter in the cerebellum

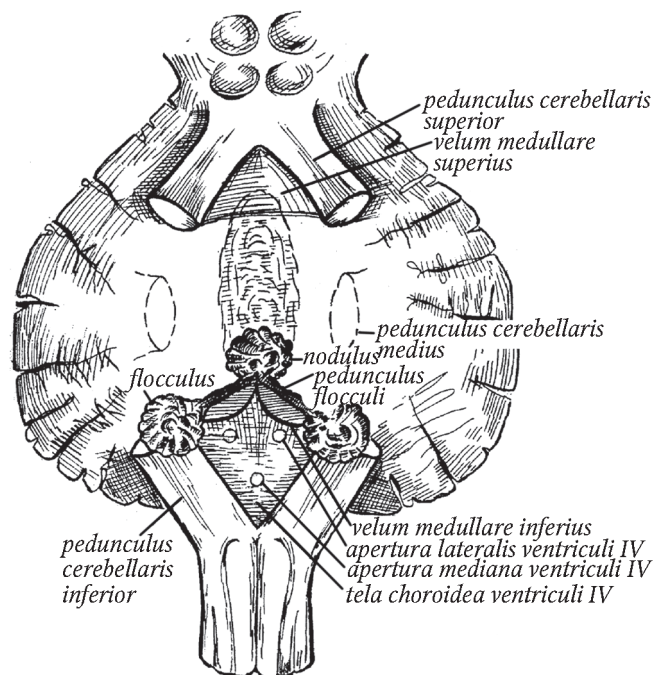


Fig. 3.16. The position of the cerebellar peduncles, superior and inferior medullary velli (schematically). Horizontal section through superior and inferior cerebellar peduncles

3.4.3. Connections of the Cerebellum with the Spinal Cord and Brain

The oldest connections of the cerebellum have been established with the organs of balance. The nerve fibres that partially form the vestibulocerebellar tract have extended from the vestibular nuclei. They enter the cerebellum via the inferior peduncles and end on the neurons in the floccular and nodular cortex. From these neurons the descending (efferent) tract arises. Its nerve fibres reach the neurons of the nucleus fastigii (the most ancient cerebellar nucleus). Via the inferior cerebellar peduncles the axons from the nucleus fastigii reach the reticular formation nuclei in the medulla oblongata. From the reticular formation through the reticulospinal tract the efferent impulses pass to the muscles of the trunk. The described neural connections of the cerebellum (vestibulo-spinal afferent tract and cerebello-reticulo-spinal tracts) played an important role in inhabitants of aquatic environment, whose locomotion was performed mainly due to the muscles of the trunk (fig. 3.17).

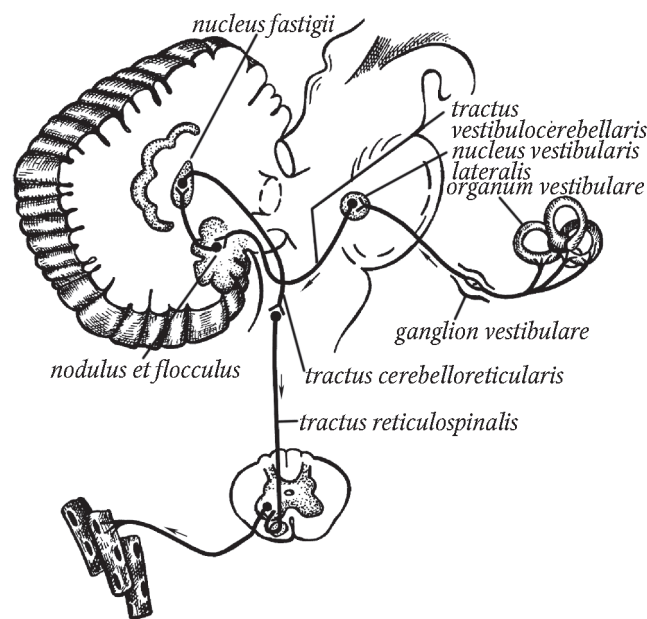


Fig. 3.17. The conduction tract of paleocerebellum

Later, due to the move of animals onto land and the development of the limbs, the afferent tracts (the anterior and posterior spinocerebellar tracts) from the receptors of the limb's muscles, tendons and joints appeared. The fibres of the posterior spinocerebellar tract (of Flechsig) pass through the inferior cerebellar peduncles to end on the neurons in the inferior vermician cortex. The fibres of the anterior spinocerebellar tract (of Gowers) enter the cerebellum via the superior cerebellar peduncles and end on the neurons in the superior vermician cortex. The efferent pathway from the neurons of the vermician cortex passes to the neurons of the nucleus globosus and emboliformis. The axons from

these nuclei leave the cerebellum via the inferior peduncles and reach the neurons in the reticular formation. Further, the efferent impulses pass through the reticulospinal tract to the limbs` s muscles (fig. 3.18).

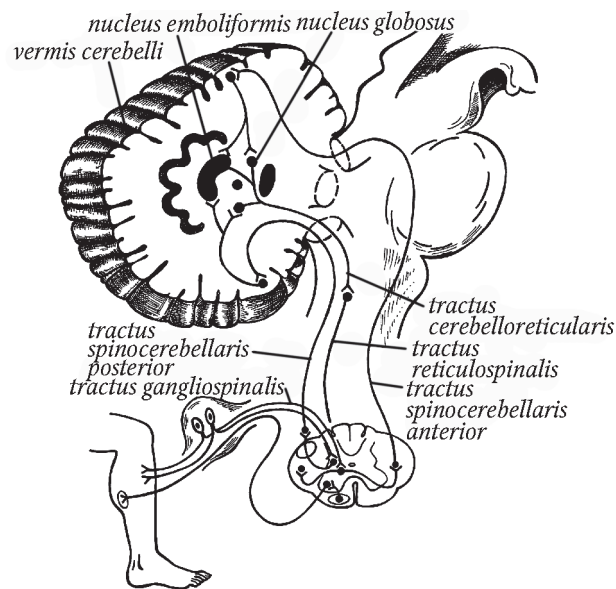


Fig. 3.18. The conduction tracts of archicerebellum

Due to the complication of the trunk and limbs, the bulbocerebellar and nucleo-cerebellar tracts were formed; they end in the middle part of the vermian cortex. The efferent tract from the neurons of this cortical area is analogous to the previous tracts.

In mammals, and especially in humans, the system of so called precerebellar nuclei was developed: the olivary and pontine nuclei. The olivary nuclei receive the impulses through the collaterals arising from the pyramidal and extrapyramidal tracts. The axons of the olivary neurons pass through the inferior cerebellar peduncles, forming the olivo-cerebellar tract. This tract` s fibres decussate in the medulla oblongata and end on the neurons in the cortex of the cerebellar hemispheres.

The pontine nuclei are the communication centers on the way of the cortico-ponto-cerebellar tract. The corticopontine tract fibres and the collaterals from the pyramidal tract end in these nuclei. The axons from the pontine nuclei pass to the opposite side and thereafter via the middle cerebellar peduncles to the neurons in the cortex of the cerebellar hemispheres. From here the cerebello-dentato-rubro-spinal tract arises; it corrects the complex voluntary movements, performed mainly by the upper limb (fig. 3.19).

The complex nervous connections of the cerebellum with the cerebral hemispheres explain the diversity of its functions. The cerebellum is not merely «organ of balance». It participates in the coordination of the work of the different muscle groups (flexors and extensors), helps to overcome the inertia of rest and inertia of motions (rapid alternating pronation and supination of the hands, extended forwards), provides the precision

of the fine movements etc. The damage to the cerebellar structures are accompanied by the disorder of its characteristic functions and manifest in such symptoms as cerebellar ataxia, intention tremor during the performance of fine movements and disorder of the coordination.

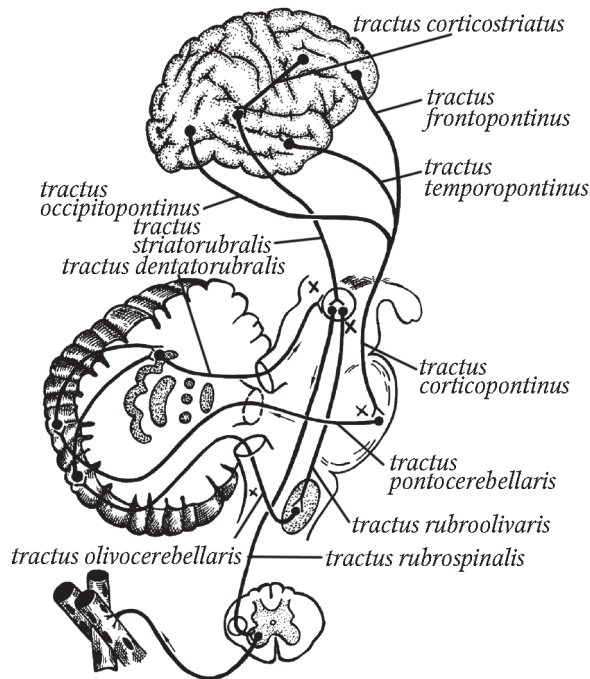


Fig. 3.19. The conduction tracts of neocerebellum

It should be noted that the efferent cerebellar tracts decussate twice (before the red nucleus and after it). Due to this, the unilateral damage to the cerebellum manifests in the disorder of the muscle functions on the same side. Even unilateral damages to the cerebellum cause the disorder of the body equilibrium.

3.4.4. Conduction Tracts of the Cerebellum

It is appropriate to group the cerebellar conduction tracts according to their location in the cerebellar peduncles (fig. 3.20).

Through the inferior cerebellar peduncles the following tracts pass:

- posterior spinocerebellar tract, *tr. spinocerebellaris posterior*;
- bulbocerebellar tract, *tr. bulbocerebellaris*;
- olivocerebellar tract, *tr. olivocerebellaris*;
- vestibulocerebellar tract, *tr. vestibulocerebellaris*;
- nucleocerebellar tract, *tr. nucleocerebellaris*;
- cerebelloolivary tract, *tr. cerebelloolivaris*;

- cerebellovestibular tract, *tr. cerebellovestibularis*;
- cerebelloreticular tract, *tr. cerebelloreticularis*.

Posterior spinocerebellar tract (afferent) is formed by the axons of the thoracic nucleus neurons. All fibres of this tract ascend on the same side without decussation in the posterolateral part of the spinal lateral funiculus. They synapse with the neurons in the inferior vermician cortex.

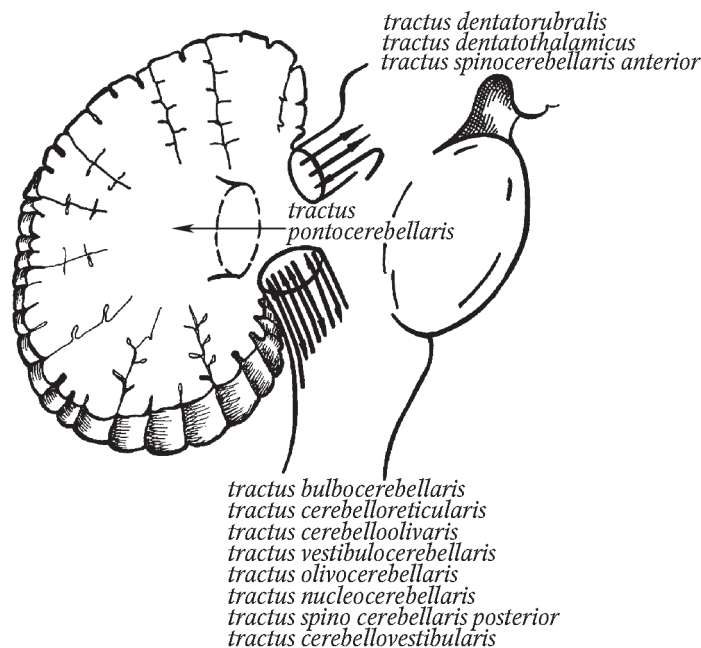


Fig. 3.20. The position of the main tracts which pass through the cerebellar peduncles (schematically)

Bulbocerebellar tract (afferent) is formed by the axons arising from the neurons situated in the communication centres of the gracile and cuneate nuclei. The tract ends on the neurons in the middle part of the vermician cortex.

Vestibulocerebellar tract (afferent) is formed by the axons from the vestibular nuclei situated in the pons (mainly from the lateral and superior vestibular nuclei). The tract ends on the neurons in the nodulus and flocculi.

Olivocerebellar tract (afferent) is formed by the axons arising from the neurons of the olivary nuclei situated in the medulla oblongata. The tract ends on the neurons in the cortex of the opposite cerebellar hemisphere.

Nucleocerebellar tract (afferent) is formed by the axons from the sensory nuclei of the IX, X, VII and V cranial nerves. The tract ends on the neurons in the middle part of the vermician cortex.

Cerebellovestibular tract (efferent) is formed by the axons of the neurons located in the floccular and nodular cortex. The tract ends on those neurons in the lateral vestibular nuclei that form the vestibulospinal tract.

Cerebelloolivary tract (association) is formed by the axons of the neurons located in the cortex of the cerebellar hemispheres. The tract ends in the olivary nuclei.

Cerebelloreticular tract (efferent) arises from the neurons of the nuclei fastigii, globosus and emboliformis. The tract ends on the reticular formation neurons in the medulla oblongata and spinal cord, whose axons form the reticulospinal tract.

Through the middle cerebellar peduncles only pontocerebellar tract, *tr. pontocerebellaris*, passes. This association tract includes the axons from pontine nuclei and ends on the neurons in the cortex of the opposite cerebellar hemisphere.

Through the superior cerebellar peduncles the following tracts pass:

- anterior spinocerebellar tract, *tr. spinocerebellaris anterior*;
- dentatorubral tract, *tr. dentatorubralis*;
- dentatothalamic tract, *tr. dentatothalamicus*.

Anterior spinocerebellar tract (afferent) is formed by the axons from the intermediomedial nuclei of both sides. At first they pass to the opposite side but then return to the same side via the superior medullary velum and end on the neurons in the superior vermician cortex.

Dentatorubral tract (association) originates from the neurons of the nucleus dentatus. The tract completely decussates through the mesencephalic inferior colliculi and end in the red nucleus situated in the midbrain.

Dentatothalamic tract (association) is formed by the axons from the nucleus dentatus and ends in the central thalamic nuclei.

3.5. The Fourth Ventricle

The fourth ventricle, *ventriculus quartus*, is the cavity of the rhombencephalon (fig. 3.21). It is the continuation of the spinal central canal. It has a floor and roof.

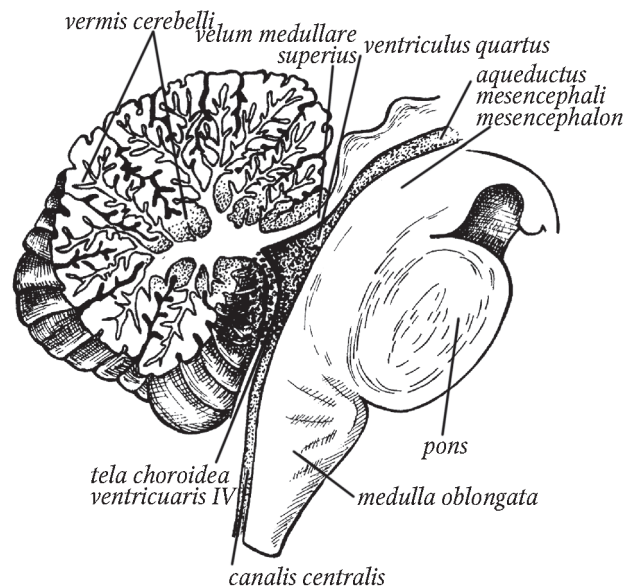


Fig. 3.21. The IV ventricle: floor, roof, communications. Median section

The floor of the IV ventricle is formed by the rhomboid fossa having the shape of a rhombus (hence the name) which is bounded by the superior and inferior cerebellar peduncles. The rhomboid fossa is divided into two halves: inferior (caudal) and superior (rostral), delimited by the medullary striae of the IV ventricle, *striae medullares ventriculi quarti*. The inferior half of the rhomboid fossa is the dorsal surface of the medulla oblongata; the superior half is the dorsal surface of the pons.

Along the midline, the rhomboid fossa is traversed by the median sulcus, *sulcus medianus*, on either side of which there is a longitudinal elevation, the medial eminence, *eminentia medialis*; laterally, it is bounded by the *sulcus limitans*. This groove is approximate border between the projection of the motor and sensory cranial nerve nuclei. The motor nuclei project medially; the sensory nuclei project laterally. The medial eminence in the rhomboid fossa's inferior angle is called the trigone of hypoglossal nerve, *trigonum n. hypoglossi*. Lateral to this trigone, also in the inferior angle, is the trigone of vagus nerve, *trigonum n. vagi*, where the vegetative parasympathetic nucleus of the vagus nerve, the dorsal vagal nucleus, projects. Above the medullary striae, the medial eminence forms a slight thickening called the facial colliculus which corresponds to the projection of the abducens nerve.

Within the rhomboid fossa the reticular formation nuclei project: so called *locus coeruleus* projects to the superolateral area of the rhomboid fossa, and the median raphe nuclei project along the midline of the medulla oblongata.

The roof of the IV ventricle has two parts, the development and structure of which are different. The anterior part of the roof is formed by a white matter plate, the superior (anterior) medullary velum, *velum medullare superius*, which stretches between the superior cerebellar peduncles. The posterior part of the roof is formed by paired inferior (posterior) medullary velum and tela choroidea. The latter is fused with a free edge of the inferior medullary velum, inferior cerebellar peduncles and spinal posterior funiculi (fig. 3.16). The inferior medullary velum, *velum medullare inferius*, stretches between the vermillion nodulus, the floccular peduncle and flocculus, and occupies the lateral part of the rhomboid fossa. The tela choroidea of the IV ventricle, *tela choroidea ventriculi quarti*, is a double layered fold of pia mater, containing the choroid plexus, *plexus choroideus*. The tela choroidea is lined by the lamina epithelialis which represents the remnants of the ependymal epithelium of the atrophied dorsal wall of the neural tube in the region of the medulla oblongata.

The IV ventricle communicates below with the central canal of the spinal cord, above with the cerebral aqueduct. Besides, in the area of the rhomboid fossa's lateral angles, in the tela choroidea there is a communication with the subarachnoid space through a paired opening called the lateral aperture, *apertura lateralis* (foramen of Luschka). One more, unpaired, opening is in the area of the rhomboid fossa's inferior angle; it is called the median aperture, *apertura mediana* (foramen of Magendie). Through these openings the cerebrospinal fluid passes from the IV ventricle into the cerebral subarachnoid space. The position of the Luschka and Magendie's foramina is shown schematically in the figure 3.16.

TEST QUESTIONS

1. Classify the brain according to the development.
2. Which parts of the brain are included into the rhombencephalon? What ventricle does it contain?

3. Describe the parts of the brain (rhombencephalon, mesencephalon, diencephalon, telencephalon); what cavities does each part contain?
4. What parts does the brain stem include?
5. Describe the zones of the brain (base, tegmentum, tectum).
6. At which level is the spinal cord continuous with the medulla oblongata?
7. Where does the medulla oblongata lie in the skull?
8. Describe the external structure of the medulla oblongata: grooves, funiculi, tubercles which can be found on its ventral and dorsal surfaces.
9. Which cranial nerves emerge from the medulla oblongata? What grooves of the medulla oblongata do the roots of these cranial nerves pass through?
10. Describe the arrangement of grey matter relatively to white matter in the medulla oblongata.
11. Describe the nuclei of the medulla oblongata. How can they be grouped? Describe their position.
12. Name the nuclei of the cranial nerves emerging from the medulla oblongata. Which of them are sensory (motor, parasympathetic)?
13. Describe white matter of the medulla oblongata: name and describe the conduction tracts passing through the medulla oblongata. Give the definition of the medial lemniscus decussation and pyramidal decussation.
14. Describe the connections of the medulla oblongata's nuclei with other parts of the brain and with the spinal cord.
15. What parts are distinguished in the pons?
16. Describe the position of the pons and its external structure.
17. Which cranial nerves emerge from the pons? Describe the position of the cranial nerve roots relatively to the pons.
18. Describe the arrangement of grey matter relatively to white matter in the pons. Describe the nuclei of the pons. How can they be grouped? Describe their position.
19. Name the nuclei of the cranial nerves emerging from the medulla oblongata. Which of them are sensory (motor, parasympathetic)?
20. Describe white matter of the pons: name and describe the conduction tracts passing through the pons.
21. Give the definition of the medial lemniscus, trigeminal lemniscus, lateral lemniscus and spinal lemniscus.
22. Describe the connections of the pons's nuclei with other parts of the central nervous system.
23. Describe the position of the cerebellum and its external structure.
24. Give the definition of the lamellae, folia and lobules of the cerebellum. Name the lobules of the vermis and hemispheres.
25. What are paleocerebellum, archicerebellum and neocerebellum? Why these parts are distinguished in the cerebellum?
26. Describe the arrangement of grey matter relatively to white matter in the cerebellum.
27. Describe the nuclei of the cerebellum.
28. Name the conduction tracts which form the middle, superior and inferior peduncles of the cerebellum.
29. Describe the connections of the cerebellum with other parts of the brain and with the spinal cord.
30. Describe the position of the fourth ventricle.
31. Describe the floor and roof of the fourth ventricle. How is the rhomboid fossa formed? Describe the position of the cerebellar velli.

32. Describe the external structure and boundaries of the rhomboid fossa. How is the facial colliculus formed? What are the medullary striae?
33. The nuclei of which cranial nerves project below (above) the medullary striae?
34. What nuclei (according to the type) project within the medial eminence; which nuclei project outside the medial eminence?
35. What nuclei project to the trigones of hypoglossal and vagus nerves?
36. What nuclei project to the vestibular areas?
37. Describe the communications of the fourth ventricle in the caudal and rostral directions.
38. Describe the structure of the tela choroidea and its position in the IV ventricle.
39. What do the lateral (Luschka's foramen) and median (Magendie's foramen) apertures communicate the fourth ventricle with? Describe the location of these foramina.

CLINICOANATOMICAL PROBLEMS

1. A patient has fracture of the skull base in the region of the clivus. What parts of the brain can be damaged?
2. A patient has tumor of the cerebellopontine angle. What cranial nerves can be damaged?
3. A patient has arachnoiditis in the region of the posterior cranial fossa, resulting in the disorder of the cerebrospinal fluid circulation. The closure of what openings caused the obstruction of the cerebrospinal fluid outflow from the ventricles?
4. A patient has hemorrhage in the IV ventricle. The nuclei of which cranial nerves are damaged?
5. A patient has the motor disorders (ataxia). The damage to which part of the brain should a doctor suppose?

3.6. Mesencephalon

3.6.1. External Structure of Mesencephalon

The mesencephalon (midbrain), *mesencephalon*, develops from the middle cerebral vesicle. It is relatively small, compared to the other parts of the brain. Its ventral surface is represented by the cerebral peduncles, *pedunculi cerebri*, and the posterior perforated substance, *substantia perforata posterior*, situated between the peduncles. The dorsal surface is formed by the quadrigeminal (tectal) plate, *lamina tecti*. The cavity of the mesencephalon is the cerebebral aqueduct, *aqueductus mesencephali* (of Sylvius).

The cerebral peduncles's ventral surfaces are shaped like two thick flattened cylinders arising from the front of the pons (fig. 3.2). Thence they diverge at an angle of 70–80 ° and immerse into the diencephalon. The anterior border of the peduncles is the optic tract, *tractus opticus*, which belongs to the diencephalon. The cerebral peduncles have white color and striated structure due to white matter fibres running in longitudinal direction. Each peduncle is demarcated into a ventral *crus cerebri*, (the base of the cerebral peduncle, *basis pedunculi cerebri*) and tegmental part, *tegmentum mesencephali*, by a bilateral lamina, the *substantia nigra*.

Along the medial edge of the cerebral peduncles there is an oculomotor sulcus, *sulcus n. oculomotorii*, where a single root of the oculomotor nerve (III cranial nerve) emerges. Along the lateral edge of the cerebral peduncle there is a lateral groove of mesencephalon, *sulcus lateralis mesencephali*; this groove is the continuation of the rhombencephalon's groove which separates the superior and middle cerebellar peduncles.

On the ventral side, the cerebral peduncles bound a depression called the interpeduncular fossa, *fossa interpeduncularis*. Here it is narrow but expands at the anterior edge of the pons and ends near the mamillary bodies which belong to the diencephalon. The surface of the interpeduncular fossa is grayish and honeycombed by openings, through which numerous vessels pass. This area is called the posterior perforated substance, *substantia perforata posterior*.

The dorsal mesencephalic surface which is formed by the quadrigeminal plate, carries four rounded eminences, superior and inferior colliculi, *colliculi superiores et inferiores* (fig. 3.3). The colliculi are separated by the grooves intersecting at a right angle. The inferior colliculi are smaller than the superior ones.

From the lateral aspect of each colliculus a brachium ascends ventrolaterally towards the diencephalon. The brachia of the superior colliculi, *brachia colliculi superiores*, longer and narrower, end in the lateral geniculate bodies. The brachia of the inferior colliculi, *brachia colliculi inferiores*, shorter and thicker, end in medial geniculate bodies.

Caudal to the inferior colliculi is a median triangular frenulum veli, *frenulum veli medullaris superioris*. On each side of the frenulum veli the root of the trochlear cranial nerve emerges. The trochlear nerve, *n. trochlearis*, IV cranial nerve, is the thinnest of all the cranial nerves and a single nerve which emerges from the brain substance on the dorsal surface. Then the nerve rounds the cerebral peduncles and appears on the ventral surface.

On the lateral mesencephalic surface, between the lateral groove and brachium of the inferior colliculus there is a triangular area called the trigone of lemnisci, *trigonum lemnisci*. The third side of the trigone is the lateral edge of the superior cerebellar peduncle. The nerve fibres comprising the lateral, medial, trigeminal and spinal lemnisci pass in this trigone through the cerebral peduncles. Thus, in this place almost all the pathways of the general sensation (that conduct the impulses to the diencephalon) and the acoustic tract concentrate. In case of the thalamic injuries and the appearance of associated unbearable pain, the operation (cordotomy) is done within the trigone of lemnisci.

The cavity of the mesencephalon is the cerebral aqueduct. It is the remnant of the cavity of the middle cerebral vesicle. The aqueduct is oriented along the axis of the brain and connects the III and IV ventricles. Its length is 15 mm; the average diameter is 1–2 mm. The aqueduct has a slight expansion in its middle part.

The opening of the cerebral aqueduct, by which the cerebral aqueduct starts from the III ventricle, is located under the posterior cerebral commissure. The opening, connecting the aqueduct to the IV ventricle, is under the superior cerebellar velum in the ventricle's upper angle.

3.6.2. Internal Structure of Mesencephalon

On the transverse section of the mesencephalon its main parts are clearly visible: above the aqueduct is the tectal plate, below are the cerebral peduncles (fig. 3.22). The transverse section also shows the substantia nigra (of Soemmering) which demarcates the base of the cerebral peduncle and the tegmentum.

The base of the cerebral peduncle is mainly formed by longitudinal descending fibres which pass from the neurons of the cerebral cortex to the nuclei of the brain stem and spinal cord. Thus, the base of the cerebral peduncle is phylogenetically new formation.

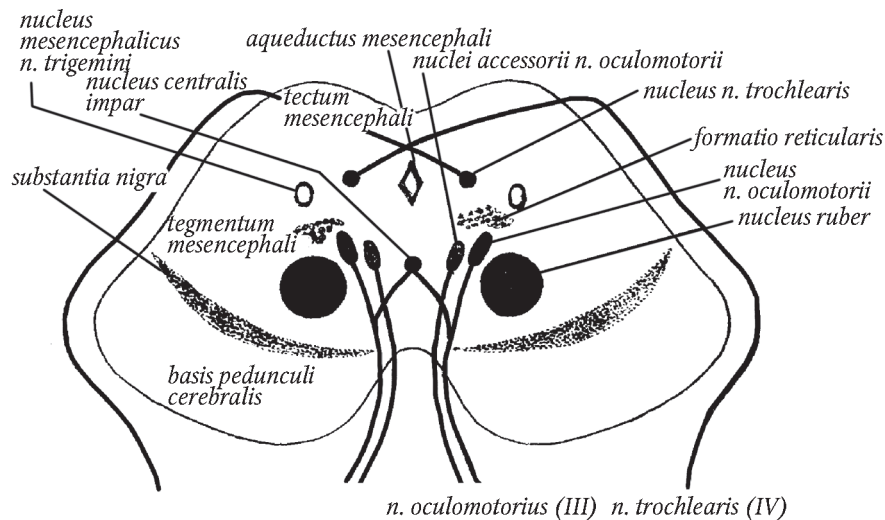


Fig. 3.22. The arrangement of the midbrain nuclei (schematically)

On the transverse section the substantia nigra has the shape of a flattened crescent with convexity directed ventrally. In the dorsal part of the substantia nigra there are strongly pigmented neurons containing a large amount of iron. The ventral part of the substantia nigra contains large disseminated neurons and the myelinated fibres passing between them.

The tegmentum of the mesencephalon contains both white and grey matter. Grey matter is represented by the red nucleus, *nucleus ruber*, and central grey substance, *substantia grisea centralis*, which surrounds the cerebral aqueduct.

The red nuclei are cylinder-shaped, situated throughout the whole mesencephalon in the center of the tegmentum in each cerebral peduncle and partially prolonged into the diencephalon.

The caudal part of the red nucleus contains large neurons; the rostral part contains mainly small neurons. Like the cells of the substantia nigra, those in the red nucleus contain iron but much smaller quantity. On the neurons of the red nucleus the following tracts end: dentatorubral, striorubral (formed by the axons from the cerebral basal nuclei) and rubronuclear. The axons arising from the large neurons of the red nucleus unite into the rubrospinal tract. The axons arising from the small neurons form the rubro-reticular and rubro-olivary tracts which end on the neurons of the reticular formation and the olivary nuclei respectively.

Ventral to the red nucleus is an unpaired interpeduncular nucleus, *nucleus interpeduncularis*. The fibres arising from epithalamic habenular nuclei, so called habenulo-interpeduncular tract, end in this nucleus. We can assume that this tract is an element of the efferent autonomic tract.

The cerebral aqueduct is surrounded by the central grey substance. The ventrolateral part of this substance, level with the inferior colliculi, contains the motor nuclei of the IV cranial, trochlear, nerve. The axons from these nuclei run dorsally, pass to the opposite side and leave the brain in the area of the frenulum veli. Cranial to the IV cranial nerve motor

nuclei (level with the superior colliculi) are the nuclei of the III cranial, oculomotor, nerve.

The oculomotor nerve has three nuclei. The motor nucleus, *nucleus n. oculomotorii*, is the largest, elongated nucleus. It is divisible into five segments, each provides the innervation of certain ocular muscles and the levator palpebrae superioris.

The segments, from up to down, innervate the following muscles:

- 1) levator palpebrae superioris;
- 2) superior rectus;
- 3) inferior obliquus;
- 4) inferior rectus;
- 5) medial rectus.

Apart from a paired motor nucleus, the oculomotor nerve has one more, unpaired, nucleus called the central nucleus of Perlia, *nucleus centralis impar*. This nucleus is interconnected with the caudal segments in the right and left main motor nuclei that are responsible for the innervation of the medial recti muscles. This provides the coordinated contraction of the medial recti muscles of the right and left eyeballs, which rotate the eyeballs and move the pupils towards the median plane. Due to its function, the central nucleus of Perlia is also called the convergence nucleus.

Dorsal to the motor nuclei near the midline are the vegetative nuclei of the oculomotor nerve, called the accessory nuclei, *nuclei accessorii n. oculomotorii* (of Yakubovich-Edinger-Westphal). The neurons in these nuclei are responsible for the innervation of the sphincter pupillae and ciliary muscle. The names of the cranial nerve nuclei associated with the mesencephalon and their functional purpose are given in table 5.

A part of the fibres from the oculomotor nerve somatic nuclei participates in the formation of the medial longitudinal fasciculus. Most fibres from all the nuclei form the oculomotor nerve root which emerges in the oculomotor sulcus.

The lateral part of the central grey substance contains the mesencephalic nucleus of the trigeminal nerve, *nucleus mesencephalicus n. trigemini*.

Between the central grey substance and the red nuclei there is a reticular formation which contains numerous small nuclei and two large nuclei. One of them is the interstitial nucleus, *nucleus interstitialis* (of Cajal), and the other is the nucleus of posterior commissure, *nucleus commissurae posterioris* (of Darschewitsch). The axons from these two nuclei form the medial longitudinal fasciculus which runs into the spinal cord (fig. 3.23).

The medial longitudinal fasciculus contains the fibres providing the connection between the reticular formation nuclei and motor nuclei of the III, IV, VI and XI cranial nerves. Thus, the interstitial nucleus and the nucleus of posterior commissure are the centres that coordinate the movements of the eyeballs and neck. The afferent impulses from the vestibular nuclei of the pons (VIII cranial nerve nuclei) pass to the reticular formation nuclei to coordinate the ocular and cervical muscle contractions that is important mainly during the vestibular loads.

Table 5

Cranial nerves associated with the midbrain, and their nuclei

The number and name of cranial nerve	The nuclei and their names		
	motor	sensory	parasympathetic
IV cranial nerve (trochlear)	Nucleus of trochlear nerve	—	—
III cranial nerve (oculomotor)	Nucleus of oculomotor nerve Central nucleus of Perlia (<i>nucleus centralis impar</i>)	—	Accessory nucleus of oculomotor nerve

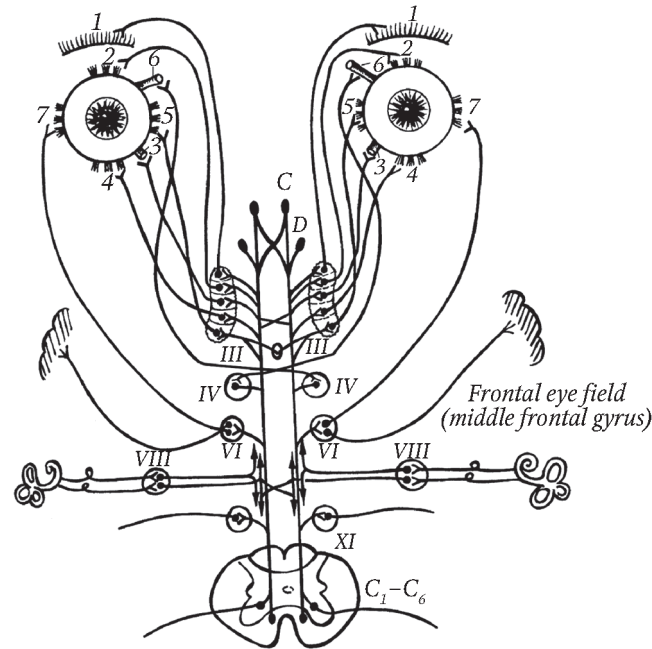


Fig. 3.23. The connections of the medial longitudinal fasciculus with the cranial nerve motor nuclei which innervate the eye and neck muscles:

C — Cajal's nucleus; D — Darksheвич's nucleus; 1 — levator palpebrae superioris muscle; 2 — superior rectus muscle; 3 — inferior oblique muscle; 4 — inferior rectus muscle; 5 — medial rectus muscle; 6 — superior oblique muscle; 7 — lateral rectus muscle; III — nucleus of the oculomotor nerve; IV — nucleus of the trochlear nerve; VI — nucleus of the abducens nerve; VIII — vestibular nuclei; XI — nucleus of the accessory nerve

Close to the medial longitudinal fasciculus is the dorsal longitudinal fasciculus, *fasciculus longitudinalis posterior*, which arises from the structures of the diencephalon. Its fibres run to the spinal and cranial vegetative nuclei. They coordinate the activity of the spinal and brain-stem vegetative centres.

Dorsal to the cerebral aqueduct is the tectum of mesencephalon. It is comprised by two pairs of the colliculi, superior and inferior, which differ in structure considerably. In humans the superior colliculi are more developed because the human receives main information through the visual organ. The superior colliculi are the midbrain integration centre and besides they are one of the subcortical centres of vision, olfaction, and tactile sense. Three thirds of the fibres from the lateral lemniscus end in the inferior colliculi. A part of the fibres from the lateral lemniscus passes to the medial geniculate body nucleus via the brachia of the inferior colliculi. Some fibres from the lateral lemniscus end in the superior colliculi. A part of the fibres from the olfactory tract, the spinal, medial and trigeminal lemnisci also pass to the superior colliculi. The superior colliculi have a layered neuronal arrangement that is typical of the integration centres (cerebral and cerebellar cortex).

The optic tract fibres end in the superficial layers of the superior colliculi. In the deep layers, the sequential synaptic switching and integration of the visual, acoustic, olfactory, gustatory and tactile senses occur.

The axons of the neurons located in the deep layers form a bundle situated lateral to the central grey substance. It comprises two tracts: tectospinal and tectonuclear. The fibres of this tract pass to the opposite side, forming the dorsal tegmental decussation, *decussatio tegmenti dorsalis*, (of Meynert) which is situated ventral to the cerebral aqueduct.

The tectospinal tract fibres end on the neurons in the nuclei proprii of the spinal anterior horns. The tectonuclear tract fibres end on the neurons in the cranial nerve motor nuclei. The tectospinal and tectonuclear tracts conduct the nervous impulses to perform the protective reflex motions (the alertness, wince, jump to the side) in response to various strong stimuli (visual, acoustic, olfactory and tactile).

The position of the main conduction tracts in the mesencephalon is shown in the diagram (fig. 3.24). The base of the cerebral peduncles develops only in higher craniates hence contains phylogenetically new conduction tracts. They are formed by the longitudinal efferent fibres which arise from the neurons of the cerebral cortex and descend to the cerebellum, pons, medulla oblongata and spinal cord. The conduction tract passing from the cerebrum to the cerebellum is interrupted in the pontine nuclei thus consists of two parts: corticopontine and pontocerebellar tracts.

A part of the corticopontine tract is formed by the frontopontine tract which occupies the medial area in the base of the cerebral peduncles. The fibres arising from the neurons of the occipital and temporal cortex occupy the lateral area in the base of the cerebral peduncles and are united into occipito-temporo-pontine tract.

The pyramidal fibres originating from the pyramidal cells of the cerebral cortex occupy the middle area in the base of the cerebral peduncles (the corticonuclear tract is medial to the corticospinal tract). The corticonuclear tract ends in the brain-stem cranial nerve nuclei. The corticospinal tract ends in the nuclei proprii of the spinal anterior horns; it occupies almost $\frac{2}{5}$ of the cerebral peduncle's base.

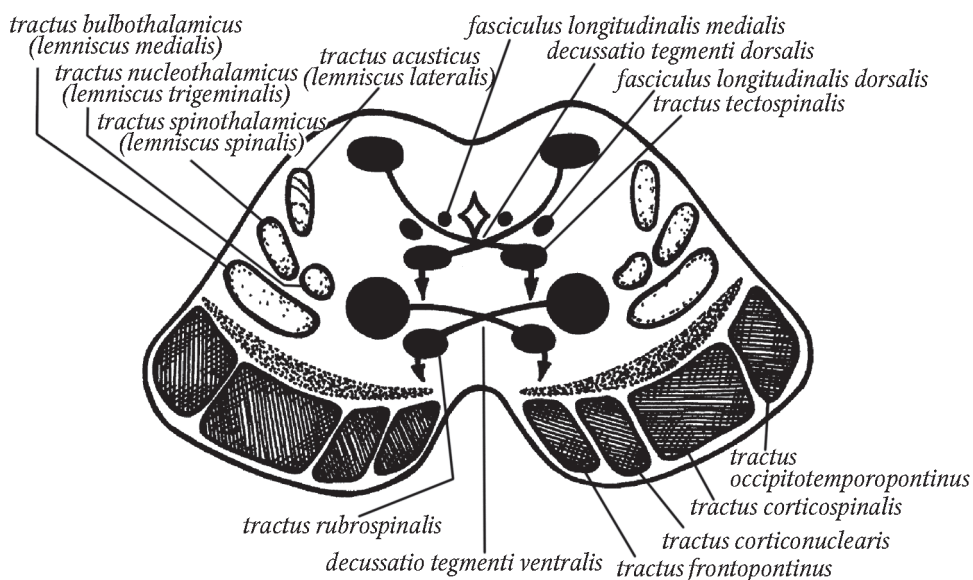


Fig. 3.24. The diagram showing the arrangement of the conduction tracts on the transverse section of the midbrain

The following afferent tracts pass in the tegmentum of the cerebral peduncles, lateral to the red nuclei: medial lemniscus, spinal lemniscus, trigeminal lemniscus and lateral lemniscus.

The medial and dorsal longitudinal fasciculi pass in the tegmentum, ventral to the central grey substance. The medial longitudinal fasciculus is formed by the axons from the interstitial nucleus and from the nucleus of posterior commissure which is located at the junction of the mesencephalon and diencephalon.

Ventral to the medial longitudinal fasciculus is the tectospinal tract, formed by the axons from the superior colliculi. In the midbrain this tract passes to the opposite side, forming the dorsal tegmental decussation (of Meynert) (vide supra).

The axons from the red nuclei make the rubrospinal tract (of Monakow). This tract also passes to the opposite side to form the ventral tegmental decussation, *decussatio tegmenti ventralis*, (of Forel) ventral to the red nuclei.

3.7. Diencephalon

The diencephalon, *diencephalon*, develops from the caudal part of the anterior cerebral vesicle, *prosencephalon*. During ontogenesis it undergoes significant changes. The ventral and dorsal walls become thinner, while the lateral walls thicken. The cavity in this segment of the neural tube significantly expands and takes the shape of a slit arranged in the median plane and called the III ventricle.

It should be noted that the dorsal (superior) wall of the III ventricle is formed only by ependymal epithelium. Above the ependymal epithelium there is a process of pia mater, which separates the diencephalon and the telencephalic structures (fornix and corpus callosum). The lateral parts of the diencephalon are directly adherent to the structures of the telencephalon.

On the lateral wall of the embryonic neural tube's cavity there is a *sulcus limitans*; in adult the *sulcus hypothalamicus* corresponds to the sulcus limitans. The hypothalamic sulcus is on the lateral wall of the III ventricle; it marks the boundary between the ventral and dorsal parts of the diencephalon.

The dorsal part of the lateral diencephalic wall develops from the alar plate of the neural tube and is called the *thalamencephalon*.

The ventral part of the lateral diencephalic wall, located below the hypothalamic sulcus, develops from the basal plate of the neural tube and is called the *hypothalamus*.

Thus, the diencephalon consists of the thalamencephalon and hypothalamus. Its cavity is the III ventricle.

3.7.1. Thalamencephalon

The thalamencephalon has three parts: a) *thalamus*; b) *epithalamus*; c) *metathalamus*. The structures of the thalamencephalon can be examined on the dorsal brain-stem surface only after the removal of the cerebral hemispheres (fig. 3.25).

Thalamus is ovoid mass, 40 mm long, 16 mm thick, 20 mm in height. The medial and dorsal thalamic surfaces are free; the ventral and lateral surfaces merge with the structures of the telencephalon. The anterior pole of the thalamus is sharpened and called the anterior tubercle, *tuberculum anterius thalami*; the posterior pole is expanded and called the *pulvinar*. The dorsal surface covered by a thin layer of white matter is separated from the caudate nucleus (the latter belongs to the telencephalon) by a white *stria terminalis*.

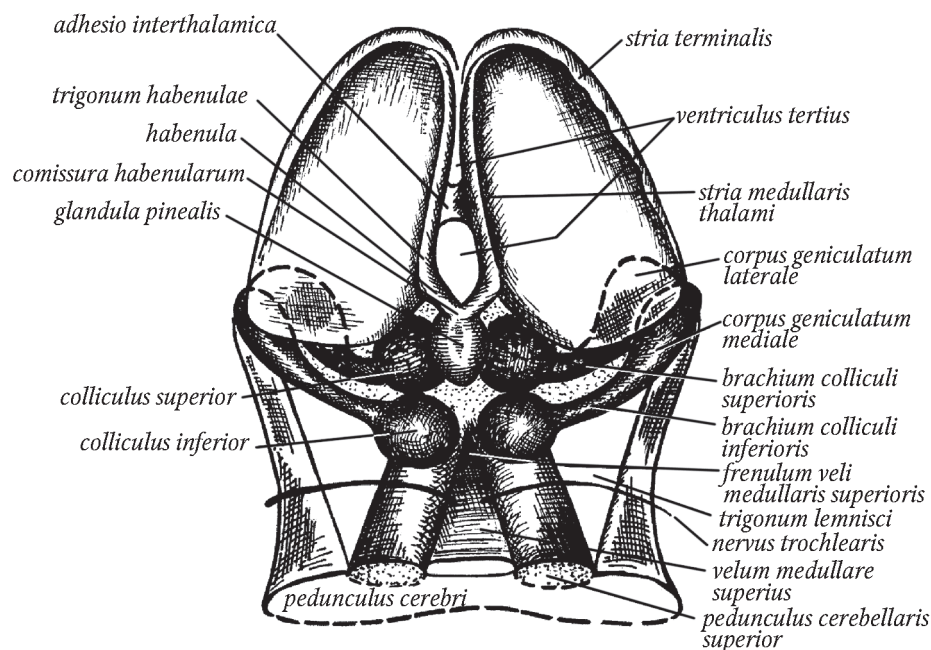


Fig. 3.25. The structures of the midbrain and diencephalon on the dorsal brain-stem surface

Anteriorly, the dorsal surface is separated from the medial surface by a white ridge, the *stria medullaris thalami*. The latter limits posteriorly a small triangular area, the *trigonum habenulae*, which belongs to the epithalamus. Most part of the dorsal thalamic surface is covered by the *tela choroidea*, under which there is a *fornix*, belonging to the telencephalon.

The medial thalamic surface is directed to the cavity of the III ventricle; it is secondarily connected to the opposite thalamus by a grey interthalamic adhesion, *adhesio interthalamica*. The lower border of the medial thalamic surface is the hypothalamic sulcus.

The epithalamus is posterior to the thalamus; it comprises the pineal gland, *glandula pinealis*, (epiphysis); *habenulae*; habenular commissure, *commissura habenularum* and habenular trigones, *trigonum habenulae*.

The pineal gland is shaped like a flattened pine cone. Its length is 7 mm, the width and height are 5 mm. It lies in a groove between the superior colliculi. The epiphysis is an endocrine gland.

At the base of the pineal gland there is a depression, the pineal recess, *recessus pinealis*, which is the continuation of the third ventricle's cavity. Below the pineal gland is the posterior cerebral commissure, *commissura cerebri posterior*, above – the habenular commissure. The latter is continuous with the *habenula* on each side. The fibres of the habenulae partially continue into the striae medullares thalami, mainly end in the habenular trigone.

The habenular trigone is a triangular area between the habenula, thalamus and superior colliculus. Here is the habenular nucleus, *nucleus habenulae*, covered by a thin layer of white matter. The axons of the habenular nucleus run to the interpeduncular

nucleus in the midbrain, forming the habenulo-interpeduncular tract, *tr. habenulo-interpeduncularis*.

The metathalamus is constituted by the medial and lateral geniculate bodies, *corpora geniculata mediales et laterales*. The medial geniculate body is a small eminence (7×5 mm), situated ventral to the thalamic pulvinar. Together with the inferior colliculi, the medial geniculate bodies play the role of the subcortical auditory centres. The nuclei of the medial geniculate body are the communication centers for the nerve impulses which run to the cerebral cortex. On the neurons of the medial geniculate body the fibres of the lateral lemniscus end.

The lateral geniculate body, *corpus geniculatum laterale*, is an elongated eminence (12×5 mm), where the optic tract ends. It lies on the inferolateral surface of the thalamic pulvinar, anterior to the medial geniculate body. The geniculate bodies are separated from each other by a wide groove. The lateral geniculate bodies together with the superior colliculi and the thalamic pulvinar carry out the function of the subcortical visual centres. The nuclei in the lateral geniculate bodies play the role of the communication centres, where the pathways to the cortical visual centres are interrupted.

3.7.2. Hypothalamus

The hypothalamus forms the inferior wall of the III ventricle. Directly under the thalamus (i. e. below the hypothalamic sulcus) there is a subthalamic region.

The subthalamic region, *regio subthalamica propria*, is a forward continuation of the midbrain tegmentum, where the red nucleus and substantia nigra are located. Lateral to the substantia nigra is an oval nucleus called the posterior hypothalamic nucleus, *nucleus hypothalamicus posterior* (nucleus of Luizi).

The ventral surface of the hypothalamus comprises from back to front the following structures: mamillary bodies, tuber cinereum, optic chiasm with optic tracts and optic nerves. Now we will describe the external form of these structures (fig. 3.26).

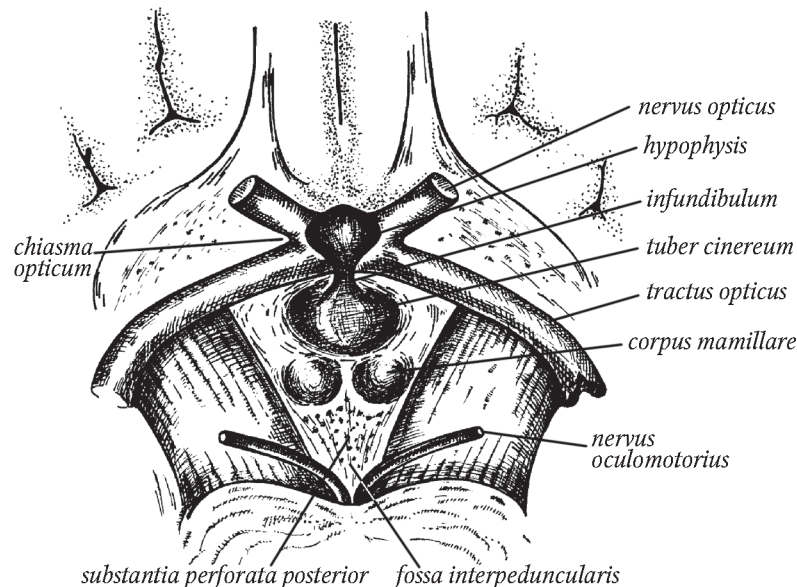


Fig. 3.26. The structures of the midbrain and diencephalon on the ventral surface of the brain stem

The mamillary body, *corpus mamillare*, paired spherical white, is about the size of 5–6 mm. Together with the anterior thalamic nuclei the mamillary bodies play the role of the subcortical olfactory centres.

The tuber cinereum is in front of the mamillary bodies. It is bounded laterally by the optic tracts, anteriorly by the optic chiasm. The tuber cinereum is an eminence consisting of grey matter. It is prolonged forward and down by the *infundibulum* which connects to the hypophysis.

The *hypophysis (glandula pituitaria)* is ovoid shaped; its transverse size is 12–15 mm; anteroposterior size is 10 mm; vertical size is 5–7 mm; the weight in adult is 0,7 g. The hypophysis consists of two lobes, anterior and posterior, together surrounded by a connective tissue sheath. The posterior lobe, *lobus posterior* (neurohypophysis), smaller, is connected to the infundibulum. Anteriorly, the posterior lobe is surrounded by the anterior lobe, *lobus anterior* (adenohypophysis). Between the anterior and posterior lobes there is a small intermediate part of the anterior lobe, separated from the anterior lobe by a narrow slit. By origin, the adenohypophysis is an epithelial protrusion of the stomatodeum. The neurohypophysis is developed by a protrusion of the ventral diencephalic wall.

In front of the tuber cinereum there is an optic chiasm, *chiasma opticum*, which looks like a quadrangular plate. The upper surface of the tuber cinereum is fused with the III ventricle's floor. The optic nerves run towards the optic chiasm; from the optic chiasm the optic tracts arise.

The optic tracts, *tractus opticus*, are the white cords merging with the brain substance. They pass dorsolaterally, round the cerebral peduncles and end in the lateral geniculate bodies.

Anterior to the optic chiasm is the *lamina terminalis* which is the continuation of the corpus callosum's ventral end (*lamina rostralis*), oriented in the frontal plane.

The ventricular surface of the hypothalamus has two median depressions: the supra-optic recess (anteriorly) and infundibular recess (posteriorly). The supraoptic recess is between the optic chiasm and lamina terminalis; the infundibular recess corresponds to the infundibulum.

Taking into account that the hypothalamus is made up of many individual structures, it is appropriate to group them topographically as follows (fig. 3.27):

1. Anterior hypothalamic region, *regio hypothalamica anterior*, or optic part, *pars optica*:

- optic chiasm, *chiasma opticum*;
- optic tract, *tractus opticus*.

2. Intermediate hypothalamic region, *regio hypothalamica intermedia*:

- subthalamic region, *regio subthalamica propria*;
- tuber cinereum;
- infundibulum;
- hypophysis.

3. Posterior hypothalamic region, *regio hypothalamica posterior*, or mamillary part, *pars mamillaris*:

- mamillary bodies, *corpora mamillaria*.

4. Dorsolateral hypothalamic region, *regio hypothalamica dorsolateralis*:

- posterior hypothalamic nucleus (*nucleus Luizi*), *nucleus hypothalamicus posterior*;
- subthalamic nucleus, *nucleus subthalamicus*;
- lateral hypothalamic nucleus, *nucleus hypothalamicus lateralis*.

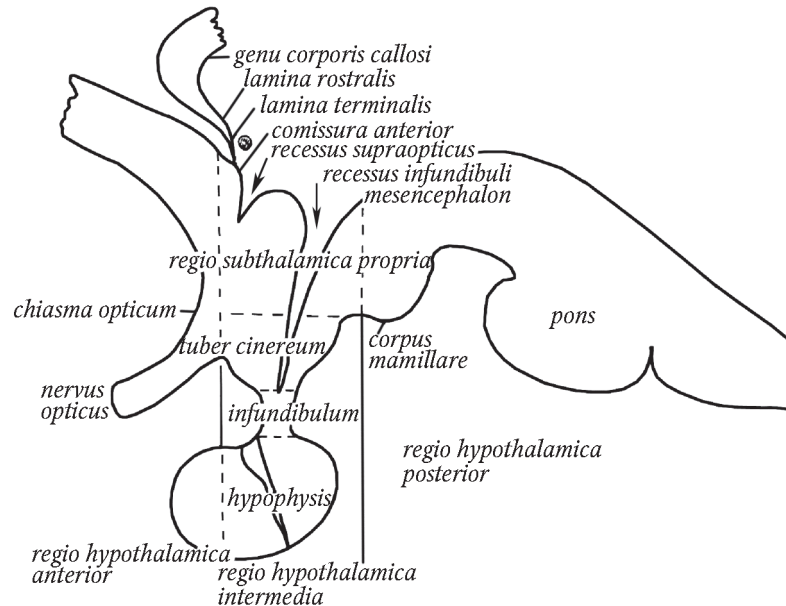


Fig. 3.27. The diagram showing the structure of the hypothalamus

3.7.3. The Third Ventricle

The diencephalic cavity is the III ventricle, *ventriculus tertius*. This is a sagittal slit oriented in the median plane. Its width is 4–5 mm; the length in its upper part (maximum) is 25 mm. Posteriorly, the III ventricle opens into the cerebral aqueduct. Via the interventricular foramina, *foramina interventricularia* (of Monro), the III ventricle communicates with the lateral ventricles.

The third ventricle's lateral walls are formed by the medial thalamic surfaces and subthalamica region; they are separated by the hypothalamic sulcus. Most part of the third ventricle's floor is formed by the structures which belong to the hypothalamus: the dorsal surface of the optic chiasm, tuber cinereum and the substance between the mamillary bodies. Posterior to the mamillary bodies are the cerebral peduncles with the posterior perforated substance between them. The floor of the third ventricle has two recesses: supraoptic and infundibular. The posterior wall of the third ventricle is comprised by the posterior cerebral commissure and pineal recess. The posterior cerebral commissure is above the entrance to the cerebral aqueduct. Above the posterior cerebral commissure is the base of the pineal gland, where the pineal recess enters. The dorsal (superior) wall of the neural tube remains as a layer of ependymal cells, the *lamina choroidea epithelialis*. The lateral edges of this lamina are fixed to the striae medullares thalami, situated between the medial and dorsal thalamic surfaces. The lamina choroidea epithelialis is covered by a double layer of pia mater, which is comprised by the tela choroidea and choroid plexus of the III ventricle. The lamina choroidea epithelialis and pia mater are firmly fused together.

The upper part of the third ventricle's anterior wall is formed by the columns of fornix; they are white cylinders, situated close to one another but diverging below. In

front of the columns there is an anterior cerebral commissure, oriented transversely. The latter is rounded on the transverse section; its diameter is about 4 mm. Below the anterior cerebral commissure, the *lamina terminalis* extends to reach the floor of the ventricle.

Posterior to the column of fornix, between it and the anterior thalamic tubercle, is the interventricular foramen (of Monro) on each side. The upper part of the foramen is occupied by the choroid plexus which prolongates into the lateral ventricles. The choroid plexuses are covered by ependyma.

3.7.4. Pathways and Centres of Diencehalon

The thalamus is mainly formed by grey matter which is divided by white matter layers into the nuclei. The fibres originating from the thalamic nuclei form so called *corona radiata* connecting the thalamus with other parts of the brain.

The thalamic nuclei are classified by function into three groups (according to Fulton):

1. The nuclei, which do not have the connections with the cerebral cortex. They are connected with the hypothalamus and nuclei of the striopallidar system. These nuclei are located dorsolaterally in the thalamus.

2. The nuclei, in which the sensory tracts (of general and special sensations) end (somatosensory nuclei). These nuclei lie ventrolaterally in the thalamus. Their axons run to the cerebral cortex.

3. The association nuclei, which connect different diencephalic centres with each other. Here also belong the nuclei of the dorsolateral thalamic and nuclei.

Taking into account the different functions of the thalamic nuclei, they can be grouped as follows (fig. 3.28):

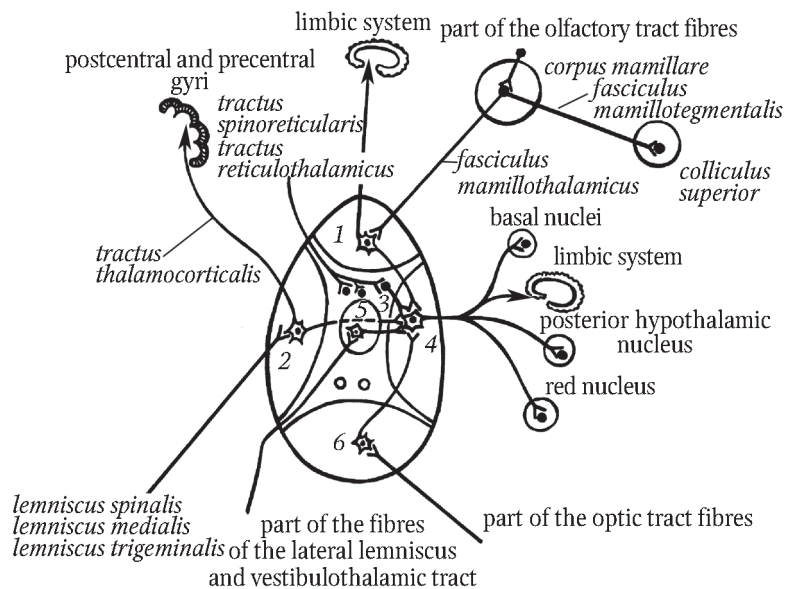


Fig. 3.28. The diagram showing the arrangement of the thalamic nuclei and their connections:
1 — anterior nuclei; 2 — ventrolateral nuclei; 3 — reticular nuclei; 4 — medial nuclei; 5 — median nuclei; 6 — posterior nuclei

1. Anterior nuclei of the thalamus, *nuclei anteriores thalami* (5–7). They are the subcortical olfactory centres and have the connections with the mammillary bodies on the same side. The nerve fibres originating from the nuclei of the mammillary bodies and ending in the anterior thalamic nuclei form the mamillothalamic tract, *fasciculus mamillothalamicus* (bundle of Vicq-d'Azir). It should be noted that a part of the axons from the mammillary body nuclei travel to the superior colliculi, forming the mamillotegmental tract, *fasciculus mamillotegmentalis*. This tract conducts the nervous impulses which provide unconditioned increase of muscle tone and unconditioned movements in response to strong olfactory stimuli. The axons from the anterior thalamic nuclei run to those parts of the cerebral cortex, which belong to the limbic system (mainly to the cortex of the frontal lobe's medial surface). A minority of the axons ends in the medial thalamic nuclei.

2. Ventrolateral nuclei of thalamus, *nuclei ventrolaterales thalami* (5–6 in number). They are the subcortical centres of general sensation. Thus, in these nuclei the fibres of the spinal, medial and trigeminal lemnisci end. The viscerosensory fibres, passing via the trigeminal lemniscus, run to the medial part of the ventrolateral thalamic nuclei, where the subcortical interoceptive centre lies. Most axons from the ventrolateral nuclei (80 %) pass through the internal capsule to the postcentral gyrus, forming the thalamocortical tract, *tractus thalamocorticalis*. Other axons (20 %) end in the medial thalamic nuclei.

3. Posterior nuclei of thalamus, *nuclei posteriores thalami*, are represented by 4–5 pulvinar nuclei. Together with the nuclei of the superior colliculi and lateral geniculate bodies they play the role of the subcortical visual centres. A part of the optic tract fibres ends in the posterior thalamic nuclei. Their axons run to the medial thalamic nuclei, subthalamic and limbic regions.

4. Median nuclei of thalamus, *nuclei mediani thalami*, include 2–3 nuclei. They are the vestibular and auditory subcortical centres. The axons from the vestibular and cochlear nuclei of the pons partially end here. Besides, the median nuclei are directly linked with the nucleus dentatus and red nucleus. The axons of the median nuclei run to the medial thalamic nuclei and to the temporal and frontal cortex.

5. Medial nuclei of thalamus, *nuclei mediales thalami*, are well defined in quantity of 4–5. The main nucleus of this group is the dorsal medial nucleus, *nucleus medialis dorsalis*. It is a subcortical centre of the extrapyramidal system which plays the role of the integration diencephalic centre. A part of the axons arising from the neurons of all main thalamic nuclei ends in the dorsal medial nucleus. Thus, it takes all information from the subcortical centres of the general and special sensations. In turn, between the dorsomedial thalamic nucleus, telencephalic basal nuclei (nuclei of striopallidum system) and the areas of the cerebral cortex that belong to the limbic system there is a two-way communication. A part of the axons from the medial thalamic nuclei has a descending direction and ends in the nuclei of the subthalamic region (nucleus of Luizi) and in the red nucleus.

6. Reticular thalamic nuclei, *nuclei reticulares thalami*. These numerous small nuclei are scattered in all parts of the thalamus and play the role of the subcortical sensory centres of the reticular formation. They have two-way communications with the nuclei of the spinal and brain-stem reticular formation.

The afferent and efferent connections of the thalamic nuclei are given in table 6.

Hypothalamus. The hypothalamic nuclei are also numerous (about 40). They are classified by location into four groups: anterior, intermediate, posterior and dorsolateral (fig. 3.29).

1. The anterior group includes the supraoptic, preoptic and paraventricular nuclei. These are neurosecretory nuclei. Their neurons produce the neurosecretion which pass-

es via the axons into the granules in the posterior hypophysial lobe. In the granules, the hormones of the neurohypophysis are produced (antidiuretic hormone and oxytocin).

2. The intermediate group is formed by the nuclei of the subthalamic region, the nuclei of the tuber cinereum and infundibulum. The subthalamic region contains the ventromedial hypothalamic, dorsomedial hypothalamic, arcuate, dorsal hypothalamic and posterior periventricular nuclei.

Table 6

The connections of the thalamic nuclei

The nuclei of the thalamus	Afferent tracts	Efferent tracts
Anterior	Mamillothalamic bundle. Thalamocortical bundle (into the frontal lobe to the limbic system)	Corticothalamic bundle (from the frontal lobe)
Ventrolateral	Spinal lemniscus. Medial lemniscus. Trigeminal lemniscus. Thalamocortical bundle (into the postcentral, precentral gyri and the superior parietal lobule)	Corticothalamic bundle (from the frontal and parietal lobes)
Posterior	Optic tract (partially). Thalamocortical bundle (into the parietal, occipital and temporal lobes)	Corticothalamic bundle (from the parietal, occipital and temporal lobes)
Median	Cerebellothalamic bundle, Vestibulothalamic tract. The small part of the lateral lemniscus fibres. Thalamostriate bundle	Striothalamic bundle
Medial	The fibres from all other thalamic nuclei. Thalamocortical bundle (into the frontal lobe to the limbic system). Thalamostriate bundle (to the basal nuclei)	Thalamo-hypothalamic bundle (to the posterior hypothalamic nucleus). Thalamorubral bundle.
Reticular	Spinoreticular tract. Reticulothalamic tract. Thalamocortical bundle (diffuse projection in all lobes of the cerebral hemispheres)	Corticothalamic bundle (from all lobes of the cerebral hemispheres)

The intermediate nuclear group adjoins the infundibular recess in the III ventricle. The numerous vessels, penetrating into the brain through the posterior perforated substance, form the plexuses around these nuclei. It is known that the intermediate nuclear group analyzes the chemical composition of blood and cerebrospinal fluid. Hence, these neurons possess the chemoreceptor and osmoreceptor properties and produce releasing factors in response to the information about the chemical composition of blood and cerebrospinal fluid. The releasing factors reach the hormone-secreting cells in the anterior hypophysial lobe (adenohypophysis) via the portal vessels. The cells of the adenohypophysis produce the *tropic* hormones (TTH, STH, GTH, ACTH, PTH etc) under the control of releasing factors (statins and liberins).

3. The posterior nuclear group is within the mamillary bodies which play the role of the subcortical olfactory centres. Each mamillary body contains the medial and lateral nuclei. These nuclei receive the information from the projection olfactory centre, the neurons of the parahippocampal gyrus. The axons from the mamillary bodies run to the superior colliculi, forming the mamillotegmental fascicle, *fasciculus mamillotegmentalis*, and to the anterior thalamic nuclei, forming the mamillothalamic fascicle, *fasciculus mamillothalamicus*.

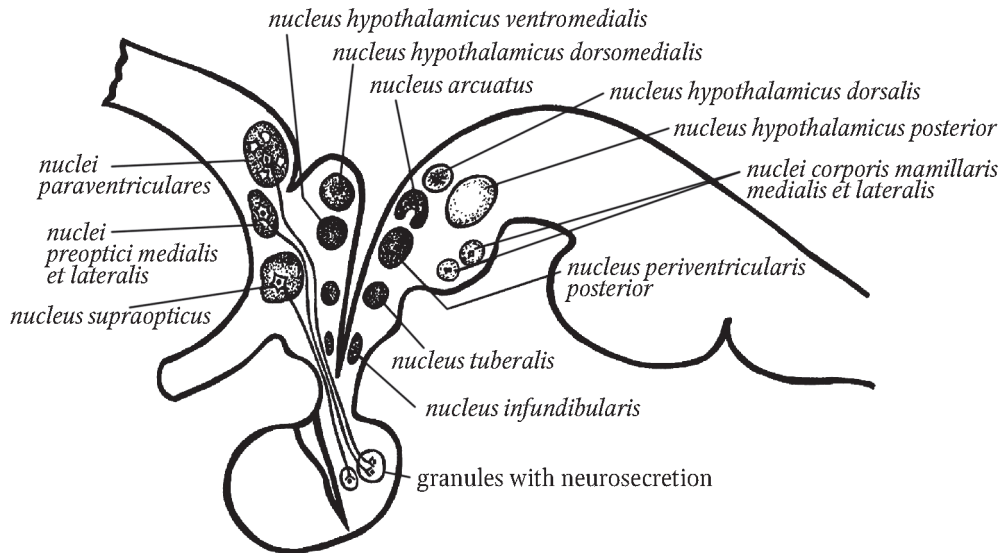


Fig. 3.29. The diagram showing the arrangement of the hypothalamic nuclei

4. The dorsolateral group comprises the posterior hypothalamic nucleus (of Luizi). This nucleus has direct connections with the medial thalamic nuclei, the telencephalic basal nuclei and with the cerebral cortex. The axons from the posterior hypothalamic nucleus end on the neurons in the anterior and intermediate hypothalamic nuclei. Hence the posterior hypothalamic nucleus is the integration centre of the subthalamic region. The damage to this nucleus causes the extrapyramidal disorders and the symptoms of the visceral dysfunction due to the impaired production of the ADH and tropic hormones.

The hypothalamus coordinates the neuronal and humoral regulation of the visceral activity hence it is considered to be the higher vegetative centre. The hypothalamic nuclei regulate the cardiovascular activity, body temperature, secretion of saliva, gastric and intestinal juices, urine, sweat etc.

According to the modern ideas about the structure of the central nervous system, the noted higher vegetative centres are controlled by the cerebral cortex.

3.8. Reticular Formation

The reticular formation is a set of anatomically and functionally interconnected neurons in the brain stem and spinal cord's cervical part, surrounded by numerous fibres running in different directions. The reticular formation is named from reticulated arrangement of its fibres.

The reticular formation elements in the cervical and upper thoracic spinal segments are located between the posterior and lateral horns; in the rhombencephalon and mesencephalon they lie in the tegmentum; in the diencephalon they are in the thalamus.

The reticular formation includes numerous discrete neurons of different form and size, and also the nuclei, situated in the brain stem. The (disseminated) neurons of the reticular formation play an important role in the segmental reflexes occurring at the

level of the brain stem. They function as intermediate neurons in such reflex acts as swallowing, corneal reflex etc.

The function of many reticular formation nuclei has been established. For example, the nuclei situated in the medulla oblongata have connections with the vegetative nuclei of vagus and glossopharyngeal nerves, and with the sympathetic nuclei of the spinal cord. Therefore, they participate in regulation of the cardiac activity, respiration, vascular tone, secretion of the glands etc.

The role of the locus coeruleus has also been known: it plays a role in sleep-wake regulation. The locus coeruleus is located in the superolateral part of the rhomboid fossa. The neurons of this nucleus produce a biological active substance, noradrenaline, which activates the neurons of the overlying cerebral parts. The activity of the locus coeruleus neurons is especially high during wake, while during deep sleep it decreases almost completely. The nuclei of the median raphe lie along the midline in the medulla oblongata and pons. Their neurons produce serotonin which causes the processes of diffuse inhibition and state of sleep.

The Cajal's and Darksheвич's nuclei, which belong to the midbrain reticular formation, are connected with the nuclei of the III, IV, VI, VIII and XI cranial nerves via the medial longitudinal fasciculus. They synchronize the functioning of these nerve centres that is important for the coordinated turn of the head and eyes. The brain-stem reticular formation is significant in the maintaining of the skeletal musculature tone; it sends the tonic impulses to gamma-motoneurons of the cranial nerve motor nuclei and motor nuclei in the spinal anterior horns. During evolution, such structures as the red nucleus and substantia nigra separated from the reticular formation.

The structural elements of the brain-stem reticular formation can be arbitrarily divided into lateral and medial parts. In the lateral part, the fibres from different afferent systems end. The collaterals from the spinal, medial, trigeminal and lateral lemnisci synapse with the disseminated cells of the reticular formation; also the axons from the sensory cranial nerve nuclei run to these cells. The neurons in the medial part give rise to the fibres which travel to the motor cranial nerve nuclei, to the cerebellum and motor nuclei in the spinal anterior horns.

The afferent structures of the reticular formation in the spinal cord, medulla oblongata, pons and midbrain transmit the information to the medial and reticular thalamic nuclei via the following tracts: spinoreticular (arising from the spinal reticular formation); reticulothalamic (arising from the reticular formation of the medulla oblongata and pons); tegmentothalamic (arising from the midbrain reticular formation).

The main descending tract is the reticulospinal tract; it starts in the brain stem and run to the nuclei proprii of the spinal anterior horns and to the intermediolateral nucleus. This tract conducts tonic impulses to gamma-motoneurons and to the association sympathetic neurons.

From the neurons of the medial and reticular thalamic nuclei to diverse regions of the cerebral cortex, the thalamocortical fibres run. These tracts spread diffusely and end not only in all cortical areas but in all layers of the cerebral cortex. Due to this, the cerebral cortex receives non-specific afferent impulses from the spinal and brain-stem reticular formation. These non-specific impulses activate the cerebral cortex that is necessary for the perception of the specific stimuli. The specific stimuli pass to the projection cortical centres via specialized afferent pathways from the communication nuclei in the thalamus and geniculate bodies. Non-specific afferent impulses play an important role in the differential conduction of impulses (selection of the afferent information) which pass to the cerebral cortex. The interruption of the non-specific afferent impulses leads to the decrease of the cortical tone, apathy and sleep state.

In turn, the cerebral cortex sends the impulses into the reticular formation via the corticoreticular tracts. These impulses mainly originate in the frontal cortex and pass via the pyramidal tracts. The corticoreticular connections either inhibit or excite the brain-stem reticular formation, correcting the passage of the impulses via the efferent pathways (selection of the efferent information).

Thus, between the reticular formation and cerebral cortex there is a two-way communication which provides the self-regulation of the nervous system activity. The body functions such as muscle tone, visceral activity, mood, attention concentration, memory etc depend on the functional state of the reticular formation.

In general, the reticular formation creates and maintains the conditions, necessary to perform the complex reflex activity with participation of the cerebral cortex.

3.9. Segmental Apparatus of Brain Stem

The brain-stem segmental apparatus is a complex of anatomically and functionally interconnected structures, intended to perform unconditioned (congenital) reflexes occurring at the level of the brain stem. These reflexes are, for example, sucking, corneal, swallowing, cough reflexes etc.

The brain-stem segmental apparatus involves the following structures:

1. The root fibres of the cranial nerves having the sensory component (V cranial nerve (trigeminal), VII cranial nerve (facial), IX cranial nerve (glossopharyngeal), X cranial nerve (vagus)). These fibres represent the central processes arising from the pseudounipolar neurons in the trigeminal ganglion (V cranial nerve), geniculate ganglion (VII cranial nerve), superior and inferior ganglia (IX and X cranial nerves), situated in the brain-stem substance. The root fibres end on the association neurons in the brain stem.
2. The association neurons, the role of which the reticular formation disseminated cells play. The axons of these cells end by synapses with the neurons in the motor cranial nerve nuclei.
3. The multipolar neurons of the motor cranial nerve nuclei (III cranial nerve (oculomotor), IV cranial nerve (trochlear), V cranial nerve (trigeminal), VI cranial nerve (abducens), VII cranial nerve (facial), IX cranial nerve (glossopharyngeal), X cranial nerve (vagus), XI cranial nerve (accessory) and XII cranial nerve (hypoglossal)).
4. Parts of the axons from the motor cranial nerve nuclei, which form the motor root fibres within the brain substance.

Other elements of the unconditioned reflex arches belong to the peripheral nervous system (the root fibres lying outside the brain stem, cranial sensory ganglia, cranial nerves and their branches).

Usually the association neurons of the brain-stem segmental apparatus transmit the nerve impulses to the neurons in the motor nuclei of several cranial nerves on the same and opposite sides. For example, the touch to the skin of a newborn's face elicits the sucking motions. This stimulus is perceived by the receptors, which represent the endings of the pseudounipolar cells situated in the trigeminal ganglion. In the brain stem the nerve impulse spreads to the neurons situated in the motor nuclei of the V, VII, IX, X, XI and XII cranial nerves. Due to this, in the sucking act the masticatory, mimic, palatine, pharyngeal, cervical and lingual muscles of both sides are involved.

TEST QUESTIONS

1. Describe the position of mesencephalon. What brain structures surround the midbrain?
2. Describe the structures on the ventral and dorsal midbrain surfaces.
3. What is the trigone of lemnisci? Why is it distinguished? How is it bounded?
4. What parts are distinguished in the mesencephalon? Describe each of them.
5. What cavity is inside the mesencephalon?
6. Describe the communications of the cerebral aqueduct.
7. Which cranial nerves arise from the mesencephalon?
8. Describe the arrangement of grey matter relatively to white matter in the midbrain.
9. Describe the nuclei of midbrain grey matter. How can they be grouped? Describe their position.
10. Name the nuclei of the cranial nerves emerging from the medulla oblongata.
11. Which of them are sensory (motor, parasympathetic)?
12. Describe the function of the red nucleus and substantia nigra.
13. What specific nuclei of the reticular formation are in the mesencephalon? What tracts start from them? Describe their function.
14. Describe the function of the nuclei in the superior and inferior colliculi.
15. Describe white matter of the mesencephalon (tracts which transit the mesencephalon, and connect mesencephalon with other parts of the CNS). What tracts pass through the base of the cerebral peduncles; what tracts pass through the midbrain tegmentum?
16. Describe the position of the diencephalon. What brain structures surround the diencephalon?
17. What parts of the diencephalon do you know? What is the boundary between them?
18. Describe the external structure of the thalamus.
19. Describe the nuclei of the thalamus, their function and their connections with other parts of the CNS.
20. What parts does the epithalamus consist of? Describe the function of each part.
21. What parts does the metathalamus include?
22. Describe the function of the nuclei in the medial and lateral geniculate bodies.
23. What structures form the hypothalamus? What parts of the hypothalamus do you know?
24. Describe the nuclei of the hypothalamus, their functions and their effect on the hypophysis.
25. Describe the function of the hypophysis.
26. Describe the structure of the anterior, posterior, lateral, middle and inferior walls of the III ventricle.
27. Describe communications of the III ventricle.
28. Describe the structure and position of the reticular formation.
29. What functions do the nuclei of the reticular formation have?
30. Describe the afferent tracts passing to the reticular formation.
31. Describe the efferent tracts arising from the reticular formation.
32. Describe the connections between the cortex and reticular formation.
33. What structures comprise the segmental apparatus of the brain-stem?

CLINICOANATOMICAL PROBLEMS

1. A patient has a damage to the substantia nigra. Where is the focus of lesion located?
2. A patient has a tumor in the midbrain region. What cranial nerves can be involved in the pathological process?

3. A patient has a tumor which compresses the communication between the III and IV ventricles. Where is this communication located?
4. A patient has a tumor of the hypophysis. Where is the tumor located in the skull base? The symptoms of the damage to which cranial nerve can be observed?
5. A child has the symptoms of premature adrenarche. The tumor which diencephalic structures can be supposed?

3.10. Telencephalon

The *telencephalon* (*cerebrum*) is derived from the anterior cerebral vesicle and comprises two cerebral hemispheres, *hemispheria cerebri*. Each hemisphere consists of: 1) the mantle, *pallium*, which develops from the dorsal wall of the cerebral vesicle; 2) the olfactory brain, *rhinencephalon*; 3) the basal nuclei, *nuclei basales*, which develop from the ventral part of the cerebral vesicle. Inside each hemisphere there is a cavity called the lateral ventricle, *ventriculus lateralis*, connected with the III ventricle.

The outer layer of the pallium is the cerebral cortex, *cortex cerebri*; under the cortex there is white matter which constitutes a greater part of the hemisphere.

3.10.1. Cerebral Cortex

The cerebral cortex is the grey matter layer of various thickness (in average 2–3 mm). The cortical surface has a complex relief characterized by numerous cerebral sulci, *sulci cerebri*, and the cerebral gyri, *gyri cerebri*, situated between the sulci. The gyri differ in form and size but in different people the main gyri are fundamentally similar and localized in certain places.

Each cerebral hemisphere has superolateral, medial and inferior surfaces. The superolateral surface, *facies superolateralis hemispherii cerebri*, is the most extensive, convex, directed up and laterally; it is separated from the medial surface by a clearly distinct superior margin, *margo superior*. A flat medial surface is directed to the longitudinal cerebral fissure, *fissura longitudinalis cerebri*, and connected by the corpus callosum to the medial surface of the other hemisphere. The inferior surface is flattened in its anterior part and concave in its posterior part. It is separated from the medial surface by the inferomedial margin, *margo inferomedialis*, and from the superolateral surface by the inferolateral margin, *margo inferolateralis*. The transverse cerebral fissure, *fissura transversa cerebri*, separates the cerebrum from the cerebellum. Three main sulci divide each hemisphere into four cerebral lobes, *lobi cerebri*.

1. The lateral sulcus, *sulcus lateralis*, starts on the inferior cerebral surface from the lateral (Sylvian) cerebral fossa, *fossa lateralis cerebri* (*Sylvii*), ascends along the lateral side and divides into three branches: anterior, ascending and posterior, *ramus anterior*, *ramus ascendens et ramus posterior*. The lateral sulcus limits the temporal lobe anterosuperiorly and separates the frontal and temporal lobes.

2. The central sulcus (of Rolando), *sulcus centralis* (*Rolandi*), oriented in the frontal plane, arises from the superior margin of the hemisphere and passes along its lateral surface. Usually it prolongates to the medial surface; its lower end slightly does not reach the Sylvian sulcus. The central sulcus divides the superior part of the hemisphere into anterior (smaller) portion, the frontal lobe, and posterior (larger) portion which includes the parietal and occipital lobes. The central sulcus is uninterrupted throughout its length.

3. The parieto-occipital sulcus, *sulcus parietooccipitalis*, lies in the posterior part of the brain on its medial surface and slightly prolongates to the superolateral surface. This sulcus separates the parietal and occipital lobes.

Now we will describe the relations between the lobes of the cerebral hemispheres. The frontal lobe occupies the superolateral hemispheric surface in front of the central sulcus, and the inferior hemispheric surface in front of the lateral sulcus. There is no boundary between the frontal and parietal lobes on the medial surface; here the lobes are separated by an imaginary continuation of the central sulcus.

The temporal lobe occupies the superolateral hemispheric surface below the lateral sulcus, and inferior hemispheric surface behind the lateral (Sylvian) fossa. On the medial surface, the temporal lobe lies below the brain stem.

The parietal lobe is in the center of the brain. On the superolateral surface, it occupies the area between the central sulcus anteriorly, the lateral sulcus inferiorly and an imaginary continuation of the parieto-occipital sulcus posteriorly. On the medial hemispheric surface, the parietal lobe is between the parieto-occipital sulcus posteriorly, an imaginary continuation of the central sulcus anteriorly and the corpus callosum inferiorly.

The occipital lobe is clearly demarcated from the parietal lobe by the parieto-occipital sulcus only on the medial hemispheric surface. On the superolateral and inferior hemispheric surfaces, the borders of the occipital lobe are defined by imaginary continuations of the parieto-occipital sulcus.

Apart from the noted four lobes, one more region called the island of Reil, or insular lobule, *insula (Reilli)*, is distinguished. It lies deeply, within the lateral sulcus and can be visualized only if the gyri which bound the lateral sulcus are opened up.

Relief of superolateral cerebral surface

The frontal lobe, *lobus frontalis*. On the superolateral surface in front of the central sulcus there are superior precentral sulcus and inferior precentral sulcus. Sometimes they merge into a single precentral sulcus, *sulcus precentralis*. From these two sulci, two frontal sulci, superior, *sulcus frontalis superior*, and inferior, *sulcus frontalis inferior*, arise and run forward (fig. 3.30).



Fig. 3.30. The diagram showing the position of the sulci and gyri on the superolateral cerebral surface (according to R. D. Sinelnikov, 1963)

The four mentioned sulci divide the superolateral surface of the frontal lobe into the following gyri. In front of the central sulcus there is a precentral gyrus, *gyrus precentralis*. The rest of this area is divided into the superior frontal gyrus, *gyrus frontalis superior* (situated above the superior frontal sulcus along the upper hemispheric margin); the middle frontal gyrus, *gyrus frontalis medius* (lies between the superior and inferior frontal sulci); the inferior frontal gyrus, *gyrus frontalis inferior* (situated between the inferior frontal sulcus and lateral sulcus). The anterior end of the cerebral hemisphere is called the frontal pole, *polus frontalis*.

The parietal lobe, *lobus parietalis*. On the superolateral surface, the postcentral sulcus, *sulcus postcentralis*, passes parallel to the central sulcus. From the postcentral sulcus, a long intraparietal sulcus, *sulcus intraparietalis*, runs sagittally. These two sulci divide the superolateral surface of the parietal lobe into three regions. Between the central and postcentral sulci there is a postcentral gyrus, *gyrus postcentralis*. It continues to the medial surface of the hemisphere. The region situated above the intraparietal sulcus is called the superior parietal lobule, *lobulus parietalis superior*. Below the intraparietal sulcus is the inferior parietal lobule, *lobulus parietalis inferior*. The latter includes two important gyri: supramarginal, *gyrus supramarginalis*, located behind the end of the lateral sulcus, and angular, *gyrus angularis*, which surrounds the posterior end of the superior temporal sulcus.

The occipital lobe, *lobus occipitalis*. It is the smallest of all the lobes. The sulci on its superolateral surface greatly vary. Here are the superior occipital sulci, *sulci occipitales superiores*, and lateral occipital sulci, *sulci occipitales laterales*, and also superior and lateral occipital gyri *gyri occipitales superiores et laterales*. The posterior end of the cerebral hemisphere is called the occipital pole, *polus occipitalis*.

The temporal lobe, *lobus temporalis*. On the superolateral surface there is a superior temporal sulcus, *sulcus temporalis superior*, which passes in the anteroposterior direction; its posterior end extends to the parietal lobe. The inferior temporal sulcus, *sulcus temporalis inferior*, lies close to the inferior margin of the temporal lobe.

Above the superior temporal sulcus is the superior temporal gyrus, *gyrus temporalis superior*, and below it, there is a middle temporal gyrus, *gyrus temporalis medius*. Along the inferior hemispheric margin, below the inferior temporal sulcus, the inferior temporal gyrus, *gyrus temporalis inferior*, passes. The anterior end of the temporal lobe is called the temporal pole, *polus temporalis*.

The insula, *insula* (insular lobule) is visible only when the borders of the lateral sulcus are opened up or after the removal of the opercula of the frontal, parietal and temporal lobes that together cover the insula. The insula resembles a cone, the base of which is surrounded by a deep circular sulcus, *sulcus circularis insulae*. The central sulcus, *sulcus centralis insulae*, divides the surface of insula into anterior and posterior lobes. The posterior lobe usually consists of only one long gyrus, *gyrus longus insulae*; the anterior lobe contains several short gyri, *gyri breves insulae*.

Relief of medial cerebral surface

The sulci of the medial cerebral surface (fig. 3.31). All the cerebral lobes extend onto the medial surface of the cerebral hemisphere. The sulcus of corpus callosum, *sulcus corporis callosi*, is the main sulcus on the medial surface; it surrounds a convex side of the corpus callosum and is continuous with the hippocampal sulcus, *sulcus hippocampalis*. Approximately midway between the sulcus of corpus callosum and upper hemispheric margin is the cingulate sulcus, *sulcus cinguli*. It turns towards the upper hemispheric margin by the posterior end called the marginal branch, *ramus marginalis*, and slightly

continues onto the superolateral surface, being posterior to the central sulcus. In front of the marginal branch, approximately above the middle of the corpus callosum, the cingulate sulcus gives the paracentral sulcus, *sulcus paracentralis*, which passes upwards. The direct continuation of the cingulate sulcus is the subparietal sulcus, *sulcus subparietalis*. Below the posterior end of the corpus callosum, two grooves which diverge to the hemispheric margin start by a common trunk: the parieto-occipital sulcus (vide supra) and calcarine sulcus, *sulcus calcarinus*. Near the occipital pole, on the inferior cerebral surface, the collateral sulcus, *sulcus collateralis*, starts; it runs forwards and continues onto the anterior portion of the temporal lobe as a rhinal sulcus, *sulcus rhinalis*.

The gyri of the medial cerebral surface. The part of the medial surface, lying above the cingulate gyrus, belongs to the frontal lobe. This is the superior frontal gyrus, extending from the superolateral surface. Posteriorly it reaches the imaginary continuation of the central sulcus. Within the parietal lobe there is a paracentral lobule, *lobulus paracentralis*, which adjoins the marginal branch of the cingulate sulcus posteriorly. The paracentral lobule connects the parietal and frontal lobes on the medial cerebral surface (more precisely, the postcentral gyrus and precentral gyrus). Between the marginal branch of the cingulate sulcus anteriorly, the parieto-occipital sulcus posteriorly and subparietal sulcus inferiorly there is a *precuneus*. The parieto-occipital sulcus and calcarine sulcus (already in the occipital lobe) limit a *cuneus*. On the medial cerebral surface there is a lingual gyrus, *gyrus lingualis*, the upper border of which adjoins the calcarine sulcus. Below the collateral sulcus is the medial occipitotemporal gyrus, *gyrus occipitotemporalis medialis*.

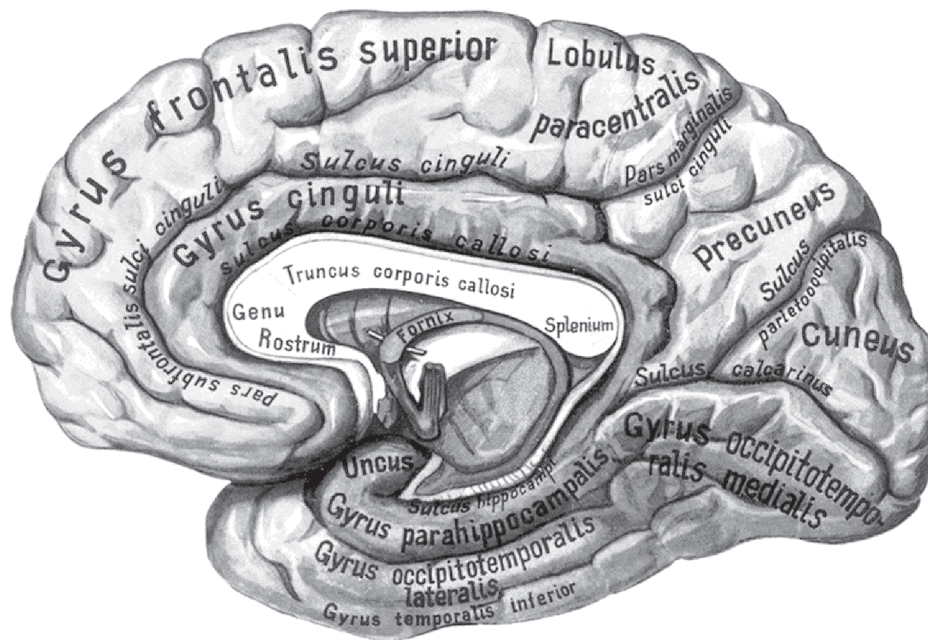


Fig. 3.31. The diagram showing the position of the sulci and gyri on the medial cerebral surface (according to R. D. Sinelnikov, 1963)

Within the temporal lobe on the medial cerebral surface, directly under the cerebral peduncles there is a parahippocampal gyrus, *gyrus parahippocampalis*, which ends anteriorly in the *uncus*. The parahippocampal gyrus and uncus are separated from the cerebral peduncles by the hippocampal sulcus, *sulcus hippocampalis*. Below the parahippocampal gyrus is the lateral occipitotemporal gyrus, *gyrus occipitotemporalis lateralis*; they are separated posteriorly by the collateral sulcus, *sulcus collateralis*, anteriorly by the rhinal sulcus, *sulcus rhinalis*.

Along the lowermost border of the temporal lobe's medial surface, the inferior temporal gyrus extends; above it, there is a lateral occipitotemporal gyrus, *gyrus occipitotemporalis lateralis*.

The gyri extending from the frontal lobe onto the temporal and surrounding the corpus callosum and cerebral peduncles together comprise the fornicate gyrus, *gyrus fornicatus*, which is considered as a limbic lobe, *lobus limbicus*. It consists of two parts: cingulate gyrus and parahippocampal gyrus connected by the isthmus, *isthmus gyri cinguli*, behind the corpus callosum's splenium. The cingulate gyrus lies between the sulcus of corpus callosum and subparietal sulcus. As mentioned above, the parahippocampal gyrus is between the hippocampal sulcus (above) and anterior ends of the collateral and rhinal sulci (below).

Relief of inferior cerebral surface

On the inferior (basal) surface of the frontal lobe there is an olfactory sulcus, *sulcus olfactorius*, passing parallel to the longitudinal cerebral fissure; lateral to it, the orbital sulci, *sulci orbitales*, are situated. Between these sulci there are the gyri of various forms: the straight gyrus, *gyrus rectus*, which is bounded by the olfactory sulcus and longitudinal cerebral fissure, and the orbital gyri, *gyri orbitales*, situated lateral to the olfactory sulcus (fig. 3.32).

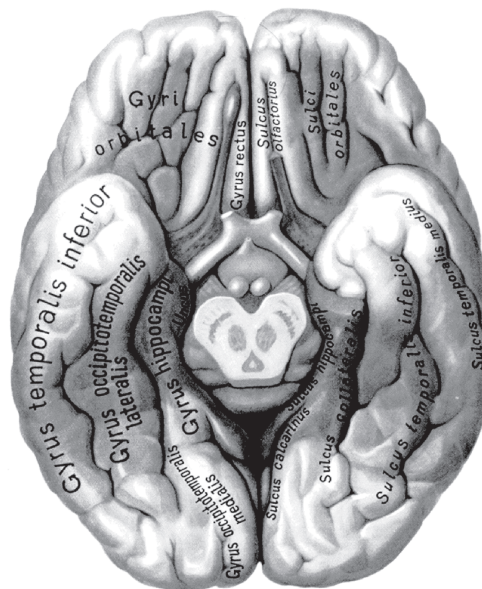


Fig. 3.32. The diagram showing the position of the sulci and gyri on the inferior cerebral surface (according to R. D. Sinelnikov, 1963)

Within the temporal and occipital lobes there is no distinct boundary between the medial and inferior surfaces: they gradually continue into each other. Due to this, the sulci and gyri situated on the medial cerebral surface in the lower parts of the occipital and temporal lobes are also visible on the inferior cerebral surface. Thus, within the occipital lobe there is a medial occipitotemporal gyrus. Within the temporal lobe there are parahippocampal, lateral occipitotemporal and inferior temporal gyri. The sequential position of the mentioned gyri is given in the lateral direction. The sulci which separate these gyri have been described above.

The given description of the cortical sulci and gyri can be considered generalized because their architectonics may individually vary.

Structure of cerebral cortex

The cerebral cortex, *cortex cerebri*, is the most important part of the brain; it is a material substrate of the higher nervous activity and main regulator of all vital body functions. The cortex analyzes and synthesizes the stimuli passing from the internal and external environment. Thus, the reflexion of the external world and conscious activity of man are associated with the cerebral cortex.

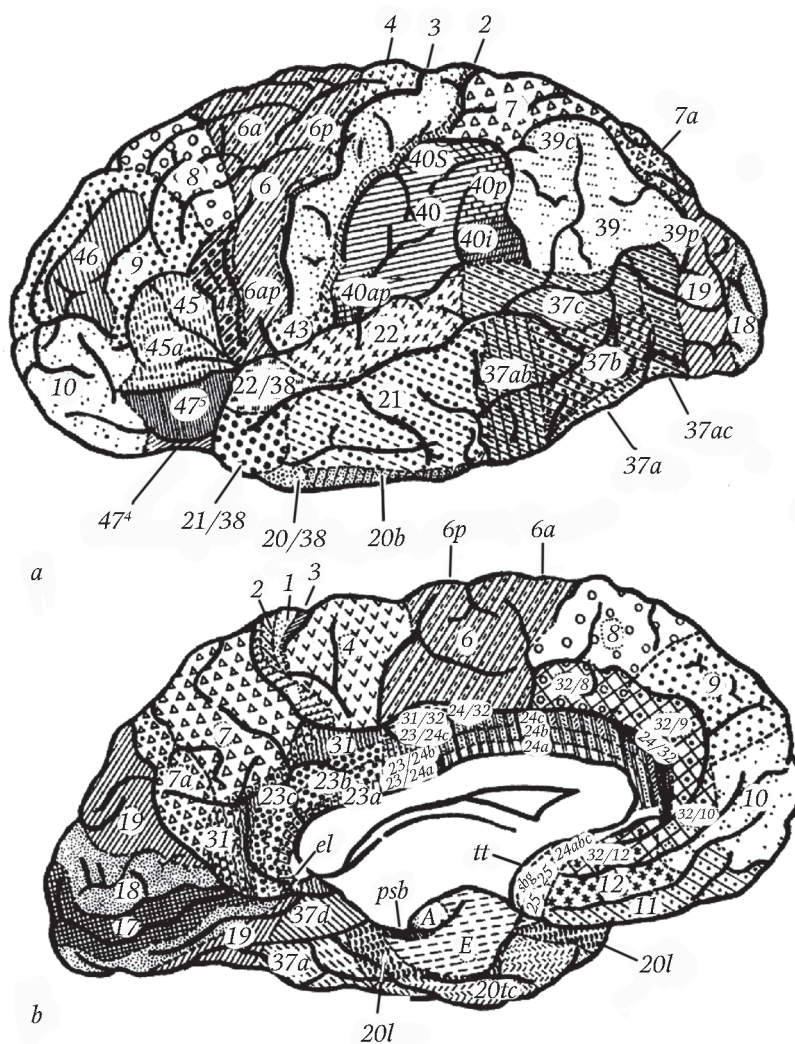
The cortex formation is one of the most progressive achievements in the brain evolution in vertebrates. Phylogenetic approaches to the study of the cortex formation reveal that the cortex has been developing gradually. For example, the cortex of fishes and amphibians carries out only the function of the olfactory analyzer. In reptiles, the new cortex which analyzes the visual information appears. The cortex in mammals occupies already the greater part of the cerebral hemispheres. It analyzes impulses of all modalities of sensation; the higher motor centres has been developing in the cortex. In higher mammals (primates and human), the rapid development of the new cortex led to the formation of the sulci and gyri, due to which the surface of the cerebral hemispheres has increased.

The cerebral cortex of the human brain can be divided into phylogenetically ancient, old and new cortex. The small part situated on the frontal lobe's ventral surface near the olfactory bulb belongs to ancient cortex, *paleocortex*. The old cortex, *archicortex*, includes the hippocampus (cornu Ammonis) which is located in the cavity of the lateral ventricles. The displacement of the archipallium to this place occurred due to significant growth of the new cortex, *neocortex*. The neocortex occupies 95 % of whole surface of the human cerebral hemisphere. The sulci appear on the cerebral cortex starts already during 5th month of the human embryo development. At first the lateral sulcus is formed; then the central, parieto-occipital, calcarine and hippocampal sulci appear. Starting from the 7th month, the development of the sulci accelerates, leading to the formation of the secondary sulci. By the time of birth, the relief of the cerebral hemispheres is mainly formed. After birth, the tertiary sulci, which determine the individual features of the cerebral hemispheres, appear.

The average square of the cerebral hemispheres by the time of the ultimate formation of the sulci in an adult is 1550 cm².

The neocortex in humans is highly differentiated compared to the neocortex in other mammals. Its thickness is uneven. In average it is 2–3 mm however, it changes not only in different parts of the hemisphere but also in different areas of the gyri. The neocortex is the most developed in the precentral and postcentral gyri, and also in the paracentral lobule. On the tops of the gyri, the cortex is usually thicker than in the depth of the sulci. In general, the cortex comprises 44 % of the whole hemisphere. The number of neurons in the cerebral cortex is 15 billions in average. However, their amount relates to the vol-

The pioneer in researches of the cortical cellular structure was V. A. Betz. Then Brodmann divided the cerebral cortex into 52 areas and indicated each of them by a certain digit. The same numbering was used in the cytoarchitectonic map which has been made in the Moscow Brain Research Institute; some areas in this map have been divided into the zones, indicated by the letter of the Latin alphabet (fig. 3.33).



a – superolateral surface; b – medial surface

The nerve cells distribute in the cortex differently. But structurally similar nerve cells unite into separate layers, the number of which varies from 5 to 8. The great part of the cerebral hemispheres consists of 6 layers. In some areas (for example, in the precentral gyrus), the fourth layer reduces; on the contrary, in the occipital lobe the fourth layer divides into three new layers.

The most external layer, the plexiform or molecular lamina, *lamina molecularis*, contains a little of small nerve cells but is mainly formed by a thick nerve fibre plexus lying parallel to the surfaces of the gyri.

The second layer, the external granular lamina, *lamina granularis externa*, contains the large number of small polygonal or round nerve cells.

The third layer, the external pyramidal lamina, *lamina pyramidalis externa*, consists of small cells like the second layer.

The fourth layer is termed the internal granular lamina, *lamina granularis interna*.

The fifth layer is a layer of the large pyramidal cells, or the ganglionic lamina, *lamina ganglionaris*; it is represented by the internal pyramidal lamina, *lamina pyramidalis interna*. It contains rather large pyramidal cells and also the giant pyramidal cells (the Betz cells). The Betz cells can be found in certain cortical areas: in the precentral gyrus (mainly in its upper part) and paracentral lobule. The apices of the pyramidal cells are directed towards the brain surface; the bases, from where the axons start, are directed to white matter. The fifth layer gives rise to efferent (descending) corticospinal and corticonuclear tracts.

The last layer, adjoining white matter, polymorphic, is represented by the multiform lamina, *lamina multiformis*, and contains the cellular elements of various forms (triangular, polygonal, oval, fusiform).

It is accepted to unite three external layers into the main outer zone; three internal layers are united into the main inner zone. The functional purpose of the laminae is determined by their cellular composition and interneuronal connections. In the molecular lamina, the fibres from other cortical layers and from opposite hemisphere terminate. There is an opinion that the neurons of the molecular lamina are directly related to the processes of memory. The external granular and external pyramidal laminae mainly contain the association neurons that perform intracortical connections hence provide analytical thought processes. These laminae are phylogenetically the youngest; they are greatly developed in the human cerebral cortex.

The internal granular lamina is the main afferent layer in the cortex. The projection nerve fibres passing from the thalamus and geniculate bodies end in this layer. The pyramidal cells of the internal pyramidal lamina give rise to efferent projection nerve fibres. The multiform lamina contains functionally heterogeneous neurons. They give rise to association and commissural fibres.

Currently the information about the structural and functional interrelation between the neurons of different cortical layers has been obtained. This permitted to create the concept of the cortical columns, or modules. Each cortical column is a vertical row of the neurons passing throughout all the cortical layers. The column has an own input and output; it is intended for processing of received information. The number of the neurons in the cortical columns is constant (usually 110; only in the visual areas they increase to 300–500). The cortical columns are surrounded by radially oriented arterioles and nerve fibres, i.e. have certain boundaries.

The cortical areas have specific myeloarchitectonics: there are radial and tangential nerve fibres. The radial fibres enter the cortex from hemispheric white matter or conversely pass from the cortex to white matter. The tangential fibres are arranged parallel

to the cortical layers and form the plexuses (stripes). The fibres passing in the stripes connect the neurons of the neighboring cortical columns. The number of the stripes is unequal in different cortical areas. It is especially great in the visual cortical areas. Based on the features of myeloarchitectonics, O.Vogt distinguished more than 100 areas in the cerebral cortex. The distribution of glia also has significant differences in diverse cortical areas; this is described by glioarchitectonics.

3.10.2. Cerebral Areas

Based on numerous clinical, pathological, electrophysiological and morphological researches, the functional purpose of the different cortical areas has been established.

The cortical areas, having certain cytoarchitectonics and nerve connections and performing certain functions, are called the nerve centres. The damage to such cortical areas manifests in the loss of their functions. The nerve centres of the cerebral hemispheres can be divided into projection and association.

The projection (primary) centres are the cortical areas which represent the cortical parts of the analyzers and have direct morphofunctional connection with the neurons of the subcortical centres via afferent and efferent pathways. They perform primary processing of received conscious afferent information and give conscious efferent impulses (voluntary motor acts).

Association centres are the cortical areas which do not have direct connection with subcortical centres but are connected with projection centres by temporary two-way communication. The association centres play essential role in the higher nervous activity (deep conscious processing of afferent information, mental activity, memory etc).

Currently the role of some cortical areas has been established. The cortical areas, which do not belong neither association nor projection centres, participate in integration activity of the brain, interconnecting the analyzers.

The projection cortical centres (areas) exist in humans and in higher vertebrates. They begin to function immediately after birth. The formation of these centres ends much earlier than the formation of the association centres. The following projection centres are clinically important:

The projection somatosensory area (of general sensation (tactile, pain, temperature and conscious proprioceptive)) is the cortex of the postcentral gyrus (areas 1, 2, 3). The fibres of the thalamocortical tract end here. Each region of the opposite body half has a distinct projection in the somatosensory area (somatotopic projection). The lower limbs and trunk project to the upper portion of the postcentral gyrus; the upper limbs project to its middle portion; and the head projects to its lower portion (sensory homunculus of Penfield). The sizes of the projection zones are in direct proportion to the number of the receptors situated in the skin of a certain region. Thus, the largest somatosensory zones correspond to the face and hand. The damage to the postcentral gyrus causes the loss of the tactile, pain, temperature sensation and the sensitivity of the muscles and joints on the opposite body half.

The projection somatomotor area (kinesthetic centre) is the motor cortical area which includes the precentral gyrus and paracentral lobule (areas 4, 6). The fibres comprising the thalamocortical tract end in the 3–4th layers of the somatomotor area. The analysis of the proprioceptive (kinesthetic) stimuli is performed there. The neurons of the 5th layer give rise to the corticospinal and corticonuclear tracts. There is a distinct projection of the motor functions in the precentral gyrus. The muscles, which perform complex and highly differentiated movements, have larger projection zones in the cortex of the precentral gyrus. The projection of the muscles of the tongue, face and hand oc-

cupies the largest zone; the projection of the muscles of the trunk and lower limbs occupies the smallest zone. The somatotopic projection to the precentral gyrus is termed the motor homunculus of Penfield. The human body projects to the opposite precentral gyrus upside down.

The afferent fibres, which end in the sensory cortical layers of the kinesthetic centre, pass via the gracile and cuneate fasciculi and via the nucleothalamic tract, conducting conscious muscular and articular sensitivity, and partially tactile impulses. The damage to the precentral gyrus leads to the impairment of the perception of the proprioceptive stimuli from the skeletal muscles, joints and periosteum thus causes the central paralysis. The central paralyse is associated with the damage to the neurons in the motor cortex, the axons of which end on the neurons of the motor nuclei of the cranial nerves or on the neurons in the nuclei proprii of the spinal anterior horns. The corticospinal and corticonuclear tracts conduct the impulses providing conscious movements and inhibit the activity of the brain-stem segmental apparatus. The somatomotor area has numerous connections via the system of association fibres with various sensory centres (of the general sensation, vision, hearing, balance etc). These connections are necessary to integrate voluntary movements.

The projection area of awareness of body parts is in the parietal lobe in the region of the intraparietal sulcus (area 40s). The somatotopic projections of all body parts are represented here. This area receives chiefly the impulses of conscious proprioceptive sensation. The main functional purpose of this projection area is to determine the position of the body and its parts in space and to evaluate the muscle tone. The damage to the superior parietal lobule results in the loss of awareness of body parts, the sense of extra limbs, failure to determine the position of the body parts in space.

The projection acoustic area occupies the middle third of the superior temporal gyrus (area 22), mainly the surface directed to the insula. It receives the fibres of the acoustic tract, arising from the medial geniculate body (subcortical acoustic centre) of the same and opposite side. Ultimately, the acoustic tract fibres pass through the acoustic radiation.

The damage to the projection acoustic area leads to the decrease of hearing in both ears (in the ear, opposite to the focus of lesion, the hearing is reduced to a greater extent). Complete deafness is observed only in case of bilateral lesion of the projection acoustic areas.

The projection visual area is localized on the medial surface of the occipital lobe, along the calcarine sulcus (area 17). It receives the fibres of the optic tract (*radiatio optica*) of the same and opposite sides, arising from the neurons of the lateral geniculate body (visual subcortical centre). The neurons of the area 17 perceive the light stimuli.

The unilateral damage to the projection visual area results in partial blindness, but in different parts of the retina. Complete blindness occurs only in case of bilateral damage to area 17.

The projection olfactory area is on the medial surface of the temporal lobe, in the cortex of the parahippocampal gyrus and uncus (limbic region — areas A, E). It receives the fibres of the olfactory tract of the same and opposite sides, arising from the neurons of the olfactory trigones. The unilateral damage to the projection olfactory area leads to the decrease of olfaction and olfactory hallucinations.

The projection area of taste lies together with the projection olfactory centre, i. e. in the limbic region. It receives the fibres of the taste pathway of the same and opposite side, arising from the neurons of the basal thalamic nuclei.

The damage to the limbic region leads to the disorders of taste and olfaction, and to the olfactory hallucinations.

The projection area of visceroreception is in the lower third of the postcentral and precentral gyri (area 43). It receives the afferent impulses from smooth musculature

and glands of the internal organs. The fibres of the interoceptive tract, arising from the ventrolateral nucleus of the thalamus, end in the cortex of area 43 (the impulses to the ventrolateral thalamic nucleus pass through the nucleothalamic tract). The cortex in the projection area of visceroreception analyzes mainly pain senses and the afferent impulses from smooth musculature.

The projection vestibular area is probably located on the dorsal surface of the temporal lobe, in the region of the middle and inferior temporal gyri (areas 20, 21); the evidences about its localization are uncertain. The adjoining parts of the parietal and frontal lobes are also involved into the vestibular analyzer. The cortex in the projection vestibular area receives the fibres arising from the central thalamic nuclei. The damage to this area manifests as spontaneous dizziness, sense of instability, sense of movements of surrounding objects and deformation of their contours.

To conclude the description of the projection areas, it should be noted that the somatosensory areas receive the afferent information from the opposite body half therefore, the damage to these areas leads to the disorder of sensations only in the opposite side. The cortical analyzers which belong to special modality of sensation (acoustic, visual, olfactory, taste, vestibular) are linked with the receptor of the corresponding sense organs on the same and opposite sides therefore, complete loss of the functions of these analyzers is observed only in damage to the corresponding areas on both sides.

Association nerve centres (areas) develop later than the projection, and the time of the corticalization (i.e. maturation of the cortex) in projection and association centres is different. Taking into account the relation of the association centres to the thought processes and verbal functions, it is considered that they develop only in the human cortex. But some researches suppose the existence of such centres in higher vertebrates also. Now we will describe the main association areas.

The association area of stereognosis (the ability to recognize an object in the absence of visual and auditory information) is situated in the superior parietal lobule (area 7). It is bilateral: in the right hemisphere for the left hand; in the left hemisphere for the right hand. The area of stereognosis receives pain, temperature, tactile and proprioceptive impulses from the projection somatosensory area (postcentral gyrus). These impulses are analyzed in the cortical association centre that leads to the recognition of previously viewed objects. The area of stereognosis is constantly developing and improving throughout life. In case of superior parietal lobule injury, patients lose the ability to recognize objects when handled without vision (astereognosis), but individual properties of objects such as form, volume, temperature, weight, density he can define correctly.

The association area of praxia (the analyzer of purposeful usual movements) occupies the inferior parietal lobule, the cortex of the supramarginal gyrus (area 40); in right-handed people it is in the left hemisphere, in left-handed in the right. If the centre of praxia is formed in both hemispheres, a man is able to use the right and left hands equally well that is termed ambidexterity.

The centre of praxia is developed as a result of numerous repetitions of complex purposeful actions. Due to the storage of temporary connections, the skilled movements are formed (for example, playing the piano, professional abilities etc.). During accumulation of life experience, the centre of praxia is constantly improving. The cortex in the supramarginal gyrus has the connections with the precentral and postcentral gyri.

After performing the synthesis and analysis in the area of praxia, the information passes to the pyramidal neurons in the precentral gyrus.

The damage to the area of praxia manifests as apraxia, i.e. the loss of voluntary purposeful movements acquired with practice.

The association visual area, or analyzer of the visual memory occupies the superolateral surface of the occipital lobe (areas 18–19), in the right-handed it is in the left hemisphere, in the left-handed in the right. It provides memorization of objects by their form, exterior view and color. It is considered that the neurons in the area 18 provide visual memory, while the neurons in the area 19 provide the orientation in an unfamiliar surrounding. The areas 18 and 19 have numerous association connections with other cortical areas, due to which the integrative visual perception occurs. The damage to the area of visual memory (area 18) leads to the visual agnosia. More often the partial agnosia is observed (a patient does not recognize his friends, home, himself in mirror). In the damage to the area 19 the distorted perception of objects is noted: the patient does not recognize familiar objects but sees them, can bypass obstacles.

The human nervous system has specific areas. These are the centres of the second-signal system, i.e. the centres that provide the ability of communication between people by means of articulate human speech. The human speech may be in the form of articulate sounds (“articulation”) or written symbols (“graphics”). Thus, in the cerebral cortex the following association speech centres develop: acoustic and visual speech centres; the motor speech centre and written speech centre. The mentioned association speech centres develop near the corresponding projection centres. They progress in certain sequence, starting from the first months after birth, and may improve till old age. Now we will describe the speech areas in accordance with the order of their formation in the cerebral cortex.

The association acoustic area, or second motor speech area of Wernicke is in the posterior third of the superior temporal gyrus. The symptoms of the damage to this area were first described in 1874 year by German neurologist and psychiatrist Wernicke. This area receives the fibres arising from the projection acoustic area (the middle third of the superior temporal gyrus). The association acoustic area starts to develop during the second–third months after birth. With the formation of this centre, a child starts to differentiate the human articulate speech among other surrounding sounds: at first only individual words, then phrases and complex sentences.

The Wernicke’s area injury leads to sensory aphasia. This is the loss of the ability to understand the personal and others’ speech; though the patient hears well, reacts to sounds, but he seems that people around speak unknown language. The lack of auditory control of own speech results in the disturbance of sentence construction; the speech becomes unclear and contains meaningless words and sounds. Thus, in case of the Wernicke’s area injury, not only the understanding of words but also pronunciation is disturbed.

The association motor speech area, or Broca’s area is in the posterior third of the inferior frontal gyrus (area 44), in immediate vicinity with the projection somatomotor area (precentral gyrus). This area was called by the name of French anatomist and surgeon Broca. In 1861 year, at a meeting of Paris anthropological society he first demonstrated the brain of the patient with the lesion in the region of the inferior frontal gyrus’s posterior third. During his life, this patient had the disorders of speech articulation.

The motor speech area starts to form during the third month of life. It develops in dominant hemisphere. The impulses from the motor speech area pass to the precentral gyrus and further via the corticonuclear tract to the muscles of the tongue, larynx, pharynx, the muscles of the head and neck.

The damage to the motor speech area results in motor aphasia (the loss or impairment of the ability to speak). The speech of such patients is slow, impeded and incoherent. But the patients can understand speech of other people.

The association visual speech area, or visual analyzer of written speech (centre of lexia) occupies the angular gyrus below the inferior parietal lobule (area 39). It

was first described by Dejerine in 1914. This area receives the impulses from the neurons situated in the projection visual centre (area 17) and analyzes the visual information about the letters, digits, symbols, the letter composition of words and understanding of their meaning. The area starts to develop from three years of age when a child begins to learn letters, digits and understand them at hearing.

The damage to this area results in alexia (impaired reading): a patient can see the letters but can not understand their meaning therefore, can not read a text.

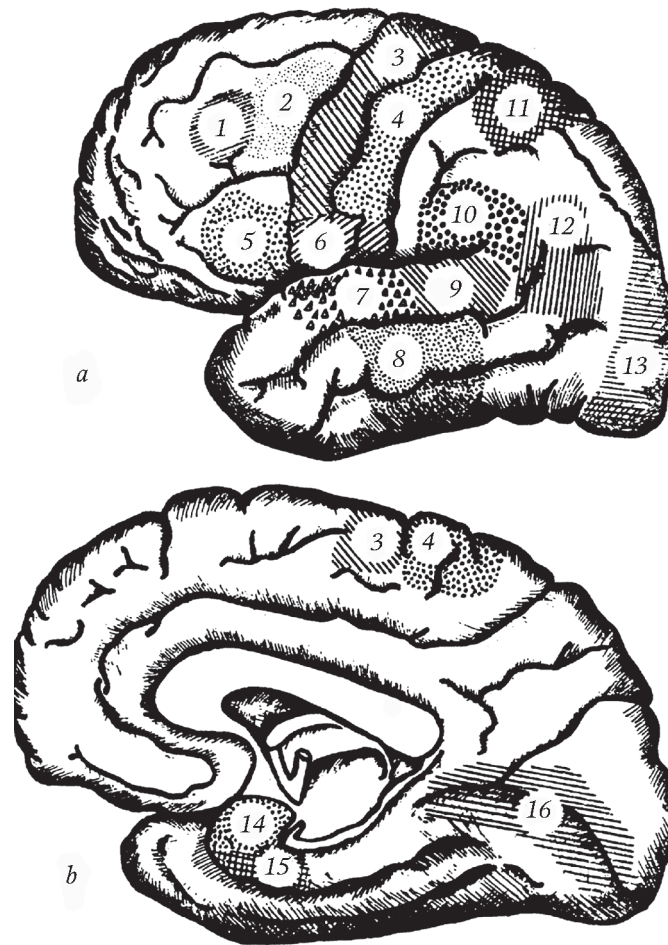


Fig. 3.34. The cortical areas (according to V. V. Turygin, 1990):

a – superolateral surface; *b* – medial surface;

1 – association area of coordinated turn of head and eyes (cortical eye field); 2 – centre of “graphia”; 3 – projection somatomotor area; 4 – projection somatosensory area; 5 – association motor speech area (Broca’s area); 6 – projection area of visceroreception; 7 – projection acoustic area; 8 – projection vestibular area; 9 – association acoustic area; 10 – centre of “praxia”; 11 – association area of stereognosis; 12 – centre of “lexia”; 13 – association visual area; 14 – projection olfactory area; 15 – projection area of taste; 16 – projection visual area

The association area of written symbols, or motor analyzer of written speech (centre of “graphia”) is in the posterior portion of the middle frontal gyrus (area 8) near the precentral gyrus. This area starts to develop during the fifth or sixth years of age. From the area of “praxia” it receives the information, intended for fine, precise movements of the hand, which is needed to write the letters, digits and to draw. The axons from the neurons situated in the area of “praxia” run to the precentral gyrus’s middle portion. After switching, the impulses pass via the corticospinal tract to the upper limb muscles. The damage to this centre leads to the inability to write letters (“agraphia”).

Thus, the speech centres have unilateral location in the cortex: in the right-handed they are in the left hemisphere, in the left-handed in the right. It should be noted that they are developing throughout life.

The association area of coordinated turn of head and eyes (cortical eye field) is in the middle frontal gyrus (area 9), anterior to the center of “graphia”. It regulates the synchronization of the turn of the head and eyes to the opposite side due to the impulses passing to the projection somatomotor area (precentral gyrus) from the proprioceptors of the ocular muscles. Besides, this area receives the impulses from the projection visual centre (the cortex in the region of the calcarine sulcus, area 17), arising from the neurons of the retina.

The position of the cortical areas is shown in the figure 3.34.

3.10.3. White Matter of the Cerebral Hemispheres

White matter comprises most part of the cerebral hemispheres. It is formed by numerous fibres which can be divided into two main groups: projection and association.

The projection fibres comprise the afferent and efferent tracts which connect the projection cortical areas with basal nuclei, brain-stem nuclei or the spinal cord nuclei.

The association fibres connect different parts of the cortex within one cerebral hemisphere or connect the same cortical areas of both hemispheres. Some of them are the axons from the sensory projection areas, which run to the sensory association areas; other pass from the association motor areas to the projection motor areas.

The projection fibres make the internal capsule, *capsula interna*, which is a stripe of white matter separating the lentiform nucleus from the caudate nucleus and thalamus. Macroscopically, it is divided into anterior limb, *crus anterior*, genu, *genu capsulae interna*, and posterior limb, *crus posterior* (fig. 3.35). The anterior limb is comprised sequentially from front to back: by the fibres running from the frontal cortex to the basal nuclei, the corticostriate tract, *tr. corticostriatus*, and then by the fibres running to the pontine nuclei, the frontopontine tract, *tr. frontopontinus*. Besides, the anterior limb transmits some fibres from the thalamic nuclei.

The genu is occupied by the corticonuclear tract, *tr. corticonuclearis*. The posterior limb comprises sequentially the corticospinal tract, *tr. corticospinalis*; thalamocortical tract, *tr. thalamocorticalis*; occipitotemporopontine tract, *tr. occipitotemporopontinus*; then the fibres arising from the medial geniculate body, so called acoustic radiation, *radiatio acustica* (the geniculotemporal tract, *tr. geniculotemporalis*); and finally, the fibres from the nucleus of the lateral geniculate body, so called optic radiation, *radiatio optica* (geniculocalcarine tract, *tr. geniculocalcarinus*).

The projection fibres also pass through the cerebral fornix, *fornix cerebri*. These fibres connect the olfactory subcortical centres (mammillary bodies) with the cortex of parahippocampal gyrus. The fornix consists of the columns, *columnae fornicis*, body, *corpus fornicis*, commissure, *commissura fornicis*, and hippocampal fimbriae, *fimbriae hippocampi*.

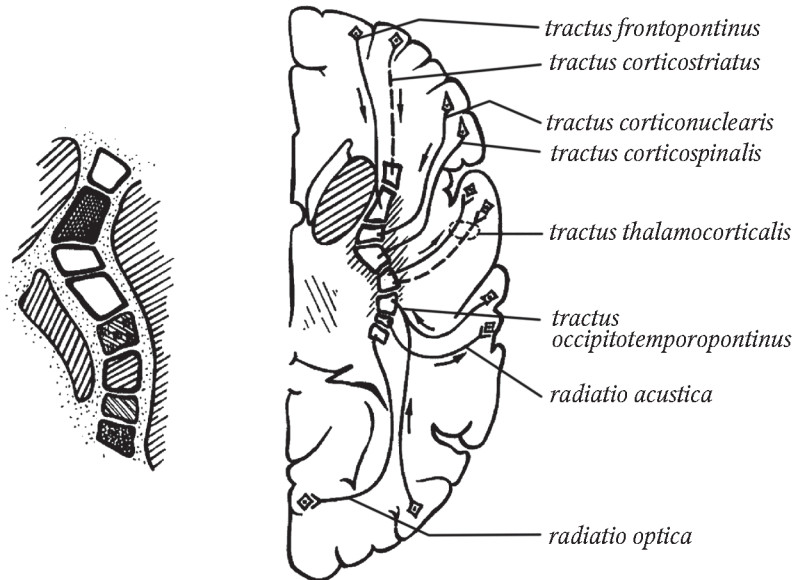


Fig. 3.35. The diagram showing the position of the conduction tracts in the internal capsule

The association fibres can be divided into two groups: association fibres proper and commissural fibres. Association fibres proper are divided into short, connecting the cortex of the neighboring gyri, and long, connecting the cortex of different lobes in the same hemisphere (fig. 3.36). The short association fibres are placed in the floors of the sulci, immediately under the cortex and do not pass beyond the limits of the corresponding cerebral lobe. Such fibres comprise the extreme capsule, *capsula extrema*, which separates the putamen and insular cortex. The long association fibres lie under the layer of the short association fibres and pass through the external capsule, *capsula externa*, which is situated between the lentiform nucleus and claustrum.

The long association fibres form the following bundles:

1. **The cingulum.** The fibres of this bundle encircle the corpus callosum. They are placed under the cortex of the fornicate gyrus on the side of the medial cerebral surface. The cingulum connects the cortical areas of the frontal, occipital and temporal lobes. The nerve fibres comprising the cingulum belong to the limbic system. Thus, in ontogenesis they develop much earlier than the other long association fibres.

2. **The superior longitudinal fasciculus, *fasciculus longitudinalis superior*.** This bundle passes at the level of the corpus callosum, lateral to the corona radiata. It surrounds the insula. The fibres of the superior longitudinal fasciculus mainly connect the cortical areas in the frontal lobe's inferior parts with the cortex of the inferior parietal lobule, temporal and occipital lobes. This fasciculus provides two-way communication between projection somatosensory areas and association motor areas (middle portion of the fasciculus); between projection somatomotor areas and association motor areas, acoustic and visual areas (posterior portion of the fasciculus). Thus, the superior longitudinal fasciculus probably provides the connection of the association areas of the second signal system with corresponding projection areas and with each other.

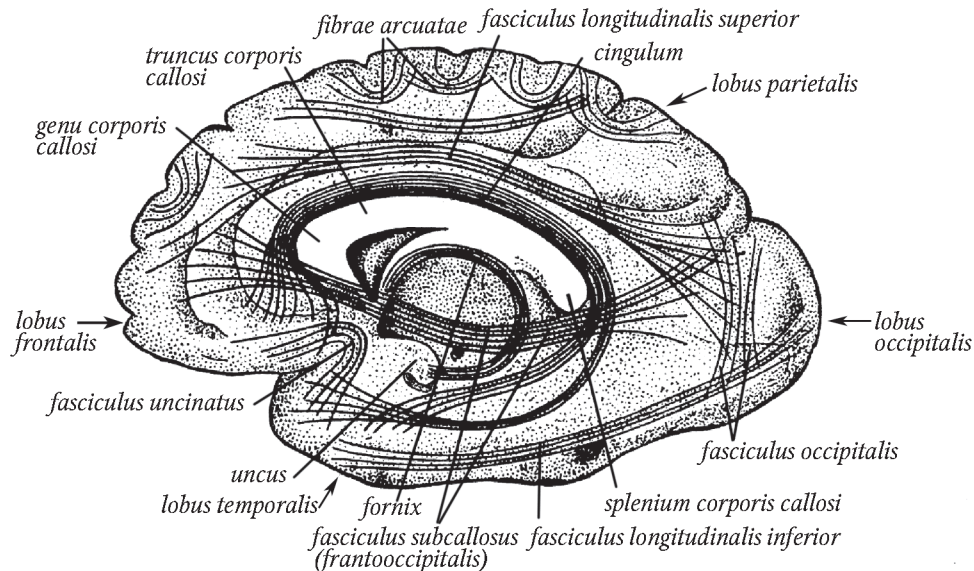


Fig. 3.36. The diagram showing the position of the association conduction tracts in the cerebral hemispheres

3. **The inferior longitudinal fasciculus, *fasciculus longitudinalis inferior*.** It lies in the inferior parts of the cerebral hemispheres. This fasciculus connects the cortical areas of the occipital and temporal lobes. Its purpose is to connect the visual cortical area and cortical centre of vegetative functions.

4. **The uncinate fasciculus, *fasciculus uncinatus*.** It connects the frontal lobe's areas with the temporal lobe's anterior portion. The fibres of this fasciculus start in the superior, middle and inferior frontal gyri and pass mainly to the cortex of the middle and inferior temporal gyri. The uncinate fasciculus provides the interaction of the vestibular analyzer which is situated in the temporal lobe.

5. **The occipitofrontal fasciculus, *fasciculus occipitofrontalis*.** It lies external to the cingulum, connecting the areas of the frontal gyri and occipital gyri. The fasciculus probably provides the connection of the visual cortical area and the areas, responsible for psychic functions.

In general, the association tracts proper execute integration and coordination of the nervous processes which occur in different cortical areas. Thus, the cortical areas are connected by numerous two-way communications.

The commissural fibres connect the same areas of both cerebral hemispheres. The largest collection of such fibres is the corpus callosum. Macroscopically it is divided into a thickened *splenium* (the most posterior part), the *truncus* (the middle part), *genu* and *rostrum*; the rostrum is continuous with *lamina rostralis* and then with *lamina terminalis*. The fibres of the corpus callosum diverge radially to different cortical areas as the radiation of corpus callosum, *radiatio corporis callosi*. The fibres in the genu curve forwards to reach the frontal poles, as the *forceps major (frontalis)*. The fibres of the splenium curve back into the occipital lobes as the *forceps minor (occipitalis)*.

It is known that the activity of the cerebral hemispheres is characterized by the functional asymmetry. The left hemisphere perceives the material objects abstractly (generalized perception). The right hemisphere perceives the same information in details, deeply, emotionally. The corpus callosum plays an important role in the coordinated harmonic activity of the right and left hemispheres. It provides two-way transmission of the information between the cerebral hemispheres.

Apart from the corpus callosum, the commissural fibres form the anterior cerebral commissure, *commissura cerebri anterior*, which lies posterior to the lamina rostralis; on the sagittal section of the brain it is oval in shape. Its fibres belong to the association conduction tracts of the rhinencephalon; they diverge into the temporal cortex. The anterior, smaller, portion of the anterior cerebral commissure contains the fibres connecting the olfactory bulb, olfactory trigone and anterior perforated substance of the right and left hemispheres. The fibres of the posterior portion connect the anteromedial parts of the temporal lobes, particularly those cortical areas of the parahippocampal gyrus which are not connected by the fibres of the corpus callosum. There are the evidences that the fibres of the anterior commissure's posterior portion relate not only to paired activity of the olfactory analyzer but also auditory and visual analyzers.

The commissure of fornix (hippocampal commissure), *commissura fornix*, is a thin triangular white matter plate situated between the crura of the fornix. Like the anterior cerebral commissure, it belongs to the olfactory conduction tracts of the rhinencephalon. The fibres of the hippocampal commissure connect the symmetrical and asymmetrical fibres of the hippocampus in the right and left hemispheres. The hippocampus is a part of the limbic system thus the commissure of fornix also relates to the appearance of some emotions (anger, fear, rage, depression).

The commissural fibres also constitute the posterior cerebral commissure, *commissura cerebri posterior*, which is situated above the entrance to the cerebral aqueduct, i.e. in the region of the III ventricle's posterior wall. The posterior cerebral commissure does not belong to the telencephalon because its fibres connect the posterior thalamic nuclei with each other and the posterior thalamic nuclei with the lateral geniculate bodies.

3.10.4. Basal Nuclei

The basal nuclei, *nuclei basales*, are the group of subcortical nuclei, which are located in the base of the cerebral hemisphere. The whole group of the basal nuclei collectively forms a grey mass having ovoid shape (fig. 3.37).

The basal nuclei include: the caudate nucleus, *nucleus caudatus*; lentiform nucleus, *nucleus lentiformis*; claustrum, *claustrum*, and amygdaloid complex, *corpus amygdaloideum*.

The caudate nucleus is an arcuate mass, arranged longitudinally in sagittal plane. Its anterior end, a thickened head, *caput nuclei caudati*, narrows into an arched body, *corpus nuclei caudati*, the free surface of which bulges into the cavity of the lateral ventricle. The body continues to curve down and tapers into the tail, *cauda nuclei caudati*. The caudate nucleus is lateral and superior to the thalamus; it arches the white matter fibres which partially prolong from the cerebral peduncles. The size of the caudate nucleus in the sagittal direction reaches 6–7 cm. The greatest width in the region of the head is about 20 mm, in the region of the tail is 3 mm.

The free surface of the caudate nucleus's head forms the lateral wall of the lateral ventricle's anterior horn. The anterior surface of the head is adherent to the frontal lobe's white matter. The free surfaces (superior and medial) of the body form the floor of the lateral ventricle's central part in the parietal lobe. The tail runs into the temporal lobe and anteriorly reaches the amygdaloid complex.

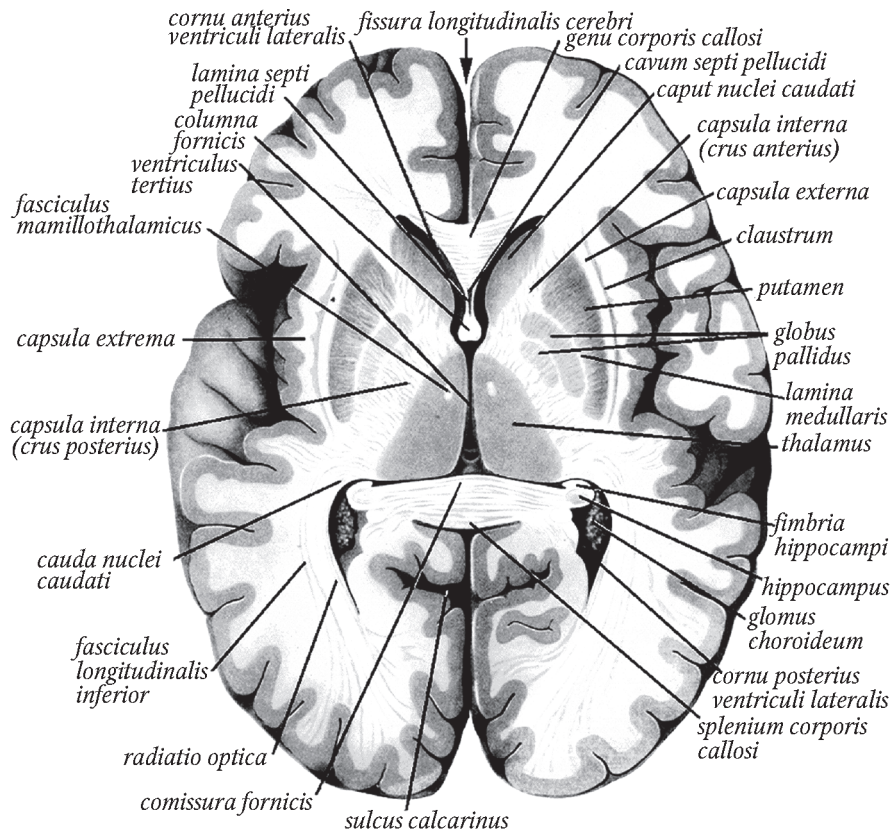


Fig. 3.37. The diagram showing the position of the basal nuclei in the cerebral hemispheres

Lateral to the caudate nucleus and thalamus is a well distinct stripe of white matter, the internal capsule, *capsula interna*, of 5–7 mm in width. The internal capsule separates the caudate nucleus from the lentiform nucleus. The latter is completely surrounded by white matter and has a wedge shape in all planes. The lentiform nucleus consists of two parts: lateral and medial. The lateral, larger, part is called the *putamen*; the medial part is the *globus pallidus*.

The putamen is grayish-pink, like the caudate nucleus. The globus pallidus differs from the putamen on a fresh section of the brain in yellowish color. A white matter stripe, the medullary lamina, separates the putamen from the globus pallidus.

The claustrum is lateral to the putamen, being separated from it by a layer of white matter, which represents the external capsule, *capsula externa*. More laterally is a white stripe called the extreme capsule, *capsula extrema*, which separates the claustrum from the insular cortex.

Between the caudate nucleus and thalamus on one side, and the lentiform nucleus on the other side there is a layer of white matter called the internal capsule, *capsula interna*.

On a horizontal section of the brain, the claustrum is shaped like a grey stripe of about 1–2 mm in width, arranged parallel to the insular cortex and separated from it

by the external capsule. The outer surface of the claustrum has dentate contours which correspond to the gyri of the insular cortex. Directing forward, the claustrum becomes thinner and closer to the amygdaloid complex. In three-dimensional image the claustrum has the shape of a disc, arranged in the sagittal plane.

The amygdaloid complex, or body, resembles an almond in shape and in sizes (around 10 mm). It lies within white matter of the temporal pole. The superior surface of the amygdaloid complex protrudes into anterior part of the lateral ventricle's inferior horn. The amygdaloid complex consists of secondary nuclei which are separated by thin stripes of white matter. The amygdaloid complex has connections with the claustrum and olfactory region (anterior perforated substance).

The caudate nucleus and putamen form together the *corpus striatum*; the corpus striatum and globus pallidus functionally constitute so called strio-pallidar system.

The structures of the strio-pallidar system balance one another and due to this optimally influence on the motor acts. The strio-pallidar system is the higher extrapyramidal center which provides the execution of various unvoluntary (automatic) movements, regulates the muscle tone hence effects the voluntary movements. In a single strio-pallidar system, the pallidum functions as an activator of the subcortical extrapyramidal structures, while the striatum as an inhibitor.

Afferent information passes to the strio-pallidar system from the medial thalamic nucleus. Besides, the striatum have connections with the cerebral cortex. In the corpus striatum, the efferent corticostriate tract ends. In its turn, the striatum sends the efferent impulses to the neurons of the globus pallidus. The efferent impulses from the globus pallidus reach the neurons in the motor nuclei of the spinal cord and cranial nerves. It should be noted that along the way from the subcortical nuclei to the motor nuclei, most fibres pass to the opposite side. Thus, the subcortical nuclei of each cerebral hemisphere are connected mainly with the opposite half body.

The basal nuclei in both hemispheres are connected by the commissural fibres which pass through the posterior cerebral commissure. This provides their coordinated work, aimed at the execution of automatic, usually stereotypical but complex reflex motor actions (walking, swimming, eating etc) which are performed "without thinking". The close connection of the strio-pallidar system with hypothalamic nuclei (posterior hypothalamic nuclei) explains its potential effect on the emotional reactions.

The clinical symptoms in damage to the strio-pallidar system are determined by the dominance of the functional disorders in the striatum or in the pallidum. Excessive inhibitory effects of the striatum (hyperfunction) lead to hypokinesia (poverty of movements, poverty of facial expression (hypomimia)). The hypofunction of the striatum leads to appearance of excessive involuntary movements (hyperkinesia) because the striatum ceases to inhibit the pallidum.

3.10.5. Lateral Ventricles

The lateral ventricles, *ventriculi laterales*, are the cavities situated in the cerebral hemispheres (fig. 3.38). They represent symmetrical slits within white matter, containing cerebrospinal fluid. Each ventricle consists of four parts corresponding to each hemispherical lobe: 1) central part, *pars centralis*, in the parietal lobe; 2) anterior (frontal) horn, *cornu anterius*, in the frontal lobe; 3) posterior (occipital) horn, *cornu posterius*, in the occipital lobe; 4) inferior (temporal) horn, *cornu inferius*, in the temporal lobe.

The central part is like a horizontal slit. Its superior wall (roof) is formed by the corpus callosum. The floor is constituted by the body of the caudate nucleus, partially by the

dorsal thalamic surface and posterior crus of the fornix. The central part contains a well-developed choroid plexus, *plexus choroideus ventriculi lateralis*; it looks like a dark brown stripe of 4–5 mm in width. It descends into the inferior horn. The roof and floor of the central part meet each other at a very acute angle therefore it does not have the lateral wall.

The anterior horn is the continuation of the central part, directing forwards and laterally. It is bounded medially by the septum pellucidum, laterally by the head of the caudate nucleus. Other walls (anterior, superior and inferior) are formed by the fibres of the forceps major from the corpus callosum. The anterior horn has the larger lumen, compared to other parts of the lateral ventricle.

The posterior horn is sharpened and convex posteriorly; its convexity is directed laterally. The superior and lateral walls of the posterior horn are formed by the fibres of the forceps minor from the corpus callosum; other walls are formed by occipital lobe white matter. On the medial wall there are two elevations: upper, the bulb of the posterior horn, *bulbus cornu posterioris* (it corresponds to the parieto-occipital sulcus situated on the medial cerebral surface) and lower, the *calcar avis* (it corresponds to the calcarine sulcus). The inferior wall of the posterior horn is triangular and slightly bulges into the ventricle's

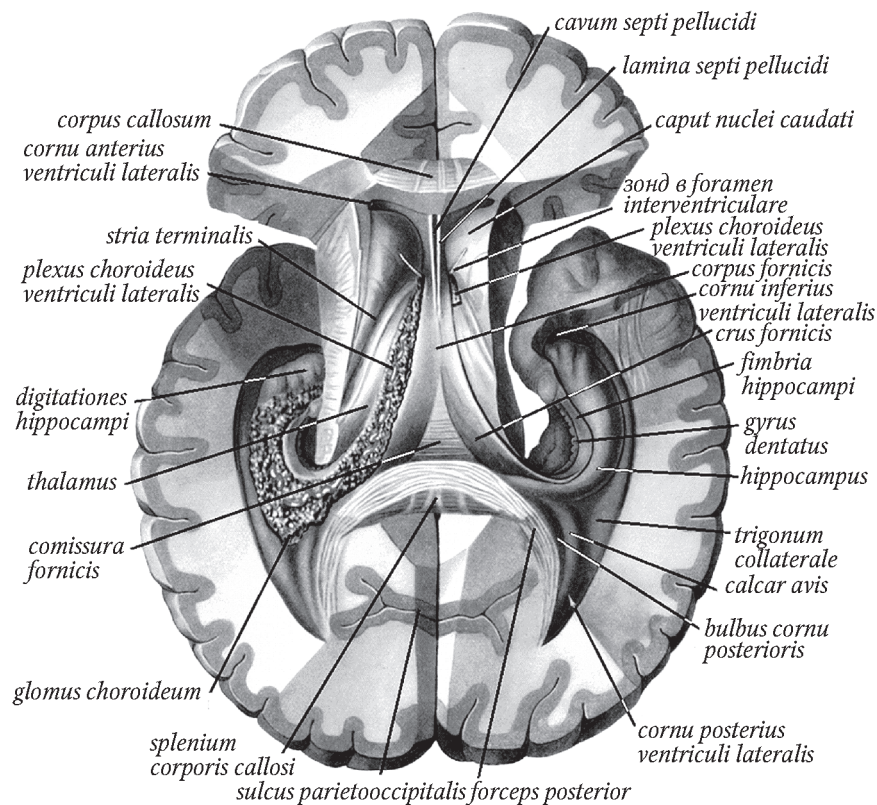


Fig. 3.38. The diagram showing the position of the basal nuclei in the cerebral hemispheres

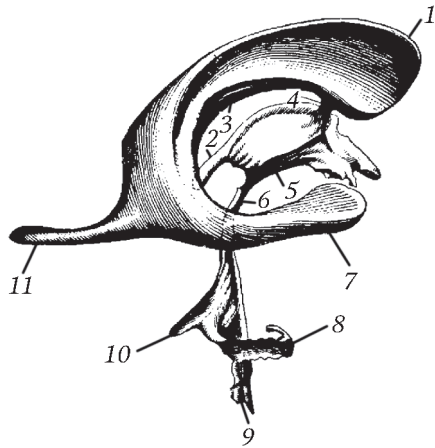


Fig. 3.39. The cerebral ventricles (the cast of their cavities):

1 – anterior horn of the lateral ventricle; 2 – pineal recess of the III ventricle; 3 – central part of the lateral ventricle; 4 – interventricular foramen; 5 – hypothalamic sulcus; 6 – cerebral aqueduct; 7 – inferior horn of the lateral ventricle; 8 – lateral aperture of the IV ventricle; 9 – median aperture of the IV ventricle; 10 – superior aperture of the IV ventricle; 11 – posterior recess of the lateral ventricle

cavity; this triangular elevation corresponds to the collateral sulcus and is called the collateral trigone, *trigonum collaterale*.

The inferior horn curves down, forwards and medially into the temporal lobe. Its lateral and superior walls are formed by temporal lobe's white matter. The medial and partially inferior wall is occupied by the hippocampus which corresponds to the parahippocampal gyrus. Along the medial border of the hippocampus, a band of white matter extends; this is the fimbria of hippocampus, *fimbria hippocampi*, which extends from the posterior crus of the fornix. On the floor of the inferior horn there is a collateral eminence, *eminencia collateralis*, which is the continuation of the collateral trigone from the posterior horn.

The lateral ventricles are communicated with the III ventricle by means of the interventricular foramen (of Monro). Through this opening the choroid plexus of the lateral ventricles enters each lateral ventricle from the cavity of the III ventricle; the choroid plexus extends to the central part and the cavities of the posterior and inferior horns (fig. 3.38). The surface of the choroid plexus, directed to the cavity of the ventricles, is lined by a thin

ependymal lamina which lines also the walls of the ventricles on the inside. The choroid plexuses produce cerebrospinal fluid.

The form and interrelations of the ventricles are shown in the figure 3.39.

3.10.6. Rhinencephalon

The rhinencephalon (olfactory brain) develops from the ventral part of the telencephalon and consists of the peripheral and central parts.

The peripheral part, the olfactory lobe, is comprised by the structures located on the cerebral base: 1) olfactory bulb, *bulbus olfactorius*; 2) olfactory tract, *tractus olfactorius*; 3) olfactory trigone, *trigonum olfactorium*; 4) anterior perforated substance, *substantia perforata anterior*.

The central part includes: 1) fornicate gyrus, *gyrus fornicatus*, which ends near the temporal pole by the uncus; 2) *hippocampus* (Ammon's horn, *cornu Ammoni*) the structure of peculiar form, situated in the cavity of the lateral ventricle's inferior horn; 3) dentate gyrus, *gyrus dentatus*, visible as a narrow stripe in the depth of the hippocampal gyrus, under the *pes hippocampi*.

3.11. The Concept of Extrapyramidal System

The extrapyramidal system, *systema extrapyramidale*, is a collection of functionally interrelated sensory and motor nuclei and extrapyramidal conduction tracts which regulate involuntary components of the motor acts (muscle tone, pose, facial expression).

The cortex influences on the extrapyramidal structures via the efferent conduction tracts. Of these tracts the main is the corticostriate tract which passes through the anterior limb of the internal capsule.

The extrapyramidal system includes the following structures:

1. **The higher subcortical extrapyramidal centre**, the strio-pallidar system, which consists of striar and pallidar systems. The striatum comprises the caudate nucleus and putamen (phylogenetically new part); the pallidum comprises the globus pallidus (older part). These structures functionally balance one another; due to this the strio-pallidar system effects the motor actions as a single system. The pallidum usually activates the motor acts, while the striatum inhibits.

2. **The subcortical sensory extrapyramidal centre**, the medial thalamic nuclei and posterior hypothalamic nucleus (Luizi).

3. **The subcortical and segmental motor centres of the extrapyramidal system:**

- 1) Red nucleus;
- 2) Substantia nigra;
- 3) Nuclei of superior colliculi;
- 4) Nuclei of reticular formation;
- 5) Vestibular nuclei;
- 6) Olivary nuclei;
- 7) Cerebellum.

4. **The efferent extrapyramidal conduction tracts** pass in the brain-stem tegmentum. The main of them are:

- 1) Rubrospinal tract;
- 2) Reticulospinal tract;
- 3) Vestibulospinal tract;
- 4) Olivospinal tract;
- 5) Tectospinal tract;
- 6) Medial longitudinal fasciculus.

The connections of the extrapyramidal system structures may be simplistically described as follows: the medial thalamic nuclei (integration centre of diencephalon) receive the information about the state of whole body periphery from the thalamic communication sensory nuclei. After coordination and integration of this information, the impulses run to the limbic cortex, precentral gyrus, posterior hypothalamic nucleus and also to the caudate and red nuclei. The striatum and pallidum function together, forming the strio-pallidar system. They send the impulses to the subcortical motor extrapyramidal centres, from where the information reaches the motor cranial nerves nuclei and motor nuclei of the spinal anterior horns via corresponding conduction tracts.

The cerebellum is involved in the extrapyramidal system by means of the tracts which connect it with thalamus, red and olivary nuclei.

Besides, the afferent tracts from the caudate nucleus and putamen run to the lateral and medial segments of the globus pallidus. The corpus striatum also has two-way connections with the substantia nigra.

Functionally, the extrapyramidal system is inseparable from the pyramidal. It provides the ordered sequence of the voluntary movements which are regulated by the pyramidal system. The extrapyramidal system is evolutionary more ancient motor system, compared to the pyramidal; it is a simpler regulator.

The extrapyramidal system provides the human ability to take a pose, optimal for upcoming act; it supports necessary ratio between the tone of muscles-synergists and

antagonists and also provides smoothness and proportionality of movements in time and space. The extrapyramidal system provides the overcoming of the inertia of rest and motions, the coordination of voluntary and involuntary (automatic) movements, spontaneous facial expression; effects on the state of the internal organs.

The damage to the extrapyramidal system leads to the polar changes of the muscle tone, impairment of rational, optimal motions (both voluntary and involuntary). The symptoms of the extrapyramidal system damage vary from motor asymmetry to different variations of excessive abnormal movements (hyperkinesia).

3.12. The Concept of Limbic System

The limbic system, *systema limbicum*, is a collection of functionally interrelated cerebral structures which provide integrative regulation of the activity of the special sense organs and internal organs, form emotional coloring of behavioral reactions, mood, memory, sleep and wake. This system is also called the visceral brain because its structures receive the information from the internal organs and participate in the regulation of their activity.

The limbic system includes the following structures:

1. Peripheral structures:

- olfactory bulb;
- olfactory tract;
- olfactory trigone;
- anterior perforated substance;
- reticular formation.

2. Subcortical structures:

- mygdaloid complex (plays important role in the providing of such reactions as aggression, caution, fear);
- anterior thalamic nuclei;
- habenular nuclei;
- nuclei of the intermediate part of the hypothalamus and mammillary bodies.

3. Higher centres of the cerebral hemispheres:

- cingulate gyrus;
- parahippocampal gyrus and uncus;
- hippocampus (situated in the inferior horn of the lateral ventricle and plays an important role in the formation of long-term memory);
- dentate gyrus;
- septum pellucidum.

4. Projection and association fibres:

- fornix (connects the mammillary bodies and parahippocampal gyrus);
- cingulum (connects the areas of the frontal, occipital and temporal lobes);
- fronto-occipital fasciculus connects the frontal and occipital lobes;
- inferior longitudinal fasciculus connects the frontal and occipital lobes.

The limbic system provides all essential body reactions (food, orientation etc.), formed on the basis of the most ancient distant sense, the olfaction. The olfaction is an integration factor of many body functions; it unites different cerebral structures into a single morphofunctional complex.

From the hippocampus a part of the fibres run to the amigdaloid complex and mammillary bodies which provides emotional coloring of behavioral reactions.

The hypothalamus contains suprasegmental vegetative centres which control the activity of the internal organs therefore, most behavioral reactions are accompanied by a

number of vegetative reactions (redness or paleness of skin, increased sweating or dryness of skin, change of the frequency of heart rhythm and breathing, change of the arterial pressure value etc). Also, the hypothalamus produces statins and liberins controlling the activity of adenohypophysis which secretes the *tropic* hormones. The *tropic* hormones effect on all peripheral endocrine glands which in their turn regulate the function of the internal organs. Hence, the limbic system participates in the regulation of all vegetative functions (activity of cardiovascular, respiratory, alimentary systems, metabolism etc).

The higher cortical centres included in the limbic system are the projection centres of different kinds of special senses: olfactory, taste, auditory, visual and vestibular. Adequate stimulation of special sense organs creates positive emotional background and good mood.

To explain the principles of the functioning of the limbic system it is suggested that the processes of excitation move cyclically from the rhinencephalon's structures along the closed circle (limbus) which involves the hippocampus, mammillary bodies, fornix, anterior thalamic nuclei, cingulate gyrus (so called circle of Papez). Receiving the information about external and internal environment of the body, the limbic system gives rise to vegetative and somatic reactions which provide adaptation of the organism to the external environment and keeping homeostasis.

3.13. General Review of the Brain

In external examination of the brain you see its convex superolateral surface and flat inferior surface, the cerebral base. The superolateral surface is marked with sulci and gyri (see their detailed description in the previous chapter). The cerebral base is formed by the basal surfaces of the cerebral hemispheres and the brain stem. Now we will describe the structures, macroscopically visible on the cerebral base.

Anteriorly you see the longitudinal cerebral fissure, *fissura longitudinalis cerebri*. One centimeter lateral and parallel to this fissure is the olfactory tract, *tractus olfactorius*. It starts with the olfactory bulb, *bulbus olfactorius*, and ends with the olfactory trigone, *trigonum olfactorium*. 15-20 bundles of fibres, the olfactory nerves, *nervi olfactorii*, approach to the bulb. Posterior to the olfactory trigone is a small area where after removal of pia mater and vessels you see numerous openings. This area is called the anterior perforated substance, *substantia perforata anterior*. Medial to it there is an optic tract, *tractus opticus*, arising from the optic chiasm, *chiasma opticum*. Anteriorly, the optic nerves, *nervi optici*, enter the chiasm. Also anteriorly, the *lamina terminalis* joins the optic chiasm. On the whole brain you may see the lamina terminalis only if you pull the chiasm backwards. Posteriorly, the *tuber cinereum* adjoins the optic chiasm; it is continuous with the *infundibulum*, which is in its turn continuous with the *hypophysis*.

The basal surface of the cerebrum's posterior part which is formed by the occipital lobes, adjoins the cerebellum almost entirely, being separated from it by a deep transverse cerebral fissure, *fissura transversa cerebri*. The longitudinal cerebral fissure, *fissura longitudinalis cerebri*, joins the transverse cerebral fissure posteriorly. The basal surfaces of the lateral cerebellar parts, that adjoin the floor of the posterior cranial fossa, are convex and form the cerebellar hemispheres, *hemispheria cerebelli*. They are separated from each other by the *vallecula cerebelli*.

Slightly raising the medulla oblongata, you see the middle part of the cerebellum, the *vermis*, which interconnects the cerebral hemispheres. The upper thickened part of the medulla oblongata contacts the pons; the lower part is directly continuous with the spinal cord. The anterior median fissure traverses the medulla oblongata to be continu-

ous with the spinal anterior median fissure. On the sides of this fissure there are the pyramids; lateral to each pyramid is an oval-shaped structure, the olive, *oliva*.

Anteriorly, the medulla is adjoined by the pons; it looks like a transverse elevation, the lateral parts of which narrow and enter the cerebellum. From the anterior border of the pons, two thick cylinders, the cerebral peduncles, *pedunculi cerebri*, arise; they diverge to enter the cerebral hemispheres. Between the peduncles there is a depression, the interpeduncular fossa, *fossa interpeduncularis*. The floor of this fossa is filled with grey matter, through which the vessels penetrate into the cerebral substance. After removing pia mater here, you can see the surface with the numerous openings; this is the posterior perforated substance, *substantia perforata posterior*. The medial surface of each cerebral peduncle carries the oculomotor sulcus. In front of the posterior perforated substance there are two white tubercles, the mammillary bodies, *corpora mamillaria*, closely adjoining the tuber cinereum.

On the base of the brain you can see the roots of all the cranial nerves (12 pairs) in sequential order. The information about places of their emergence from the brain and cranial cavity is represented in the table 7.

We need to complement the data represented in the table:

1) the trochlear nerve is a single of the 12 pairs of the cranial nerves which emerges on the dorsal surface of the brain; it then rounds the cerebral peduncle from the lateral side and, passing through the fissure between the peduncle and temporal lobe, appears on the cerebral base;

2) spinal roots, *radices spinales*, (6–7) of the accessory nerve unite into a thin trunk which ascends along the spinal cord between the anterior and posterior spinal roots. This trunk enters the cranial cavity through the foramen magnum to join the accessory nerve's cranial roots, *radices craniales*. The accessory nerve leaves the cranial cavity through the jugular foramen;

3) it is impossible to differentiate the roots of the IX, X and XI cranial nerves near the brain because here they lie closely to each other here. To differentiate these roots, you need follow them in the centripetal direction (from the jugular foramen) where these three nerves already represent the separate trunks.

On the median section you see an extensive medial cerebral surface, directed the longitudinal cerebral fissure and hanging over the brain stem (fig. 3.31). The median section of the corpus callosum which interconnects the cerebral hemispheres is well-defined. The middle part of the corpus callosum is the trunk, *truncus corporis callosi*, which ends posteriorly by the *splenium*, and anteriorly curves ventrally, forming the *genu*. The end of the genu abruptly narrows into the *rostrum* which is continuous with the *lamina rostralis* and further into the *lamina terminalis*. The latter is fused with the optic chiasm.

From the corpus callosum's inferior surface, in the region of its middle third, a white cord separates: this is the column of the fornix, *columna fornicis*. It curves down to enter the cerebral substance. In front of the column (between it and the corpus callosum) there is a *lamina septi pellucidi* having an irregular triangular shape. The laminae septi pellucidi of both sides form together the *septum pellucidum* which separates the anterior horns of the lateral ventricles from each other. In the lower angle of the septum pellucidum you notice a small oval structure: this is the section of the anterior cerebral commissure, *commissura cerebri anterior*, lying transversely; posterior to it is the columns of the fornix, anterior to it is the lamina rostralis.

On the median section of the brain you can see only the medial surface of the thalamus, which together with the medial surface of the other thalamus limit the III ventricle, *ventriculus tertius*, oriented vertically in the median plane. Often the medial surfaces of

Table 7

The places of the emergence of the cranial nerves from the brain and cranial cavity

The number of the cranial nerve	The place of the emergence from the brain	The place of the emergence from the cranial cavity
I. Olfactory nerves	Olfactory bulb	Cribriform plate of the ethmoid bone
II. Optic nerve	Optic chiasm	Optic canal
III. Oculomotor nerve	Oculomotor sulcus (on the medial side of the cerebral peduncle, in the interpeduncular fossa)	Superior orbital fissure
IV. Trochlear nerve	Dorsally, behind the quadrigeminal plate, near the frenulum veli; rounds the cerebral peduncles	Superior orbital fissure
V. Trigeminal nerve	From the pons, at the junction with the middle cerebellar peduncles, close to its anterior edge	Ophthalmic nerve: superior orbital fissure;
VI. Abducens nerve	Posterior edge of the pons, in the groove between the pons and pyramid of the medulla oblongata	Maxillary nerve: foramen rotundum;
VII. Facial nerve	Cerebellopontine angle	Mandibular nerve: foramen ovale
VIII. Vestibulocochlear nerve	Cerebellopontine angle	Superior orbital fissure
IX. Glossopharyngeal nerve	In the upper part of the medulla oblongata's posterolateral sulcus	Internal acoustic porus – internal acoustic meatus – facial canal – stylomastoid foramen
X. Vagus nerve	The posterolateral sulcus of the medulla oblongata, caudal to the glossopharyngeal nerve	Internal acoustic porus
XI. Accessory nerve	Its superior roots pass through the lower part of the posterolateral sulcus;	Jugular foramen
XII. Hypoglossal nerve	Its inferior roots pass between anterior and posterior spinal roots	Jugular foramen
	Anterolateral sulcus of the medulla oblongata, between the pyramid and olive	Jugular foramen
		Hypoglossal canal

both thalami are connected by means of the interthalamic adhesion, *adhesio inter-thalamica*. At the superoposterior ends of the thalami, under the *splenium corporis callosi* there is a superior appendage of the brain, the pineal gland (epiphysis), *glandula pinealis*.

Below the pineal gland you see the median section of the posterior cerebral commissure (epithalamic commissure), *commissura cerebri posterior*, arranged transversely. Between the column of the fornix and the anterior thalamic end on each side there is a small interventricular foramen, *foramen interventriculare* (of Monro), connecting the cavity of the III ventricle with the lateral ventricles situated in the cerebral hemispheres.

From the interventricular foramen, the hypothalamic sulcus, *sulcus hypothalamicus*, runs backwards, curving around the interthalamic adhesion. Below this sulcus there is a *hypothalamus*. It comprises the optic chiasm, infundibulum, hypophysis and mammillary bodies which are described above.

Posterior to the thalamus are the structures of the midbrain, the dorsal surface of which has the shape of a plate with four well-defined tubercles, the colliculi; together they constitute the quadrigeminal (tectal) plate, *lamina tecti* (*lamina quadrigemina*). On the median section you see only two colliculi of the corresponding side (superior and inferior, *colliculus superior et colliculus inferior*). Under the tectal lamina there is a narrow slit, interconnecting the III and IV ventricles. This is the cerebral aqueduct, *aqueductus cerebri* (of Sylvius). Ventral to it are the cerebral peduncles, *pedunculi cerebri*. On the median section through the interpeduncular fossa you can see the place where the oculomotor nerve emerges.

Caudal to the mentioned structures are the parts that belong to the rhombencephalon: cerebellum, pons and medulla oblongata. The cavity of the rhombencephalon is the IV ventricle, *ventriculus quartus*. The floor of the IV ventricle is formed by the dorsal surfaces of the medulla oblongata and pons, which make the rhomboid fossa. The roof of the IV ventricle is formed by the superior medullary velum, vermillion nodule and tela choroidea of the IV ventricle.

On the frontal section of the brain through the central part of the lateral ventricles, you can see free (superior, lateral and inferior) surfaces of the cerebral hemispheres. The medial cerebral surfaces are separated by the median cerebral fissure. On the floor of this fissure there is a corpus callosum which is continuous with white matter of both cerebral hemispheres.

The white matter is covered by the cerebral cortex, *cortex cerebri*. The frontal section allows assess the depth of the sulci and the height of the gyri. The Sylvian sulcus is especially demonstrative. On the floor of this sulcus, the *insula* is hidden. Ventral to the corpus callosum is the fornix. Below the fornix you see an unpaired cavity of the III ventricle, situated between the two thalami, and laterally a paired cavity of the lateral ventricles.

In white matter the basal nuclei are located: closer to the median plane is the caudate nucleus, *nucleus caudatus*; lateral to the caudate nucleus is the lentiform nucleus, *nucleus lentiformis*, and closer to the insular cortex is the *claustrum*. Also you see the white matter layers which separate the basal nuclei from each other and from the structures adjoining them: internal, external and extreme capsules, *capsulae interna, externa et extrema*. Medial to the internal capsule is the thalamus, and along the midline there is a cavity of the III ventricle.

3.14. Meninges of the Brain

The cerebral meninges are the direct continuation of the spinal cord meninges (dura mater, arachnoid mater and pia mater). The arachnoid mater and pia mater together are called the *leptomeninges*.

The cerebral dura mater, *dura mater encephali*, or *pachymeninx*, is a dense whitish connective-tissue membrane. Its external surface immediately adjoins the skull bones. It represents the internal periosteum of the skull bones that is the main difference between the cerebral dura mater and the spinal. The inner surface of the dura mater, directed to the brain, is lined with endothelium therefore, smooth and shiny. Between the dura mater and arachnoidea there is a narrow slit-like subdural space, *spatium subdurale*, filled with small amount of cerebrospinal fluid. In the region of the calvaria the dura mater is weakly linked with the skull bones, being fixed mainly in the places of the sutures. On the contrary, in the skull base the dura mater is firmly fused with the bones, especially with the ethmoidal lamina cribrosa and the temporal pyramid. In some places the dura mater splits into two layers. Such a splitting is observed in the areas of the venous sinuses and also in the region of the trigeminal impression at the apex of the temporal bone's pyramid where in the trigeminal cavity, *cavum trigeminale*, the trigeminal ganglion lies.

The dura mater is folded inwards as four septa that pass between the parts of the brain and separate them from each other (fig. 3.40).

The falx cerebri, is a strong process of dura mater, descending sagittally between the cerebral hemispheres in the longitudinal fissure. It is attached along the midline of the calvaria to the borders of the groove for superior sagittal sinus. Its narrow anterior end is fixed to the crista galli; a broad posterior end blends with the tentorium cerebelli.

The tentorium cerebelli is a horizontally stretched dural lamina, slightly convex upwards like a gable roof. This lamina is attached along the borders of the groove for transverse sinus situated on the occipital bone and along the superior borders of the temporal bones' pyramids. The tentorium lies in the transverse cerebral fissure and separates the occipital lobes from underlying cerebellum.

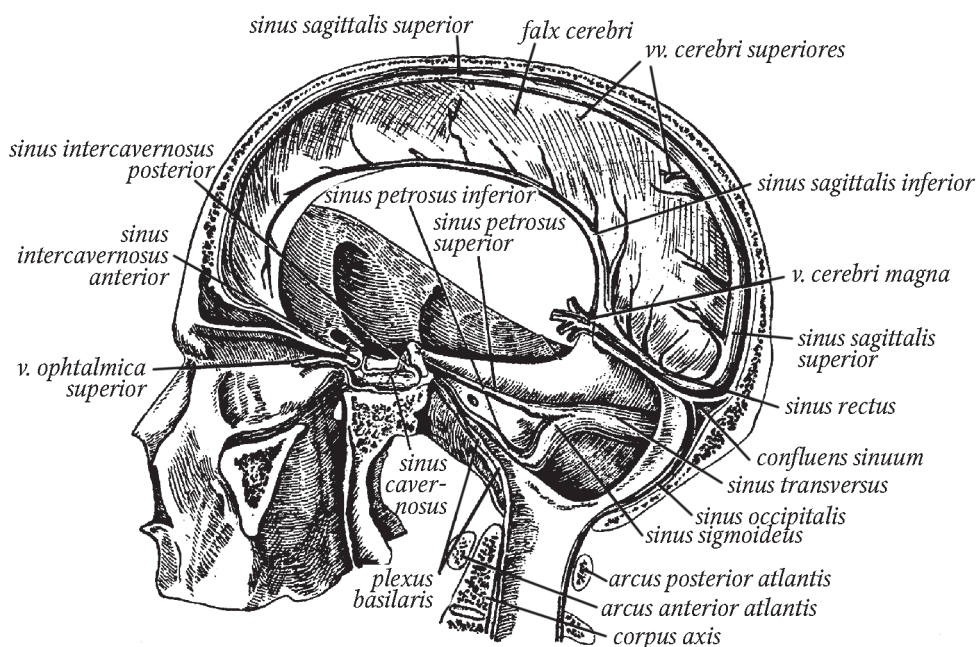


Fig. 3.40. The processes and sinuses of the cerebral dura mater

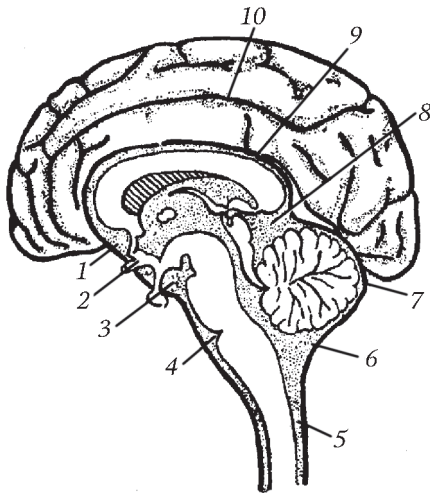


Fig. 3.41. The subarachnoid cisterns:

1 — chiasmatic cistern; 2 — optic chiasm; 3 — interpeduncular cistern; 4 — pontine cistern; 5 — subarachnoid space; 6 — cerebellomedullary cistern; 7 — cerebral arachnoid; 8 — cistern of the greater cerebral vein; 9 — cistern of the corpus callosum; 10 — the subarachnoid space within the cortical gyri

The *falx cerebelli* is a small process of dura mater; it descends in the midline along the internal occipital crest. Its end divides into two small folds that are attached to the sides of the foramen magnum. The *falx cerebelli* enters the posterior cerebellar notch.

The *diaphragma sellae* forms a roof over the sella turcica, almost completely covering the hypophysis; a small, central, opening in it transmits the infundibulum, to which the hypophysis is attached.

The cerebral arachnoid mater, *arachnoidea mater encephali*, like the spinal arachnoid, is thin, transparent and devoid of the vessels. It is covered by endothelium on the inside and outside and separated from the dura mater by the subdural space, *spatium subdurale*. The cerebral arachnoid invests the brain loosely and does not enter the sulci or fissures. Thus, between the arachnoid and pia mater there is a subarachnoid space, *spatium subarachnoideum*, which is filled with cerebrospinal fluid, *liquor cerebrospinalis*, and traversed by thin trabeculae connecting these membranes. Wherever the brain and skull are not closely

adapted, the arachnoid is separated from the pia by wide intervals, named the subarachnoid cisterns (fig. 3.41).

The largest, cerebello-medullary cistern, *cisterna cerebellomedullaris*, is between the ventral surface of the cerebellum and medulla oblongata. It is divided into two parts: posterior cerebello-medullary cistern, *cisterna cerebellomedullaris posterior*, (*cisterna magna*) and lateral cerebello-medullary cistern, *cisterna cerebellomedullaris lateralis*. At the dorsal surface of the pons, the posterior cerebello-medullary cistern is continuous with the pontocerebellar cistern, *cisterna pontocerebellaris*. Above, in the region of the transverse cerebral fissure, near the great cerebral vein there is a cistern of the great cerebral vein, *cisterna venae magnae cerebri* (of Galen), or quadrigeminal cistern, *cisterna quadrigeminalis*.

Ventral to the pons is the *cisterna pontis* which is continuous with the interpeduncular cistern, *cisterna interpeduncularis*. The latter is continuous with the *cisterna chiasmatis* lying in front of the optic chiasm. The collection of the cisterns surrounding the mid-brain is called the ambient cistern, *cisterna ambiens*. This cistern communicates on both sides with the cistern of the lateral fossa, *cisterna fossae lateralis cerebri*, situated in the Sylvian sulcus. Apart from the mentioned cisterns, there are the pericallosal cistern, *cisterna pericallosa*, and the cistern of lamina terminalis, *cisterna laminae terminalis*.

The subarachnoid space is represented by a network of widely interconnecting canals. At the foramen magnum the cerebral subarachnoid space is continuous with the spinal subarachnoid space. Besides, the subarachnoid space directly communicates with the cerebral ventricles through the openings in the region of the IV ventricle's posterior wall: median aperture, *apertura mediana ventriculi IV* (*foramen Magendī*), which opens into the posterior cerebello-medullary cistern, and two lateral apertures, *aperturae late-*

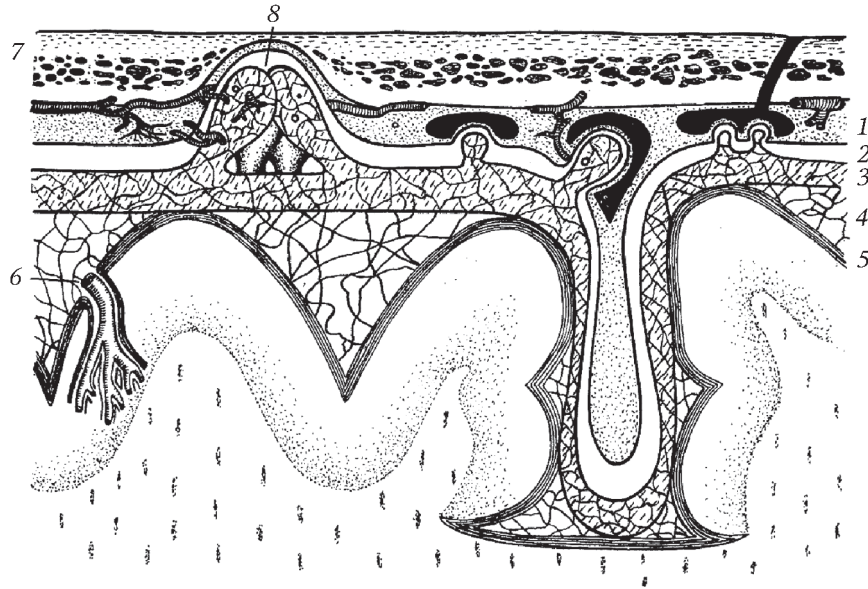


Fig. 3.42. The diagram showing the interrelations of the cerebral meninges and position of Pacchioni's granulations:

1 — cerebral dura mater (is thin in the area of the arachnoid granulation); 2 — subdural space; 3 — cerebral arachnoid; 4 — subarachnoid space; 5 — cerebral pia mater; 6 — cerebral blood vessel; 7 — skull bone; 8 — arachnoid granulations (of Pacchioni)

rales ventriculi IV (foramen Luschka), leading into the pontocerebellar cistern, *cisterna pontocerebellaris*. The subarachnoid space contains the pial vessels which are protected from compression by connective-tissue trabeculae and cerebrospinal fluid.

The structural feature of the arachnoid is the presence of so called arachnoid granulations (of Pacchioni), *granulationes arachnoideae*, which represent small round protrusions having greyish-pink color and bulging into the cavities of the venous sinuses (fig. 3.42). The granulations are arranged in groups and especially well-developed along the superior sagittal sinus. Along the other sinuses their number is lesser. They are present both in children and adults but reach the greatest sizes in elderly. While increasing in size, the granulations press on the bones and form on their inner surface the depressions termed the granular foveolae, *foveolae granulares*. The Pacchioni's granulations have been researched by Key and Retzius, who first established that the granulations play a major role in the resorption of the cerebrospinal fluid.

The cerebral pia mater, *pia mater encephali*, closely envelops the whole of the brain, dipping between cerebral gyri and sulci. The pia mater is a vascular membrane containing a plexus of minute blood vessels which penetrate into the brain; the pia mater forms adventitia around these vessels. Between the adventitia and the brain a perivascular space exists; it communicates with the subarachnoid space. In some places the pial vessels are strongly developed and form the choroid plexuses, *plexus choroidei*. They are present in all the cerebral ventricles (*plexus choroideus ventriculi quarti*, *plexus choroideus ventriculi tertii*, *plexus choroideus ventriculi laterales*). The pia mater is highly innervated by the nerves arising from the superior cervical ganglion of the sympathetic trunk. The nervous fibres accompany the vessels.

The cerebrospinal fluid, *liquor cerebrospinalis*, filling the subarachnoid and subdural spaces of the brain and spinal cord differs from other fluids of the body. Only endo- and perilymph of the inner ear and aqueous humor of the eyeball are similar to it. The cerebrospinal fluid is formed by transudation from the choroid plexuses of the pia mater, the epithelial layer of which is like a glandular epithelium.

The structures producing the cerebrospinal fluid form the blood-brain (hematoencephalic) barrier which possesses selective permeability to substances. Hence, some substances may pass into the cerebrospinal fluid, while the others are delayed by the blood-brain barrier that plays a great role for the protection of the brain from harmful influences. Thus, the cerebrospinal fluid is not only mechanical protection for the brain and the vessels lying on its base, but also a special internal medium which provides the optimal functioning of the central nervous system. The cerebrospinal fluid feeds the nervous system, passing to the brain substance through the periaventricular spaces. The space containing the cerebrospinal fluid is closed. The outflow of the fluid occurs by the way of the filtration mainly into the venous system through the Pacchioni's granulations and partially into the lymphatic system through the perineural spaces, into which the meninges continue.

TEST QUESTIONS:

1. Name the parts of the telencephalon.
2. What lobes do the cerebral hemispheres have? Describe the boundaries of the lobes. Where is the insula located?
3. Describe the sulci and gyri of the superolateral cerebral surface.
4. Describe the sulci and gyri of the medial cerebral surface.
5. Name the components of the fornicate gyrus? What is its function?
6. Describe the sulci and gyri of the inferior cerebral surface.
7. Give the definition of the cerebral cortex. What is its thickness?
8. Give the characteristic of the paleocortex. What parts does it consist of?
9. Give the characteristic of the archicortex. What parts does it include?
10. Give the characteristic of the neocortex. What parts does it include?
11. Name the layers of the cerebral cortex. Describe the features of each layer.
12. Give the definition of the cortical column.
13. Give the definition of myeloarchitectonics, cytoarchitectonics and glioarchitectonics.
14. Give the definition of the nerve centre. Give the definition of the projection and association nerve centres (areas). What are the differences between them?
15. Name and describe the projection cortical centres.
16. Name and describe the association cortical centres. Give the definition of the second signal system. Which cortical centers are unilateral? Which cortical centers have opposite location?
17. Describe the symptoms of the damage to the cortical areas.
18. What groups of white matter fasciculi are distinguished in the telencephalon?
19. Describe the location and function of the projection fibres.
20. Describe the position, macroscopical structure and components of the internal capsule.
21. Describe the structure and function of the fornix.
22. Describe the position and function of the association fibre fasciculi.
23. Describe the position of the external and extreme capsules.
24. Describe the position and function of the cerebral commissures.
25. Describe the parts of the corpus callosum.

26. Name the basal nuclei of the telencephalon, describe their position and function.
27. Give the definition of the strio-pallidar system; describe its function.
28. Name the parts of the lateral ventricles, describe their position. What brain structures limit the parts of the lateral ventricles? Describe the communications of the lateral ventricles.
29. Name the parts of the rhinencephalon (peripheral and central).
30. Name the components of the extrapyramidal system and describe its function.
31. Name the components of the limbic system and describe its function.
32. Name the meninges of the brain in sequence. Describe the intermeningeal spaces.
33. What process does the dura mater give?
34. Describe the features of the arachnoid mater.
35. Name the subarachnoid cisterns; describe their localization.
36. Describe the circulation of the cerebrospinal fluid (production, passage, absorption, function).
37. Give the definition and name the components of hematoencephalic barrier.

CLINICOANATOMICAL PROBLEMS

1. A patient has spastic paralysis of the left body half and the loss of speech. In what hemisphere and gyri is the lesion localized?
2. A patient has the loss of general sensation in the right half of the body. In what gyrus and in what hemisphere should a doctor find the lesion?
3. A patient has intracranial injury with damage to the middle frontal gyrus. What symptoms can be observed?
4. A patient has hemorrhage into the lateral ventricles. Where the blood can penetrate?
5. A patient has motor aphasia. Where is the lesion located?

4. CONDUCTION TRACTS OF CENTRAL NERVOUS SYSTEM

4.1. General Characteristic of the Conduction Tracts

The conduction tract is a chain of anatomically and functionally interconnected neurons which provide the conduction of the same nervous impulses in strictly defined direction.

The anatomical interconnection of the neurons is provided by the synapses between the neuronal processes or between the processes and cell bodies. Two main laws of the conduction of the nervous impulses (the law of dynamic polarization of the nerve cell and the law of dynamic polarization of the synapsis) explain the phylogenetically developed principle of the functioning of the nervous system: the unidirectional spreading of the nerve impulse within the reflex arch. As we know, the reflex arch consists of three parts: afferent, association and efferent. According to these parts, in the complex reflex arches which perform their reaction with participation of the brain, three groups of the conduction tracts are distinguished: afferent, association and efferent.

The afferent nerve pathways conduct the nerve impulses from receptor to an integration centre. The afferent pathways which end in the brain-stem integration centres carry the impulses of unconscious sensation, while the pathways which end in the projection centres of the cerebral cortex convey the impulses of conscious sensation.

As usual, the afferent tracts include not less than three neurons. The first neuron (sensory) is in the periphery (in the sensory ganglia of the spinal and cranial nerves). The second neuron (intermediate, or association) lies in the communication centre, i.e. in the nucleus consisting of intermediate neurons. There may be several communication centres. The last neuron is a neuron of an integration centre.

The association nerve pathways conduct the nerve impulses from one integration centre to another, i.e. provide interconnection between the integration centres. These conduction tracts are also multi-neuronal.

The efferent nerve pathways conduct the nerve impulses from an integration centre to effector (effector organ).

The efferent conduction tracts arising from the neurons of the cerebral cortex are termed cortical. As usual, these neurons lie in the fifth (ganglionic) layer of the cerebral hemispheres. Most of them are pyramidal in shape therefore the cortical tracts are also called pyramidal. The cortical tracts provide the execution of complex motor acts.

The efferent conduction tracts arising from the neurons of the brain stem integration centres are termed extrapyramidal. They conduct the impulses providing the muscle tone and complex unconscious motor reflex arches.

The fibres of both pyramidal and extrapyramidal tracts end on the neurons in the spinal anterior horns or on the neurons in the motor cranial nerve nuclei.

To conclude the general characteristic of the conduction tracts, it is necessary to give the definition of a nerve tract. The nerve tract is a collection of axons that form the nerve fibre bundles localized in strictly defined places of the central nervous system and conducting the same in function nervous impulses. Hence, the nerve tract is just a component of the conduction tract. The afferent and association conduction tracts consist of several sequential nerve tracts. The efferent conduction tracts are usually represented by a single tract.

Most reflex reactions in humans and higher animals occur with participation of the integration cerebral centres. The integration centres can be divisible into two groups: subcortical (in the cerebellum and diencephalon) and cortical (the projection areas of the cerebral cortex).

4.2. Afferent Tracts

The afferent nerve pathways can be classified as the tracts of conscious and unconscious perception. The tracts of conscious perception end in the projection (integration) cortical areas; the tracts of unconscious perception end in the subcortical integration centres (cerebellum, superior mesencephalic colliculi and thalamus). The afferent tracts are divided into tracts of general and special sensation (table 8).

Table 8

Afferent conduction tracts

Tracts of general sensation			Tracts of special sensation
Superficial (exteroceptive) pain, temperature and tactile	Deep (proprioceptive)	Interoceptive (visceroceptive)	Visual; vestibular; auditory; olfactory; gustatory

The main afferent tracts of conscious general sensation are:

- 1) the tract of pain, temperature and tactile sensation from the trunk, limbs and neck, *tractus gangliospinothalamocorticalis*;
- 2) the tract of proprioceptive (deep) sensation from the trunk, limbs and neck, *tr. gangliobulbothalamocorticalis*;
- 3) the tract of all kinds of general sensation from the head, *tr. ganglionucleothalamocorticalis*.

The main afferent tracts of unconscious general sensation are:

- 1) anterior spinocerebellar tract (of Gowers), *tr. spinocerebellaris anterior*;
- 2) posterior spinocerebellar tract (of Flechsig), *tr. spinocerebellaris posterior*;
- 3) nucleocerebellar tract, *tr. nucleocerebellaris*.

4.2.1. Tracts of General Sensitivity

The Tract of Exteroceptive Sensitivity

The tract of pain, temperature and tactile sensation (ganglio-spino-thalamocortical tract, *tractus gangliospinothalamocorticalis*) starts from the exteroceptors of the skin of the trunk, limbs and neck (fig. 4.1). Since the skin forms the body coat, this kind of sensation is also called superficial or exteroceptive. The skin is innervated in accordance with the principle of segmentation, i.e. each segment has a certain zone of the cutaneous innervation (dermatome).

For each kind of the superficial sensation there are specialized exteroceptors which represent the contact receptors where the nerve impulses occur under the immediate effect of a stimulus. The pain is perceived by free nerve endings; the warm by Ruffini endings; the cold by end bulbs of Krause; the touch and pressure by the corpuscles of Meissner, Golgi-Mazzoni endings and Merkel cells.

The impulses arising in the exteroceptors run through the peripheral processes of the pseudounipolar cells to their somata situated in the spinal ganglia. The peripheral

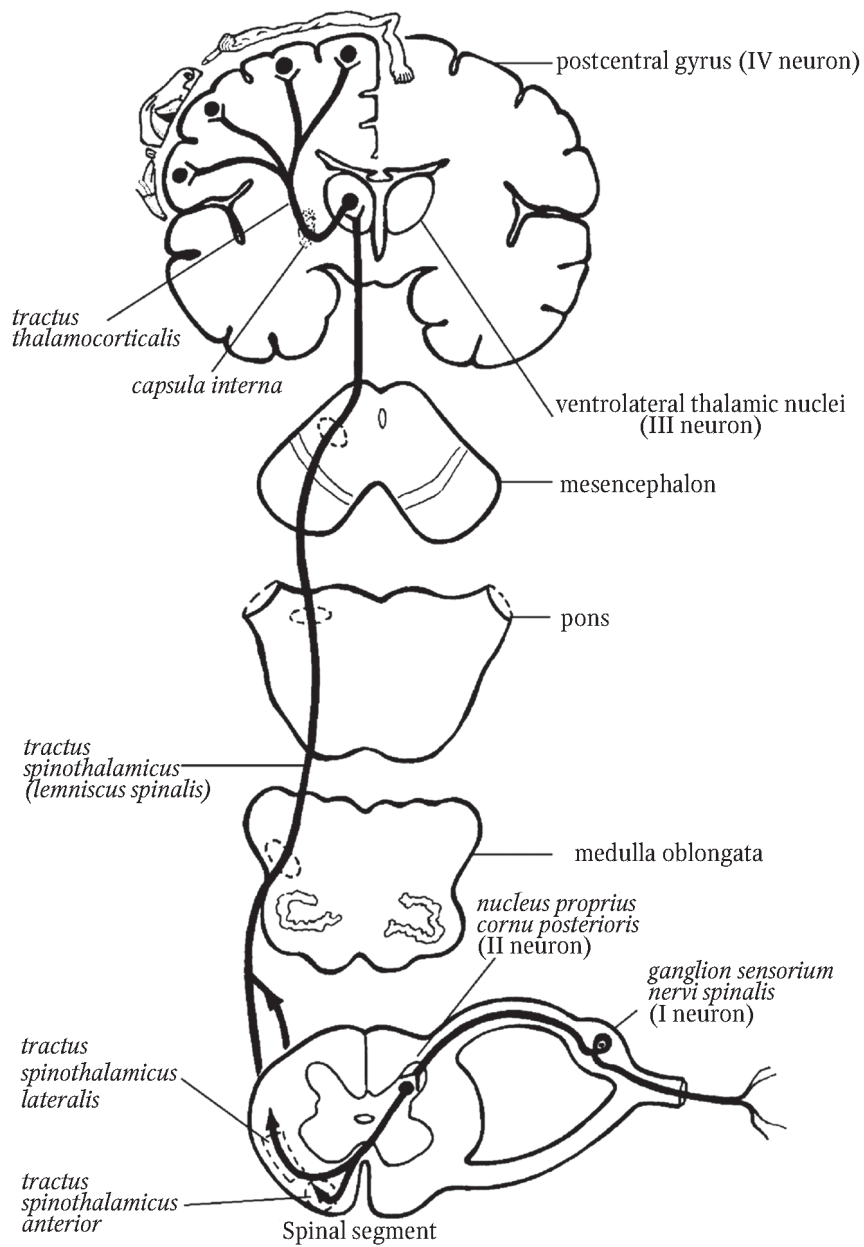


Fig. 4.1. Tract of pain and temperature sensation

processes of the pseudounipolar neurons pass via the branches of the spinal nerves (until the sensory spinal ganglia which contain the cell bodies of the first neurons). The central processes of the pseudounipolar cells run through the posterior spinal roots into the spinal cord. They give off the numerous collaterals to the cells of grey matter situated in the area of the posterior horn's apex (the cells of the gelatinous substance, spongy and terminal zones). The majority of the central processes synapse with the neurons of the posterior horn's nucleus proprius. The tract extending from the posterior root ganglion to the intermediate neuron can be termed the ganglio-spinal tract.

The axons from the neurons of the gelatinous substance, spongy and terminal zones (the second-order neurons) convey the nerve impulses to the neurons of the anterior horn's motor nuclei of the same segment and also of the overlying and underlying spinal segments, i.e. participate in the occurrence of the congenital reflexes. The axons from the neurons of the *nucleus proprius cornu posterioris* (the second-order neurons) form the bundle (spinothalamic tract) conducting the nerve impulses to the thalamus.

In the spinal cord, the spino-thalamic tracts have the following features:

- 1) 100 % of their fibres pass to the opposite side;
- 2) the fibres pass to the opposite side through the white commissure with the ascent 2–3 segments above the initial level;
- 3) the fibres are grouped in accordance with the kinds of sensation. The fibres conducting the pain and temperature sensation form the lateral spinothalamic tract. The fibres conducting the tactile sense form mainly anterior spinothalamic tract. The tactile sense from the skin of the perineum is conducted in the spinal cord through the central spinothalamic tract which surrounds the central canal;
- 4) the fibres of the lateral and anterior spinothalamic tracts are arranged eccentrically, i.e. the fibres from the lower spinal segments, which innervate the lower limbs and lower body part, are grouped in the lateral part of the tract, while the fibres from the upper segments are located in the medial part.

In the medulla oblongata, the lateral, anterior and central tracts unite into a single spinothalamic tract, *tr. spinothalamicus*, located dorsal to the olivary nucleus. Here this tract gets one more name, the spinal lemniscus, *lemniscus spinalis*. The spinothalamic tract gradually deflects dorsolaterally, passing in the tegmentum of the pons and mid-brain. The spinothalamic tract's fibres ultimately synapse with the neurons of the ventrolateral thalamic nuclei (the third-order neurons).

The majority of the axons arising from the third-order neurons (65–70 %) run through the middle of the internal capsule's posterior limb into the postcentral gyrus (the projection somatosensory area). They synapse with the neurons of the IV cortical layer, spreading in the gyrus according to the somatotopic projection (the sensory homunculus of Penfield). Some fibres (5–10 %) end on the neurons of the IV cortical layer in the superior parietal lobule (the projection area of awareness of body parts). The tract formed by the axons of the third-order neurons is called the thalamocortical tract, *tractus thalamocorticalis*.

It should be noted that a part of the axons arising from the third-order neurons (up to 20 %) run from the ventrolateral thalamic nuclei into the medial thalamic nuclei (the sensory integration centre of the extrapyramidal system). This centre provides unconscious regulation of the muscle tone in response to the stimulation of the exteroceptors.

Thus, the tract of the superficial, or exteroceptive, sensation includes three sequential tracts:

- 1) *tractus gangliospinalis*;
- 2) *tractus spinothalamicus* (*lemniscus spinalis*);

3) *tractus thalamocorticalis*.

Taking into consideration the features of the location of these tracts, we can determine the level of the damage to the nerve structures. The damage to the spinal ganglia, posterior spinal roots or posterior horn's nucleus proprius results in the disorders of the superficial sensation on the same side. The damage to the fibres of the spinothalamic tract, neurons of the ventrolateral thalamic nuclei and fibres of the thalamocortical tract leads to the disorders of the sensation on the opposite side.

The Tract of Conscious Proprioceptive Sense

The tract of conscious proprioceptive (deep) sense (fig. 4.2) conducts the nervous impulses from the proprioceptors (ganglio-bulbo-thalamo-cortical tract, *tractus gangliobulbothalamocorticalis*). Proprioceptive sense is the information about the state of the proprioceptors located in the muscles, tendons, ligaments, joint capsules and periosteum, i.e. the information about functional state of the locomotor apparatus. It allows us to assess the muscle tone, position of the body parts in space, the sense of vibration, weight and pressure.

The proprioceptors form the largest group of the receptor structures, represented by the muscle spindles and encapsulated receptors. They react to the change of the muscle tone, contraction or stretching of the muscles, tension of the tendons, ligaments or joint capsules. The encapsulated receptors also perceive the tactile sense therefore the tract of conscious proprioceptive sense partially conducts the tactile impulses too.

The nerve impulses from the proprioceptors pass via the peripheral processes of the pseudounipolar neurons to their bodies which are located in the spinal ganglia. The central processes of the pseudounipolar neurons through the posterior spinal roots enter the corresponding spinal segment. In the spinal cord they give the collaterals to the neurons of grey mater over the posterior horn (to the segmental apparatus). Most fibres, bypassing grey mater, run to the posterior funiculus.

In the posterior funiculus the central processes of the pseudounipolar neurons make two bundles: a medial gracile fasciculus, *fasciculus gracilis* (of Goll) and lateral cuneate fasciculus, *fasciculus cuneatus* (of Burdach). The gracile fasciculus passes throughout whole spinal cord, while the cuneate fasciculus appears only from the level of the fourth thoracic segment. The thickness of each fasciculus gradually increases in the cranial direction.

The Goll's fasciculus conducts the impulses of the proprioceptive sense from the lower limbs and lower half of the trunk. The fasciculus receives the fibres from lower 19 spinal ganglia of the same side (1 coccygeal, 5 sacral, 5 lumbar and 8 thoracic). The Burdach's fasciculus includes the fibres from 12 upper spinal ganglia, i.e. it conducts the proprioceptive impulses from the upper half of the trunk, upper limbs and neck. The arrangement of the fibres in the gracile and cuneate fasciculi is as follows: the fibres from the underlying spinal ganglia lie medially; from the overlying ganglia - laterally. The number of the fibres passing into the fasciculi from different spinal ganglia is unequal. It is determined by the mass of musculature innervated by a certain segment and the number of the proprioceptors in this mass. The greatest number of the nerve fibres pass from the spinal ganglia which provide the innervation of the limbs.

The gracile and cuneate fasciculi ascend through posterior funiculi to the gracile and cuneate tubercles, *tuberculum gracile et tuberculum cuneatum*, in the medulla oblongata. The parts of these tracts, formed by the central processes of the pseudounipolar neurons of the spinal ganglia, can be called the gangliobulbar tract, *tr. gangliobulbaris*.

The axons of the second-order neurons, whose bodies are in the gracile and cuneate nuclei, form two groups of the fibres. The first group, the internal arcuate fibres,

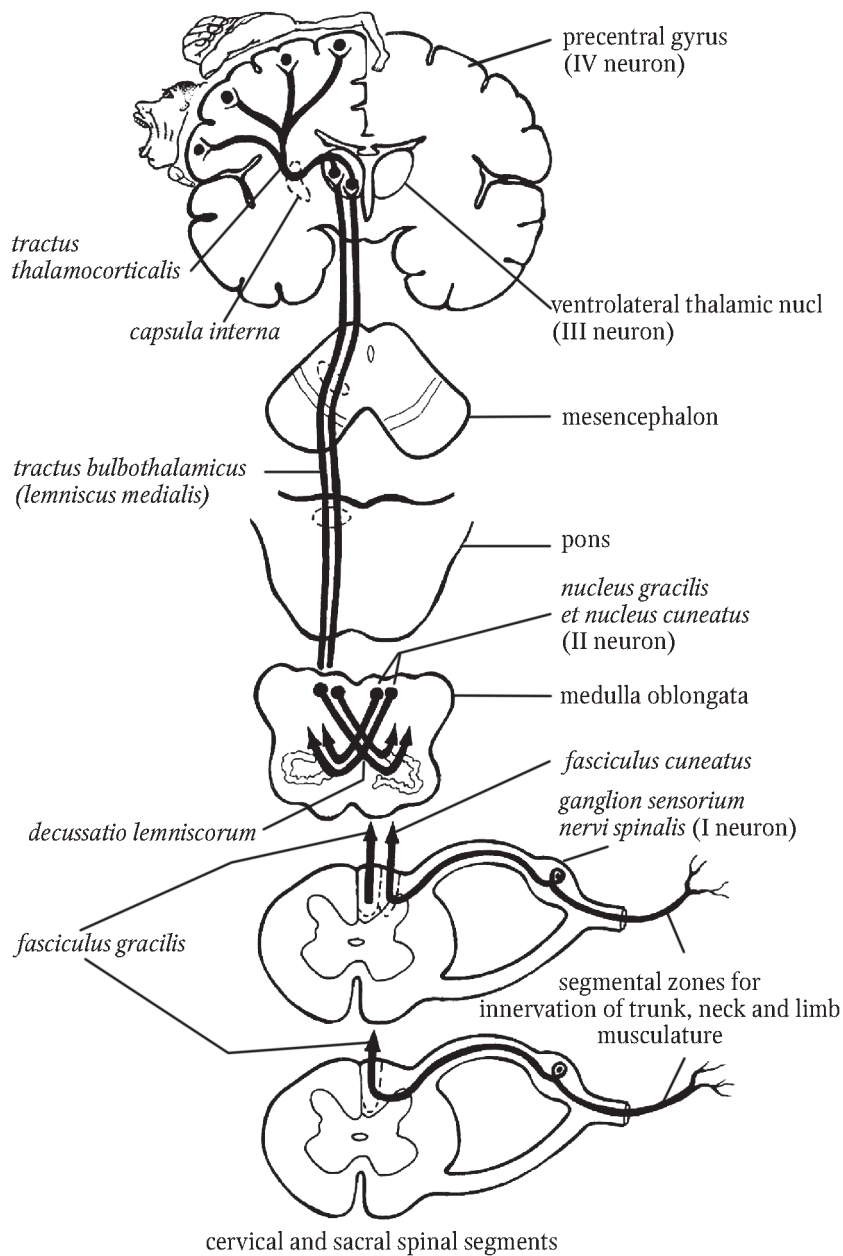


Fig. 4.2. Tract of proprioceptive sensation

fibrae arcuatae internae, crosses to the opposite side in the region between the olives, curves as a loop and ascends upwards. This bundle is termed the bulbothalamic tract, *tractus bulbothalamicus* (the medial lemniscus, *lemniscus medialis*). The decussation of the internal arcuate fibres is called the decussation of the medial lemniscus, *decussatio lemniscorum medialis*.

Passing through the brain stem, the bulbothalamic tract lie in the tegmentum, near the spinothalamic tract and end on the neurons of the ventrolateral thalamic nuclei.

A smaller part of the axons arising from the second-order neurons, which composes the second group of the fibres called the external arcuate fibres, run into the cerebellum via its inferior peduncle. There are anterior and posterior external arcuate fibres. The anterior external arcuate fibres pass from the gracile and cuneate nuclei of the opposite side, curving around the ventral surface of the pyramids and olives, while the posterior external arcuate fibres pass along the same side. In the inferior cerebellar peduncle, the external arcuate fibres unite into the bundle called the bulbocerebellar tract, *tractus bulbocerebellaris*. Its fibres end on the neurons in the middle vermal cortex. They conduct the impulses of unconscious proprioceptive sense.

The axons of the neurons, whose bodies lie in the ventrolateral thalamic nuclei, mainly run to the projection cortical centres. They chiefly end (60 %) in the IV layer of the precentral gyrus's cortex (the projection somatomotor area). A smaller part of the fibres (30 %) pass to the cortex of the postcentral gyrus (the projection somatosensory area), and even smaller part (10 %) run to the superior parietal lobule (the projection area of awareness of body parts). The somatotopic projection is from the opposite body side because the bulbothalamic tracts decussate in the medulla oblongata.

The tract from the ventrolateral thalamic nuclei to the projection cortical areas is termed the thalamocortical tract, *tractus thalamocorticalis*. It passes through the middle of the internal capsule's posterior limb. It should be noted that the axons of the third-order neurons run to the neurons in the medial thalamic nuclei (subcortical sensory centre of the extrapyramidal system).

The tract of conscious proprioceptive sense appeared phylogenetically later than the other afferent tracts.

If this tract is damaged, perception of the position of the body parts in space is disordered; a patient loses the perception of his pose, his motions. With closed eyes a patient can not determine the direction of his movements at the joints, the position of his body parts. The coordination of movements is also disordered; the gait becomes uncertain, the motions become awkward and disproportional.

The Tract of General Sensation from the Face

The tract of general sensation from the face region (ganglio-nucleo-thalamo-cortical tract, *tr. ganglionucleothalamocorticalis*) conducts the impulses of pain, temperature, tactile and proprioceptive sensation from the face via the trigeminal nerve sensory branches. The impulses from the exteroceptors of the forehead, medial angle of the eye, root of the nose, upper eyelid and parietal region pass through the ophthalmic nerve fibres; from the exteroceptors of the lower eyelid, cheek, upper lip and temporal region – through the maxillary nerve; from the exteroceptors of the lower lip, cheek, chin and partially of the external ear auricle – through the mandibular nerve. The impulses from the proprioceptors of the mimic muscles are conducted through all mentioned the trigeminal nerve divisions; the impulses from the proprioceptors of the masticatory muscles pass through the mandibular nerve. Apart from the face region, the trigeminal nerve provides sensory innervation (pain, temperature and tactile) of the mucous membranes,

lips, gums, nasal cavity, paranasal sinuses, lacrimal sac, lacrimal gland and eyeball, and also upper and lower teeth.

All the three trigeminal nerve divisions run to the trigeminal (Gasserian) ganglion which comprises the somata of pseudounipolar neurons (the first-order neurons of this sensory tract).

The central processes of the pseudounipolar neurons enter the pons via the sensory trigeminal nerve root and run to the sensory trigeminal nerve nuclei. The fibres conducting tactile sense from the facial skin, the impulses of pain, temperature and tactile sense from deep tissues and organs of the head run to the pontine nucleus; the fibres conducting the impulses of pain and temperature sense from the facial skin run to the spinal nucleus; the fibres conducting the proprioceptive impulses from the mimic and masticatory muscles run to the mesencephalic nucleus.

The majority of the axons arising from the second-order neurons pass to the opposite side to form the nucleothalamic tract, *tr. nucleothalamicus*, which end in the ventrolateral thalamic nuclei. In the brain stem this tract lies near spinothalamic tract and is known as the trigeminal lemniscus, *lemniscus trigeminalis*.

A smaller part of the axons arising from the second-order neurons run in the same side to the middle vermal cortex, forming the nucleocerebellar tract, *tr. nucleocerebellaris*. This tract passes through the inferior cerebellar peduncles.

The axons of the third-order neurons situated in the ventrolateral thalamic nuclei run through the internal capsule's posterior limb to the neurons in the somatosensory and somatomotor cortical areas and the area of awareness of body parts area. They pass via the thalamocortical tract, *tr. thalamocorticalis*, to end on the neurons of the mentioned areas, in that place where the head region is projected. The thalamocortical tract fibres conducting the impulses of general sensation from the head region are distributed as follows: 60 % run to the postcentral gyrus; 30 % run to the precentral gyrus; and 10 % run to the superior parietal lobule. A small part of the axons arising from the third-order neuron pass to the medial thalamic nucleus (subcortical sensory centre of the extrapyramidal system).

The Tract of Interoceptive Tract

The conduction tract of interoceptive sensation starts from the interoceptors situated in the viscera, vessels, smooth musculature and the glands of the skin. The interoceptors perceive mechanical stimuli, changes of pressure and chemical composition of environment, i. e. they are mechano-, baro- and osmoreceptors.

Many internal organs (digestive, respiratory and urogenital) have double afferent innervation: spinal and brain-stem. Spinal afferent innervation of the thoracic organs is performed by the cervical and thoracic splanchnic nerves; the afferent innervation of the abdominal cavity organs and vessels is provided by the greater and lesser splanchnic nerves; the pelvic organs are innervated by the pelvic splanchnic nerves. These nerves contain the peripheral processes of the pseudounipolar neurons located in the spinal ganglia. The central processes enter the spinal cord via the posterior spinal roots and end on the bodies and dendrites of the intermediate neurons of the interoceptive tract, which are situated in the grey intermediate substance, posterior to the intermediolateral nucleus. The number of the axons arising from the second-order neurons is small therefore they do not form independent tracts. They pass mainly in the posterior spinal funiculus, near the proper spinal cord fasciculi and in the lateral funiculus, adjoining the lateral spinothalamic tract. The axons of the second-order neurons end in the thalamus on the neurons in the basal nuclei (subcortical centre of viscerosensation).

The brain-stem afferent innervation is performed by the branches of the vagus, glossopharyngeal and facial nerves, which contain the peripheral processes of the pseudounipolar neurons (from the interoceptors to the sensory ganglia (superior, inferior and geniculate ganglia)). The central processes enter the brain stem (pons and medulla oblongata) and end on the neurons in the nucleus of solitary tract which is the common nucleus for the VII, IX and X cranial nerves. The axons from the neurons of the solitary nucleus pass via the nucleothalamic tract to end on the neurons in the basal thalamic nuclei.

The axons of the interoceptive tract's third-order neurons, arising from the basal thalamic nuclei, mainly run through the middle of the internal capsule's posterior limb into the cerebral cortex. This fibre group passes via the thalamocortical tract, *tractus thalamocorticalis*. The projection cortical area of viscerosception is in the lower part of the postcentral gyrus. But only a part of the axons end here. The major part runs to the precentral gyrus and the gyri of the frontal and temporal lobes. Due to this, very often it is impossible to localize the sensations perceived by the interoceptors from the internal organs exactly and to give exact characteristic of their manifestation.

A smaller part of the axons arising from the third-order neurons pass from the basal thalamic nuclei to medial thalamic nuclei (subcortical sensory centre of the extrapyramidal system). The noted connections of the thalamus may explain reflective changes of the skeletal muscle tone in the diseases of the internal organs.

Tracts of Unconscious Proprioceptive Sensation

The tracts of unconscious proprioceptive sensation are the most ancient phylogenetically. They developed due to appearance of the vestibular centre, the cerebellum, in the metencephalon. It receives the impulses from the receptors situated in the muscles, tendons, joint capsules, periosteum. The cerebellum analyzes this information, and as a result, unconsciously regulates the muscle tone, coordination and synergism of motions and supports the body balance.

There are several conduction tracts of unconscious proprioceptive sensation: anterior spinocerebellar, posterior spinocerebellar, spino-reticular, spino-olivary. The anterior and posterior spinocerebellar tracts are main. Their function is similar in many aspects but the anterior spinocerebellar tract conducts impulses from proprioceptors of the muscle groups, while the posterior spinocerebellar conducts impulses from every single muscle. Hence, the posterior spinocerebellar tract brings to the cerebellum more detailed and precise information from the proprioceptors. Also, the impulses to the cerebellum pass via additional tracts indirectly from the olivary nuclei and the nuclei of the reticular formation.

Posterior Spinocerebellar Tract

The posterior spinocerebellar tract, *tr. spinocerebellaris posterior* (fig. 4.3), is also called the bundle of Flechsig, named after a German neurologist and neurohistologist. The first-order neurons of this tract are the pseudounipolar neurons situated in the spinal ganglia. The peripheral processes of these neurons pass at first through the spinal nerves, then through the spinal nerve branches and end by proprioceptors in the muscles, tendons, ligaments, joint capsules and periosteum of the trunk, limbs and neck. The central processes enter the spinal cord as *tractus gangliospinalis* via the posterior roots and penetrate into grey matter, ending on the neurons in the thoracic nucleus. The thoracic nucleus is well-defined in C_{VII}-L_{II} spinal segments. The axons arising from the neurons of the thoracic nucleus (the second-order neurons) run to the lateral funiculus

of the same side. They form the posterior spinocerebellar tract passing in the posterolateral part of the lateral funiculus. This tract takes the fibres from every segment and increases up to the level of the seventh cervical segment (then the square of the tract does not change). The tract passes in the dorsal medulla and enters the cerebellum via its inferior peduncle to end on the neurons in the inferior vermician cortex.

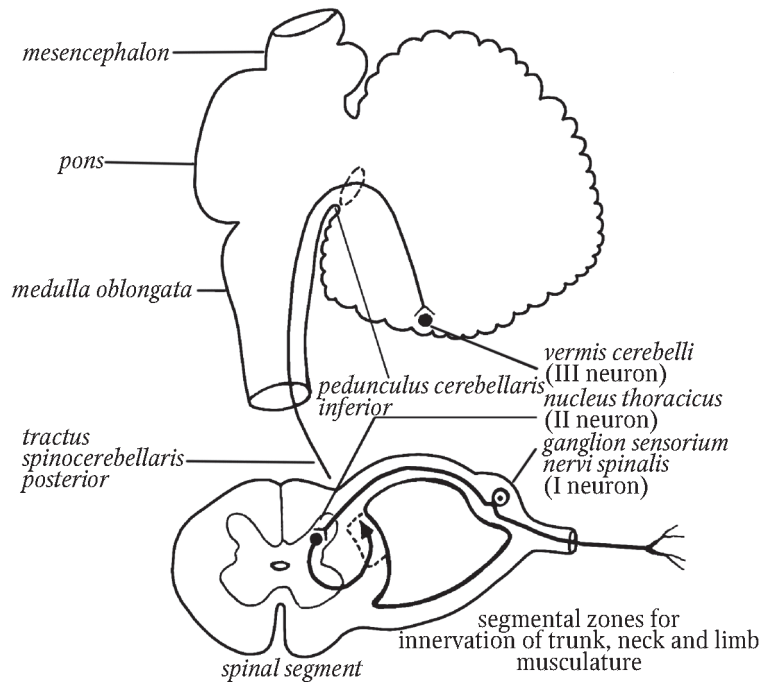


Fig. 4.3. Posterior spinocerebellar tract (of Flechsig)

Anterior Spinocerebellar Tract

The anterior spinocerebellar tract, *tr. spinocerebellaris anterior* (fig. 4.4), is also called the bundle of Gowers, named after a British neurologist.

The first part of the Gowers and Flechsig bundles are represented by similar structures. The bodies of the receptor neurons (pseudounipolar cells) are in the spinal ganglia. Through the spinal nerves and their branches the peripheral processes of these neurons reach the proprioceptors of the trunk, limbs and neck, which are located in the muscles, tendons, joint capsules and periosteum. The central processes enter spinal grey matter via the posterior spinal roots. In the spinal cord they end in the intermediomedial nucleus. The axons of these neurons (90 %) run to the opposite side through the anterior white commissure and then pass in the anterolateral part of the lateral funiculus. 10 % of the axons run to the anterolateral part of the lateral funiculus of the same side. Thus, the lateral funiculus contains the anterior spinocerebellar tract formed by the axons from the intermediomedial nucleus of mainly opposite side, and partially of the same side. The tract ascends, increasing every segment. The fibres from the lower spinal segments occupy the medial portion of the tract; the fibres from each overlying segment join

the tract laterally. In the medulla oblongata the tract lies dorsally, between the olive and inferior cerebellar peduncles. Then it runs to the pontine tegmentum, and at the junction of the pons and midbrain the anterior spinocerebellar tract abruptly turns in the dorsal direction. Via the superior medullary velum, the fibres that decussated in the spinal cord return to the same side and then pass through the superior cerebellar peduncle to reach the superior vermician cortex.

Because the nerve fibres comprising the Gowers bundle decussate twice (in the anterior white commissure and superior medullary velum), the impulses of unconscious proprioceptive sensation are conducted into the cerebellum from the same body half.

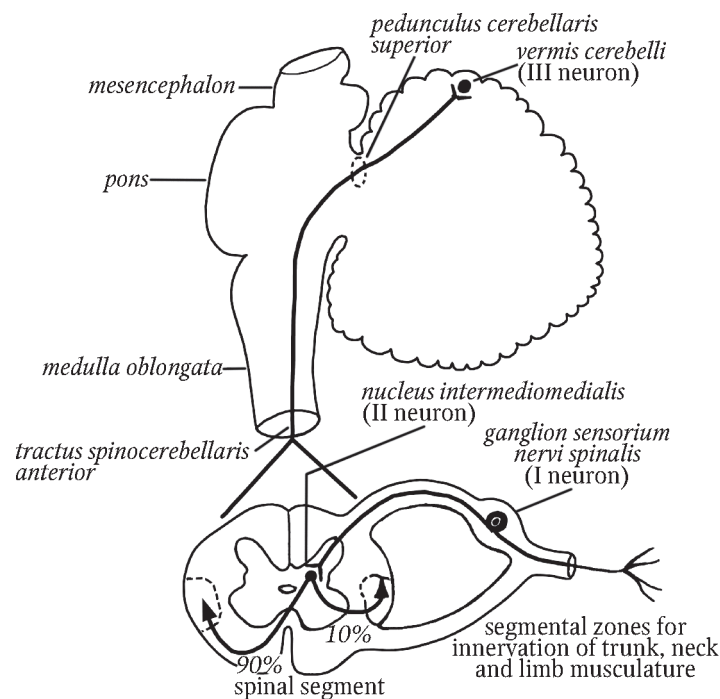


Fig. 4.4. Anterior spinocerebellar tract (of Gowers)

4.2.2. Tracts of Special Sensitivity

We will describe the tracts of special sensation sequentially, in accordance with the phylogenetic development of the nerve centres in the brain. The centres of special sensation developed in the following order: at first the centre of balance, then the centres of hearing, vision, taste and finally the olfactory center. The noted centres were connected with corresponding afferent tracts and organs, where the receptors were located. According to I.P. Pavlov, the morphofunctional connection of receptors, afferent conduction tracts and associated with them centres represents the **analyzer** of certain forms of sensation.

Vestibular (Statokinetic) Pathway

The vestibular analyzer provides the perception of the vestibular stimuli, the conduction of the nerve impulses to the vestibular nerve centres, the analysis and integration of the received information. Together with the motor, cutaneous and visual analyzers, the vestibular analyzer supports the body balance in various movements and participates in the reactions of the body during space orientation. Due to this, the vestibular analyzer is also called the analyzer of balance and gravitation. The certain function of the vestibular analyzer is to receive the information about the position of the head, its movements and hence about position of the body in space.

The receptors of the statokinetic analyzer are placed in the organe of balance which is represented by the three semicircular ducts, utricle and saccule located within the vestibular labyrinth of the inner ear. In the ampules of the semicircular ducts, the receptors are represented by the cells of the ampullar crests; in the utricle and saccule – by the cells of the maculae or otolith apparatus. These receptors are the primary sensory hair cells surrounded by the support cells. The vibration of the endolymph causes the deflection of hair-cell stereocilia, or the stereocilia undergo the pressure of the otolith apparatus` s crystals. This leads to the appearance of the stimuli.

The hair cells of the semicircular ducts` s ampullar crests detect the movements of the head or combined movements of the head and body in a certain plane (horizontal, sagittal and frontal). They perceive the angular accelerations associated with the changes of the balance. The perception of the stimulus is caused by the inertial displacement of the endolymph in the semicircular ducts which are arranged in the planes corresponding to the movements of the head and body. The sensory hair cells of the utricle and saccule signal about the change of the body position relatively to the centre of the earth gravity and perceive the vertical accelerations associated with the gravitational field. At the basis of the hair cells, the peripheral processes of the bipolar cells branch; the bodies of these cells lie in the vestibular ganglion, *ganglion vestibulare*. The latter is on the floor of the internal acoustic meatus in the temporal bone.

The central processes of the vestibular ganglion form the vestibular root, *radix vestibularis*, of the vestibulocochlear nerve. It joins the cochlear root of the same nerve and enters the pontine substance through the cerebellopontine angle. In the pons the fibres of the vestibular root divide into ascending and descending which run to the vestibular nuclei situated in the lateral angle of the rhomboid fossa, *area vestibularis*. The ascending fibres end on the neurons in the superior vestibular nucleus, *nucleus vestibularis superior* (Bechterew` s nucleus); the descending fibres – on the neurons in the medial vestibular nucleus (of Schwalbe), lateral vestibular nucleus (of Deiters) and inferior vestibular nucleus (of Roller), *nucleus vestibularis inferior*.

The axons from the vestibular nuclei form several bundles which run into the spinal cord, cerebellum, thalamus and enter the medial and dorsal longitudinal fasciculi.

A part of the axons from the Deiters` s nucleus and the axons from the Roller` s nucleus descend to the spinal cord as the vestibulospinal tract, *tr. vestibulospinalis* (fig. 3.10). This tract passes at the junction of the lateral and anterior spinal funiculi, ending every segment on the neurons of the anterior horn motor nuclei. It conveys the motor impulses to the muscles of the neck, trunk and limbs, providing the unconscious support of the body balance during the vestibular loads.

A part of the axons from the Deiters and Schwalbe` s nuclei form the vestibulocerebellar tract, *tr. vestibulocerebellaris*. This tract passes via the inferior cerebellar peduncles and end in the vermis. It should be noted that the neurons of the Deiters` s nucleus have

a feedback connection with the cerebellum by means of the cerebellovestibular tract, *tr. cerebellovestibularis*. Through this tract the cerebellum indirectly influences on the spinal cord.

A part of the axons from the Deiters' nucleus neurons enter the medial longitudinal fasciculus of the same and opposite side and end in the interstitial nucleus (of Cajal), *nucleus interstitialis*, nucleus of posterior commissure (of Darschewitsch), *nucleus commissure posterior*. These nuclei which refer to the midbrain reticular formation provide the connection between the organ of balance (through the Deiters' nucleus) and the cranial nerve nuclei (III, IV, VI and XI) which innervate the muscles of the eyeball and neck. The connections of the Deiters' nucleus allow us to keep the direction of the sight during the change of the head position.

A part of the axons from the Deiters' nucleus enter the dorsal longitudinal fasciculus and synapse with the neurons of the posterior hypothalamic nucleus. The latter provides the connection between the organ of balance (through the Deiters' nucleus) with vegetative nuclei (of the III, VII, IX, X cranial nerves). The noted connections of the Deiters' nucleus explain the appearance of the vegetative reactions (nausea, vomiting, pallor of skin, cold extremities, increased sweating, increased peristalsis of the gastrointestinal tract, slowing heart rate, lowering blood pressure, constriction of the pupils etc.) in response to excessive stimulations of the vestibular apparatus.

Conscious analysis of the vestibular stimuli (determination of the head position, degree of the body tilt in space) is performed only in the cerebral cortex. The nerve impulses reach the cortical areas by the following way. A part of the axons from the Deiters and Schwalbe's nuclei pass to the opposite side forming the vestibulothalamic tract, *tr. vestibulothalamicus*. This tract is included into the bulbothalamic tract and end on the neurons in the median thalamic nuclei. The axons from the median thalamic nuclei mainly run through the internal capsule's posterior limb to the cortical area of the vestibular analyzer (the cortex of the medial and inferior temporal gyri). We suppose that the information into these cortical areas also comes indirectly from the somatomotor, somatosensory areas and the area of awareness of body parts. These connections explain the generalization of the effects in response to the vestibular stimuli. The smaller part of the axons from the median thalamic nuclei end in the median thalamic nuclei (the subcortical sensory centre of the extrapyramidal system), which provide unconscious regulation of the muscle tone during the vestibular loads.

The diseases of the vestibular apparatus (labyrinth), the damage to the vestibular nuclei in the pons are accompanied by dizziness, disorder of balance and coordination of movements, nystagmus (the involuntary rhythmic movements of the eyeballs) and vegetative disorders. The damage to the cortical vestibular areas manifests also in the impairment of the spatial orientation. Finally, it should be noted that the regular trainings allow us to adapt to the vestibular loads.

Auditory Pathway

The auditory analyzer (fig. 3.9) provides the perception of the acoustic stimuli, conduction of the nerve impulses to the nerve centres, analysis and integration of the perceived information. The function of the auditory analyzer is multi-faceted. First of all, the auditory analyzer allows people to communicate through speech. Hearing allows us to receive and analyse the sound information coming from external environment, to determine the direction of the sound, the power and timbre of the sound. Due to the auditory memory we can define the identity of the sound to a certain person or object.

The receptors perceiving the sound stimuli are placed in the auditory organ (the organ of Corti). The organ of Corti is located in the cochlear duct and represented by the inner and outer hair cells surrounded by the supporting epithelial cells. The inner hair cells are arranged in one row; their number is 3500. The outer hair cells form 3–5 rows; their number is around 20 000. Each hair cell carries about 50 hairs (stereocilia) on its apical surface; they are washed by endolymph. The bodies of the hair cells and surrounding supporting cells lie on the basilar membrane. The latter consists of 24 000 transverse fibres, the length of which increases from the apex to the base of the cochlea. The stereocilia of the sensory cells reach the tectorial membrane.

The mechanism of the sound perception is complex. At first the sound is captured by the external ear auricle, directs into the external acoustic meatus and causes vibrations of the tympanic membrane. Further the vibrations are transmitted to the auditory ossicles (malleus, incus and stapes). The stapes closes the fenestra vestibuli of the internal ear's osseous labyrinth and causes the displacement of the perilymph in the scala vestibuli and then in the scala tympani. The vibrations of the perilymph are transmitted to the endolymph through the secondary tympanic membrane. The basilar membrane vibrates only in those parts which are in resonance with the frequency of the sound wave. It is established that such parts of the basilar membrane for low sounds are placed at the apex of the cochlea; for high sounds – at the base. The human ear perceives the sound waves with the frequency of vibrations from 16 to 21 000 Hz. For speech sounds the optimal interval is 1000–4000 Hz. The sound perception occurs due to the stimulation of the sensory cell stereocilia situated on a certain part of the basilar membrane. The mechanical stimulus transforms into the nerve impulse which is conveyed from the outer hair cells to the peripheral processes of the bipolar cells.

The bipolar cells are the first-order neurons of the auditory tract. Their bodies comprise the cochlear ganglion, *ganglion cochleare*, (the spiral ganglion, *ganglion spirale*) located in the spiral canal of the cochlea. The spiral ganglion contains about 31 000 neurons. The central processes of the bipolar neurons unite into a bundle which is called the cochlear root of the vestibulocochlear nerve, *radix cochlearis n. vestibulocochlearis*. This root passes through the opening situated on the floor of the internal acoustic meatus, join the vestibular root and run to the cerebellopontine angle. At the angle, the fibres of the cochlear root enter the pontine substance to end on the neurons in the anterior and posterior cochlear nuclei. These nuclei lie in the lateral angle of the rhomboid fossa and contain the second-order neurons of the auditory tract.

The axons from the anterior cochlear nucleus pass in the medial direction to end on the neurons in the anterior and posterior nuclei of the trapezoid body, *nuclei corporis trapezoidei anterior et posterior*, on the same and opposite sides. The fibres running to the opposite side participate in the formation of the trapezoid body in the pons. The axons from the posterior cochlear nucleus appear on the dorsal pontine surface and cross the rhomboid fossa transversely as the medullary striae. At the region of the median sulcus they dip in the pontine substance and through the trapezoid body reach its posterior nucleus of the opposite side. Thus, the third-order neurons of the auditory tract are in the trapezoid body.

The collection of the axons arising from the third-order neurons comprises the lateral lemniscus. It should be noted that a part of the fibres enter the lateral lemniscus immediately from the neurons of the anterior and posterior cochlear nuclei, passing the through trapezoid body's nuclei without making synaptic contacts. These fibres are interrupted on the neurons scattered along the lateral lemniscus, which are described together as the nucleus of the lemniscus, *nucleus lemnisci*. In the pons, the fibres of the lat-

eral lemniscus abruptly change their direction becoming vertical to run upwards. In the isthmus rhombencephali, they lie superficially, placed at the area of *trigonum lemnisci*. A smaller portion of the lateral lemniscus` s fibres end on the neurons in the subcortical auditory centre, the inferior midbrain colliculi. A major portion of the fibres reach the second subcortical auditory centre, the nuclei of the medial geniculate bodies. The third subcortical centre is the median thalamic nuclei which are connected with the subcortical sensory centre of the extrapyramidal system. The nuclei of the subcortical centres contain the fourth-order neurons of the auditory tract.

The axons from the inferior colliculus run to the midbrain integration centre situated in the superior colliculus. From its cells the tectospinal and tectonuclear tracts start; they descend to the nuclei proprii of the anterior spinal horns and to the motor cranial nerve nuclei. The noted tracts conduct the efferent impulses providing unconscious congenital motor reactions of the musculature of the trunk, limbs, head and eyeball to the sudden acoustic stimuli.

It should be noted that the cells of the inferior colliculus` s nuclei are also connected with the motor nuclei of the V, VII cranial nerves and with the nuclei of the opposite inferior colliculus. These connections provide the regulation of the work of the auditory muscles. In particular, the trigeminal motor nucleus unconsciously provides the contraction of the tensor tympani in response to the sound stimuli; the facial motor nucleus – the contraction of the stapedius. The two-way connections of the inferior colliculi provide the coordinated work of the subcortical centres and innervated by them structures.

The axons from the medial geniculate bodies pass through the internal capsule` s posterior limb and then fan out as the acoustic radiation into the middle part of the superior temporal gyrus (the projection acoustic area). Because only small portion of the auditory tract fibres pass on the same side, the projection acoustic centre receives the information mainly from the opposite side.

Following the principle of feedback connection, the cerebral cortex influences on the subcortical auditory centres and indirectly on the organ of Corti. The latter receives the axons from the posterior nucleus of the trapezoid body (the superior olivary nucleus) that comprise the olivocochlear tract; its fibres end on the hair cells. The cortical connections with the organ of Corti contribute to more precise perception of sounds, the perception of whisper speech and protect from excessively strong sounds.

A small portion of the lateral lemniscus` s fibres run to the neurons in the median thalamic nuclei. The axons from these nuclei conduct the information to the diencephalic integration centre, the medial thalamic nuclei. The medial thalamic nuclei are connected with the motor centres of the extrapyramidal system, limbic system and hypothalamus. The noted structures regulate the muscle tone, perform the various emotional reactions and change the activity of the internal organs in response to sound stimuli.

The damage to the organ of Corti, cochlear nerve and cochlear nuclei leads to unilateral deafness. The unilateral damage to the lateral lemniscus, medial geniculate body and projection acoustic area results in the decreased hearing in both ears. The damage to the association acoustic area (the posterior part of the superior temporal gyrus) causes the auditory hallucinations.

Visual Pathway

The visual analyzer (fig. 4.5) provides the perception of the visual stimuli, conduction of the nerve impulses to the visual nerve centres, analysis and integration of the perceived information.

The visual analyzer is the most important in cognition of the external world. Up to 90 % of the information about the objects (their sizes, color, spatial relationship etc.)

passes through it to the cerebral cortex. Besides, the visual analyzer possesses the ability of accumulation, storage and recognition of the previously known information (the visual memory).

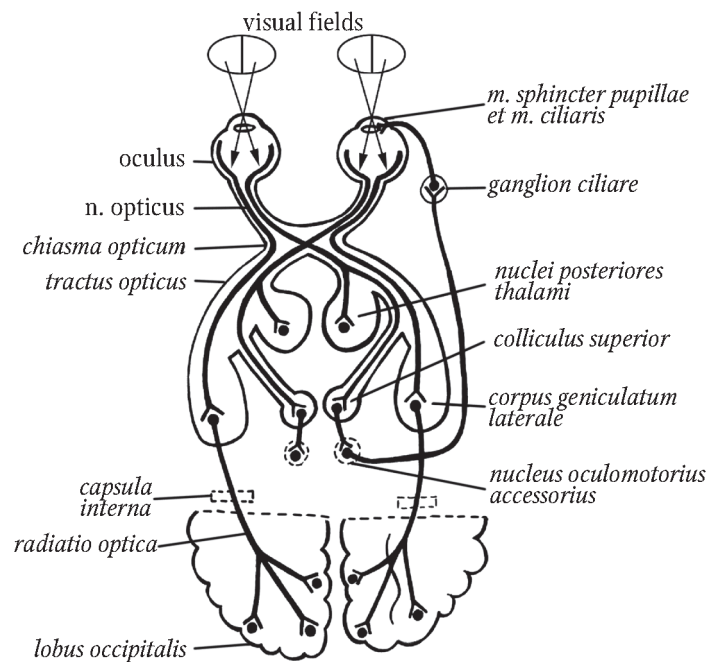


Fig. 4.5. Visual pathway

The receptors of the visual apparatus are placed in the optic part of the retina adjusted to the perception of the light stimuli. The retina has a complex structure. It comprises 10 layers of cell elements, different in structure and functional purpose. The receptors of the visual organ are the cone and rod cells situated in the ninth in depth layer. There are 100–150 million of the rod cells in the retina; they occupy almost entire surface of its optic part and responsible for vision at low light level (scotopic vision). The number of the cone cells is only 5–7 million; they are concentrated mainly in the region of the macula. The cone cells are responsible for vision in well-lit conditions and allow color perception (photopic vision).

The place for high-acuity vision is the macula. It lies in the retina, 4 mm lateral to the optic disc. The rod and cone cells are stimulated by light which penetrates into the deep retinal layers. Due to the enzymes (rhodopsin and iodopsin), in the receptors the photochemical reactions occur; they transform the energy of the light stimulus into the nervous impulses. The nerve impulses are conducted to the peripheral processes of the bipolar neurons. The bipolar cells are the first-order neurons in the visual pathway (they lie in the internal nuclear lamina of the retina). There are two kinds of the bipolar neurons: giant and small. The giant bipolar neurons connect with the rod cells, each with 100–200 rods. The small bipolar neurons connect with only cone cells, each with not more than 30 cones. The central processes of the bipolar neurons are rather short; they

synapse with the multipolar neurons in the retinal ganglionic cell lamina. The ganglion cells (the second-order neurons in the visual pathway) are usually large and commonly contact with several bipolar neurons simultaneously. The axons arising from the ganglion cells pass to the retinal surface and converge at the optic disc (blind spot) to form the trunk of the optic nerve containing about 1 million of nerve fibres.

The optic nerve leaves the orbit through the optic canal and in the cranial cavity it forms the optic chiasm with the opposite optic nerve. But only medial fibres ($\frac{2}{3}$) of the nerve cross each other in the optic chiasm; the lateral fibres do not cross. The medial fibres run from the inner parts of the retina, which perceive the visual information from the lateral sides due to the intersection of the light rays in the lens. The lateral fibres run to the optic tract of the same side. They arise from the lateral parts of the retina, which perceive the light from the nasal part of the visual field. The incomplete decussation of the visual pathway is of the great physiological importance. It provides the conduction of the nervous impulses from each eyeball to both hemispheres hence provides the stereoscopic vision and possibility of synchronous eyeballs' movements.

The optic chiasm is continuous with the optic tracts. Each tract contains the fibres from the same parts of the both eyes' retina. Thus, the right optic tract contains the lateral fibres from the right half of the right eyeball and medial (crossing) fibres from the right half of the left eyeball. Hence, the right optic tract conducts the nerve impulses passing from the nasal half of the right eye's visual field and temporal half of the left eye's visual field.

At the lateral edge of the cerebral peduncle, the optic tract divides into three bundles running to the subcortical visual centres: superior colliculi, lateral geniculate bodies and posterior thalamic nuclei.

The superior colliculi receive just small part of fibres, which provide the pupillary reflex and unconscious motor reactions in response to the light stimuli. The axons from the superior colliculus pass to the accessory nucleus of the oculomotor nerve (Yacubovich-Edinger-Westphal nucleus) to the same and opposite sides, to the reticular formation cells, to the motor nuclei of the III, IV and VI cranial nerves and to the Cajal's nucleus, from which the medial longitudinal fasciculus originates. The accessory nucleus's cells send the axons to the ciliary ganglion which performs the parasympathetic innervation of the sphincter pupillae and ciliary muscle. Normally, when one eye is exposed to light, both pupils contract because the optic fibres running from the superior colliculus connect with the oculomotor nerve's accessory nucleus of the same and opposite sides. The ciliary muscle provides the accommodation of the eye (the ability of the eye to see sharply the objects which are located at various distances in front of the eye). The accommodation is performed due to the change of the lens curvature. The dilator pupillae receives the sympathetic innervation from the sympathetic centre located in the spinal cord (the segments $C_8 - Th_1$), which is connected with the neurons of the superior colliculus by means of the reticular formation. The connections of the superior colliculus's cells with the parasympathetic and sympathetic nerve centres which innervate the iridial muscles allow the iris to regulate the light stream coming to the retina. In the increased light intensity, the pupil constricts; in the darkness – dilates. The reaction of the pupil to the light is called the pupillary light, or photopupillary, reflex.

The connections of the neurons comprising the superior colliculus's nucleus with the neurons of the III, IV and VI cranial nerves provide the motor reaction of the ocular muscles to the light stimuli. This also provides the binocular vision in which objects are perceived simultaneously by both eyes.

The connections of the superior colliculus's neurons allow us to perform coordinated movements of the eyes and head that is important for the support of the body balance.

Lastly, a part of the axons from the superior colliculus run to the midbrain integration centre, also situated in the superior colliculus. The neurons of the superior colliculus give rise to the tectospinal and tectonuclear tracts. These tracts convey the efferent nerve impulses performing unconscious motor reactions of the musculature of the trunk, limbs, head and eyes to the sudden strong light stimuli.

The main subcortical visual centre is the lateral geniculate body. Most axons of the optic tract end on its neurons (the third order neurons of the visual pathway). The axons of these neurons form a compact bundle which passes through the posterior part of the internal capsule's posterior limb and then fans out as the optic radiation, *radiatio optica* (radiation Gracile, or geniculocalcarine tract), to end on the neurons in the projection visual area. The latter is on the medial surface of the occipital lobe, on the sides of the calcarine sulcus (area 17). The fibres conducting the impulses from the macula end in the depth of the calcarine sulcus.

The projection of the retina to the cerebral cortex has been established. The upper half of the retina projects to the neurons in the upper edge of the calcarine sulcus; the lower half — to the neurons in the lower edge of the calcarine sulcus. These neurons are grouped in the columns arranged radially relatively to the cortical surface. Each column analyzes and synthesizes the only certain parameter of the visual information (size, form, color, the distance to the object etc). The cortical areas adjoining to the projection visual area, in particular within the areas 18 and 19, analyze, synthesize and integrate more complex visual information, the recognition of previously seen objects, the elements of visual abstraction.

Finally, a small portion of the optic tract's fibres run to the neurons of the posterior thalamic nuclei. The axons of these cells convey the visual information to the diencephalic integration centre, the medial thalamic nuclei. They are interconnected with the motor extrapyramidal centres, limbic system and hypothalamus. The noted structures regulate the muscle tone, perform various emotional reactions, change the work of the internal organs in response to the visual stimuli.

The disorders of the visual analyzer's function are diverse and depend on the level of the damage.

The trauma or neuritis of the optic nerve, which involve all its fibres, leads to full blindness (amaurosis) in one eye. The partial damage to the fibres or destruction of the retinal reflexogenic zones (detachment, hemorrhage) result in the focal visual field defect (scotoma).

The traumatic destruction of the optic chiasm is accompanied by full blindness in both eyes. The tumors of the hypophysis may compress the inner part of the optic chiasm, which manifest in loss of vision in the lateral half of visual field (bitemporal hemianopsia). Binasal hemianopsia occurs if the optic chiasm is compressed from the lateral sides.

The damage to the optic nerve, lateral geniculate body, optic radiation or projection visual area leads to hemianopsia (partial blindness in the same visual fields of both eyes). The lesion in the association visual areas (areas 18 and 19) is accompanied with loss of the ability to recognize objects, the distortion of the form of objects and even visual hallucinations.

Gustatory Pathway

The gustatory pathway (fig. 4.6) provides perception of the taste stimuli, conduction of the nervous impulses to the gustatory nerve centres, analysis and integration of the received information.

The taste pathway plays an important role in the work of the alimentary system. It brings the information about the chemical composition, taste and properties of food.

Besides, being situated at the beginning of the alimentary tract, the gustatory receptors contribute to the reflex secretion by the digestive glands (salivary glands, the glands of the gastrointestinal tract, liver, pancreas), regulating their activity.

The gustatory receptors are in the oral cavity and represented by the gustatory cells which are placed in the taste buds. The number of the taste buds varies from 3000 to 9000. They are mainly located on the tongue in the region of the fungiform, vallate and filiform papillae. Smaller number of the taste buds is in the mucosal epithelium lining the lips, soft palate, palatine arches, pharynx and epiglottis. A collection of the taste buds situated in the oral cavity comprises the gustatory organ.

In the centre of the taste bud there is a pit, where the dissolved in saliva substances come. The apical parts of the gustatory (receptor) cells are directed to the taste pit; the

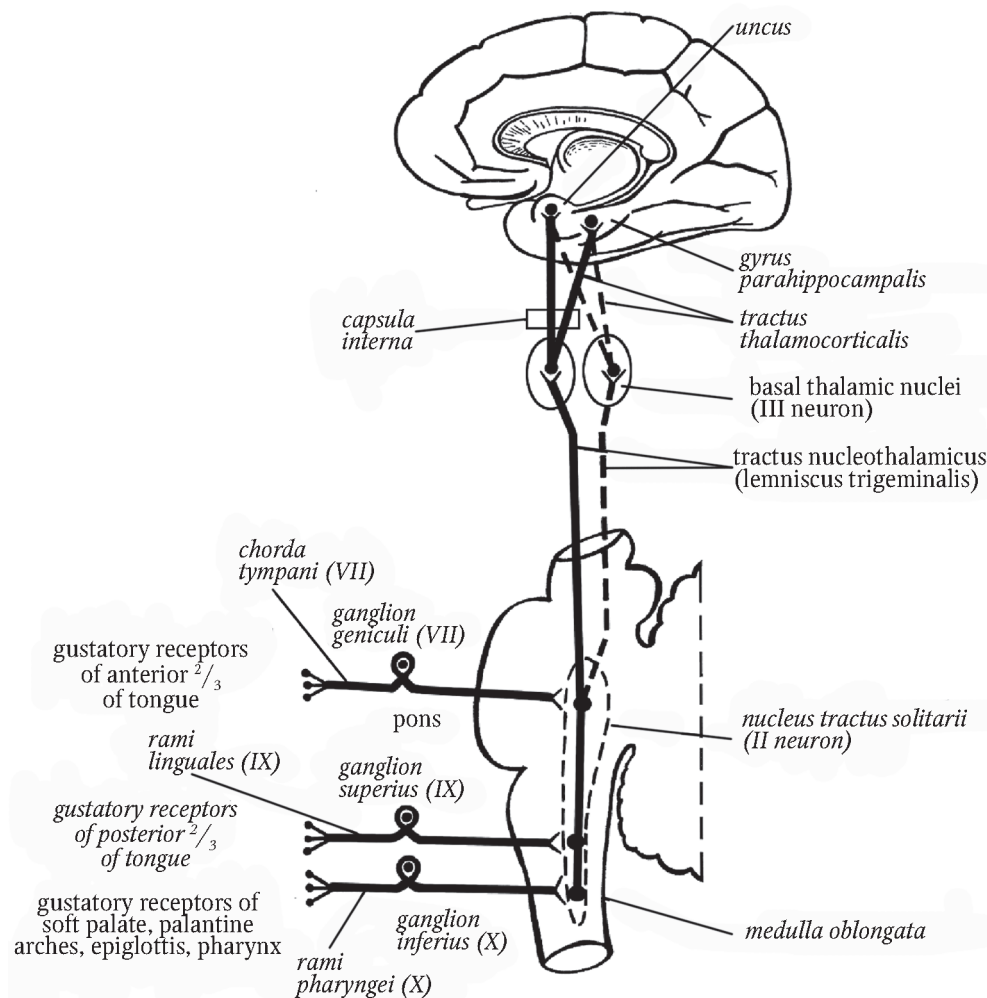


Fig. 4.6. Gustatory pathway

number of the cells varies from 2 to 8. The gustatory cells are specialized: sweet taste is perceived by the lingual apex, sour – by the lateral side of the tongue, bitter – by the lingual tongue, salt – by the entire lingual surface. In the gustatory cells the chemical stimulus transforms into the nerve impulse. The impulses pass through the synapses to the receptor endings of the sensory neurons.

The first-order (sensory) neurons of the taste pathway are represented by the pseudounipolar neurons located in three different ganglia: geniculate ganglion of the facial nerve, superior ganglion of the glossopharyngeal nerve and inferior ganglion of the vagus nerve.

The peripheral processes of the pseudounipolar neurons situated in the geniculate ganglion run to the taste buds in the anterior $\frac{2}{3}$ of the tongue via the chorda tympani (the branch of the facial nerve). The central processes pass via the facial nerve to enter the pons through the cerebellopontine angle.

The peripheral processes of the neurons situated in the glossopharyngeal nerve's superior ganglion run to the taste buds in the posterior third of the tongue via its lingual branch. The central processes form the glossopharyngeal nerve roots and enter the medulla oblongata through its posterolateral sulcus. The peripheral processes of the receptor neurons situated in the vagus nerve's inferior ganglion pass to the taste buds of the pharynx, epiglottis, palate via its pharyngeal branches; the central processes, like those of the glossopharyngeal nerve, enter the medulla oblongata through the posterolateral sulcus.

Entering the brain, the central processes of the receptor cells from all three ganglia run to the nucleus of solitary tract, where synapse with the second-order neurons. Most axons from the second-order neurons make a decussation and pass through the nucleothalamic tract to the basal (ventral) thalamic nuclei. Thus, only small portion of the fibres run to the thalamus on the same side.

The axons from the third-order neurons mainly pass through the thalamocortical tract to the projection gustatory centre. They end on the neurons in the uncus and parahippocampal gyrus. Smaller part of the axons from the third-order neurons situated in the basal thalamic nuclei run to the medial thalamic nuclei (diencephalic integration centre). Thence the information passes to the subcortical motor centres of the extrapyramidal system and to the structures of the limbic system, in particular, to the amygdaloid complex.

The damage to the chorda tympani and lingual branches of the glossopharyngeal nerve leads to the disorders of taste on the same side of the tongue.

The damage to the basal thalamic nuclei, thalamocortical tract, projection gustatory area leads to partial decrease of taste on the opposite side.

If the amygdaloid complex is injured, a patient can not define the taste, although perceives it (taste agnosia).

A full loss of taste is called ageusia, the decrease of taste - hypogeusia, perversion of taste sensations - disgeusia.

Olfactory Pathway

The olfactory pathway (fig. 4.7) provides the perception of the olfactory stimuli, conduction of the nervous impulses to the olfactory nerve centres, analysis and integration of the perceived information.

The olfactory organ plays an important role in human life. It allows us to control the quality of inspired air, the food quality; together with other sensory organs it allows us to orientate in surrounding environment. The presence of the olfactory memory, the ability to recognize the previously met smells are of great importance for humans.

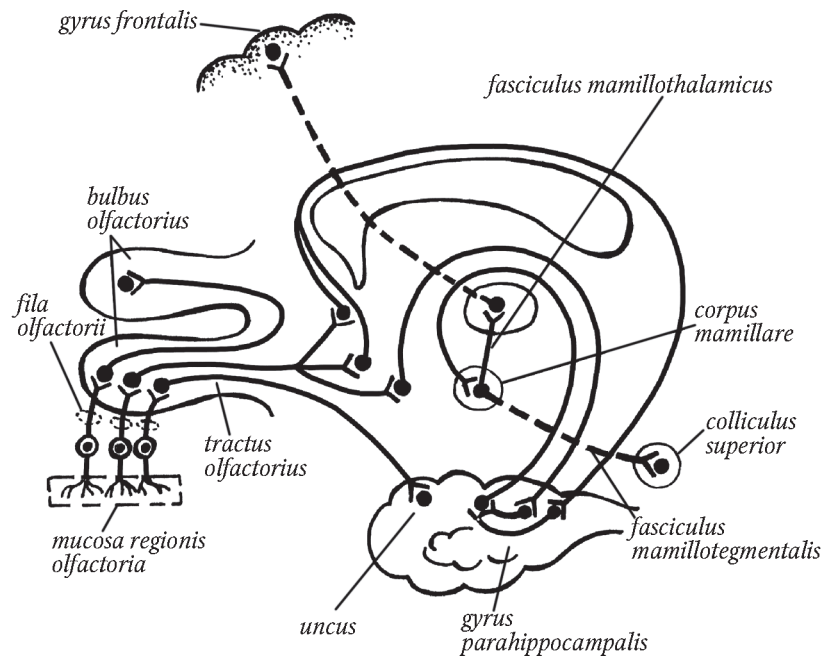


Fig. 4.7. Olfactory pathway

The receptors which perceive the olfactory stimuli are placed in the olfactory region of the nasal mucosa. They occupy the area about 1 cm² within the superior nasal meatus, superior nasal concha and upper part of the nasal septum. The receptors are represented by the branching of the peripheral processes from the bipolar cells located in the nasal mucosa. The number of the olfactory bipolar (receptor) neurons in human is 10 million. The peripheral processes of these cells are short; each carries 10–15 hair-like cilia protruding into the mucus which covers the surface of the olfactory epithelium.

Odorous substances coming with inspired air into the superior nasal meatus dissolve in the mucus. The olfactory cilia react with the molecules of the odorous substances and transform the energy of the chemical stimulus into the nerve impulses.

The central processes of the receptor cells are non-myelinated; they collect into 15–20 bundles (olfactory nerves, *nn. olfactorii*). The olfactory nerves pass through the cribriform plate of the ethmoid bone into the cranial cavity and end in the olfactory bulb by synapses with the dendrites of the mitral cells. It should be noted that up to 1000 olfactory fibres synapse with one mitral cell. Hence, the olfactory information starts to concentrate already in the olfactory bulb.

The axons of the second-order neurons (mitral cells) unite into the olfactory tract and at the olfactory trigone diverge into three bundles: medial, intermediate and lateral. The fibres of the medial bundle run through the anterior cerebral commissure into the opposite olfactory tract to end on the mitral cells in the opposite olfactory bulb. The fibres comprising the intermediate bundle synapse with the neurons of the olfactory

trigone, anterior perforated substance and nuclei of the septum pellucidum. A part of the intermediate bundle's fibres run to the noted structures on the opposite side. The fibres of the largest lateral bundle pass directly to the olfactory cortical area and end on the neurons in the archicortex, uncus and parahippocampal gyrus. Thus, in the olfactory pathway the nerve impulses at first pass not to the subcortical olfactory centres but to the cerebral cortex (uncus and parahippocampal gyrus): this is the feature of this pathway.

The axons from the third-order neurons located in the olfactory trigone and anterior perforated substance also run to the olfactory cortical area (uncus and parahippocampal gyrus) by the different ways: through the medial longitudinal stria situated on the dorsal surface of the corpus callosum; through the fornix and cingulum.

From the projection olfactory area (uncus and parahippocampal gyrus) the nerve impulses run to the mammillary bodies through the projection fibres of the fornix. Apart from the mammillary bodies, there is one more subcortical olfactory centre: the anterior thalamic nuclei. The subcortical olfactory centres are connected by the mamillothalamic fasciculus, *fasciculus mamillothalamicus* (bundle of Vicq d'Azur).

The axons from the anterior thalamic nuclei in turn form two bundles: one runs to the projection olfactory area in the neocortex, situated on the ventral surface of the frontal lobes; another, smaller part pass to the diencephalic integration centre, the medial thalamic nuclei. The noted centres are connected with the extrapyramidal system, limbic system and the reticular formation nuclei. The connections between the anterior thalamic nuclei and the brain-stem integration centres explain the change of the muscle tone, emotional reactions and reflex motor reactions occurring in response to the olfactory stimuli.

The medial nuclei of the mammillary bodies are interconnected with the midbrain integration centre, the superior colliculi, by the mamilloreticular fasciculus, *fasciculus mamilloreticularis*. The neurons of the superior colliculi give rise to the tectospinal and tectonuclear tracts. These tracts conduct the efferent nerve impulses performing the reflex motor reactions of the muscles of the trunk, limbs, head and eyeballs in response to sudden strong smells.

The diseases of the nasal mucosa, tumors of the cerebral base and frontal lobe reduce the ability to smell (hyposmia) or lead to the full loss of the ability to smell (anosmia). The allergic conditions involving the nasal mucosa often cause the increased olfactory acuity (hyperosmia). The damage to the temporal lobe in the area of the uncus and parahippocampal gyrus is accompanied by olfactory hallucinations.

4.3. Efferent Tracts

The main efferent conduction tracts are:

- 1) corticospinal tract, *tr. corticospinalis*;
- 2) corticonuclear tract, *tr. corticonuclearis*.

The main extrapyramidal tracts having an important functional and clinical value are:

- 1) tectospinal tract, *tr. tectospinalis*;
- 2) rubrospinal tract, *tr. rubrospinalis*;
- 3) vestibulospinal tract, *tr. vestibulospinalis*;
- 4) reticulospinal tract, *tr. reticulospinalis*;
- 5) olivospinal tract, *tr. olivospinalis*;
- 6) medial longitudinal fasciculus, *fasciculus longitudinalis medialis*;
- 7) dorsal longitudinal fasciculus, *fasciculus longitudinalis posterior*.

4.3.1. Pyramidal Tracts

Corticospinal Tract

The corticospinal tract, *tractus corticospinalis*, (fig. 4.8) belongs to the pyramidal tracts. It conducts conscious (voluntary) motor nerve impulses providing the control of the skeletal musculature of the trunk and limbs, and execution of precise, highly differentiated motions. Besides, the tract conveys the inhibitory impulses to the neurons comprising the motor nuclei of the spinal anterior horn, i.e. inhibits the spinal segmental apparatus.

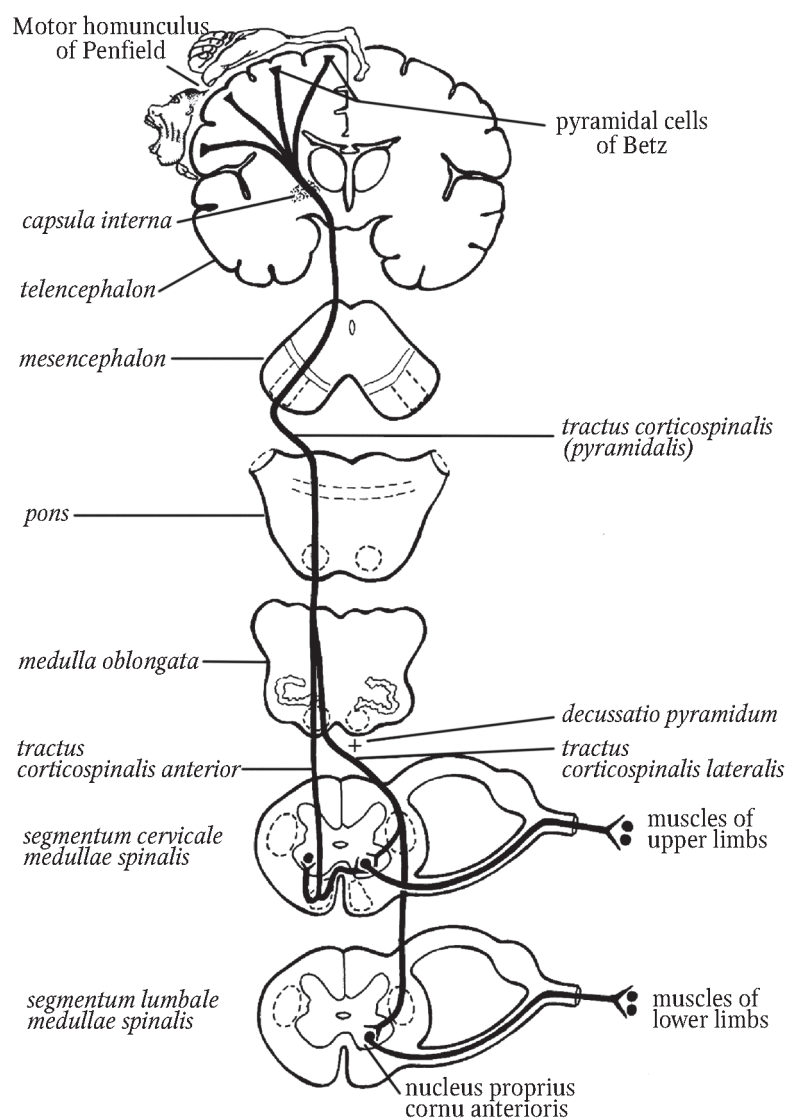


Fig. 4.8. Corticospinal tracts (anterior and lateral)

The corticospinal tract is formed by the axons arising from the pyramidal neurons which are situated mainly in the precentral gyrus and paracentral lobule ($\frac{2}{3}$). A part of the axons arise from the postcentral gyrus and superior parietal lobule ($\frac{1}{3}$). The pyramidal neurons lie in the V layer of the cerebral hemispheres; they are represented by the giant pyramidal cells of Betz and by the large pyramidal cells. The number of these cells within the precentral gyrus is about 35 000. But the counting of the fibres comprising the corticospinal tract has revealed that their number reaches 800 000–1 000 000. Hence, we may conclude that the corticospinal tract contains not only the axons of the giant and large pyramidal cells but also of the middle pyramidal cells.

In the precentral gyrus the pyramidal cells are arranged according to the motor homunculus of Penfield: the uppermost parts of the precentral gyrus contain the neurons that give rise to the efferent tracts for the innervation of the lower limb muscles; the paracentral lobule contains the somatotopic projection of the foot muscles, laterally is the projection of the femoral and crural muscles; further there are the neurons giving rise to the efferent nerve pathways to the trunk musculature; the middle third of the precentral gyrus is occupied by the neurons providing the innervation of the upper limb muscles (above – for the muscles of the upper arm, below – for the muscles of the forearm and hand). It should be noted that the square of the projection somatotopic zones in the cortex is directly proportional to the complexity of the movements performed by a certain muscle group. The somatotopic projection of the hand muscles has the largest square.

The axons arising from the pyramidal cells collect into a compact bundle called the corticospinal tract. The latter descends into the internal capsule where occupies the anterior $\frac{2}{3}$ of its posterior limb. The arrangement of this tract's fibres in the internal capsule is as follows: the fibres for the upper limb muscles pass in direct vicinity to the genu; behind them – the fibres for the trunk muscles; and then the fibres for the lower limb muscles are placed.

Then the corticospinal tract passes through the ventral part of the brain stem. In the midbrain it occupies $\frac{3}{5}$ of the transverse section of the cerebral peduncle. In the pons it diverges into many small bundles separated from each other by numerous pontine nuclei. In the medulla oblongata, the scattered bundles collect again into a single large bundle which passes through the pyramid. At the junction between the medulla and spinal cord most fibres (80 %) cross to the opposite side, forming the pyramidal decussation, *decussatio pyramidum*. 20 % of the fibres from the pyramid stay on the same side to continue into the anterior spinal funiculus. They form the anterior corticospinal tract, *tr. corticospinalis anterior*. The decussated fibres run into the lateral spinal funiculus, occupying its posteromedial part. This is the largest bundle in the lateral funiculus, called the lateral corticospinal tract, *tr. corticospinalis lateralis*.

Thus, being a single throughout the brain stem, the corticospinal tract divides in the spinal cord into two independent tracts.

The lateral corticospinal tract gradually becomes thinner in caudal direction, although it passes throughout the whole spinal cord. Most fibres separate from it in the region of the spinal cord enlargements, whose segments contain the effector neurons which are responsible for innervation of the limbs' muscles. It should be noted that the fibres in the lateral corticospinal tract are arranged as follows: in the medial portion of the tract the fibres to the cervical and thoracic segments pass; hence, the fibres in the lateral portion are longer. Reaching own segment, the fibres leave the tract to end on the neurons in the nuclei proprii of the spinal anterior horns.

The anterior corticospinal tract passes in the anterior spinal funiculus throughout only the cervical and thoracic segments. This is a small bundle, most fibres of which

cross every segment to the opposite side through the white commissure and end on the neurons in the nuclei proprii of the anterior horns. A small portion of the fibres do not cross and end on the neurons in the nuclei proprii of the same side. These fibres provide the innervation of the trunk musculature.

Thus, the corticospinal tracts contain three groups of the fibres for innervation of the trunk musculature: non-decussated fibres of the anterior corticospinal tract and decussated fibres of the anterior and lateral corticospinal tracts. Hence, the segmental apparatus of the spinal cord, which is responsible for innervation of the trunk musculature (especially of the respiratory muscles), is under triple inhibitory influence of the cerebral cortical neurons from the same and opposite sides.

The nerve fibres of both anterior and lateral corticospinal tracts on their way give numerous collaterals. In result, one nerve fibre brings the nerve impulses to several spinal segments simultaneously. It has been established that only 20 % of the corticospinal tract's fibres end directly on the large alpha cells contained in the nuclei proprii of the anterior horns. These fibres are interconnected by the motoneurons providing the innervation of the forearm and hand muscles. Direct cortical regulation is necessary for execution of complex and precise movements. About 80 % of the corticospinal tract fibres are connected with the motoneurons through the intermediate neurons situated in the spinal anterior horns. The noted fibres pass mainly in the lateral corticospinal tract.

The axons from the second-order neurons (motoneurons) situated in the motor nuclei of the anterior horns leave the spinal cord via the anterior spinal roots. Then they pass via the spinal nerves and their branches to the skeletal muscles. The damage to the pyramidal neurons leads to the central paralysis (the loss of the motor functions) or paresis (the decrease of the motor functions). The central paralysis is characterized by the increased tone of paralyzed muscles (hypertonus), the increased tendon reflexes (hyperreflexia), the loss of the skin reflexes and appearance of uncontrolled small movements (hyperkinesia). These symptoms are caused by the absence of the inhibitory influence on the spinal segmental apparatus. If the corticospinal tract is injured at the level of the cervical segments, the paralysis of the upper and lower limbs on the same side occurs. If the lesion is in the precentral gyrus or in the brain stem, the paralysis of the limbs occurs on the opposite side because the corticospinal tract's fibres make the decussation.

The damage to the peripheral motor neuron or its axon leads to peripheral paralysis, which manifests in atonia, areflexia and atrophy. In this state the movements are completely absent, the muscles eventually atrophy and are replaced with adipose and connective tissue.

Corticonuclear Tract

The corticonuclear tract, *tractus corticonuclearis*, (fig. 4.9, 4.10) belong to the descending motor pyramidal tracts. It conducts conscious (voluntary) motor impulses providing the control of the musculature of the head and partially of the neck, execution of precise and highly differentiated movements. Besides, the tract conducts inhibitory impulses from the cerebral cortex to the neurons of the cranial nerve motor nuclei (III, IV, V, VI, VII, IX, X, XI and XII), i.e. inhibits the brain-stem segmental apparatus.

The corticonuclear tract is formed by the axons arising from the pyramidal cells located in the V cortical layer. Most axons are derived from the cells of the precentral gyrus's inferolateral third (about 70 %), smaller portion – from the neurons of the postcentral gyrus' inferior third (about 20 %), the rest – from the neurons of the superior parietal lobule. The axons from the neurons of the postcentral gyrus's lower third are

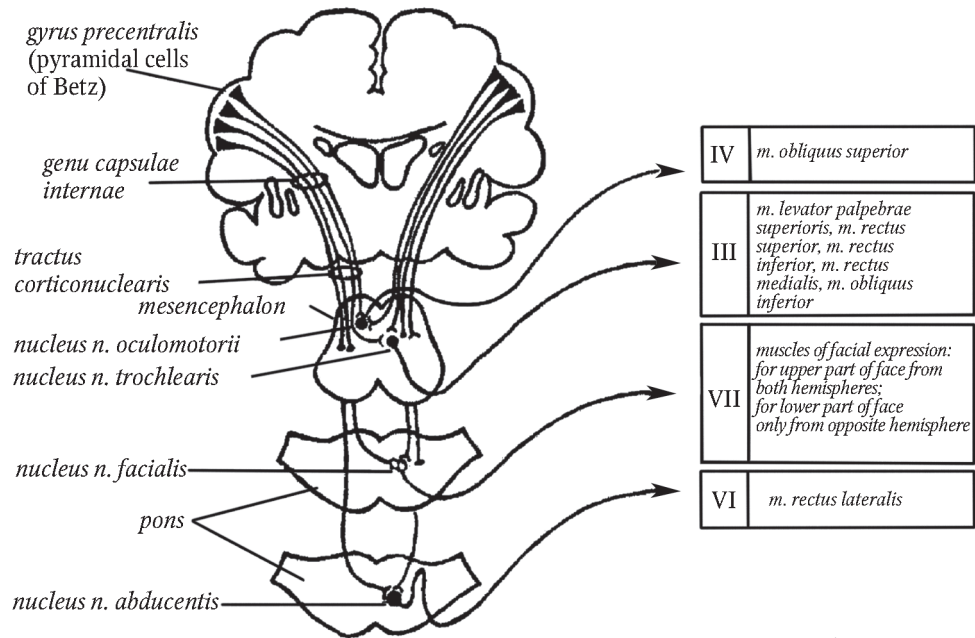


Fig. 4.9. Corticonuclear tract connecting the cerebral cortex with the nuclei of III, IV, VI and VII cranial nerves

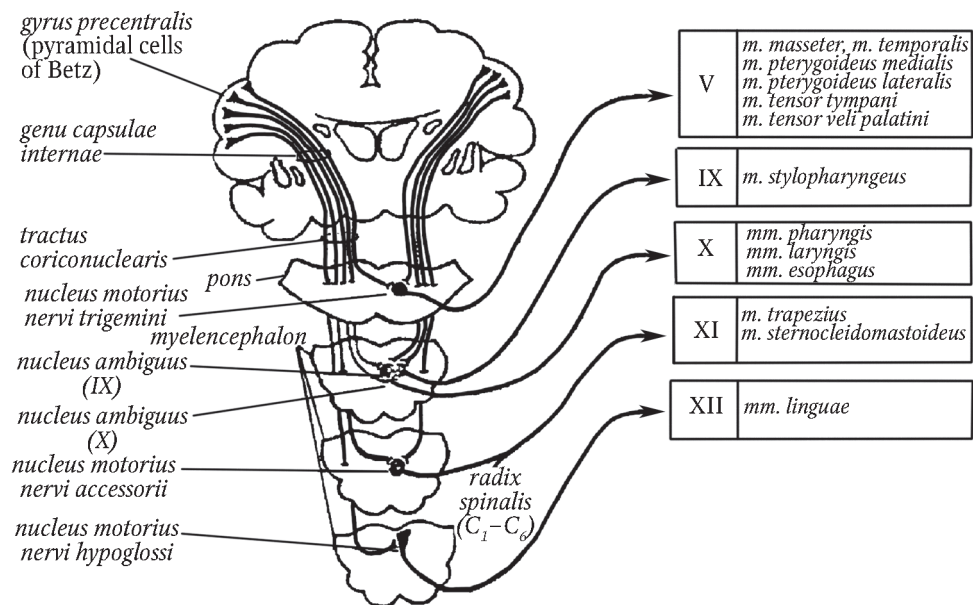


Fig. 4.10. Corticonuclear tract connecting the cerebral cortex with the nuclei of V, IX, X, XI and XII cranial nerves

involved into the corticospinal tract because the masticatory and mimic muscles, the muscles of the soft palate, pharynx and larynx project to the cortex of this gyrus.

The axons from the pyramidal cells fan into a bundle which passes through the internal capsule's genu. Further, the corticonuclear tract traverses the ventral part of the brain stem: the middle of the cerebral peduncles, base of the pons and pyramids of the medulla oblongata. In the pyramids, it occupies the medial position.

In the midbrain, from the corticonuclear tract a part of the fibres separate to end in the motor nuclei of the oculomotor (III) and trochlear (IV) cranial nerves of the same and opposite sides. The axons from the oculomotor nerve motor nucleus run to the levator palpebrae superioris, superior, medial and inferior recti muscles and inferior oblique muscle of the eyeball. The axons from the trochlear nerve motor nucleus pass to the superior oblique muscle of the eyeball.

In the pons, from the corticospinal tract one more fibre portion separates; they pass in the dorsal direction and end in the motor nuclei of the V, VI and VII cranial nerves. The fibres to the nuclei of the V and VI cranial nerves come from the same and opposite sides, while in the motor nucleus of the VII cranial nerve mainly the fibres from the opposite hemisphere end. Only part of the fibres associated with the innervation of the mimic muscles end in the facial nerve motor nuclei of both opposite and same sides. The axons from the trigeminal nerve motor nucleus innervate the lateral and medial pterygoid, temporalis and masseter, the mylohyoid, anterior belly of digastric, tensor veli palatini and tensor tympani. The axons from the motoneurons of the abducens nerve nucleus run to the lateral rectus muscle of the eyeball. The axons from the facial nerve motor nucleus innervate the mimic muscles, posterior belly of digastric, stylohyoid and platysma.

A small part of the corticospinal tract fibres reach the medulla oblongata and upper cervical spinal segments. These fibres also incline dorsally and end in the motor nuclei of the IX, X, XI and XII cranial nerves. The nuclei of the IX, X and XI nerves receive the fibres from both hemispheres, while the nucleus of the XII nerve – only from the opposite hemisphere. The axons from the motoneurons of the nucleus ambiguus, common for the IX and X cranial nerves, innervate the stylopharyngeus, the muscles of the pharynx, soft palate, larynx and upper oesophagus. The axons from the motoneurons of the accessory nerve nucleus run to the trapezius and sternocleidomastoid. At last, the axons from the motoneurons of the hypoglossal nucleus innervate the lingual muscles.

The unilateral destruction of the pyramidal neurons in the lower part of the precentral gyrus or the damage to the corticospinal tract causes not paralysis but paresis (limitation of voluntary movements and the decrease of muscle contractile force) because the motoneurons of the cranial nerve motor nuclei mostly receive the impulses from both hemispheres (with the exception of the tongue and mimic muscles). The hypoglossal nucleus's neurons receive the decussated corticospinal tract fibres therefore their damage causes the paralysis of the tongue muscles on the opposite side. The motoneurons of the facial nerve motor nucleus, associated with the innervation of the lower half of the face, receive only decussated fibres. The motoneurons associated with the innervation of the upper half of the face receive the fibres from the same and opposite sides. Therefore, complete paralysis occurs only in the lower half of the face on the side, opposite to defeat; in the upper half only paresis of the mimic muscles occurs. Only bilateral damage to the cortical areas or corticospinal tracts results in the occurrence of the central paralysis.

The destruction of all motoneurons in the cranial nerve motor nuclei or damage to their axons leads to the occurrence of peripheral paralysis which manifests in the following symptoms: the disappearance of reflexes (areflexia), the loss of the muscle tone (atonia) and muscle atrophy.

4.3.2. Extrapyramidal Tracts

Rubrospinal Tract

The red nucleus is a main coordination centre of the extrapyramidal system. It has numerous connections with the cerebral cortex, strio-pallidar system, thalamus, subthalamic region and cerebellum. The nerve impulses coming to the red nucleus's neurons from the cerebral cortex, the nuclei of the strio-pallidar system and diencephalon pass after processing through the rubrospinal tract (fig. 4.11). This tract provides the execution of complex usual movements (walking, running), provides the plasticity of these movements, contributes to the keeping of a certain pose throughout long time and also maintains the skeletal muscle tone.

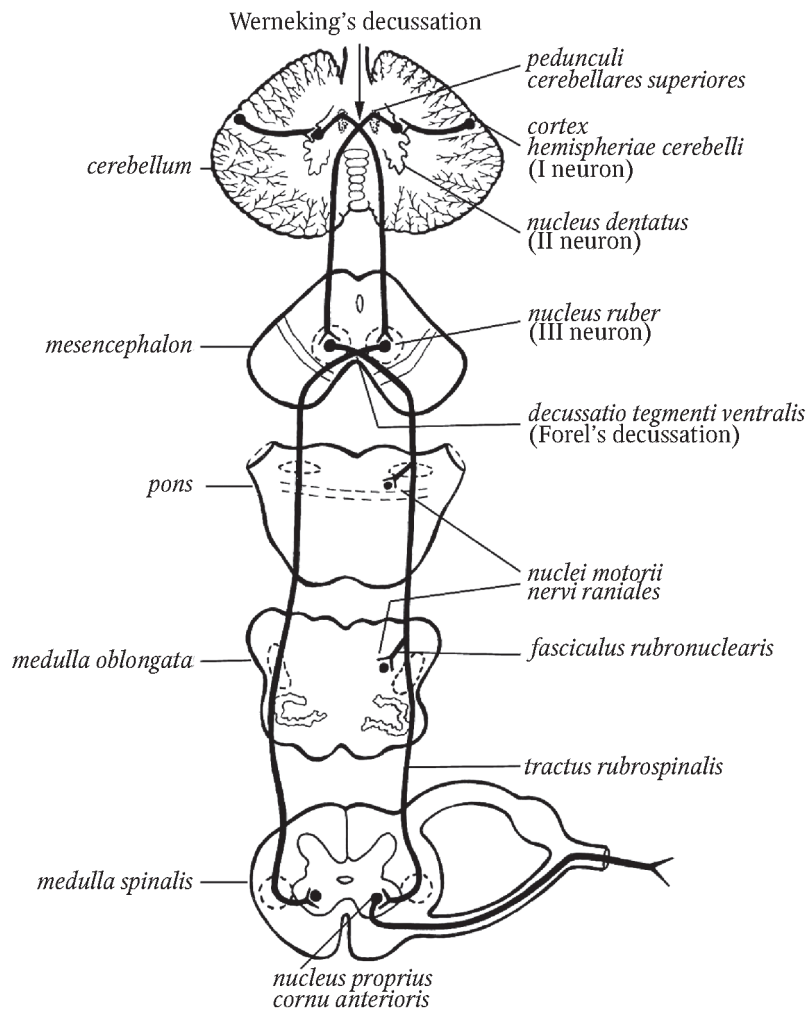


Fig. 4.11. Rubrospinal tract

The axons from the neurons of the cerebral cortex, mainly from the frontal lobe, make the corticorubral tract, *tr. corticorubralis*, which passes through the internal capsule's anterior limb. A minority of fibres end directly on small multipolar cells in the red nucleus. Most fibres move to the strio-pallidar system nuclei (basal nuclei), in particular, to the caudate nucleus and putamen. The bundle ending on the striate system neurons is called the corticostriate tract, *tr. corticostriatus*. From the striate system neurons to the red nucleus the striorubral tract, *tr. striorubralis*, runs. The neurons of the globus pallidus are also connected to it.

From the neurons of the cerebral cortex to the diencephalon the thalamocortical fasciculus, *fasciculus corticothalamicus*, passes. Of the diencephalic structures the medial thalamic nuclei (subcortical sensory extrapyramidal centre) and posterior hypothalamic nuclei are connected to the red nucleus. The axons from the diencephalic nuclei collect into the thalamorubral fasciculus, *fasciculus thalamorubralis*, which end on the neurons in the red nucleus and substantia nigra. The substantia nigra's neurons also have connections with the red nucleus.

The nerve impulses passing to the red nucleus from the cerebellum correct its activity. They provide the execution of fine purposeful movements and prevent inertia during the movements.

The cerebellum is connected to the red nucleus by means of two- neuronal cerebellorubral tract, *tr. cerebellorubralis*. The first-order neurons of this pathway are the cells of the cerebellar cortex, whose axons end in the dentate nucleus. The second-order neurons are the dentate nucleus cells, the axons of which leave the cerebellum via its superior peduncles. The cerebellorubral tract enters the midbrain, crosses same tract from the opposite side at the level of the inferior colliculi as the decussation of the superior cerebellar peduncles (decussation of Werneking) and end in the red nucleus.

Thus, the red nuclei play the role of essential relay stations which coordinate and integrate the work of the different motor centres. The red nuclei are the main motor centres of the extrapyramidal system. The neurons of each red nucleus give rise to a descending rubrospinal tract, *tr. rubrospinalis* (Monakow's bundle) and rubronuclear tract, *tr. rubronuclearis*. They are efferent extrapyramidal tracts starting from the large multipolar neurons of the red nucleus. Their axons immediately pass to the opposite side to form the ventral tegmental decussation (Forel's decussation).

The rubronuclear tract passes in the brain-stem tegmentum and ends in the cranial nerve motor nuclei. Their axons run to the skeletal muscles of the eyeball, head, pharynx, larynx and upper oesophagus, providing their efferent innervation.

The rubrospinal tract descends in the lateral spinal funiculus, anterior to the lateral corticospinal tract. Gradually it becomes thinner because its axons end every segment on the motoneurons in the nuclei proprii of the anterior spinal horns on the same side. The axons from the motoneurons leave the spinal cord via the anterior spinal root and then through the spinal nerves reach the skeletal muscles.

Tectospinal Tract

The tectospinal tract, *tractus tectospinalis*, is a descending motor pathway which refers to the extrapyramidal system (fig. 4.12). It performs the reflex reactions in response to sudden strong visual, auditory, tactile and olfactory stimuli. The first-order neurons of the tectospinal tract are placed in the midbrain superior colliculi. The information to this subcortical integration centre passes from the subcortical visual centre (the nucleus of the superior colliculus), from the subcortical auditory centre (the nucleus of the inferior colliculus), from the subcortical olfactory centre (the nucleus of the mammillary body)

and from the collaterals from the conduction pathways of general sensation (*lemniscus spinalis*, *lemniscus medialis*, *lemniscus trigeminalis*).

The axons from the first-order neurons run ventrally and up, bypass the central grey substance of the midbrain and move to the opposite side. The decussation of the tectospinal tract fibres from opposite sides is called the dorsal tegmental decussation, *decussatio tegmenti dorsalis* (Meynert decussation). It is also called the fountain decussation that reflects the course of its nerve fibres. Further the tract travels through the dorsal pons near the medial longitudinal fasciculus. In the brain stem the tract gives off the fibres which end in the cranial nerve motor nuclei. These fibres are described as the tectonuclear tract, *fasciculus tectonuclearis*. They provide protective reactions with participation of the head and neck muscles.

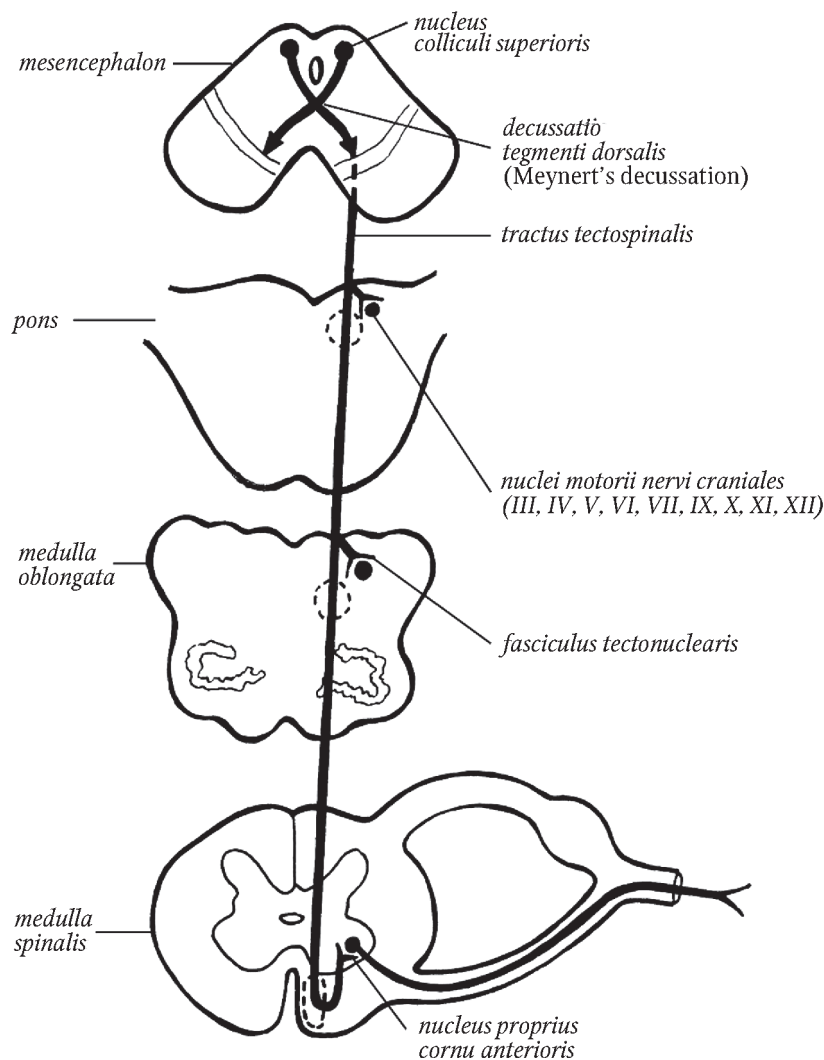


Fig. 4.12. Tectospinal tract

In the medulla, the tectospinal tract approaches to the dorsal surface of the pyramids and run into the anterior spinal funiculus. In the spinal cord it occupies the most medial part of the anterior funiculus, bounding the anterior median fissure.

The tectospinal tract passes throughout the whole spinal cord. Gradually it becomes thinner, giving every segments the branches to alpha-motoneurons in the anterior horn's nuclei proprii on the same side. The axons from the motoneurons convey the nerve impulses to the musculature of the trunk and limbs.

The damage to the tectospinal tract results in loss of the reflexes to sudden visual, auditory, olfactory and tactile stimulations.

Reticulospinal Tract

The reticulospinal tract, *tractus reticulospinalis*, (fig. 3.17, 3.18) is a descending efferent extrapyramidal pathway which provides the execution of complex reflex acts (breathing, grasping movements) requiring the simultaneous contraction of many muscle groups. Hence, it coordinates these movements. The reticulospinal tract conducts the impulses which activate or inhibit motoneurons situated in the nuclei proprii of the spinal anterior horns. Besides, the tract transfers the impulses to gamma-motoneurons which provide the skeletal muscle tone.

The first-order neurons of the reticulospinal tract are placed in the brain-stem reticular formation. Their axons descend to form a bundle situated in the anterior funiculus. This bundle is well-defined only in the cervical and upper thoracic spinal segments. Every segment it becomes thinner, giving off the fibres to gamma-motoneurons in the nuclei proprii of the spinal anterior horns. The axons from these neurons run to the skeletal muscles.

Vestibulospinal Tract

The vestibulospinal tract, *tractus vestibulospinalis*, is a descending motor extrapyramidal tract. It provides the reflex motor acts which correct the body balance when it is taken out of its normal upright position. The vestibulospinal tract is formed by the axons from the lateral and inferior vestibular nuclei (Deiters and Roller's nuclei). In the medulla, it is placed in the dorsal part. In the spinal cord, it passes between the lateral and anterior funiculi therefore it is pierced by anterior spinal root fibres oriented horizontally. The vestibulospinal tract fibres end every segment on alpha-motoneurons in the nuclei proprii of the spinal anterior horns. The axons from the motoneurons leave the spinal cord via the anterior spinal roots to reach the skeletal muscles.

Olivospinal Tract

The olivospinal tract, *tractus olivospinalis*, is a descending motor extrapyramidal tract (fig. 3.19). It provides the reflex support of the cervical muscles and motor acts which contribute to the keeping of the body balance.

The olivospinal tract arises from the neurons of the inferior olivary nucleus located in the medulla oblongata. Being phylogenetically new, the inferior olivary nucleus is directly connected with the frontal cortex (cortico-olivary tract, *tr. corticoolivaris*), red nucleus (rubro-olivary tract, *tr. rubroolivaris*) and cerebellar cortex (cerebello-olivary tract, *tr. olivocerebellaris*). The axons from the inferior olivary nucleus's cells collect into a bundle, the olivospinal tract, passing in the anteromedial part of the spinal lateral funiculus. It is present only in the upper six cervical segments.

The olivospinal tract fibres end on alpha-motoneurons in the nuclei proprii of the spinal anterior horns. The axons from the motoneurons leave the spinal cord via the anterior spinal roots to reach the cervical muscles.

Medial Longitudinal Fasciculus

The medial longitudinal fasciculus *fasciculus longitudinalis medialis*, (MLF) (fig. 3.23) is a collection of descending and ascending fibres which coordinate the movements of eye-balls and head. This is important for the support of the body balance and is possible due to morphofunctional interconnections between the nerve centres providing innervation of the extraocular muscles (motor nuclei of the III, IV and VI cranial nerves), the centres providing innervation of the cervical muscles (motor nuclei of the XI cranial nerve and the nuclei proprii of the spinal anterior horns) and the vestibular centre (nucleus of Deiters). The work of these centres is coordinated by the large reticular formation nuclei: the interstitial nucleus (of Cajal) and posterior commissural nucleus (of Darkshevich).

The noted nuclei lie rostrally in the midbrain, in the central grey substance. The axons from their nuclei neurons form the medial longitudinal fasciculus which passes under the grey central substance close to the midline. It does not change the position, when passes through the dorsal pons but inclines ventrally in the medulla. Then it travels in the anterior spinal funiculus, between the anterior horn and white commissure; it is present only in the upper six cervical segments.

Within the midbrain, the fibres from the dorsal longitudinal fasciculus (which unites the vegetative centres) join the medial longitudinal fasciculus. The connection between these two fasciculi explains the occurrence of vegetative reactions during vestibular loads. The fibres from the medial longitudinal fasciculus run to the oculomotor nucleus. This nucleus consists of five segments, each of them is responsible for innervation of a certain eye muscle: the neurons of the upper segment (I) innervate the levator palpebrae superioris; II segment — superior rectus; III segment — inferior oblique; IV segment — inferior rectus; V segment — medial rectus. The neurons of the I, II and IV segments receive the fibres from ipsilateral medial longitudinal fasciculus; the neurons of the III segment - from the contralateral. The neurons of the V segment also synapse with the neurons of the central nucleus (convergence nucleus of Perlia) and are connected to the ipsilateral MLF. They allow us to move the eyes medially and provide eye convergence (simultaneous movement of both eyes in opposite directions).

Further, within the midbrain, the fibres from MLF run to the neurons of the opposite trochlear nucleus. This nucleus is responsible for the innervation of the superior oblique eye muscle.

In the pons, the axons from Deiters' nucleus (VIII cranial nerve) join the MLF; they ascend to the interstitial nucleus cells. The MLF gives the fibres to the abducens nucleus (VI cranial nerve), responsible for innervation of the lateral rectus eye muscle. Lastly, in the medulla and spinal cord, the fibres from the MLF travel to the accessory nerve nucleus (XI cranial nerve) and motor nuclei of the anterior spinal cord in upper six cervical segments, which are responsible for innervation of the cervical muscles.

Apart from general coordination of the eye and head movements, the MLF integrate the activity of the ocular muscles. It connects the neurons of the oculomotor and trochlear nuclei hence controls the contraction of the lateral and medial recti, providing their coordinated turn to the side. During this movement the lateral rectus muscle of one eye and medial rectus muscle of the other eye contract together.

The damage to the interstitial nucleus or MLF disturbs the coordinated work of the ocular muscles. More often this manifests as nystagmus (rapid contractions of extraocular muscles; with a fixed sight, the movements directed to the side occur). Nystagmus may be horizontal, vertical and rotatory. Nystagmus is often accompanied by vestibular disorders (dizziness) and vegetative disorders (nausea, vomiting etc.).

Dorsal Longitudinal Fasciculus

The dorsal longitudinal fasciculus, *fasciculus longitudinalis posterior*, (DLF) is a collection of ascending and descending fibres interconnecting the brain-stem and spinal vegetative centres. The dorsal longitudinal fasciculus (of Schutz) arises from the cells of the posterior hypothalamic nuclei. The axons collect into a bundle passing between the diencephalon and mesencephalon. Further it runs in immediate vicinity to the cerebral aqueduct. In the midbrain, DLF gives off the fibres to the oculomotor nerve's accessory nucleus. In the pons, DLF gives off the fibres to the lacrimal and superior salivatory nucleus of the facial nerve. In the medulla, its fibres run to the glossopharyngeal nerve's inferior salivatory nucleus and dorsal vagal nucleus. In the spinal cord, the DLF is placed as a narrow band in the lateral funiculus near the lateral corticospinal tract. Its fibres end every segment on the neurons in the intermediolateral nuclei (vegetative sympathetic spinal centres). A minority of the DLF fibres separate in the lumbar segments and lie near the central canal. This bundle is called the paraependimal fasciculus, *fasciculus paraependimalis*. Its fibres end on the neurons in the sacral parasympathetic nuclei. The axons from the parasympathetic and sympathetic nuclei leave the brain stem or spinal cord via the cranial or spinal nerves to reach the internal organs, vessels and glands. Thus, the DLF plays a very important integration role in the regulation of vital body functions.

4.4. Association tracts

The association conduction tracts interconnect the cerebral integration nerve centres. The main association tracts are:

- 1) corticocerebellar tract, *tr. corticocerebellaris*;
- 2) cerebellotegmental tract, *tr. cerebellotegmentalis*;
- 3) cerebellothalamic tract, *tr. cerebellothalamicus*;
- 4) corticothalamic tract, *tr. corticothalamicus*.

Of the association tracts, the corticocerebellar is the most important functionally and clinically. The corticothalamic, cerebellothalamic and cerebellotegmental tracts are represented by scattered subtle fibres. Thus, these tracts functionally do not play primary role.

Corticocerebellar Tract

The corticocerebellar tract, *tractus corticocerebellaris* (fig. 4.13), is a descending association two-neuronal pathway. It controls the activity of the cerebellum, contributes to execution of purposeful movements which are performed with the pyramidal tracts.

E. K. Sepp has revealed the role of the corticocerebellar tract and noted that each voluntary (pyramidal) impulse is accompanied by the corticocerebellar impulse which corrects the main. The correction means that the cerebellar impulse causes the excitation of muscles-antagonists hence liquidate inertial motion caused by the muscle contraction due to the pyramidal impulse.

The first-order neurons of the corticocerebellar tract lie in the V cortical layer. Their axons move into the pons and here collect into the corticopontine tract, *tractus corticopontinus*, which synapse with the neurons in the pontine nuclei on the same side. In the overlying parts of the brain stem it is formed by several bundles which start from different places. There are two main tracts: fronto-pontine and occipito-temporo-pontine. The fronto-pontine tract, *tractus frontopontinus*, arises from the neurons of the frontal cortex. It partially forms the corona radiata, then collect into a bundle which passes

through the internal capsule's anterior limb. In the midbrain it is placed in the medial part of the cerebral peduncle's base. In the pons it ends in the pontine nuclei.

The occipito-temporo-pontine tract, *tractus occipitotemporopontinus*, is formed by the axons from the occipital, temporal and parietal cortical neurons. As a compact bundle it passes through the middle of the internal capsule's posterior limb; then through the lateral part of the cerebral peduncle's base and in the pons it joins the fronto-pontine tract to end in the pontine nuclei.

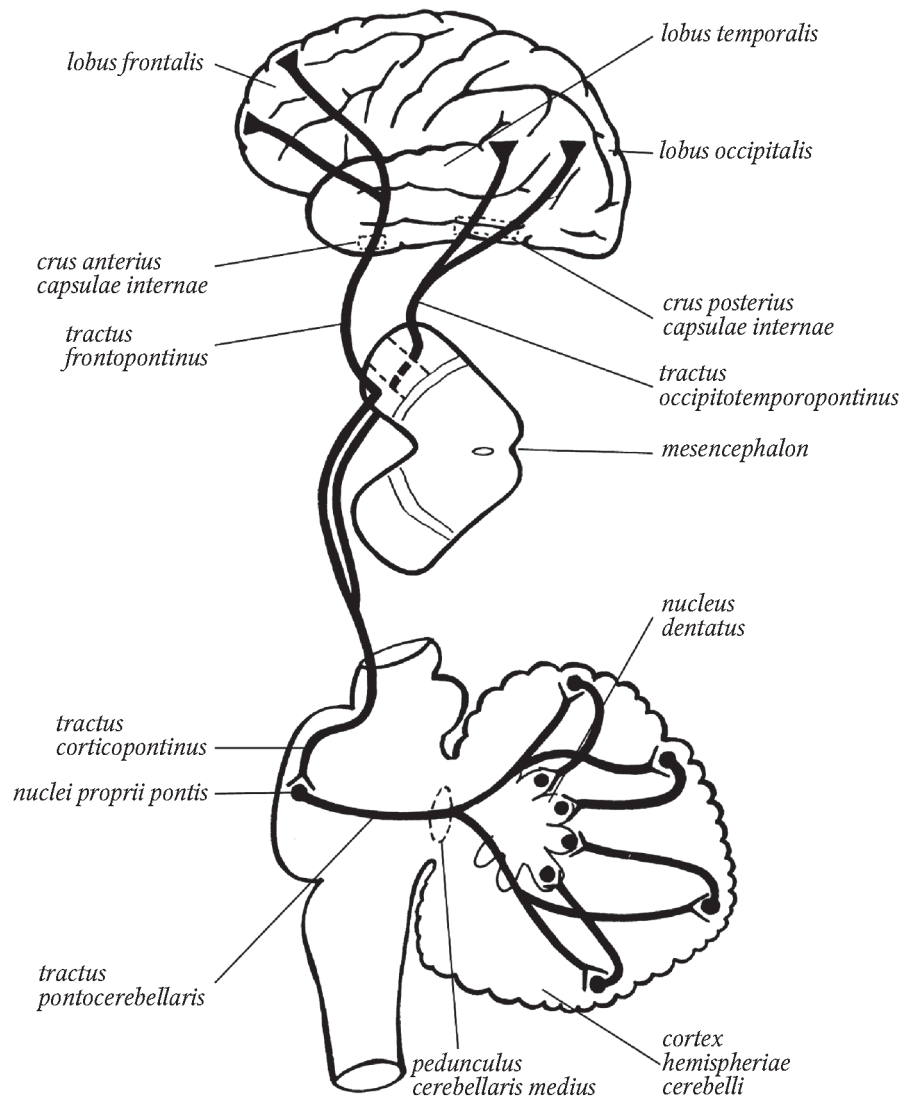


Fig. 4.13. Corticocerebellar tract

The second-order neurons of the corticocerebellar tract are the pontine neurons. Their axons run horizontally through the pons to its opposite side as numerous small bundles. Then they unite into a single very large bundle which constitutes the middle cerebellar peduncle. This bundle is called the pontocerebellar tract, *tractus pontocerebellaris*. Its fibres end on the cerebellar cortical neurons. Thus, the cortex of each hemisphere is connected to the cerebellar cortex by the corticocerebellar tract from the opposite side. The cerebellar cortex as well as the cerebral cortex has a certain somatotopic projection. The hand and especially fingers occupies the most extensive zone in this projection because they perform highly differentiated complex movements.

Further the nerve impulses from the cerebellar cortex pass through the cerebello-dentate and dentato-rubral tract. The latter ends in the red nucleus. The rubrospinal tract was described above. We should only accentuate that the efferent cerebellar tracts make two decussations: Werneking and Forel's decussations. Due to the double decussation the descending fibres originating from the cerebellum reach the muscles on the same side. Thus, the impulses from the right cerebellar hemisphere pass to the motoneurons of the anterior spinal horns on the right side and further to the muscles of the right body half.

The damage to the corticocerebellar tract or cerebellum manifests in cerebellar disorder symptoms. The movements of such patients become inadequate to their purpose. They are excessive, awkward and asynchronous. Besides, gait disorders are observed. A patient walks unsteadily, staggers, his legs are wide apart. The coordination of movements is disturbed on the side of lesion. Speech becomes scanning.

TEST QUESTIONS

1. Give the definition of the conduction tracts.
2. Describe the functions of the afferent, efferent and association conduction tracts.
3. Name the afferent tracts of general sensation.
4. Name the tracts of special sensation.
5. Why the tracts are usually decussated?
6. What are the structural differences between the tracts of the exteroceptive sensation from the skin of the body and from the skin of the face?
7. What are the functional differences between the tracts of the deep sensation to the brain and to the cerebellum?
8. How many neurons may be included into an ascending conduction tract?
9. Where are the sensory (first-order) neurons of the ascending conduction tracts located?
10. Where may the second-order neurons of an ascending conduction tract be located?
11. Where are the third neurons of the ascending conduction tracts located?
12. Where do the ascending conduction tracts start and where do they end?
13. The ends of which ascending conduction tracts are on the opposite side?
14. Describe each ascending conduction tract of general sensation (function; beginning; location of the neurons; level of decussation; position in the spinal cord, brain stem, diencephalon and telencephalon; end; symptoms of lesion).
15. Describe the vestibular pathway: function; location of its receptors; location of the first order neurons; formation of the vestibular root; location of the second-order neurons; describe the connections of the vestibular nuclei; describe the vestibulo-thalamic tract; location of the third-order neurons; end (cortical area); symptoms of lesion.
16. Describe the auditory pathway: function; location of its receptors; location of the first-order neurons; formation of the cochlear root; location of the second-order neurons; location of the third-order neurons; describe the formation of the lateral lemniscus; location of the fourth-order neurons (subcortical auditory centres, and their connections); end (cortical area); symptoms of lesion.
17. Describe the visual pathway: function; location of its receptors; location of the first order neurons; location of the second order neurons; formation of the optic nerve; formation of the optic chiasm; location of the third-order neurons (subcortical visual centres, and their connections); end (cortical area); symptoms of lesion.
18. Describe the gustatory pathway: function; location of its receptors; location of the first-order neurons; through which cranial nerves do the taste impulses pass; location of the second-order neurons; location of the third-order neurons, and their connections; end (cortical area); symptoms of lesion.
19. Describe the olfactory pathway: function; location of its receptors; location of the first-order neurons; formation of olfactory nerves; location of the second-order neurons; the ways of the second-order neuron axons; location of the third-order neurons; the ways of the third-order neuron axons; cortical olfactory area; subcortical olfactory centres, and their connections; symptoms of lesion.
20. Describe the structural and functional differences between the pyramidal and extrapyramidal tracts?
21. Name the pyramidal and extrapyramidal tracts.
22. How many neurons are included into a descending conduction tract?
23. Where may the sensory (first-order) neurons of the descending conducting tracts be located?

24. Where may the second-order neurons of the descending conducting tracts be located?
25. Which descending tracts are decussated?
26. Describe each descending conduction tract (function; beginning; location of the neurons; level of decussation; position in the telencephalon, diencephalon, brain stem and spinal cord; end; symptoms of lesion).
27. Name the association conduction tracts and describe the corticocerebellar tract.

CLINICOANATOMICAL PROBLEMS

1. A patient has paralysis of the right body half. Which tracts are damaged in the spinal cord?
2. A doctor is examining a patient with disorder of conscious proprioceptive sensation from the lower body half and lower limbs. Where is the lesion?
3. A patient has hemorrhage in the midbrain tegmentum, on the right. The red nucleus is damaged. Explain, in what body side the symptoms of the rubrospinal tract damage will be observed.
4. A patient lost sensation in the left body half. Which gyrus, in which hemisphere, is damaged?
5. A patient has left-sided paralysis of the body half because of pyramidal tract injury, and central damage to XI and XII cranial nerves. Where is the lesion located?

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CENTRAL NERVOUS SYSTEM
ЦЕНТРАЛЬНАЯ НЕРВНАЯ СИСТЕМА

The manual for medical students

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