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АНАТОМИЯ ЧЕЛОВЕКА

УЧЕБНИК НА АНГЛИЙСКОМ ЯЗЫКЕ

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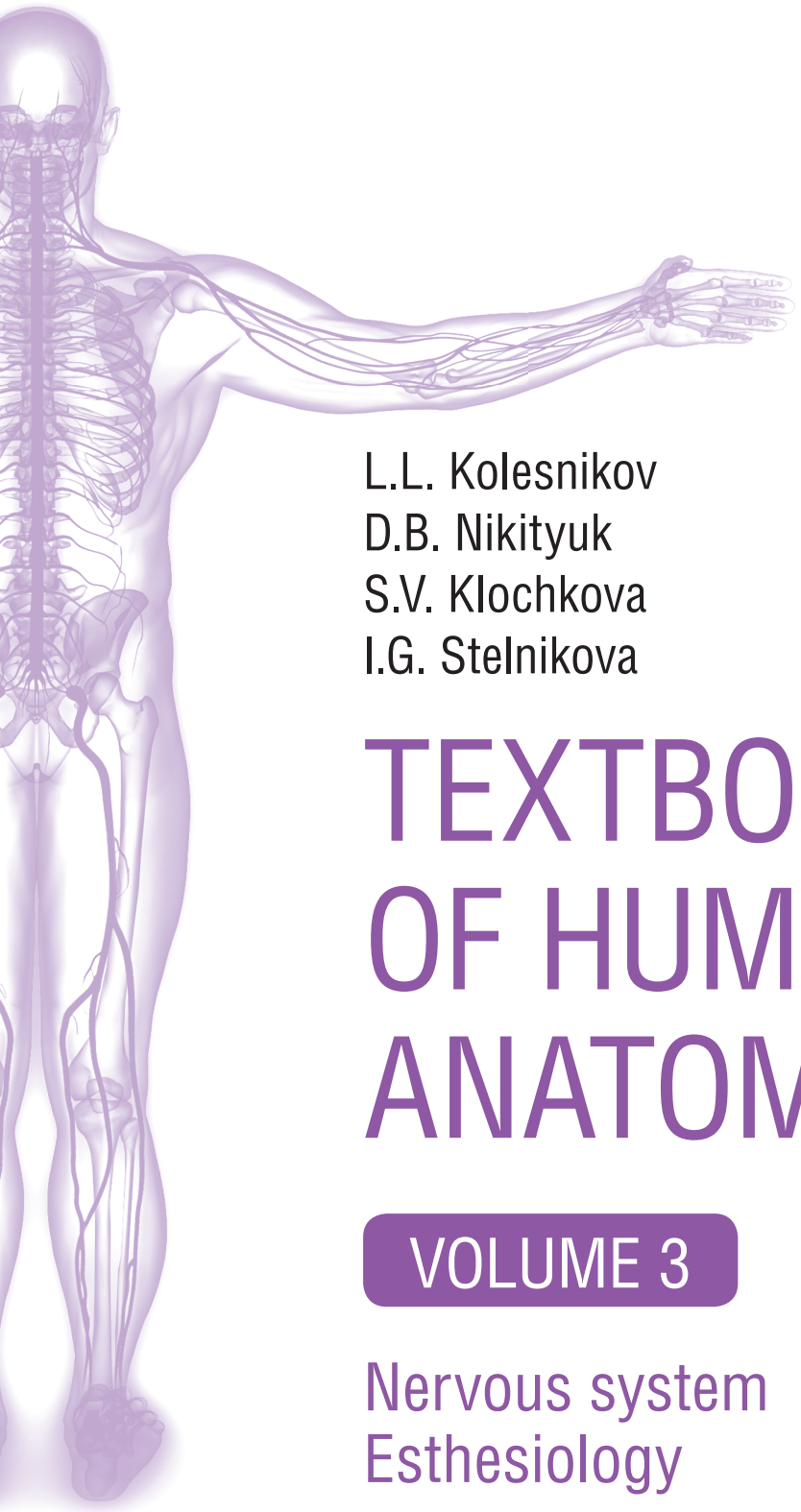

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PATHWAYS OF THE BRAIN AND SPINAL CORD

The brain and spinal cord have association pathways, commissural pathways and projection pathways. Projection pathways are afferent (sensitive) and efferent (motor). There are conscious sensitivity pathways projected to integration centres of the cortex of the hemispheres, and unconscious sensitivity pathways extending to subcortical integration centres in the cerebellum, mesencephalon, and thalamus. Sensitivity includes general sensitivity and special sensitivity (visual, vestibular, auditory, smell, gustatory). General sensitivity is divided into superficial reception, deep reception and intero(re)ception (viscerosensation). Superficial reception is exteroceptive sensibility that includes sensations of pain, temperature, and touch. Deep reception is proprioceptive [posture] sensibility. Motor activity consists of voluntary movements, involuntary movements, muscular tone and secretion which are realized through the unconscious and conscious efferent pathways. Commissural and association pathways connect integrative centres.

In essence, ascending sensory projections related to the general senses consist of a sequence of three neurons that extends from a peripheral receptor to contralateral cerebral cortex. These are often referred to as primary, secondary and tertiary neurons or first-, second-, and third-order neurons. Primary afferents have peripherally situated sensory endings and cell bodies that lie in dorsal root ganglia or sensory ganglia associated with the cranial nerves. Their axons enter the CNS through spinal or trigeminal nerves and terminate by synapsing on the cell bodies of ipsilateral second-order neurons: the precise location of this termination depends upon the modality.

Afferent pathways

1. **Conscious pathways for proprioceptive sensation (*tractus gangliobulbothalamocorticalis*).** The receptor field is lodged in each muscle, bone, and joint.

The bodies of the **first-order neurons** are in spinal ganglia (Fig. 50). Dendrites connect with the receptors and compose branches of the spinal

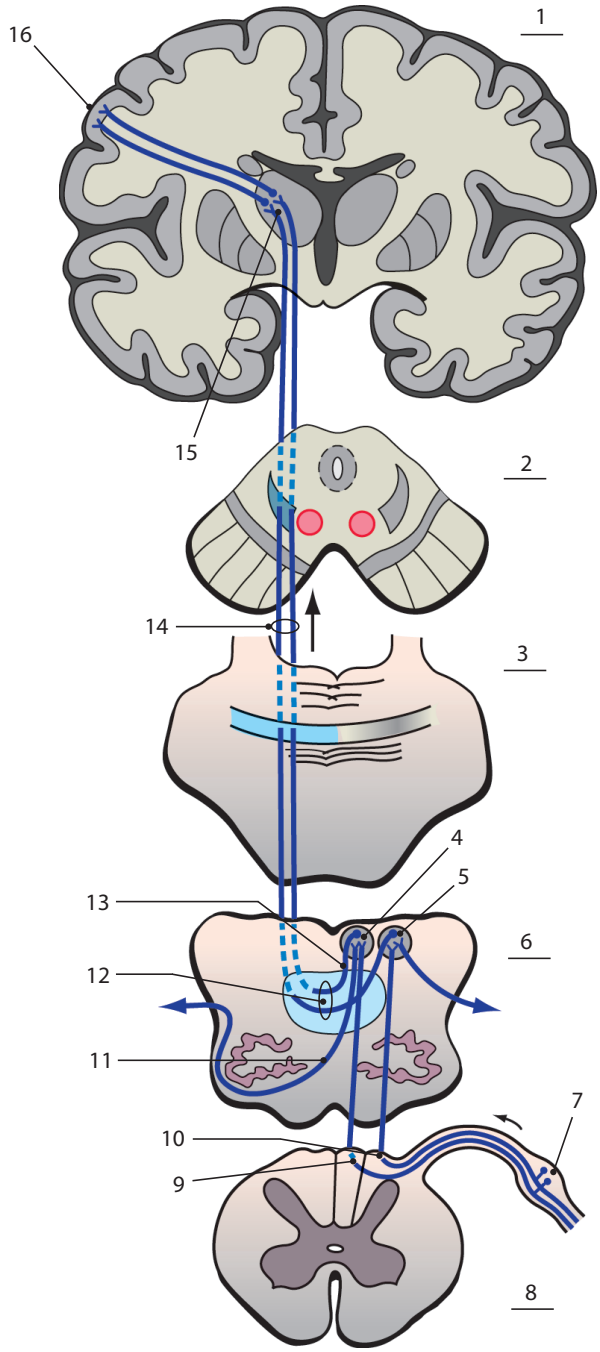

Fig. 50. Conscious pathways for proprioceptive sensation: 1 — telencephalon; 2 — mesencephalon (midbrain); 3 — pons; 4 — gracile nucleus; 5 — cuneate nucleus; 6 — medulla oblongata; 7 — spinal ganglion; 8 — spinal cord; 9 — gracile fasciculus; 10 — cuneate fasciculus; 11 — external arcuate fibres; 12 — decussation of medial lemniscus; 13 — internal arcuate fibres; 14 — medial lemniscus; 15 — thalamus; 16 — postcentral gyrus

nerves. Axons from the lower limbs and lower part of the body form the gracile Goll's fasciculus (Co, S, L, T5–12 spinal segments), axons from the upper limbs and upper part of the body organize the cuneate Burdach's fasciculus (C, T1–4 spinal segments), both fasciculi are named the gangliobulbar tract.

Axons synapse on the **second-order neurons** that are gracile and cuneate nuclei of the medulla oblongata. Axons of the second-order neurons are termed internal arcuate fibres, they cross and form the medial lemniscus and decussation of the medial lemniscus. This part is named the bulbothalamic tract.

Axons connect with the bodies of the **third-order neurons** in the thalamus (*nucll. ventrolaterales thalami*). Axons of the third-order neurons are termed thalamocortical (thalamoparietal) fibres. This tract goes via the posterior limb of the internal capsule and synapses on the fourth-order neurons in the fourth layer of the precentral gyrus, postcentral gyrus, and superior parietal lobule.

Conscious afferent pathways for proprioceptive sensation from the face start from the receptor field located in the muscles of the head, bones of the skull, and temporomandibular joint. The bodies of the **first-order neurons** are in the trigeminal ganglion of the trigeminal nerve [V]. The **second-order neurons** are the mesencephalic nucleus of the trigeminal nerve. Axons of the second-order neurons cross the brainstem and go to the thalamus (trigeminal lemniscus). The third-order neurons are the ventrolateral nuclei of the thalamus. Axons of the third-order neurons are named thalamoparietal fibres. This tract goes via the posterior limb of the internal capsule and synapses on the fourth-order neurons in the fourth layer of the precentral gyrus, postcentral gyrus, superior parietal lobule.

2. **Unconscious proprioceptive [posture] pathways** are the **posterior spinocerebellar Flechsig's tract** and **anterior spinocerebellar Gowers' tract.** The receptor fields lie in each separate muscle (posterior) or in the group of muscles (anterior).

The bodies of the **first-order neurons** are in spinal ganglia (Figs. 51, 52). Dendrites connect with the receptors and form branches of spinal nerves.

Axons synapse on the **second-order neurons** which are posterior thoracic Clarke's nuclei for the posterior tract and intermediomedial nuclei for the anterior tract. Axons of the second-order neurons compose the posterior spinocerebellar tract situated in the lateral funiculus of the same side and in the inferior cerebellar peduncle. Axons of the second-order neurons organize the anterior spinocerebellar tract lodged in the lateral funiculus of the opposite side (90% of fibres) and the same side (10% of fibres); then it ascends in the medulla oblongata and pons, crosses and forms the superior medullary velum. After that it passes through the superior cerebellar peduncle. Axons connect with the bodies of the third-order neurons in the inferior cortex (posterior) or the superior cortex (anterior) of the cerebellar vermis.

3. **Conscious pathways for exteroceptive sensation (pain, temperature) in the body, extremities and neck (*tr. gangliospinothalamocorticalis*).** The receptor field lies in the skin.

Bodies of the **first-order neurons** are in the spinal ganglia (Fig. 47). Dendrites connect with the receptors and compose branches of spinal nerves.

Axons synapse on the **second-order neurons** in the spinal cord (*nucl. proprius cornu posterioris*). Axons of the second-order neurons cross the spinal cord to the opposite side via the commissura alba, then organize the lateral spinothalamic tract. It is named the spinal lemniscus in the brainstem.

Axons connect with the bodies of the **third-order neurons** in the thalamus (*nucll. ventrolaterales thalami*). Axons of the third-order neurons are termed thalamocortical fibres. These fibres go via the posterior limb of the internal capsule and synapse on the fourth-order neurons in the fourth layer of the postcentral gyrus, superior parietal lobule.

4. **Conscious pathways for exteroceptive sensation (touch) in the body, extremities and neck (*tr. gangliobulbothalamocorticalis* and *tr. gangliospinothalamocorticalis*).** The receptor field lies in the skin.

Bodies of the **first-order neurons** are in the spinal ganglia (Fig. 53, *see* Fig. 50). Dendrites connect with the receptors and form branches of spinal nerves. For deep sensitivity axons from the lower

Fig. 51. Unconscious proprioception [posture] pathways (posterior spinocerebellar Flechsig's tract): 1 — cerebellar cortex; 2 — inferior cerebellar peduncle; 3 — spinal ganglion; 4 — posterior spinocerebellar tract; 5 — spinal cord; 6 — posterior thoracic nucleus; 7 — medulla oblongata; 8 — vermis of cerebellum [I–X]; 9 — globose nucleus

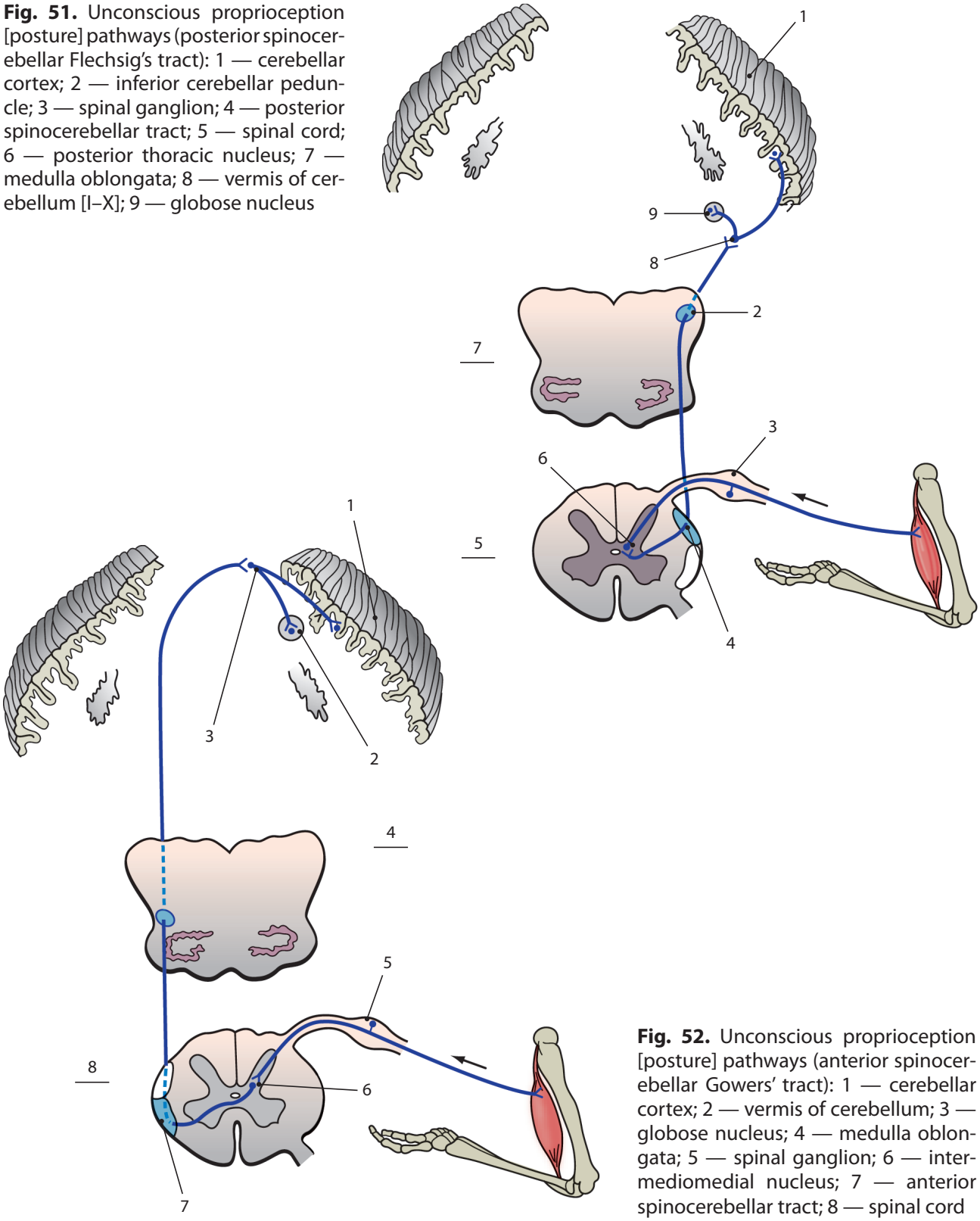

Fig. 52. Unconscious proprioception [posture] pathways (anterior spinocerebellar Gowers' tract): 1 — cerebellar cortex; 2 — vermis of cerebellum; 3 — globose nucleus; 4 — medulla oblongata; 5 — spinal ganglion; 6 — intermediomedial nucleus; 7 — anterior spinocerebellar tract; 8 — spinal cord

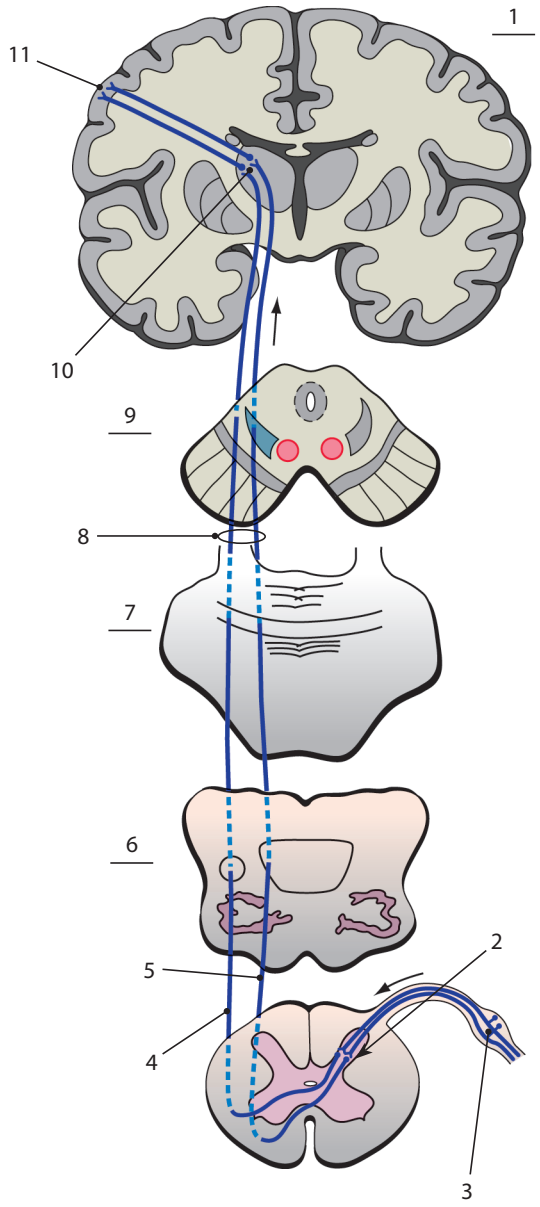

Fig. 53. Conscious pathways for exteroceptive sensation (pain, temperature, touch) from the body, extremities and neck: 1 — telencephalon; 2 — nucleus proprius, substantia gelatinosa; 3 — spinal ganglion; 4 — lateral spinothalamic tract; 5 — anterior spinothalamic tract; 6 — medulla oblongata; 7 — pons; 8 — spinal lemniscus; 9 — mesencephalon (midbrain); 10 — thalamus; 11 — postcentral gyrus

limbs and lower part of the body compose the gracile Goll's fasciculus (Co, S, L, T5–12 spinal segments), axons from the upper limbs and upper part of the body organize the cuneate Burdach's fasciculus (C, T1–4 spinal segments). Axons synapse on the **second-order neurons** in the medulla oblongata (*nucll. gracilis et cuneatus*).

For superficial sensitivity axons connect with the **second-order neurons** in the spinal cord (*substantia gelatinosa cornu posterioris*). Axons of the second-order neurons cross (upper 2–3 segments, from lower segments to the lateral side) via the commissura alba, then form the anterior spinothalamic tract. It is named the spinal lemniscus in the brainstem.

All axons connect with the bodies of the **third-order neurons** in the thalamus (*nucll. ventrolaterales thalami*). Axons of the third-order neurons are termed the thalamocortical (thalamoparietal) fibres. This tract goes via the posterior limb of the internal capsule and synapses on the fourth-order neurons in the fourth layer of the postcentral gyrus, superior parietal lobule.

5. **Conscious afferent pathways for exteroceptive sensation in the face.** The receptor field is located in the skin of the face, mucosa of the oral cavity and nasal cavity, conjunctiva, larynx, pharynx, external ear, cranial dura mater (pain, temperature, touch). The three nerves for these sensations are the trigeminal, glossopharyngeal and vagus nerve.

Bodies of the **first-order neurons** are in the trigeminal ganglion of the trigeminal nerve [V], in the superior and inferior ganglia of the glossopharyngeal nerve [IX], in the superior and inferior ganglia of the vagus nerve [X].

Bodies of the **second-order neurons** are nuclei of the solitary tract for the glossopharyngeal nerve and vagus nerve. Axons of the second-order neurons cross the brainstem and go to the thalamus (nucleothalamic fibres). Bodies of the **second-order neurons** are the principal sensory nucleus of the trigeminal nerve (for tactile information) and spinal nucleus of the trigeminal nerve (for pain and temperature). Axons of the second-order neurons cross the brainstem and go to the thalamus (trigeminal lemniscus).

The **third-order neurons** are the ventrolateral nuclei of the thalamus. Axons of the third-order neurons are named the thalamocortical (thalamoparietal) fibres. This tract goes via the posterior limb of the internal capsule and synapses on the fourth-order neurons in the fourth layer of the postcentral gyrus, superior parietal lobule.

6. **Visceral ascending (afferent) pathways** from the viscera and blood vessels include three neurons. Afferent impulses probably mediate visceral sensations such as hunger, nausea, sexual excitement, vesical distension, etc. Visceral pain fibres follow these routes. Although viscera are insensitive to cutting, crushing or burning, excessive tension in smooth muscle and in certain pathological conditions produce visceral pain. In visceral disease, vague pain may be felt near the viscus itself (visceral pain) or in the cutaneous area or other tissue whose somatic afferents enter spinal segments receiving afferents from the viscus; the phenomenon is known as referred pain.

Bodies of the **first-order neurons** are in the spinal ganglia and ganglia of cranial nerves. Visceral afferent fibres are the peripheral processes (dendrites) of pseudounipolar cell bodies located in ganglia. They are contained in the vagus, glossopharyngeal, and facial nerves, in the second to fourth sacral spinal nerves, distributed with the pelvic splanchnic nerves, and in thoracic and upper lumbar spinal nerves, spread through rami communicantes.

Bodies of the **second-order neurons** are nuclei of the solitary tract for the facial, glossopharyngeal and vagus nerves and nuclei of the posterior grey column of the spinal cord. Axons of the second-order neurons cross the brainstem or the spinal cord and go to the thalamus.

The **third-order neurons** are the ventrolateral nuclei of the thalamus. Axons of the third-order neurons are named thalamocortical (thalamoparietal) fibres. This tract goes via the posterior limb of the internal capsule and synapses on the fourth-order neurons in the inferior portions of the pre- and postcentral gyri, in the limbic lobe and other areas.

7. **Pathways of the smell (olfactory) analyzer.** The receptor field is located in the mucosa of the nasal cavity in the olfactory region that includes the superior nasal meatus, superior nasal concha, and nasal septum (Fig. 54).

Bodies of the **first-order neurons** are bipolar; dendrites extend to the surface of the olfactory epithelium and compose dendritic bulbs. Axons (olfactory nerves) pass through the cribriform plate of the ethmoid to the anterior cranial fossa.

Bbodies of the **second-order neurons** are mitral and tufted cells of olfactory bulbs. Axons of these neurons form the olfactory tract.

The **third-order neurons** are the nuclei of the olfactory trigone. Axons of the third-order neurons are organized in the lateral and medial olfactory striae.

The lateral olfactory stria follows the anterolateral margin of the anterior perforated substance to the insula, where it bends posteromedially to the uncus and parahippocampal gyrus.

The medial olfactory stria passes medially along the rostral boundary of the anterior perforated substance towards the medial continuation of the diagonal band of Broca. Together, they curve up on the medial aspect of the hemisphere, anterior to the attachment of the lamina terminalis. They synapse on the subcallosal area (**fourth-order neurons**). Axons of these neurons go to the uncus and parahippocampal gyrus via the indusium griseum, lateral and medial longitudinal striae or via the cingulum. A part of the neurons of the subcallosal area spread their axons to the nuclei of the septum pellucidum (**fifth-order neurons**).

A part of the **third-order neurons** is nuclei of the anterior perforated substance. Their axons go to the nuclei of the septum pellucidum (**fourth-order neurons**). Their axons extend to the hippocampus, dentate gyrus and uncus via the fornix and cingulum. A part of these axons travels to the nuclei of the septum pellucidum of the opposite side through the anterior commissure.

The cortical end of the smell analyzer is the uncus, hippocampus, dentate gyrus and parahippocampal gyrus. Impulses from these centres come to the subcortical centres (mammillary bodies, amygdaloid body, thalamic nuclei) that join the efferent pathways. The mammillothalamic and

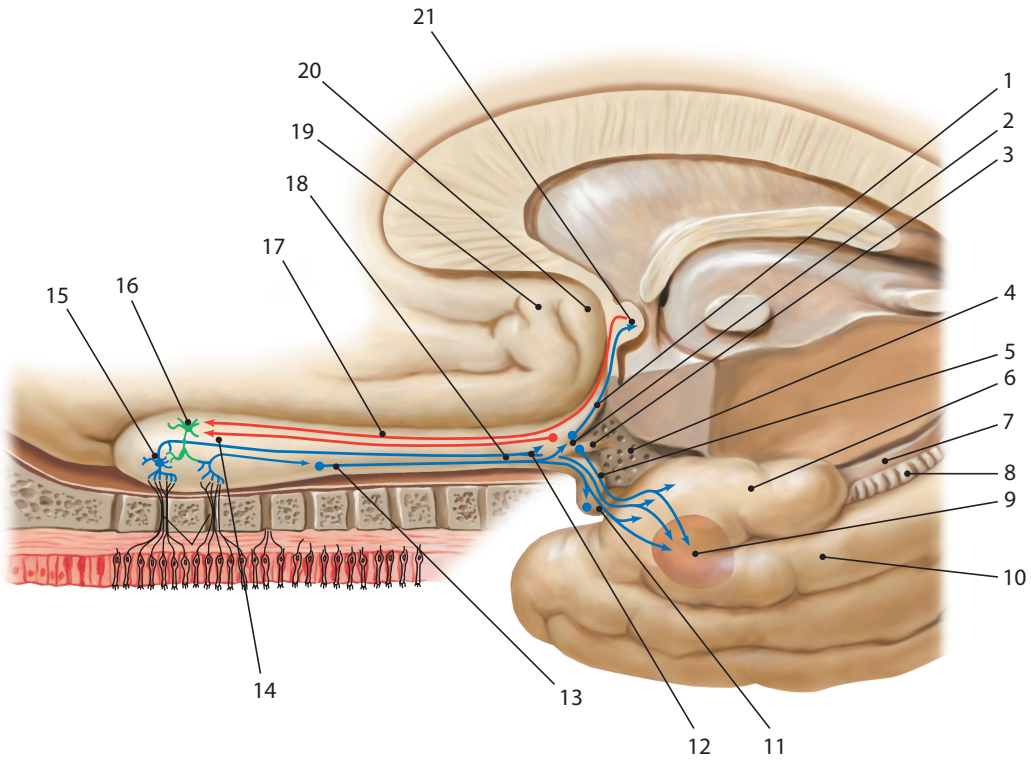

Fig. 54. Pathway of the olfactory analyzer: 1 — medial stria; 2 — olfactory trigone; 3 — olfactory tubercle; 4 — anterior perforated substance; 5 — lateral stria; 6 — uncus; 7 — fimbria of hippocampus; 8 — dentate gyrus; 9 — amygdaloid body; 10 — parahippocampal gyrus; 11 — nucleus of lateral olfactory tract; 12 — olfactory tract; 13 — anterior olfactory nucleus; 14 — olfactory bulb; 15 — mitral cells; 16 — granule cell; 17 — efferent fibers to olfactory bulb; 18 — afferent fibers from olfactory bulb; 19 — subcallosal area; 20 — paraterminal gyrus; 21 — anterior commissure — projections course to the contralateral olfactory bulb

mammillotegmental fasciculi are connections of subcortical centres.

8. **Pathways of the gustatory (taste) analyzer.** The receptor field is located in the mucosa of the oral cavity and pharynx. Taste from the anterior two thirds of the tongue, floor of the mouth, and palate is recognized by the facial nerve; gustatory information from the posterior third of the tongue and soft palate is provided by the glossopharyngeal nerve; taste from the epiglottis and extreme pharyngeal part comes via the vagus nerve (Fig. 55).

Bodies of the **first-order neurons** are in the geniculate ganglion of the facial nerve [VII], in the inferior ganglion of the glossopharyngeal nerve [IX], in the superior and inferior ganglia of the vagus nerve [X]. Dendrites are the chorda tympani [VII], lingual branches [IX] and superior laryngeal nerve [X]. Axons constitute the proper trunks of these nerves.

Bodies of the **second-order neurons** are nuclei of the solitary tract for all nerves. Axons of these neurons cross the brainstem and go to the thalamus (nucleothalamic fibres).

The **third-order neurons** are the anterior nuclei of the thalamus. Their axons synapse on the neurons of the paleocortex and archicortex, uncus, parahippocampal gyrus (cortical end of the analyzer).

9. **Pathways of the acoustic (auditory, hearing) analyzer.** The receptor field is situated in the spiral organ (Fig. 56).

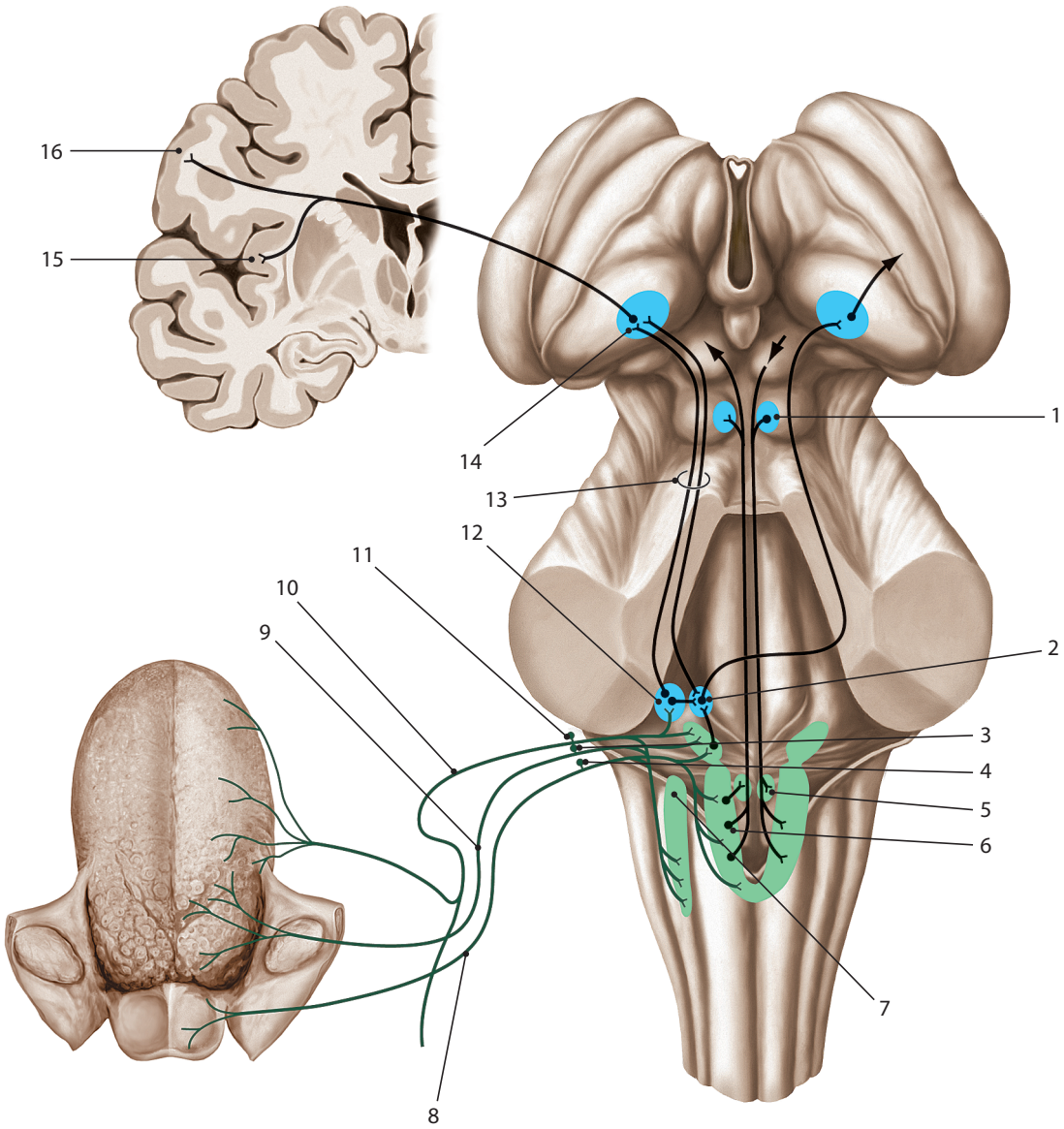

Fig. 55. Pathway of the taste analyzer: 1 — posterior tegmental nucleus; 2 — medial parabrachial nucleus; 3 — inferior ganglion (glossopharyngeal nerve [IX]); 4 — inferior ganglion (vagus nerve [X]); 5 — posterior nucleus of vagus nerve [X]; 6 — nuclei of solitary tract; 7 — spinal nucleus of trigeminal nerve; 8 — vagus nerve [X]; 9 — glossopharyngeal nerve [IX]; 10 — chorda tympani (facial nerve [VII]); 11 — geniculate ganglion (facial nerve [VII]); 12 — interstitial solitary nucleus; 13 — trigeminal lemniscus, posterior trigeminothalamic tract; 14 — thalamus, ventral posteromedial nucleus; 15 — insula; 16 — postcentral gyrus

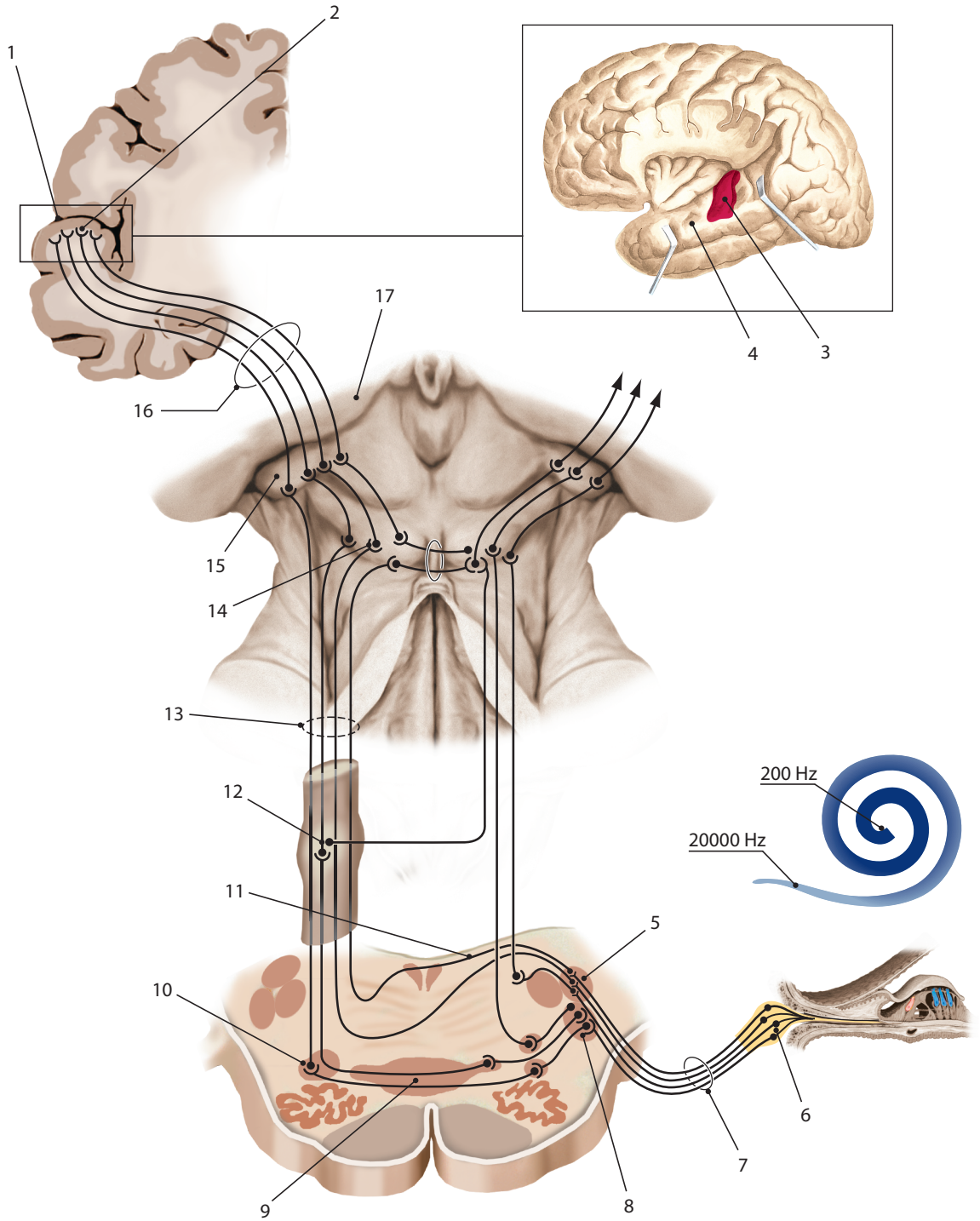

Fig. 56. Pathway of the acoustic analyzer: 1 — lateral sulcus; 2, 3 — transverse temporal gyri; 4 — superior temporal gyrus; 5 — posterior cochlear nucleus; 6 — cochlear ganglion; 7 — cochlear nerve; 8 — anterior cochlear nucleus; 9 — trapezoid body; 10 — superior olivary nucleus; 11 — medullary stria of fourth ventricle; 12 — nuclei of lateral lemniscus; 13 — lateral lemniscus; 14 — inferior colliculus; 15 — medial geniculate body; 16 — acoustic radiation; 17 — thalamus

Bodies of the **first-order neurons** are in the spiral, or cochlear ganglion located in the spiral canal of the modiolus. 90–95% of dendrites from a spiral ganglion terminate at inner hair cells, 5–10% of dendrites terminate at outer hair cells. Axons form the cochlear nerve of the VIII cranial nerve and come through the internal acoustic opening into the posterior cranial fossa. The entrance to the brain is through the cerebellopontine angle (medullopontine sulcus).

Bodies of the **second-order neurons** are the dorsal (posterior) and ventral (anterior) cochlear nuclei in the pons. Most axons go to the opposite side (80%) and least fibres (20%) continue to the same side. Axons of these neurons in the pons are termed medullary striae of the fourth ventricle, dorsal (posterior) acoustic stria, intermediate acoustic stria and ventral (anterior) acoustic stria.

Bodies of the **third-order neurons** are the superior olivary nucleus, nuclei of the trapezoid body, cochlear nuclei in the pons, nuclei of the lateral lemniscus in the isthmus. These nuclei are the primary auditory centre. Nuclei of the lateral lemniscus send fibres to the opposite lemniscus (commissure). Axons from the third-order neurons compose the lateral lemniscus.

Bodies of the **fourth-order neurons** are nuclei of the inferior colliculus, medial geniculate nuclei and thalamic nuclei; they are the subcortical centres of the analyzer. Both inferior colliculi are joined by the *commissure*. Both medial geniculate bodies are connected by fibres in the *ventral supra-optic commissure* (*von Gudden's commissure*). Axons of medial geniculate nuclei organize the acoustic radiation. The fibres of the acoustic radiation run through the posterior limb of the internal capsule and ascend to the primary auditory cortex in the middle third of the superior temporal gyrus (transverse temporal Heschl's gyri).

Localization of sound is possible due to the fact that sound reaches two ears with varying intensity and at different times. Crossings of the auditory pathways transform these differences into information.

10. **Pathways of the vestibular (statokinetic, balance) analyzer.** The receptor fields lie in the membranous ampullae of semicircular ducts, saccule and utricle (Fig. 57).

Bodies of the **first-order neurons** are in the vestibular ganglion located on the floor of the internal acoustic meatus. Dendrites connect with the receptors. Axons compose the vestibular nerve of the VIII cranial nerve and come through the internal acoustic opening into the posterior cranial fossa. The entrance into the brain is the cerebellopontine angle (medullopontine sulcus).

Bodies of the **second-order neurons** are the superior, inferior, medial and lateral vestibular nuclei situated in the vestibular area of the rhomboid fossa. Their axons project to motor nuclei in the brainstem and upper spinal cord, and to the cerebellum and thalamus.

Bodies of the **third-order neurons** are positioned in the thalamus. Axons of the third-order neurons synapse on the neurons in the middle and inferior temporal gyri (Brodmann's areas 20, 21).

11. **Pathways of the visual analyzer.** The receptor field is organized by cones and rods in the retina.

Bodies of the **first-order neurons** are in the outer nuclear layer.

Bodies of the **second-order neurons** (bipolar cells) are in the inner nuclear layer.

Bodies of the **third-order neurons** are in the ganglionic layer. Axons of the third-order neurons form the optic nerve (Fig. 58).

The left and right nerves collect information from the left and right fields of vision. Optic nerves are crossed to compose the chiasma. Medial parts of optic nerves constitute the optic chiasma, the lateral parts go to their own side. Two optic tracts extend from the chiasma. The right optic tract consists of the fibres from the temporal (lateral) side of the right retina and the nasal (medial) side of the left retina. The left optic tract is made by fibres from the temporal part of the left retina and the nasal part of the right retina.

Bodies of the **fourth-order neurons** are nuclei of the superior colliculus, pretectal nuclei, lateral geniculate nuclei and thalamic nuclei. They are the subcortical centres of the analyzer. Axons of the lateral geniculate nuclei and posterior thalamic nuclei constitute optic radiation and go to the primary visual cortex in the calcarine sulcus of the occipital lobe.

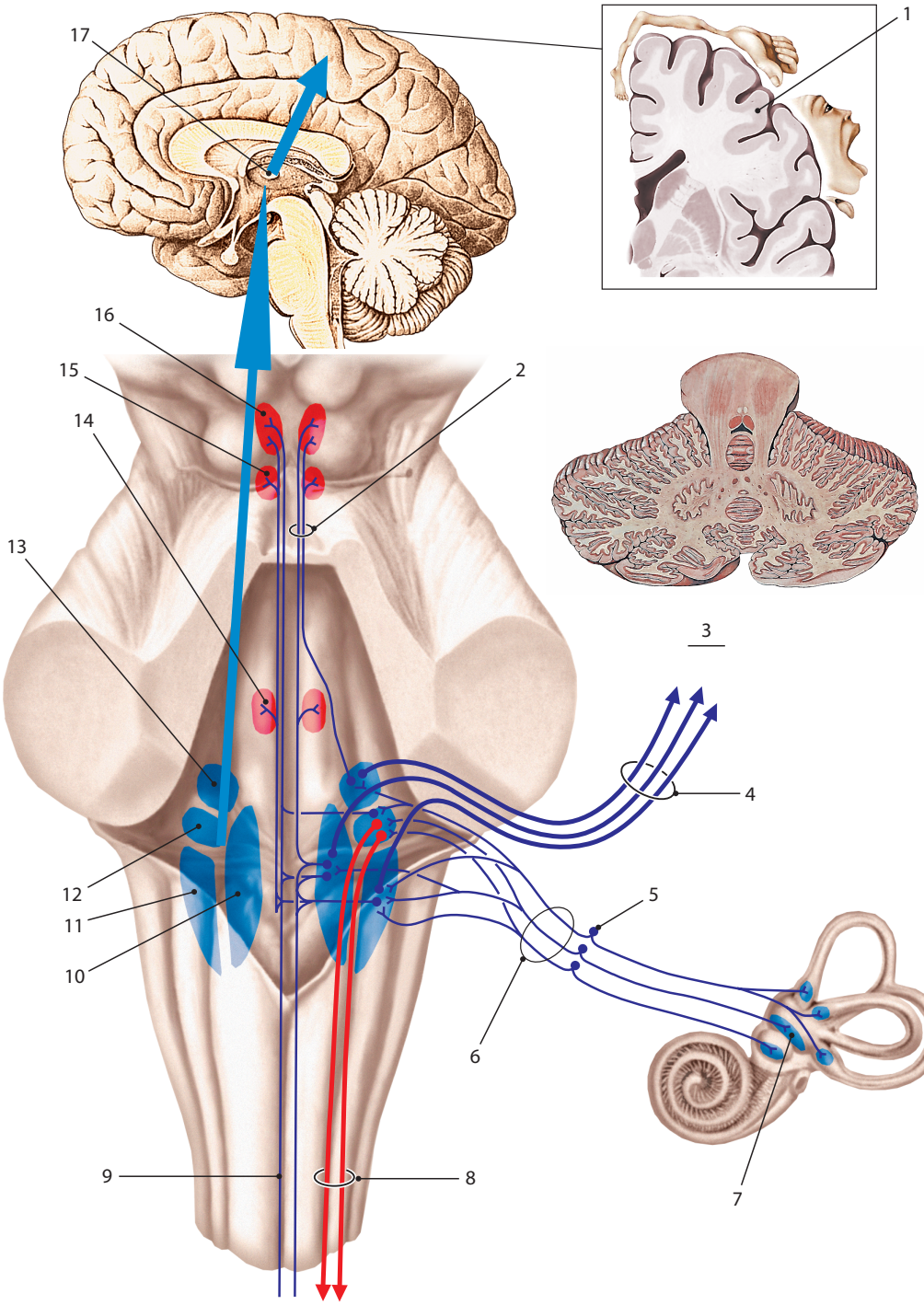

Fig. 57. Pathway of the vestibular analyzer: 1 — postcentral gyrus; 2 — medial longitudinal fasciculus; 3 — cerebellum; 4 — vestibulocerebellar fibres and cerebellovestibular fibres; 5 — vestibular ganglion; 6 — vestibular nerve; 7 — ampullary crest, maculae of utricle, maculae of saccule; 8 — lateral vestibulospinal tract; 9 — medial longitudinal fasciculus; 10 — medial vestibular nucleus; 11 — inferior vestibular nucleus; 12 — lateral vestibular nucleus; 13 — superior vestibular nucleus; 14 — nucleus of abducens nerve; 15 — nucleus of trochlear nerve; 16 — nucleus of oculomotor nerve; 17 — thalamus

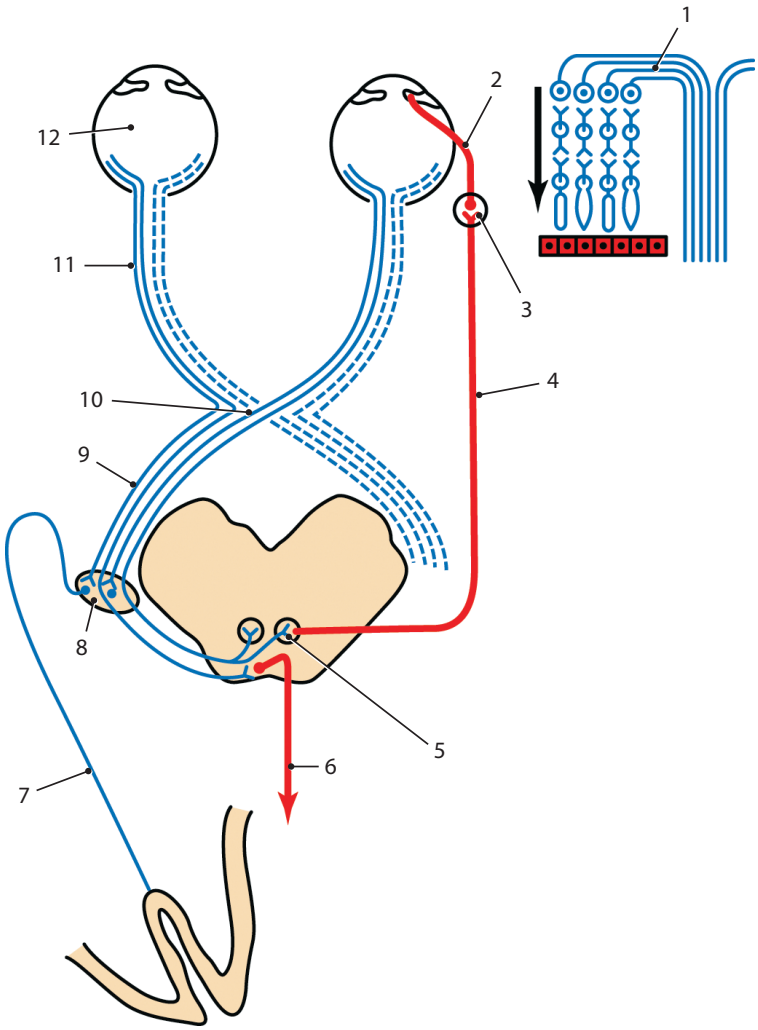

Fig. 58. Pathway of the visual analyzer: 1 — structure of the retina and optical nerve (the arrow shows the direction of light in the retina); 2 — short ciliary nerves; 3 — ciliary ganglion; 4 — oculomotor nerve; 5 — accessory oculomotor nuclei; 6 — tectospinal tract; 7 — optic radiation; 8 — lateral geniculate body, thalamic nuclei; 9 — optic tract; 10 — optic chiasm; 11 — optic nerve; 12 — eyeball

Efferent pathways

1. **Pyramidal tracts.** The principal function of the *corticospinal* and *corticonuclear fibres* is to manage fine, fractionated movements, particularly of those parts of the body where delicate muscular control is required. Corticonuclear fibres organize the activity of motor neurons within the cranial nerve nuclei. These tracts are particularly important in speech (corticonuclear fibres) and movement of the hand (corticospinal fibres). Both pyramidal tracts inhibit reflexes of the segmental apparatus of the spinal cord and brainstem. Central neurons (upper motor neuron) and peripheral neurons (lower motor neuron) contribute efferent descending pathways (Fig. 59).

Corticospinal fibres (pyramidal tract) originate from widespread regions of the cerebral cortex, including the primary motor cortex of the frontal lobe (area 4) and the premotor cortex (area 6). Pyramidal cells are located in the fifth layer of the precentral gyrus, paracentral lobule (two thirds) and superior parietal lobule (one third). Axons descend via the posterior limb of the internal capsule, then throughout the base of the brainstem. Just rostral to the level of the spinomedullary junction, approximately 75–90% of the corticospinal fibres in the pyramid cross the median plane in the motor decussation (decussation of the pyramids) and continue caudally as the lateral corticospinal tract. The rest of the fibres extends uncrossed as

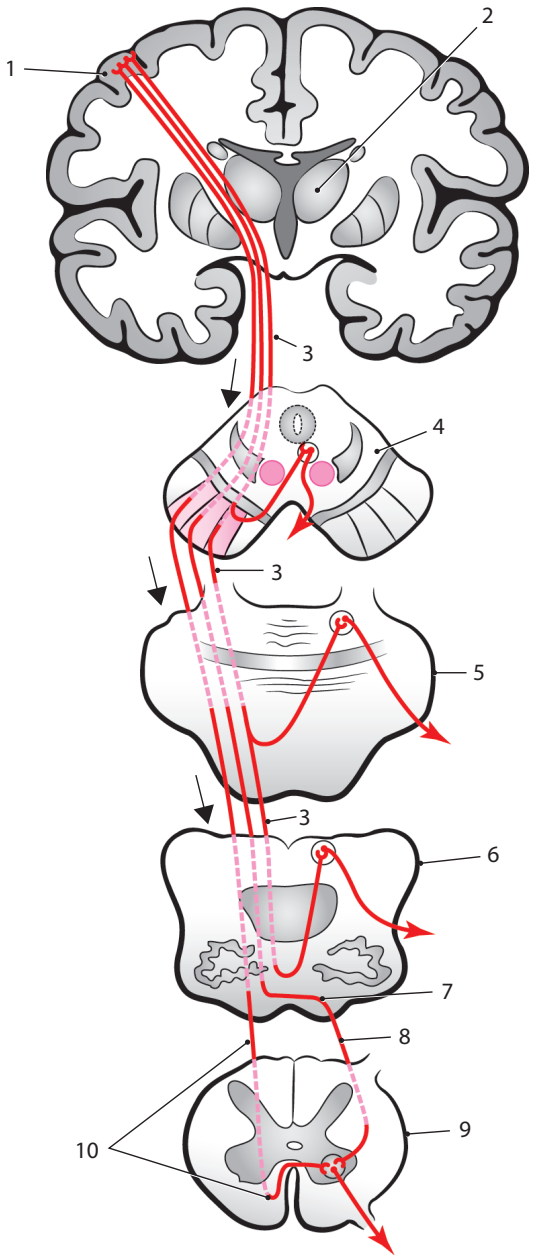

Fig. 59. Pyramidal tracts: 1 — precentral gyrus; 2 — thalamus; 3 — corticobulbar fibres; 4 — transverse section of mesencephalon; 5 — transverse section of the pons; 6 — transverse section of medulla oblongata; 7 — decussation of pyramids; 8 — lateral corticospinal fibres; 9 — spinal cord; 10 — anterior corticospinal fibres. The arrows show the direction of nerve impulses

the ventral corticospinal tract. The lateral corticospinal tract descends in the lateral funiculus throughout most of the length of the spinal cord. It occupies an oval area, ventrolateral to the dorsal horn and medial to the dorsal spinocerebellar tract. The tract diminishes in size as its fibres terminate in progressively lower spinal segments until about the fourth sacral segment; its axons synapse on ipsilateral spinal neurons. The smaller ventral corticospinal tract descends in the anterior funiculus. It lies close to the anterior median fissure. The ventral tract usually disappears completely at midthoracic cord levels. Near their termination, most fibres of the tract cross the median plane in the anterior white commissure to synapse on contralateral neurons.

Peripheral neurons are multipolar cells of the anterior columns of the spinal grey matter (α-motor neurons) which give axons to the muscles.

Muscles of the trunk and perineum are controlled by fibres of the lateral and ventral corticospinal tracts of the same side and by the anterior corticospinal tract of the opposite side.

The concept of upper and lower motor neurons is fundamental to the clinical description of the effects of lesions of the motor system. The signs and symptoms of upper and lower motor neuron lesions are very different and are indicative of the anatomical site of the lesion.

Lesions of the corticospinal system in humans result in permanent paresis or paralysis.

Isolated transection of corticospinal fibres at the level of the pyramid (pyramidotomy) produces flaccid paralysis or paresis of the contralateral limbs and loss of independent hand and finger movements. Damage of pyramidal cells or destruction of corticospinal fibres at the level of the internal capsule, commonly caused by a cerebral vascular accident ("stroke") or tumor growth, results in contralateral hemiplegia. The paralysis is initially flaccid, but later becomes spastic, and is most marked in distal muscles of the extremities, especially those concerned with individual movements of the fingers and hand. Associated signs on the paralysed side are hyperactive deep tendon reflexes, hypertonicity, loss of superficial abdominal and cremasteric

reflexes, and appearance of dorsiflexion of the toes (Babinski's sign) in response to stroking the sole of the foot. A combination of paralysis, increased tendon reflex activity and hypertension is referred to as spasticity. Lesions of the superior cervical segments produce homolateral paralyses of the upper and lower extremities.

Lower motor neuron lesions cause paralysis or paresis of specific muscles due to their loss of direct innervation. There is also loss or reduction of tendon reflex activity and reduced muscle tone. Spontaneous muscular contractions occur, and affected muscles atrophy over time.

Pyramidal cells of *corticonuclear fibres* are situated in the fifth layer of the inferior third of the precentral gyrus (70%), the inferior third of the postcentral gyrus (20%) and superior parietal lobule. The opposite half of the body (extra-ocular muscles, mimetic muscles, mastication muscles, muscles of the soft palate, pharynx and larynx) is represented in a detailed somatotopic fashion in the postcentral gyrus. Corticofugal fibres descend through the genu of the internal capsule and pass into the brainstem, where they synapse on motor nuclei of cranial nerves.

Peripheral neurons are multipolar cells of the nucleus of the oculomotor nerve and nucleus of the trochlear nerve placed in the midbrain, the motor nucleus of the trigeminal nerve, the nucleus of the abducent nerve and the motor nucleus of the facial nerve in the pons, the nucleus of the hypoglossal nerve, nucleus ambiguus [IX, X, XI] in the medulla oblongata and nucleus of the accessory nerve in the anterior horn of the spinal cord. Neurons of the III, IV, V, VI, IX, X, XI cranial nerves are believed to receive bilateral (for the same side and opposite side) corticonuclear fibres. These neurons send axons to muscles.

Neurons supplying lower facial muscles [VII] only obtain a contralateral innervation. Clinically, lesion of upper and lower motor neurons of the facial nerve can be differentiated because lesion of upper neurons results in paralysis that is confined to the contralateral lower face, whilst lesion of lower neurons results in a complete ipsilateral paralysis (Bell's palsy). Mimetic muscles of the upper part of the face [VII] are innervated by both hemispheres.

The nucleus of the XII nerve collects contralateral corticobulbar fibres. Damage of pyramidal cells or their axons produces a contralateral lingual paralysis without hemiatrophy; the protruded tongue deviates to the paralysed side.

Lesions of lower motor neurons (motor nuclei of cranial nerves) cause paralysis accompanied by atrophy, atonia, and areflexia.

2. **Extrapyramidal tracts.** The extrapyramidal system regulates movements of muscles and muscular tone. The extrapyramidal system consists of basal nuclei, subthalamic nucleus (corpus Luisi), red nucleus, substantia nigra, vestibular nuclei, cerebellum, nuclei of superior and inferior colliculi, and reticular formation of the brainstem. The extrapyramidal system and pyramidal system are functionally interrelated in the control of movement. Two systems encode the parameters of force, velocity and direction, but the extrapyramidal system regulates primarily the activity both during the terminal phase of a movement and preceding the movement. Thus, there is an overlap of activity in two systems for all parameters in movements of limbs and even of individual digits. The corticospinal system is most active for the period of learning new movements, whereas the extrapyramidal system is most active during the execution of learnt automated movements. The cerebellum plays a role in motor learning, and so the rubro-olivary system could switch the control of movements from the corticospinal to the extrapyramidal system for programmed automation.

Basal ganglia appear to be involved in selection of appropriate movements and suppression of inappropriate ones. Disorders of basal ganglia cause either too little movement (akinesia) or abnormal involuntary movements (dyskinesia) as well as tremor and abnormalities of muscle tone. The cerebellum has rich connections with the brainstem, particularly the reticular and vestibular nuclei, and with the thalamus. It is concerned with coordination of movement: cerebellar disorders cause ataxia, intention tremor and hypotension.

The main efferent pathways of the extrapyramidal system include the *rubrospinal tract*, *tectospinal tract*, *vestibulospinal tracts*, *reticulospinal fibres* and *olivospinal fibres*.

Peripheral motoneurons in all tracts are multipolar cells of anterior columns of the spinal grey matter (α-motor neurons) which give axons to the muscles.

The **rubrospinal tract** arises from neurons in the red nucleus situated centrally in the tegmentum of the midbrain (Fig. 60). Axons of these neurons form the tract. The tract crosses to the opposite

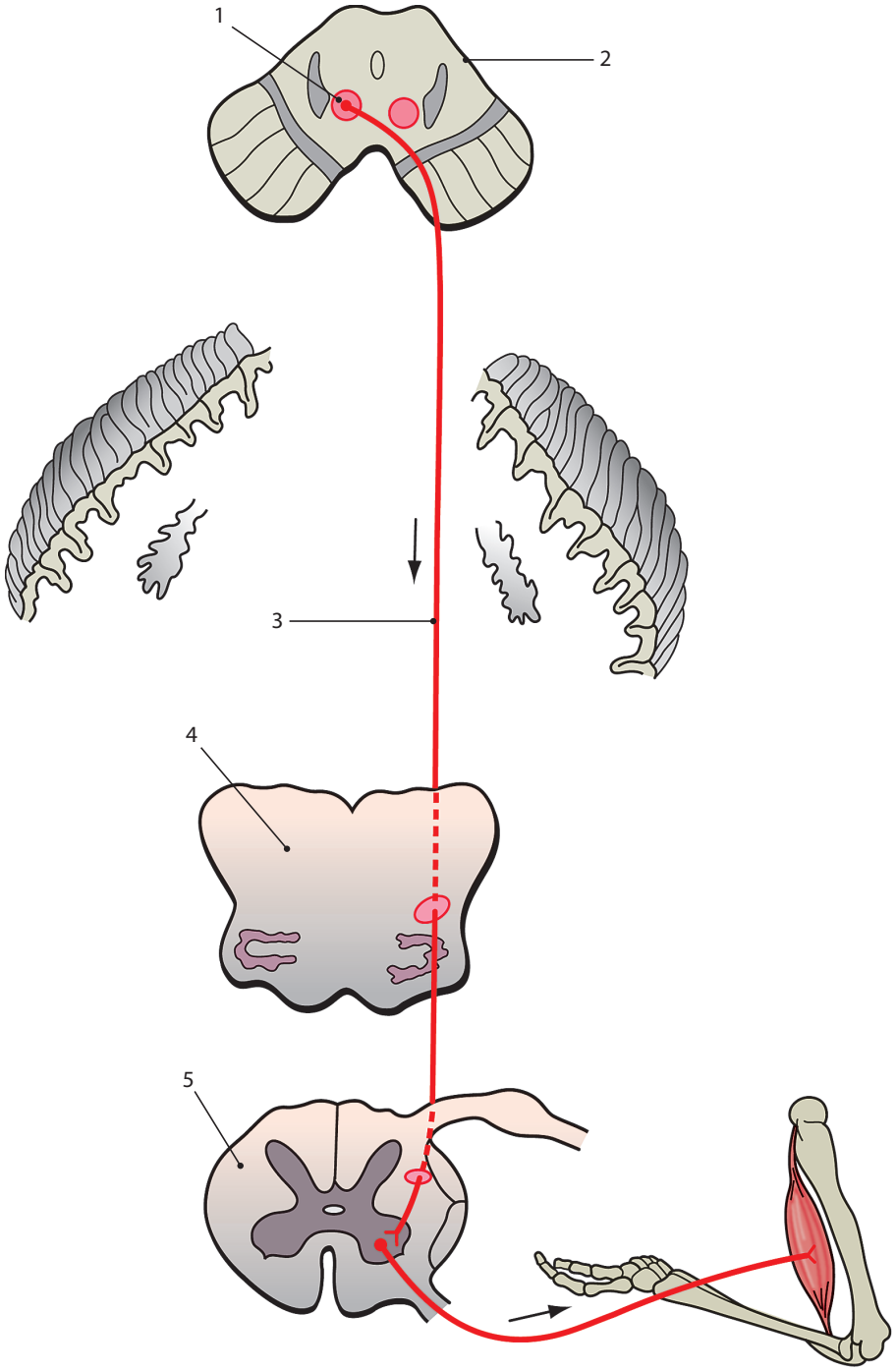

Fig. 60. The rubrospinal tract: 1 — red nucleus; 2 — mesencephalon (midbrain); 3 — rubrospinal tract; 4 — medulla oblongata; 5 — spinal cord

side and composes the *anterior tegmental decussation*. The tract descends in the lateral funiculus of the spinal cord. Effects of rubrospinal fibres on α- and γ-motor neurons are similar to those of corticospinal fibres.

The **tectospinal tract** arises from neurons in the intermediate and deep layers of the superior colliculus of the midbrain. It crosses ventral to the periaqueductal grey matter in the dorsal tegmental decussation and descends in the medial part of the ventral funiculus of the spinal cord. Fibres synapse on motor neurons serving muscles in the neck. It is the youngest extrapyramidal pathway. In animals, central collicular stimulation produces contralateral head movement as well as movements involving the eyes, trunk and limbs, which implicates the superior colliculus in the integration of vision and body movement.

The *lateral vestibulospinal tract* arises from neurons of the lateral vestibular nucleus (Deiters' nucleus). It descends ipsilaterally. Axons of the lateral vestibulospinal tract are excitatory to motor neurons of extensor muscles of the neck, back and limbs, and are involved in antigravity maintenance of posture. The lateral tract axons also inhibit motor neurons of flexor limb muscles. The *medial vestibulospinal tract* arises mainly from neurons in the medial vestibular nucleus. It contains both crossed and uncrossed fibres. Axons of the medial tract inhibit the motor neurons that innervate axial muscles of the neck and upper part of the back. Both tracts are located in the anterior funiculus of the spinal cord.

The **reticulospinal fibres** pass from the brainstem reticular formation to the spinal cord. Medial reticulospinal fibres are responsible for posture, steering of the head and trunk movements in response to external stimuli, and crude, stereotyped movements of the limbs. Lateral reticulospinal fibres are involved in the control of pain perception and in motor functions.

The **olivospinal fibres** descend from the inferior olivary nucleus of the medulla oblongata. Axons of these neurons are lodged in the lateral funiculus of the spinal cord on the same side.

Damage to extrapyramidal pathways will result in spastic paralysis.

It is important to note that both pyramidal and extrapyramidal descending influences ultimately meet at the motoneuron to modulate its activity.

3. **Visceral descending (efferent) pathways** differ from their somatic equivalents in that the former are interrupted by peripheral synapses, there being a sequence of least two neurons between the CNS and the target structure. They are referred to as preganglionic and postganglionic neurons, respectively. The somata of preganglionic neurons are positioned in the visceral efferent nuclei of the brainstem and in the lateral grey columns of the spinal cord. Sympathetic preganglionic neurons are intermediolateral nuclei in the C8–L3 segments. Parasympathetic preganglionic neurons are nuclei of cranial nerves of the brainstem and sacral parasympathetic nuclei in the S2–S4 segments. Preganglionic axons exit from the CNS in certain cranial and spinal nerves and then pass to peripheral ganglia, where they synapse with postganglionic neurons. Postganglionic neurons are more numerous than preganglionic ones; one preganglionic neuron can contact with 15 to 20 postganglionic neurons, which permits the wide distribution of many autonomic effects.

Autonomic activity is not initiated or controlled solely by the reflex connections of visceral ascending pathways, nor do impulses in these pathways necessarily activate visceral efferents. For example, in many situations demanding sympathetic activity the initiator is somatic and typically arises either from the special senses or the skin. Peripheral autonomic activity is integrated at higher levels in the brainstem and cerebrum, including various nuclei of the brainstem reticular formation, thalamus and hypothalamus, the limbic lobe and prefrontal neocortex, together with the ascending and descending pathways which interconnect these regions.

Impulses descend from the cortex to the basal nuclei, cerebellum, and hypothalamus.

The *dorsal*, or *posterior longitudinal Schütz's fasciculus* (*fasciculus longitudinalis dorsalis* seu *posterior*) starts in the diencephalon and connects with

autonomic preganglionic neurons controlling salivation, secretory activity and motility of visceral internal organs, and motor nuclei for mastication and deglutition.

QUESTIONS FOR SELF-CONTROL

1. Give details of development of cerabral vesicles.
2. Name the nuclei of the medulla oblongata.
3. Describe the centres of the cerebellum.
4. Explain projection of the nuclei to the rhomboid fossa.
5. Name the nuclei of the midbrain.
6. What anatomical structures are assigned to the hypothalamus?
7. Give details of the structure of the third ventricle.
8. Explain the sulci and gyri of the superolateral surface of the cerebral hemisphere.
9. List the sulci and gyri of the inferior surface of the cerebral hemisphere.
10. Name the sulci and gyri of the medial surface of the cerebral hemisphere.
11. Explain the structure of the isocortex of the cerebral hemisphere.
12. Give details of cortical centres of the visual, auditory, smell and taste analyzers.
13. What formations are assigned to the rhinencephalon?
14. Describe the basal nuclei of the brain.
15. Name long association fibres.
16. What pathways are located in the posterior limb of the internal capsule?
17. Give details of the structure of corticonuclear and corticospinal (pyramidal) pathways.
18. Explain the formations included in the extrapyramidal system.
19. Name the subarchnoid cisterns.