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# RESPIRATORY SYSTEM. HEART. ENDOCRINE SYSTEM

# ДЫХАТЕЛЬНАЯ СИСТЕМА. СЕРДЦЕ. ЭНДОКРИННАЯ СИСТЕМА

**The manual for medical students**

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

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Структура пособия соответствует современным стандартам медицинского образования в России и важнейшим европейским стандартам. Английская и латинская терминология приведены в соответствии с Международной анатомической номенклатурой.

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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. — musculi
N., n. — nervus
Nn., nn. — nervi
R., r. — ramus
Rr., rr. — rami
S., s. — sulcus

# PREFACE

The creation of the manual "Respiratory System. Heart. Endocrine 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 «Дыхательная система. Сердце. Эндокринная 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 изучаются 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. RESPIRATORY SYSTEM

The respiratory system (*systema respiratorium*) comprises the respiratory tract (airways) and respiratory organs proper, the lungs.

Because of the vertical position of the human body the respiratory tract is divided into upper airways and lower airways. The upper airways include the nasal cavity, nasopharynx and oropharynx; the lower airways include the larynx, trachea, bronchi (together with their intrapulmonary branching, i.e. bronchial tree).

The respiratory tract represents the system of tubes, having an osseous or cartilaginous skeleton, due to which they can not contract to close the lumen of the airways. The lumen of the respiratory tract opens constantly, and despite of the abrupt change of the pressure from positive to negative, the air circulates freely to both sides during inspiration and expiration.

The inner surface of the airways is lined by the mucous membrane which is covered by ciliated columnar epithelium and contains numerous glands secreting the mucus. Due to this the inspired air is cleaned, humidified and warmed. Among the respiratory organs the larynx is the most complex organ, performing the function of phonation. The air passes through the airways to the lungs where the exchange of gases between the air and blood (by diffusion of oxygen and carbon dioxide) occurs in the alveoli.

## 1.1. Nose

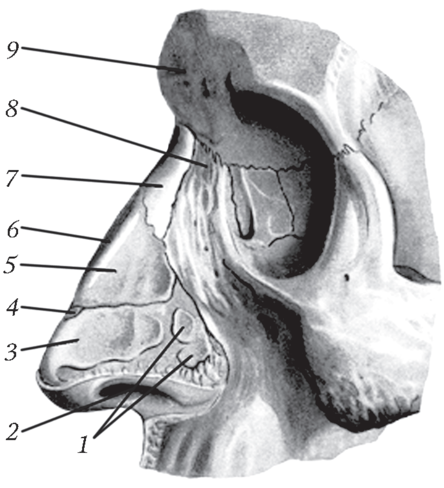


Fig. 1.1. Skeleton of external nose:

*1* — minor alar cartilages (*cartilagines alares minores*); *2* — nostrils (*nares*); *3* — accessory nasal cartilages (*cartilagines nasi accessoriae*); *4* — lateral nasal cartilage (*cartilago nasi lateralis*); *5* — lateral nasal cartilage (*cartilago nasi lateralis*); *6* — septal nasal cartilage (*cartilago septi nasi*); *7* — nasal bone (*os nasale*); *8* — frontal process of maxilla (*processus frontalis maxillae*); *9* — frontal bone (*os frontale*)

The nose includes the external nose and the nasal cavity (internal nose).

**External nose**, *nasus externus* (in Greek *rhis*, *rhinos*) is the projection of the facial skull, having the shape of an irregular trihedral pyramid. It comprises the root, dorsum, apex and alae (wings). The form and length of the nasal dorsum, position of nasal root depend on individual and age features.

The root of nose, *radix nasi*, is in the upper part of the face and is separated from the forehead by a depression known as the glabella, *glabella*. The lateral sides of the external nose join along the midline to form the dorsum of nose, *dorsum nasi*, and the inferior parts of the lateral sides form the alae of nose, *alae nasi*. Downwards, the nasal dorsum is continuous with the apex of nose, *apex nasi*. The alae limit the nostrils, *nares*, which transmit the air into the nasal cavity and from it. Along the midline the nostrils are separated by the mobile (membranous) part of the nasal septum.

The ossesous skeleton of the upper part of the nose is formed partially by the frontal and nasal bones, and laterally, on either side it is supplemented by the frontal process of

the maxilla. The bony structures of the external nose are continuous with its cartilaginous frame (fig. 1.1). The basic cartilage of the external nose`s cartilaginous part is a lateral nasal cartilage, *cartilago nasi lateralis*. It has a triangular form. Its upper edge is connected to the nasal bone and upper part of the maxillary frontal process. The medial edge is fused with the opposite lateral nasal cartilage to form the continuation of the nasal dorsum. The inferior edge adjoins the major alar cartilage, *cartilago alaris major*. The latter is paired and has a shape of an oval plate, from which the medial and lateral crura arise. The medial crura are fused together from the opposite sides, forming the continuation of the nasal dorsum, and below they form the apex of nose. The lateral crura limit the borders of the nasal openings (nostrils). Usually in the connective tissue between the lateral nasal and major alar cartilages there are one or two accessory nasal cartilages, *cartilagines nasi accessoriae*.

Besides the major cartilages, the nasal alae contain the connective tissue providing the changeability of alae shape. One-two minor alar cartilages, *cartilagines alares minores,* lie in the posterior areas of this connective tissue. The connective tissue limits the lower parts of the nostrils.

The osseo-cartilaginous skeleton of the external nose is covered from outside by thin skin which is closely linked with underlying mimic muscle, the nasalis. The latter is partly covered by the levator labii superioris. The nasalis arises from the maxillary alveolar process near the canine and lateral incisor teeth and is divided into transverse and alar parts. The transverse part is formed by the lateral fascicles of the nasalis, which rise and bridge the cartilaginous part of the nasal dorsum. The nasalis is connected with the opposite muscle by the tendinous aponeurosis. During contraction, the fibers of the transverse part compress the nose, i.e. narrow the nostrils. The alar part is formed by the medial fascicles which are attached to the skin of the nasal ala. During contraction, it depresses the nasal ala.

**The nasal cavity**, *cavitas nasi*, is between the anterior cranial fossa (above), the oral cavity (below) and orbits (laterally). The nasal septum, *septum nasi*, divides the nasal cavity into two halves, unequal in size. Anteriorly, the nasal cavity opens outward through the nasal openings named the nostrils, *nares*. Posteriorly, it communicates with the nasopharynx by means of the openings termed choanae, *choanae*.

The nasal cavity has three walls: superior, lateral and inferior.

The superior wall (roof) is constituted by the nasal bones, partially by the frontal bone, by the cribriform plate of ethmoid bone and the anterior and inferior walls of the sphenoidal body. The cribriform plate of ethmoid bone is perforated by about 30 openings transmitting the olfactory nerves.

The lateral wall of the nasal cavity is formed by the frontal process and nasal surface of maxilla, the lacrimal bone, ethmoidal labyrinth, inferior nasal concha, perpendicular plate of the palatine bone and the medial plate of the sphenoidal pterygoid process. The lateral wall shows three elevations: the superior, middle and inferior nasal conchae, separating the superior, middle and inferior nasal meatuses. The superior and middle nasal conchae are the parts of the ethmoid bone, while the inferior nasal concha is an individual bone (fig. 1.2).

The inferior wall (floor) is formed by the palatine processes of both maxillae and horizontal plates of both palatine bones. At the anterior end of the nasal floor there is an incisive canal which transmits the nasopalatine nerve passing from the nasal cavity into the oral cavity. The horizontal plates of palatine bones limit the choanae from below.

The nasal septum is termed by clinicians the medial wall of the nasal cavity. It is constituted by the perpendicular plate of ethmoid bone, sphenoidal crest and rostrum, vo-

mer, by the nasal crests of maxilla and of palatine bone. The posterior edge of the vomer bounds the choanae from the medial side. The septal nasal cartilage, *cartilago septi nasi*, quadrilateral, is connected to the anterior parts of the ethmoidal perpendicular plate. The posteroinferior edge of the cartilage is placed in the grooves of the vomer and of the maxillary nasal crest. Its anterosuperior edge is connected to the nasal bones to form the anterior part of the nasal dorsum. The nasal septum`s osseous part is 2–3 mm thick and the cartilaginous part is 3–7 mm thick.

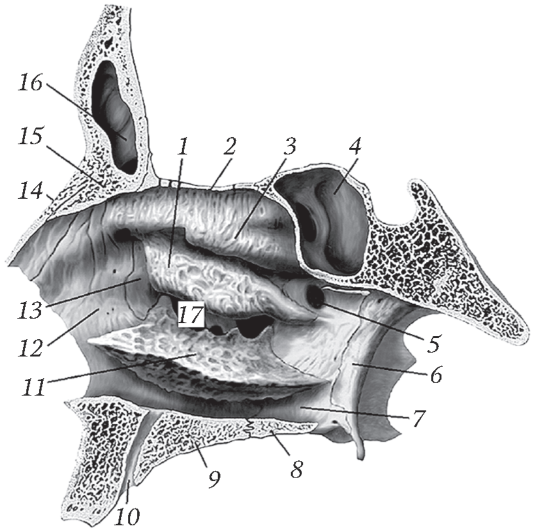


Fig. 1.2. Lateral wall of nasal cavity (sagittal section):

*1* — middle nasal concha (*concha nasalis media*); *2* — cribriform plate (*lamina cribrosa*); *3* — superior nasal concha (*concha nasalis superior*); *4* — sphenoidal sinus (*sinus sphenoidalis*); *5* — sphenopalatine foramen (*foramen sphenopalatinum*); *6* — medial plate of pterygoid process (*lamina medialis processus pterygoidei*); *7* — perpendicular plate of palatine bone (*lamina perpendicularis ossis palatini*); *8* — horizontal plate of palatine bone (*lamina horizontalis ossis palatini*); *9* — palatine process of maxilla (*processus palatinus maxillae*); *10* — incisive canal (*canalis incisivus*); *11* — inferior nasal concha (*concha nasalis inferior*); *12* — frontal process of maxilla (*processus frontalis maxillae*); *13* — lacrimal bone (*os lacrimale*); *14* — nasal bone (*os nasale*); *15* — nasal spine of frontal bone (*spina nasalis ossis frontalis*) ; *16* — frontal sinus (*sinus frontalis*); 17 — maxillary hiatus (*hiatus maxillaris*)

The nasal cavity is divided into the vestibule, *vestibulum nasi*, and nasal cavity proper, *cavitas nasi propria*. The boundary between these parts is an elevation, the limen nasi, *limen nasi*, situated on the lateral nasal wall. The nasal vestibule is lined by the skin bearing special hairs (vibrissae).

The nasal cavity proper has four nasal meatuses: common, inferior, middle and superior.

The common nasal meatus, *meatus nasi communis*, is a space between the nasal septum from the medial side, nasal conchae from the lateral side, nasal roof from above and nasal floor from below. Other three nasal meatuses are in the lateral parts of the nasal cavity.

The inferior nasal meatus, *meatus nasi inferior*, is between the inferior nasal concha above and nasal floor below. On the lateral wall of this meatus, about 10 mm behind the

anterior end of the inferior nasal concha is the opening of the nasolacrimal canal, *canalis nasolacrimalis*. The lateral wall of the inferior nasal meatus is uneven in thickness: below, it is thick and contains spongy substance; towards the inferior nasal concha and to the middle, it becomes thinner and is constructed only from plate of compact substance. In regard to this, the puncture of the maxillary sinus is advisable to perform exactly here, penetrating into the depth of 20 mm from the anterior end of the inferior nasal concha.

The middle nasal meatus, *meatus nasi medius*, is between the middle and inferior nasal conchae. Its lateral wall is also constructed from a thin plate of compact substance. It is covered by the mucosa which forms a double layer near a curved cleft called semilunar hiatus, *hiatus semilunaris*. The latter is bounded anteriorly, at the level of the inferior nasal concha`s anterior end, by the ethmoid`s uncinate process, and posteriorly by the wall of the largest cell of the ethmoid bone, called the ethmoidal bulla, *bulla ethmoidalis*.

The paranasal sinuses, *sinus paranasales*, open into the semilunar hiatus. The frontal sinus opens into the anterior part of the middle nasal meatus; the anterior and middle cells of the ethmoidal labyrinth open into its middle part; the maxillary sinus opens into its posterior part. The localization of the opening of the maxillary sinus corresponds to a depression called the infundibulum, *infundibulum*. At the posterior end of the middle nasal concha there is a sphenopalatine foramen, *foramen sphenopalatinum*, transmitting the sphenopalatine vessels and nerve.

The superior nasal meatus, *meatus nasi superior*, is limited by the superior and middle nasal conchae. The posterior ethmoidal cells and sphenoidal sinus open into it. The sphenoidal sinus opens immediately into the spheno-ethmoidal recess situated under the posterior end of the superior nasal concha.

The walls of the nasal cavity proper are covered by mucosa, 1—2 mm thick; the square of its surface is 65–160 cm$^2$. According to the local functions, the mucosa can be divided into the respiratory and olfactory region.

The respiratory region, *regio respiratoria*, is the area of the mucosa extending from the nasal floor to the middle of the middle nasal concha; it is thicker and covered by ciliated pseudostritified columnar epithelium containing the ciliated cells, goblet cells and also basal cells.

The ciliated epitheliocytes have contractile cilia, 3—5 mcm long, which move the dust particles and also the mucus produced by mucous glands. The apical surfaces of the basal epitheliocytes bear microvilli (cytoplasmic processes, 1,5–1,8 mcm long). The epithelium lies on the basement membrane which adjoins the connective tissue containing a lot of elastic fibers, terminal parts of the glands and lymph nodes.

In the subepithelial layer there are numerous tubulo-alveolar glands which are divided into mucous, serous and mixed. Deep layers of the respiratory tract`s mucous membrane contain the vascular plexuses, the feature of which is the presence of the cavernous bodies (sinusoids). The cavernous bodies are the enlarged veins having the smooth muscle cells in their walls. The cavernous bodies provide the warming of the air passing through the nasal cavity.

The cavernous bodies are especially well-developed in the area of the inferior nasal concha, where they form the cavernous plexuses of conchae, *plexus cavernosi concharum*. The similar plexuses are also situated in the anterior part of the nasal septum. These places are called the Kisselbach`s areas, *locus Kisselbachii*. Because of the superficial localization of the venous plexuses and arteries, whose muscles are weak (i.e. posses a weak contractile ability), these regions have a tendency to the increased bleeding.

The nasal breathing is more physiological than the oral breathing, because in the nasal cavity the inspired air is cleaned, humidified and warmed.

The olfactory region, *regio olfactoria*, is an area of the mucosa over the upper third of the nasal septum, superior nasal conchae and over the superior portion of the middle nasal conchae. Its square is about 500 mm2. The epithelium of the mucosa in this region contains the olfactory receptors and supporting cells. The supporting cells have no cilia. The secretion of the glands of the olfactory region is more watery than the secretion of the glands of the respiratory region.

## 1.2. Paranasal Sinuses

The paranasal sinuses, *sinus paranasales*, are the pneumatic (air) cavities situated inside the bones of the neurocranium and viscerocranium, lined by the mucous membrane, communicating with the nasal cavity and playing the role of the resonators of voice. Their mucosa is thin and adherent to the periosteum, it has no cavernous bodies, its subepithelial layer is weakly developed.

The paranasal sinuses are the maxillary sinus (Highmore`s antrum), *sinus maxillaris*; frontal sinus, *sinus frontalis*; sphenoidal sinus, *sinus sphenoidalis*; ethmoidal cells, *cellulae ethmoidales*.

**Maxillary sinus.** The maxillary sinus is within the maxillary body and resembles a pyramid in shape. It has medial, anterolateral, superior and inferior walls. The apex of the pyramid is directed to the maxillary tuberosity and adjoins the pterygopalatine fossa.

The medial wall of the maxillary sinus is formed by the part of the lateral nasal wall. Usually it is quadrilateral, thickened inferiorly. In the area of the middle nasal meatus it becomes thinner and have dehiscences shielded by a double layer of the mucosa. A funnel-shaped opening of the maxillary sinus (maxillary hiatus, *hiatus maxillaris*) is in the folds of the mucosa; it opens into the nasal cavity. The maxillary hiatus is above the floor of the maxillary sinus therefore, in the case of inflammation, the drainage of an exudate is blocked. Sometimes, besides the usual opening one more, accessory, opening is present; it is behind and below the main opening.

The anterolateral wall is triangular. In its middle part there is a depression, the canine fossa. Here is the thinnest part of the anterolateral wall. This place is used in surgery to open the sinus. The anterolateral and medial walls join to form a bony promontory.

The posterolateral wall has a shape of an irregular quadrangle. The posterosuperior angle of the wall closely adjoins the posterior cells of the ethmoidal labyrinth and the sphenoidal sinus.

The superior wall (roof) of the sinus is the thinnest and triangular; it forms the inferior orbital wall. It is traversed by the infraorbital groove which is continuous with the infraorbital canal. The groove and the canal transmit the infraorbital vessels and nerve. The inferior wall (floor) is formed by the alveolar process of maxilla. In some cases the roots of the canine and premolar teeth project into the maxillary sinus therefore, the inflammatory diseases of the teeth may cause the inflammation of the sinus (highmoritis).

The size and form of the maxillary sinus vary depending on the individual features and age of a person. Its capacity is between 3–5 $cm^3$ to 30–40 $cm^3$. Often the sinuses are asymmetric.

**Frontal sinus.** The frontal sinus is inside the squama frontalis and has the form of a trihedral pyramid, the base of which is directed down, and the apex of which is directed up. The sinus has anterior, posterior and inferior walls. The anterior wall is formed by a diploic bone; it is the thickest (1-6 mm thick), while the posterior wall is the thinnest. The thickness of the anterior wall is greater in the region of the superciliary arches. Superolaterally, the anterior and posterior walls join together at an acute angle. The inferior wall consists of the nasal and orbital parts. The nasal part is formed by spongy

bone. The orbital part is thin and has a cellular structure because the ethmoidal air cells penetrate into it. The frontal sinus communicates with the nasal cavity through the frontonasal canal which opens by the semilunar hiatus into the anterior part of the middle nasal meatus.

Usually the frontal sinus is a paired cavity separated by the septum, but sometimes the septum is absent. The medial wall (the septum between the sinuses) passes vertically, deviating only in the upper part. More rarely the sinus is multichambered. Its length is various. The sinus may be sited in the squama frontals, superciliary arches or in the orbital part of the frontal bone. Its average capacity is 3–5 $cm^3$, but sometimes it reaches 12 $cm^3$.

**Sphenoidal sinus.** The sphenoidal sinus is within the sphenoidal body; it has superior, inferior, posterior, anterior and lateral walls. The superior wall is the floor of the sella turcica hence it is related to the hypophisis which lies on the sella turcica. The inferior wall is the thickest (8–10 mm); it partly forms the pharyngeal fornix. The posterior wall of the sinus is also thick and connected with the occipital bone`s clivus. The thickness of the lateral walls varies, but does not exceed 1–2 mm. The internal carotid artery, oculomotor, trochlear, ophthalmic and abducent nerves pass through the cavernous sinus in the immediate vicinity of the lateral walls. The sphenoidal sinus is divided by the septum into two, usually asymmetric, halves. In the anterior wall each sinus has an opening called the sphenoidal aperture, *apertura sinus sphenoidalis*, which opens into the sphenoethmoidal recess, *recessus sphenoethmoidalis*, behind the superior nasal concha. In case of inflammation the communication of the sinus with the nasal cavity provides the outflow of the exudate immediately into the nasopharynx.

Approximately in 75 % of subjects the sphenoidal sinus increases in size, adjoining the posterior cells of the ethmoidal labyrinth.

**Cells of ethmoidal labyrinth.** The ethmoidal labyrinth is represented by 7—12 air cells situated between the frontal sinus (above), sphenoidal sinus (behind) and maxillary sinus (laterally). The air cells are divided into three groups: anterior, middle and posterior. The anterior and middle ethmoidal cells open into the middle nasal meatus, and the posterior cells open into the superior nasal meatus.

Laterally the air cells adjoin the orbital plate of the ethmoid, which forms the medial wall of the orbit. If the labyrinth is hyperpneumatized, the anterior cells reach the superior wall of the orbit. Superiorly the labyrinth is related to the anterior cranial fossa therefore, the inflammation of the labyrinth may cause the intracranial complications. The medial wall of the ethmoidal labyrinth is formed by the part of the nasal cavity`s lateral wall above the inferior nasal concha. Often the ethmoidal cells are displaced to the orbit (to the region of the superior or medial orbital walls).

## 1.3. Larynx

The larynx, *larynx*, is a respiratory tube intended for the air conduction and for phonation. The larynx is constructed from the cartilages of different form, connected by the ligaments and synovial joints and moved by highly differentiated musculature. The laryngeal cavity is lined by the mucous membrane.

The larynx is situated in the anterior region of the neck. Superiorly, it connects to the hyoid bone, and inferiorly, it is continuous with the trachea. Behind the larynx is the laryngeal part of the pharynx; on the sides there are the neurovascular bundles of the neck and the lobes of the thyroid gland. The anterior surface of the larynx is covered by the infrahyoid cervical muscles: sternohyoid, sternothyroid, thyrohyoid. The larynx is communicated with the pharyngeal cavity through the laryngeal inlet, *aditus laryngis*.

The upper border of the larynx (the upper border of the thyroid cartilage) is at the level of the intervertebral disc between the IV and V vertebral bodies; the lower border (the lower border of the thyroid cartilage) is opposite the upper edge of the VII cervical body. The rima glottidis is at the level of the V vertebra. In females the larynx is a little higher than in males; in children it is higher than in adults. Thus, the larynx, *descensus laryngis*, descends with age.

Above, the larynx is connected to the hyoid bone by the ligaments, and below it is connected to the sternum by the muscles. It is highly mobile: it performs significant motions in the vertical direction during swallowing and phonation, and also it may be passively displaced to the sides. The larynx is mobile due to its close connection with the pharynx situated behind the larynx; the pharynx, in its turn, is linked with the prevertebral lamina of the proper cervical fascia by areolar tissue.

### 1.3.1. Laryngeal Cartilages

The skeleton of the larynx is comprised of the cartilages: unpaired cricoid, thyroid and epiglottic cartilages and paired arytenoid, corniculate, cuneiform and triticeal cartilages.

**Thyroid cartilage**, *cartilago thyroidea* (fig. 1.3), hyaline, the largest of all the laryngeal cartilages, shields some structures of the larynx: arythenoid cartilages, vocal folds etc. It consists of two symmetrical (right and left) quadrilateral laminae, *laminae dextra et sinistra*, which converge anteriorly and are fused at a nearly right angle in males and at an obtuse angle in females and widely diverge posteriorly. Each lamina has four borders: inferior, passing almost horizontally; superior, curved like letter S; posterior, vertical; and anterior, the shortest, fused with the anterior border of the opposite lamina. The junction of the anterior border of the laminae forms the subcutaneous laryngeal prominence, *prominentia laryngea*, ('Adam`s apple'). This projection is well marked in men but scarcely visible in women.

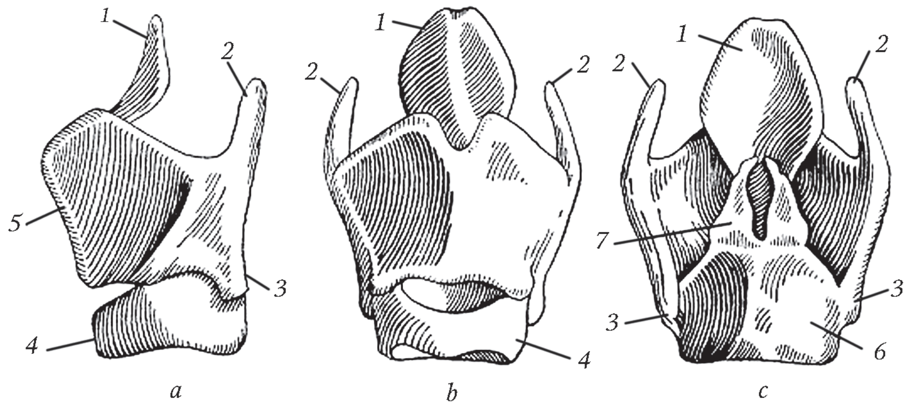


Fig. 1.3. Laryngeal cartilages:

*a* – lateral aspect; *b* – anterior aspect; *c* – posterior aspect;

*1* — epiglottic cartilage (*cartilago epiglottica*); *2* — superior horn of thyroid cartilage (*cornu superius cartilaginis thyroideae*); *3* — inferior horn of thyroid cartilage (*cornu inferius cartilaginis thyroideae*); *4* — arch of cricoid cartilage (*arcus cartilaginis cricoideae*); *5* — thyroid cartilage (*cartilago thyroidea*); *6* — lamina of cricoid cartilage (*lamina cartilaginis cricoideae*); *7* — arytenoid cartilage (*cartilago arytenoidea*)

Above the laryngeal prominence is a superior thyroid notch, *incisura thyroidea superior*, and sometimes below it there is an inferior thyroid notch, *incisura thyroidea inferior*. The paired processes, termed the horns, arise from the posterosuperior and posteroinferior angles of the laminae. The superior horn, *cornu superius*, much longer than the inferior one, is connected to the hyoid bone. The inferior horn, *cornu inferius*, shorter, bears on its apex a small articular facet which articulates with the thyroid articular surface, *facies articularis thyroidea*, of the cricoid cartilage.

On the exterior surface of the lamina an oblique line, *linea obliqua*, runs diagonally from the inferior to superior border of the lamina; the sternothyroid and thyrohyoid are attached to this line.

**Cricoid cartilage**, *cartilago cricoidea* (fig. 1.3, 1.4), hyaline, forms the base of the larynx; below, it is firmly joined to the first tracheal cartilage. The thyroid and arytenoid cartilages are movably connected with the cricoid cartilage. This cartilage has a shape of a signet ring; it consists of an arch and lamina, *arcus cartilaginis cricoideae cum lamina cartilaginis cricoideae*. The lower edge of the cartilage is horizontal; the lamina is directed backwards. On the exterior surface of the lamina, along the midline there is a vertical ridge; on either side of this ridge there is a depression. The cricoid cartilage bear two pairs of the articular surfaces: thyroid articular surfaces, *facies articularis thyroidea*, and arytenoid articular surfaces, *facies articularis arytenoidea*. The thyroid articular surface is small, slightly elevated area which is situated on the external surface of the cartilage`s lateral part. The arytenoid articular surface, convex and ellipsoid, lies along the upper edge of the lamina of the cricoid cartilage, slightly lateral to the midline.

**Epiglottic cartilage**, *cartilago epiglottica*, is an unpaired elastic cartilage situated behind the root of the tongue above the laryngeal inlet. The epiglottic cartilage, covered by the mucosa, is called the epiglottis, *epiglottis*. It is leaf-shaped (fig. 1.3, 1.5, *a*):

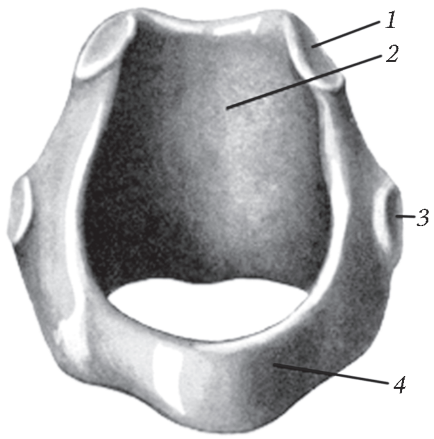


Fig. 1.4. Cricoid cartilage (anterosuperior aspect):

*1* — arytenoid articular surface (*facies articularis arytenoidea*); *2* — lamina of cricoid cartilage (*lamina cartilaginis cricoideae*); *3* — thyroid articular surface (*facies articularis thyroidea*); *4* — arch of cricoid cartilage (*arcus cartilaginis cricoideae*)

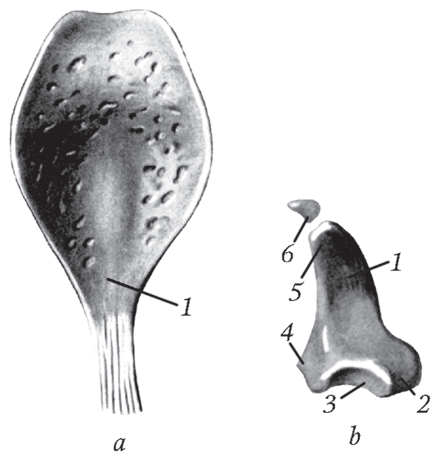


Fig. 1.5. Laryngeal cartilages:

*a* – epiglottic cartilage (posterior aspect): *1* – epiglottic stalk (*petiolus epiglottidis*);
*b* – right arytenoid and corniculate cartilages (posterior aspect): *1* – posterior surface; *2* – muscular process; *3* – articular surface; *4* – vocal process; *5* – apex of arytenoid cartilage; *6* – corniculate cartilage

expands above and tapers into a stalk, *petiolus epiglottidis*, below. The stalk is attached to the posterior surface of the thyroid cartilage below its superior notch. The anterior surface of the epiglottis is convex and directed to the tongue; the posterior surface is concave and directed to the laryngeal cavity. The mucosa of the epiglottis is honeycombed by the numerous pits containing the mucous glands.

**Arytenoid cartilage**, *cartilago arytenoidea* (fig. 1.3, 1.5, *b*), is almost wholly hyaline except its vocal process, *processus vocalis*, which is elastic. The cartilage resembles a trihedral pyramid having a base and apex. The base of the arytenoid cartilage, *basis cartilaginis arytenoideae*, is triangular, slightly concave, directed down and bears the articular surface for the articulation with the lamina of the cricoid cartilage. The apex of the arytenoids cartilage, *apex cartilaginis arytenoideae*, is sharp and slightly inclined backwards. The base has two well-distinct processes: vocal, *processus vocalis*, and muscular, *processus muscularis*. The vocal process is sharp and projects forwards; to the vocal process the vocal ligament is attached. The muscular process is more massive and obtuse; the laryngeal muscles are attached to it. The cricoid cartilage has three surfaces: anterolateral, medial and posterior. The anterolateral surface, *facies anterolateralis*, is the widest; its lower part has a small oblong fovea, *fovea oblongata*, to which the vocalis is attached. The medial surface, *facies medialis*, is the narrowest; it is directed to the same surface of the opposite arytenoid cartilage. The posterior surface, *facies posterior*, is greatly concave; the transverse and oblique arytenoids are attached to it.

**Corniculate cartilage**, *cartilago corniculata* (fig. 1.5, *b*), is a small, elastic, conical cartilage, the base of which is attached to the apex of arytenoid cartilage and the apex of which is slightly inclined backwards and medially. Each lies in the aryepiglottic mucosal fold, *plica aryepiglottica*, and protrudes through the mucosa as the corniculate tubercle, *tuberculum corniculatum*.

**Cuneiform cartilage**, *cartilago cuneiformis*, is elastic, a little bigger than the corniculate cartilage, inconstant in form and size. It is also located in the aryepiglottic fold anterosuperior to the corniculate cartilage and protrudes through the mucosa as the cuneiform tubercle, *tuberculum cuneiforme*.

**Triticeal cartilage**, *cartilago triticea*, not always present, is situated in the lateral thyrohyoid ligaments connecting the superior horns of thyroid cartilage with the greater horns of the hyoid bone.

With age (usually after 20 years of age) the laryngeal cartilages undergo enchondral ossification. First points of the osseous tissue appear in the thyroid cartilage. Later the cricoid cartilage and then the base of the arytenoid cartilage ossify.

### 1.3.2. Articulations of Larynx

The laryngeal cartilages are connected to each other by means of the synovial joints and ligaments. Among the laryngeal articulations there are two paired synovial joints which provide the mobility of the laryngeal cartilages (fig. 1.3, 1.6).

**Cricothyroid joint**, *articulatio cricothyroidea*, is the articulation between the inferior horn of the thyroid cartilage and articular facet on the anterolateral surface of the cricoid cartilage. The right and left cricothyroid joints are functionally united into a single combined joint permitting the movements of the thyroid cartilage around the frontal axis. During the contraction of the muscles, the thyroid cartilage inclines forwards, moving apart from the lamina of the cricoid cartilage and from the arytenoid cartilages, and then comes back to the initial position, closer to cricoid and arytenoid cartilages.

**Cricoarytenoid joint**, *articulatio cricoarytenoidea*, is formed by the articulation of the concave articular surface on the base of the arytenoids cartilage and the convex ar-

ticular surface on the upper edge of the lamina of the cricoid cartilage. Its capsule is very thin and only posteriorly is reinforced by the cry-coarytenoid ligament, *ligamentum cricoarytenoideum*. At this joint the arytenoids cartilage rotates around the vertical axis, moving the vocal processes laterally or medially, increasing or decreasing the rima glottidis.

The laryngeal cartilages are also connected by the solid joints, the ligaments. The cricothyroid ligament, *ligamentum cricothyroideum* (conical ligament, *ligamentum conicum*), extends from the arch of the cricoid cartilage to the lower edge of the thyroid cartilage. It is composed of the elastic fibers and conically expands below.

The epiglottic stalk, *petiolus epiglottidis*, is connected to the inner surface of the thyroid cartilage near its superior notch by the thyro-epiglottic ligament, *ligamentum thyroepiglotticum*.

The wide part of the epiglottis is attached to the body of the hyoid bone by the hyoepiglottic ligament, *ligamentum hyoepiglotticum*. When the larynx descends, this ligament is stretched to set the epiglottis vertically. This provides unimpeded entrance of the air into the laryngeal cavity. Besides, the epiglottis is connected to the root of the tongue by the median and lateral glossoepglottic ligaments, *ligamenta glossoepiglottica medianum et lateralia*.

***Vocal ligament***, *ligamentum vocale*, paired, is inside the vocal fold. It is stretched between the inner angle of the thyroid cartilage and the arytenoid vocal process and composed of the elastic fibers. In fact, it represents the upper border of the elastic cone, *conus elasticus*.

***Vestibular ligament***, *ligamentum vestibulare*, paired, is in the vocal fold. It extends from the arytenoid cartilage (above the vocal process) to the inner surface of the thyroid cartilage`s angle; it is fibrous with the small amount of elastic fibers. The vestibular fold is the lower thickened part of the quadrangular membrane, *membrana quadrangularis*, which forms together with the elastic cone the fibrous-elastic membrane of the larynx (vide infra).

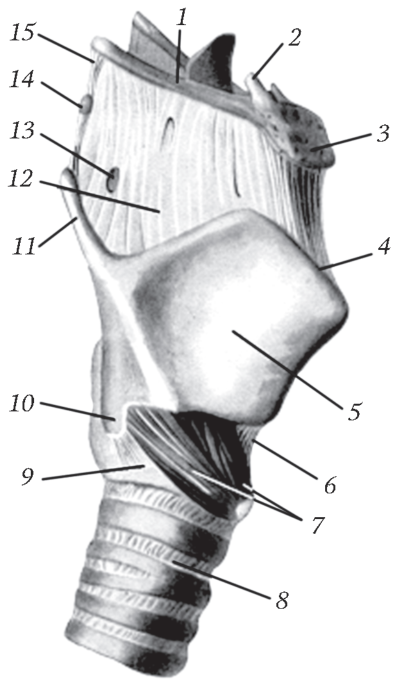


Fig. 1.6. Larynx (lateral aspect):

*1* — greater horn of hyoid bone (*cornu majus ossis hyoidei*); *2* — lesser horn of hyoid bone (*cornu minus ossis hyoidei*); *3* — body of hyoid bone (*corpus ossis hyoidei*); *4* — superior thyroid notch (*incisura thyroidea superior*); *5* — thyroid cartilage (*cartilago thyroidea*); *6* — cricothyroid ligament (*ligamentum cricothyroideum*); *7* — cricothyroid muscle (*m. cricothyroideus*); *8* — trachea (*trachea*); *9* — cricoid cartilage (*cartilago cricoidea*); *10* — inferior horn of thyroid cartilage (*cornu inferius cartilaginis thyroideae*); *11* — superior horn of thyroid cartilage (*cornu superius cartilaginis thyroideae*); *12* — thyrohyoid membrane (*membrana thyrohyoidea*); *13* — openings for superior laryngeal artery and vein; *14* — triticeal cartilage (*cartilago triticea*); *15* — lateral thyrohyoid ligament (*ligamentum thyrohyoideum laterale*)

The corniculate cartilage is connected to the apex of the arytenoid cartilage by the arycorniculate synchondrosis, *synchondrosis arycorniculata*.

The larynx is attached to the hyoid bone by the thyrohyoid membrane, *membrana thyrohyoidea*. The median and lateral parts of the membrane are thickened and form the

ligaments: unpaired median thyrohyoid ligament, *ligamentum thyrohyoideum medianum*, and paired lateral thyrohyoid ligament, *ligamentum thyrohyoideum laterale*. The latter connects the superior horns of thyroid cartilage to the greater horns of hyoid bone. It usually contains the triticeal cartilage.

The larynx is attached to the pharynx by two ligaments: short (paired) corniculopharyngeal ligament, *ligamentum corniculopharyngeum*, passing from the corniculate cartilage backwards and medially, and unpaired cricopharyngeal ligament, *ligamentum cricopharyngeum*, formed by the union of the previous ligaments on the posterior surface of the cricoid cartilage`s lamina. The larynx is connected to the trachea by a circular cricotracheal ligament, *ligamentum cricotracheale*.

### 1.3.3. Laryngeal Muscles

All the laryngeal muscles are striated (skeletal) and functionally they are consciously controlled. The muscles of the larynx are divided into laryngeo-skeletal, which connect the larynx to the bones of the skeleton, and proper laryngeal muscles. The laryngeo-skeletal muscles comprise the sternothyroid and thyrohyoid (infrahyoid muscles, which have been already described in chapter "Myology"). The sternothyroid pulls the larynx down, and the thyrohyoid rises it up.

The proper laryngeal muscles originate from and insert to the laryngeal cartilages. Topographically they are divided into two groups: extrinsic and intrinsic. The extrinsic muscles include the paired cricothyroid. All other muscles are intrinsic. They lie on the posterolateral surface of the larynx, in the vocal and aryepiglottic folds. Among the existing classifications of the laryngeal muscles the functional classification is used more often.

#### *Functional classification of laryngeal muscles:*

**I. *Muscles which modify the rima glottidis:***

1 — dilators (*m. cricoarytenoideus posterior*);

2 — constrictors (*m. cricoarytenoideus lateralis; m. thyroarytenoideus; m. arytenoideus transversus; m. arytenoideus obliquus*).

**II. *Muscles regulating tension of vocal ligaments:***

1 — tensors (*m. cricothyroideus*);

2 — relaxors (*m. vocalis — pars interna m. thyroarytenoideus*).

**III. *Muscles which modify the laryngeal inlet:*** (*m. aryepiglotticus; m. ceratocricoideus*).

**IV. *Muscles of epiglottis*** (*m. thyroepiglotticus*).

**Posterior cricoarytenoid**, *m. cricoarytenoideus posterior* (fig. 1.7), paired, is the muscle which dilates the rima glottidis. It arises from the posterior surface of the cricoid lamina and then ascends laterally to be attached to the arytenoid muscular process. It acts on the cricoarytenoid joint: pulls the muscular process backwards and down, rotating the arytenoid cartilage laterally around the vertical axis thus moving the vocal processes laterally, to open the rima glottidis.

**Lateral cricoarytenoid**, *m. cricoarytenoideus lateralis* (fig. 1.7), paired, arises from the arch and lateral surface of the cricoid cartilage and runs obliquely up and backwards to the muscular process of arytenoid cartilage. From the lateral side this muscle is covered by the lamina of the thyroid cartilage. During contraction, it pulls the arytenoid muscular process forwards and down, rotating the arytenoid cartilage medially around the vertical axis. Thus, the vocal processes are moved medially, the vocal ligaments are

drawn together and the rima glottidis becomes narrow. So, the lateral cricoarytenoid is an antagonist of the posterior cricoarytenoid.

**Thyroarytenoid**, *m. thyroarytenoideus* (fig. 1.7, 1.8), paired and quadrilateral, connects the thyroid and arytenoid cartilages. It extends from the inner aspect of the thyroid angle, ascending backwards to the arytenoid muscular process. The action of this muscle is similar to the action of the preceding muscle. Thus, the lateral cricoarytenoid and thyroarytenoid are synergists.

**Transverse arytenoid**, *m. arytenoideus transversus* (fig. 1.7), unpaired, occupies the concavity of the arytenoids cartilage`s posterior surface; its lower edge reaches the cricoid cartilage, and the upper edge slightly does not reach the corniculate cartilages. The muscle fibers run transversely and connect the lateral edges and the muscular processes of the opposite arytenoids cartilages. The muscle approximates the arytenoids cartilages and narrows the rima glottidis.

**Oblique arytenoid**, *m. arytenoideus obliquus* (fig. 1.7), paired, is arranged in two crossed fascicles lying superficial to the preceding muscle. It extends obliquely up and medially from the muscular process of one arytenoid to the lateral edge of the opposite arytenoid cartilage, near its apex. Both oblique arytenoid muscles approximate the arytenoid cartilages, narrowing the rima glottidis. These muscles are the synergists of the transverse arytenoid muscles.

**Cricothyroid**, *m. cricothyroideus* (fig. 1.6, 1.8), paired, is the strongest of all the laryngeal muscles. It arises from the anterior surface of the cricoid cartilage`s arch by two fan-shaped fascicles, which ascend laterally and are attached to the inner and outer surfaces of the lower edge of the thyroid cartilage (straight part, *pars recta*); and to inferior thyroid horn and the capsule of the cricothyroid joint (oblique part, *pars obliqua*).

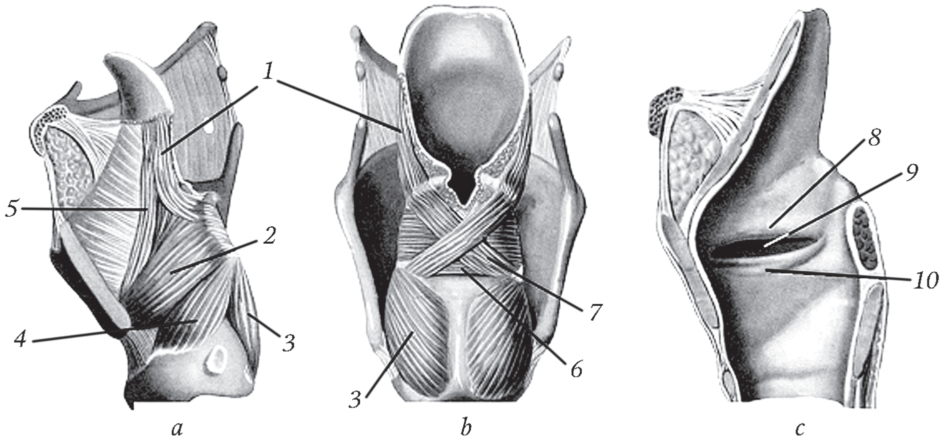


Fig. 1.7. Laryngeal muscles:

*a* – lateral aspect (the left greater horn of the hyoid bone and the left lamina of the thyroid cartilage have been partially removed); *b* – posterior aspect; *c* – median section of larynx;

*1* — aryepiglottic (*m. aryepiglotticus*); *2* — thyroarytenoid (*m. thyroarytenoideus*); *3* — posterior cricoarytenoid (*m. cricoarytenoideus posterior*); *4* — lateral cricoarytenoid (*m. cricoarytenoideus lateralis*); *5* — thyroepiglottic (*m. thyroepiglotticus*); *6* — transverse arytenoid (*m. arytenoideus transversus*); *7* — oblique arytenoid (*m. arytenoideus obliquus*); *8* — vestibular fold (*plica vestibularis*); *9* — laryngeal ventricle (*ventriculus laryngis*); *10* — vocal fold (*plica vocalis*)

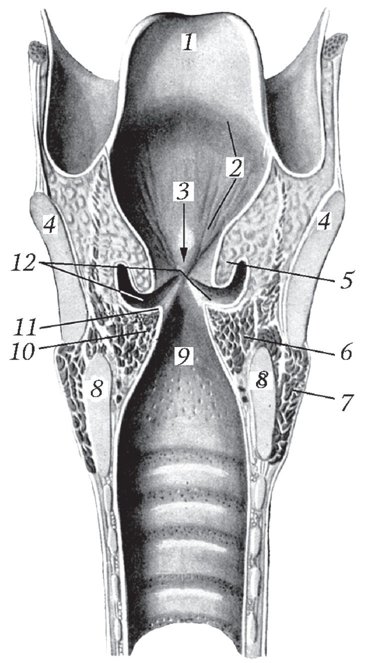


Fig. 1.8. Larynx (frontal section; posterior aspect):

*1* — epiglottis (*epiglottis*); *2* — laryngeal vestibule (*vestibulum laryngis*); *3* — rima vestibuli (*rima vestibuli*); *4* — thyroid cartilage (*cartilago thyroidea*); *5* — vestibular fold (*plica vestibularis*); *6* — thyroarytenoid (*m. thyroarytenoideus*); *7* — cricothyroid (*m. cricothyroideus*); *8* — cricoid cartilage (*cartilago cricoidea*); *9* — infraglottic cavity (*cavitas infraglottica*); *10* — vocalis muscle (*m. vocalis*); *11* — vocal fold (*plica vocalis*); *12* — laryngeal ventricle (*ventriculus laryngis*)

The muscle acts on the cricothyroid joint, moving the thyroid cartilage apart from the cricoid arch. During the contraction, the cricothyroid muscles incline the thyroid cartilage forwards increasing the distance between the thyroid and arytenoids cartilages and thus tensing the vocal ligaments; the rima glottidis is closed.

**Vocalis muscle**, *m. vocalis* (fig. 1.8), paired, is an antagonist of the cricothyroid. It lies in the vocal fold, arising from the lower part of the inner aspect of the thyroid angle. The muscle fascicles pass sagittally and are attached to the lateral surface of the arytenoid vocal process. In fact they are formed by the inner fascicles of the thyroarytenoid muscle. The fibers of the vocalis muscle closely adjoin the vocal ligament and blend with it. They are not parallel to the vocal ligament but oriented in different directions: horizontally, vertically, obliquely, at an angle to the rima glottidis. The muscle may contract entirely (approximating the vocal process to the thyroid cartilage and making the vocal ligament shorter and thicker thus relaxing it) or by its individual fascicles. When the oblique fascicles contract the vocal ligament relaxes not entirely but only in its some parts. During relaxation, the vocal ligaments become a little thicker thus the rima glottidis slightly narrows.

**Aryepiglottic**, *m. aryepiglotticus* (fig. 1.7), paired, is in the aryepiglottic mucosal fold. It runs from the apex of the arytenoid cartilage to the lateral border of the epiglottis. Some fascicles of the oblique arytenoid are continuous with the aryepiglottic. Both aryepiglottic muscles together with the oblique arytenoids narrow the laryngeal inlet. The contraction of these muscles (during swallowing) inclines the epiglottis backwards and closes the laryngeal inlet to prevent the passage of the food bolus to the respiratory tract.

**Ceratocricoid**, *m. ceratocricoideus*, paired, arises from the lateral thyrohyoid ligament and triticeal cartilages and is attached to the cricoid lamina. The muscle acts as a sphincter of the laryngeal inlet.

**Thyroepiglottic**, *m. thyroepiglotticus*, paired, is a muscle of the epiglottis. It is a small muscle bundle extending between the anterior surface of the epiglottic cartilage and the inner surface of the thyroid cartilage. The muscle elevates the epiglottis.

### 1.3.4. Laryngeal Cavity

The laryngeal cavity, *cavitas laryngis*, resembles the form of a sand-glass on the frontal section (fig. 1.8): in the middle it is narrow; up and down it is expanded. The laryngeal cavity can be conventionally divided into three parts: superior, the laryngeal vestibule,

*vestibulum laryngis*; middle, the intermediate part of larynx, *pars intermedia larynges*; and inferior, the infraglottic cavity, *cavitas infraglottica*.

The vestibule is communicated with the pharynx through the laryngeal inlet, *aditus laryngis* (fig. 1.7, 1.9). It is bounded anteriorly by the upper edge of the epiglottis; laterally by a paired mucosal fold called the aryepiglottic fold, *plica aryepiglottica*, connecting the edge of the epiglottis to the apex of arytenoid cartilage; posteriorly by an unpaired interarytenoid fold, *plica interarytenoidea*, which connects the apices of the arytenoid cartilages and bridges the interarytenoid notch, *incisura interarytenoidea*. In the posterior part of the aryepiglottic fold there are two small tubercles: corniculate and cuneiform, *tuberculum corniculatum et tuberculum cuneiforme*, formed by the corniculate and cuneiform cartilages located inside the fold. Below, the laryngeal vestibule narrows and becomes a funnel-shaped.

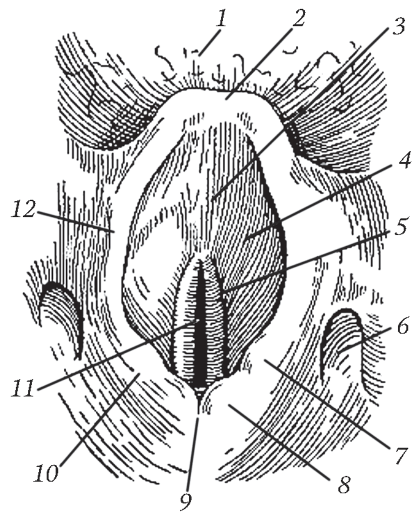


Fig. 1.9. Laryngeal inlet and laryngeal vestibule:

*1* — root of tongue (*radix linguae*); *2* — epiglottis (*epiglottis*); *3* — epiglottic tubercle (*tuberculum epiglotticum*); *4* — laryngeal vestibule (*vestibulum laryngis*); *5* — vocal fold (*plica vocalis*); *6* — piriform recess (*recessus piriformis*); *7* — cuneiform tubercle (*tuberculum cuneiforme*); *8* — corniculate tubercle (*tuberculum corniculatum*); *9* — interarytenoid notch (*incisura interarytenoidea*); *10* — rima glottidis (*rima glottidis*); *11* — vestibular fold (*plica vestibularis*); *12* — aryepiglottic fold (*plica aryepiglottica*)

The laryngeal vestibule is separated from the intermediate part by the vestibular folds, *plicae vestibulares*, which are formed by the mucosa and called the false vocal folds. Between them there is a fissure, the rima vestibuli, *rima vestibuli*. The anterior wall of the vestibule is 3—4 cm in height. It is formed by the posterior surface of the epiglottis where along the midline the epiglottic tubercle, *tuberculum epiglotticum*, projects; the tubercle is formed by the protruded epiglottic stalk. The posterior wall is significantly shorter (1–1,5 cm) and is represented by the arytenoid cartilages and interarytenoid notch.

The intermediate part of the larynx is the narrowest. It extends from the vestibular folds above to the vocal folds below. Between the vestibular and vocal folds on either side of the larynx there is a laryngeal ventricle, *ventriculus laryngis (Morganii)* (fig. 1.7, 1.9). Therefore, the intermediate part of the larynx is also called the interventricular part, *pars interventricularis*. Each ventricle is a blind pouch in the lateral wall of the larynx, having the shape of a depression elongated in sagittal plane. The ventricles play the role of resonators during phonation, and also help to warm inspired air.

The narrowest part of the laryngeal cavity is the rima glottidis, or vocalis, *rima glottidis seu rima vocalis*, oriented sagittaly (fig. 1.9). From the sides it is limited by the vocal folds, *plicae vocales*. The vocal fold differs from the vestibular fold in its structure and exterior view. It represents the double layer of the mucosa but its border is sharper and paler than the border of the vestibular fold, and located closer to the midline. The vocal fold encloses the vocal ligament (lies medially, near the free border of the fold); the vocalis muscle (lies laterally); the posterior part of the fold contains the arytenoid vocal process.

The rima glottidis has two parts: anterior, intermembranous part, *pars intermembranacea*, (vocal part, *pars vocalis*), limited by the vocal folds; and posterior, intercartilaginous part, *pars intercartilaginea* (respiratory part, *pars respiratoria*), bounded by the arytenoid vocal processes (fig. 1.10). The length of the rima glottidis (anteroposterior size) is 20–24 mm in males and 16–20 mm in females. The intermembranous part ($^3/_4$ of the whole length of the rima glottidis) is narrower and longer. The intercartilaginous part is wider and shorter. The size of the rima glottidis correlates with the intensity of the breathing. In quite breathing the width of the rima glottidis is about 5 mm, while in deep breathing and loud cry it reaches 15 mm, but during phonation it may abruptly narrow.

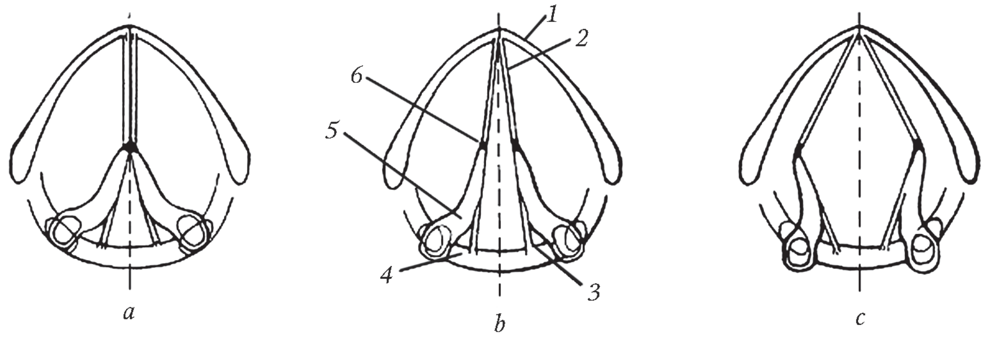


Fig. 1.10. Different positions of vocal ligaments (scheme):
*a* – phonation (closed rima glottidis); *b* – quiet respiration ("resting" position); c – forced respiration (rima glottidis is maximally opened);
*1* – thyroid cartilage (*cartilago thyroidea*); *2* – vocal ligament (*ligamentum vocale*); *3* – cricoarytenoid ligament (*ligamentum cricoarytenoideum*); *4* – cricoid cartilage (*cartilago cricoidea*); *5* – arytenoid cartilage (*cartilago arytenoidea*); *6* – vocal process (*processus vocalis*)

The form of the rima glottidis may be examined in details during laryngoscopy (using a laryngeal mirror). This method allows a doctor to observe clearly the root of the tongue, the laryngeal inlet, rima vestibuli and rima glottidis (fig. 1.11). In forced breathing the trachea and tracheal bifurcation are visible.

Due to coordinating contractions of the laryngeal muscles, the vocal ligaments tense in great or less degree. The air stream, passing through the rima glottidis during expiration, causes the vibration of the vocal ligaments. The vibrations of the ligaments are transmitted to the air above the larynx resulting in the sound production. The timbre, peculiar to each person, depends on the length, thickness and tension of the vocal ligaments. All the laryngeal muscles participate in phonation.

The larynx is fixed by the muscles lying above and below the hyoid bone, i.e. laryngeo-skeletal muscles. The cricothyroid muscles tilt the thyroid cartilage forward to tense the vocal ligaments, and slightly narrow the rima glottidis. The closure of the rima glottidis is provided by simultaneous contraction of the lateral cricoarytenoid, thyroaritenoid, transverse and oblique arytenoid muscles and also vocalis. All these muscles have a single antagonist: the posterior cricoarytenoid muscle which dilates the rima glottidis.

The lower part of the laryngeal cavity, located under the rima glottidis, the infraglottic cavity, gradually expands to be continuous with the trachea.

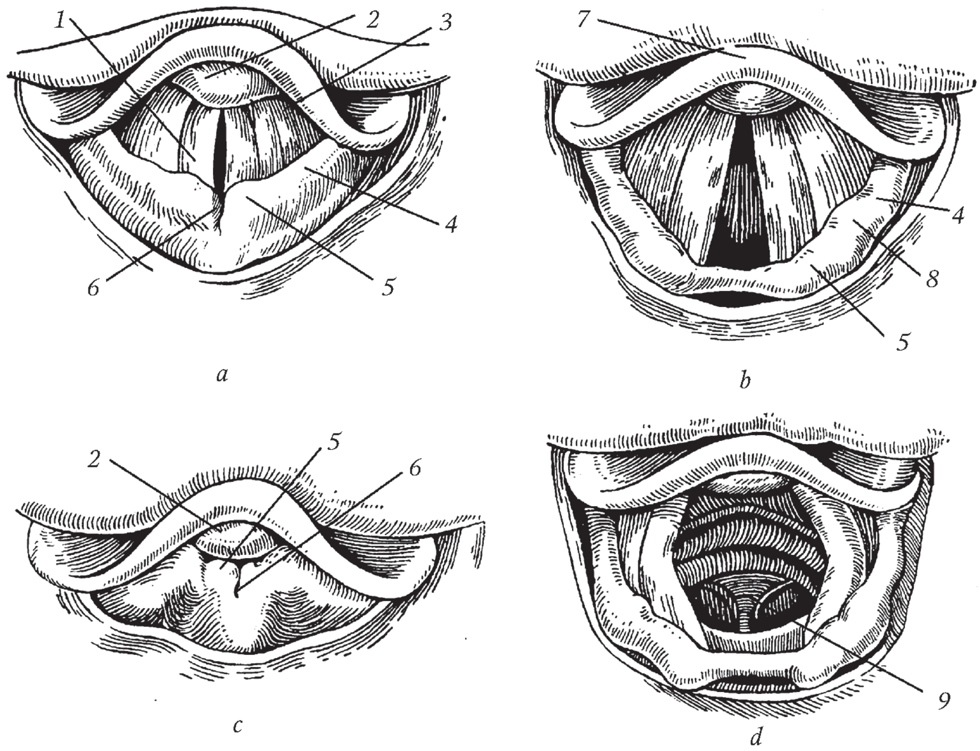


Fig. 1.11. Different shapes of rima glottidis, observed during laryngoscopy:

*a* — the vocal ligaments are tensed, the rima glottidis is almost closed (during the pronunciation of high sounds); *b* — quiet respiration (the moment of inspiration); *c* — full closure of the laryngeal inlet; *d* — deep inspiration, the rima glottidis is fully opened; the tracheal mucosa is visible;

*1* — vocal fold (*plica vocalis*); *2* — epiglottic tubercle (*tuberculum epiglotticum*); *3* — vestibular fold (*plica vestibularis*); *4* — aryepiglottic fold (*plica aryepiglottica*); *5* — corniculate tubercle (*tuberculum corniculatum*); *6* — interarytenoid notch (*incisura interarytenoidea*); *7* — epiglottis (*epiglottis*); *8* — cuneiform tubercle (*tuberculum cuneiforme*); *9* — tracheal bifurcation (*bifurcatio tracheae*)

### 1.3.5. Structure of Laryngeal Wall

The frame of the laryngeal wall is formed by the cartilages and their joints. The striated muscles covered by adventitia, lie outside. From inside the laryngeal cavity is lined by the mucous membrane. It is thin, has pale-pink color; the mucosa over the vocal folds is almost white. The mucosa is covered by ciliated columnar epithelium and contains the sero-mucous glands. These glands are especially numerous in the area of the vestibular folds, laryngeal ventricles and posterior surface of the epiglottis. Their secretion humidifies the vocal folds. The mucosa over the vocal folds is covered by stratified squamous epithelium; it is firmly fused with the submucosa and does not contain the glands. In other parts of the larynx the mucosa is linked with the submucosa loosely, especially over the vestibular folds. Here the swelling causing breathing difficulty may occur (false croup).

The submucosa contains a lot of fibrous and elastic fibers which form the fibrous-elastic membrane of the larynx, *membrana fibroelastica laryngis*. It consists of two parts: quadrangular membrane and elastic cone. The quadrangular membrane, *membrana quadrangularis*, is under the mucosa of the laryngeal vestibule. Above, it reaches the arytenoids cartilages, and below, its free border forms the vestibular ligament which lies in the vestibular fold.

The elastic cone, *conus elasticus*, is under the mucosa of the infraglottic cavity. It represents the elastic membrane having the shape of a tent. The fibers of the elastic cone arise from the upper edge of the cricoid arch, ascend medially as a cricothyroid ligament and are attached to the inner surface of the thyroid cartilage, near its angle, and posteriorly to the bases and arytenoid vocal processes. The upper free margin of the elastic cone, stretched between the thyroid cartilage anteriorly and arytenoid vocal processes posteriorly, forms the vocal ligament on either side of the larynx. Unlike the vestibular ligament, the vocal ligament is constructed from only elastic fibers hence, is thinner.

## TEST QUESTIONS

1. Describe the structure of the walls of the nasal cavity. What cartilages and bones form the walls of the nasal cavity? Describe the structure of the nasal septum. What openings lead into the nasal cavity? What openings communicate the nasal cavity with the nasopharynx?
2. What is the nasal meatus? Describe the meatuses of the nasal cavity and their communications (what sinuses or canals are opened into each meatus).
3. Describe the paranasal sinuses (their walls, relations with the surrounding structures, their communications and function).
4. Describe the features of the nasal mucosa.
5. Describe the skeletotopy of the larynx and its relations with surrounding organs.
6. Describe the cartilages of the larynx.
7. What ligaments connecting the laryngeal cartilages do you know?
8. Describe the synovial joints of the laryngeal cartilages and the movements at these joints.
9. What groups of the laryngeal muscles are distinguished?
10. Describe the origin and insertion of the laryngeal muscles and their action.
11. Describe the laryngeal cavity: the layers, the parts.
12. Describe the functioning of the vocal apparatus.

## CLINICOANATOMICAL PROBLEMS

1. The radiograph shows the darkness and the level of a fluid in the right maxillary sinus. The highmoritis is diagnosed. An ENT-doctor has to do the puncture of the sinus to evacuate the pus. Through which nasal meatus and at what depth should he put in the needle to perform the puncture?
2. A patient with diphtheria has a difficult breathing because of the significant closure of the tracheal lumen by the diphtheritic membrane. It is necessary to perform the intubation (to insert the tube through the larynx into the trachea). Through which organs (in sequence) will a doctor insert the tube? What length will this tube be?
3. ENT-doctor is performing the laryngoscopy. What signs help him to distinguish the true and false vocal folds?

## 1.4. Trachea

The trachea, *trachea*, is a hollow tube, 11—13 cm long, slightly flattened from front to back. The transverse size of the trachea is 15—18 mm. Immediately above the bifurcation, the diameter of the trachea is the smallest (fig. 1.12).

The trachea arises at the level of the intervertebral disc between the bodies of the VI–VII cervical vertebrae. Opposite the intervertebral disc between the IV and V thoracic vertebrae the trachea divides into two principal bronchi, forming the tracheal bifurcation, *bifurcatio tracheae*. Here the trachea has a prominence projected into its lumen and called the carina of trachea, *carina tracheae*. In the region of the bifurcation the trachea is firmly attached to the surrounding organs, while its upper part may slightly displace, because it is surrounded by areolar tissue.

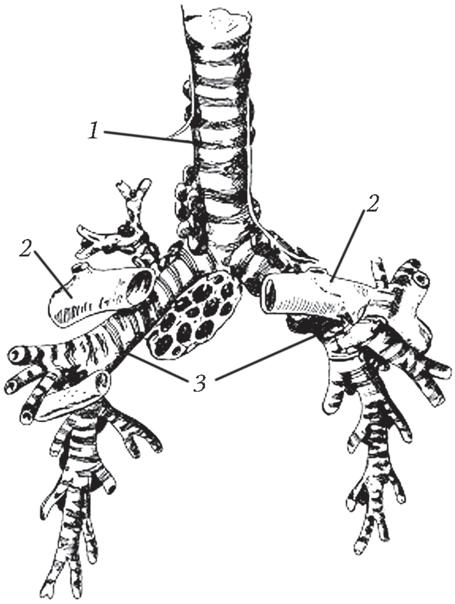


Fig. 1.12. Trachea and bronchi (anterior aspect):
*1* — trachea; *2* — left and right pulmonary arteries; *3* — principal bronchi

Topographically the trachea is divided into two parts: cervical, *pars cervicalis*, and thoracic, *pars thoracica*. The thoracic part is longer and begins at the level of the superior thoracic aperture.

In the neck in front of the trachea there is a parietal lamina of endocervical fascia fused with the pretracheal lamina of proper cervical fascia. The latter encloses the sternothyroid and sternohyoid. Immediately behind them there is a pretracheal space, *spatium pretracheale*, containing the fat and inferior thyroid veins. The thyroid gland adjoins the cervical part of the trachea. Its isthmus embraces the II—IV tracheal cartilages from the anterior side, while its right and left lobes descend to the V–VI tracheal cartilages. The oesophagus is behind and slightly to the left of the trachea. In the grooves between the trachea and oesophagus the laryngeal recurrent nerves pass. To the right and to the left of the trachea are the neuro-vascular cervical bundles.

The thoracic part of the trachea passes in the mediastinum, conditionally separating it into anterior and posterior. In front of the thoracic part of the trachea, immediately above the bifurcation is the aortic arch which rounds the trachea from the left. Also anterior to the trachea are the brachiocephalic trunk, left brachiocephalic vein, commencement of the left common carotid artery and fat, and in children the thymus. The fat situated in front of the trachea contains numerous lymph nodes; they are especially numerous opposite the tracheal bifurcation (fig. 1.12).

**Structure of trachea.** The skeleton of the trachea is formed by the incomplete tracheal cartilages, *cartilagines tracheales*, having the shape of semirings. Each is like an arch occupying approximately two thirds of the trachea`s circumference with the free ends directed backwards. The number of the cartilages is inconstant (15–20), their shape is various. The width (height) of the cartilages is 3–4 mm, their thickness is

1–2 mm. The uppermost cartilage is the widest and connected to the cricoid cartilage. The tracheal cartilages are hyaline, covered by perichondrium and connected by the annular ligaments, *ligamenta annularia*, which are two times narrower than the cartilages. Directing backwards, the annular ligaments are continuous with the posterior membranous wall, *paries membranaceus*. The annular ligaments are composed of the connective-tissue fascicles arranged parallelly to the length of the trachea. The membranous wall contains well-marked fascicles of smooth tracheal muscles, *musculi tracheales*, oriented transversely. From outside the trachea is covered by adventitia. Owing to the tracheal cartilages, annular ligaments and membranous wall the trachea possesses a great extensibility and elasticity, but at the same time the cartilaginous skeleton of the trachea supports the tracheal lumen that is necessary for the air circulation.

The inner surface of the trachea is lined by the mucosa covered by ciliated columnar epithelium, contains the mucous glands and lymph nodes. The lamina propria of the mucosa has a network of elastic fibers. The submucosa in the region of the annular ligaments and membranous wall contains a lot of small tracheal glands, *glandulae tracheales*, elaborating the mixed secretion.

## 1.5. Bronchi

The principal bronchi (right and left), *bronchi principales dexter et sinister*, arise from the trachea at the level of the intervertebral disc between the IV and V thoracic vertebrae and run to the hilum of the corresponding lung (fig. 1.12). The bronchi diverge at an angle of about 70 °, but the right bronchus is more vertical, shorter and wider than the left bronchus. Its greater width and more vertical course explain why inhaled foreign bodies enter the right principal bronchus more often than the left. The length of the right bronchus (from the beginning to the branching into the lobar bronchi) is about 3 cm; the length of the left bronchus is about 4—5 cm. Before the drainage into the superior vena cava the azygos vein arches over the right principal bronchus. Below the right principal bronchus is the right pulmonary artery. Above the left principal bronchus there are the left pulmonary artery and the aortic arch, and behind it there are the oesophagus and descending aorta.

The wall of the principal bronchi is similar to the wall of the trachea in structure. The skeleton of the principal bronchi is formed by the cartilaginous (hyaline) incomplete rings (6–8 in the right bronchus, and 9—12 in the left bronchus). The posterior wall of the bronchi is membranous and composed of mainly smooth muscles. From inside the principal bronchi are lined by the mucosa with the ciliated columnar epithelium, from outside they are covered by adventitia.

The larynx, trachea and principal bronchi form the airways, constantly opened, because their walls contain the cartilaginous incomplete rings. The vibrations of cilia of the respiratory epithelium evacuate outwards the particles of dust, bacterias etc, which enter the respiratory tract during inspiration.

## 1.6. Lungs

The right and left lungs (fig. 1.13), *pulmo dexter et pulmo sinister* (in Greek *pneumon*), are placed in the right and left halves of the thoracic cavity. Each is covered by the pleural sac. The lungs are separated from each other by the organs comprising the mediastinum; below they are in contact with the diaphragm; anteriorly, posteriorly and on the sides they adjoin the walls of the thoracic cavity.

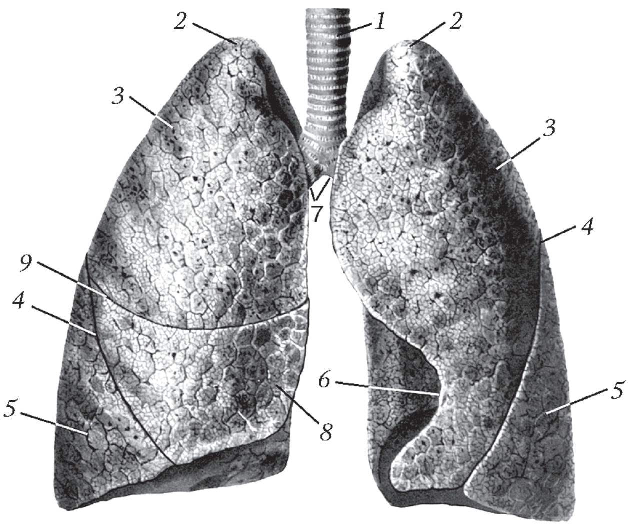


Fig. 1.13. Trachea, principal bronchi and lungs (anterior aspect):

*1* — trachea (*trachea*); *2* — apex of lung (*apex pulmonis*); *3* — superior lobe (*lobus superior*); *4* — oblique fissure (*fissure obliqua*); *5* — inferior lobe (*lobus inferior*); *6* — cardiac notch (*incisura cardiaca*); *7* — principal bronchi (*bronchi principales*); *8* — middle lobe (*lobus medius*); *9* — horizontal fissure of the right lung (*fissura horizontalis pulmonis dextri*)

The form and size of the right and left lungs are unequal. The total weight of the right lung is approximately 10 % greater than the weight of the left lung. The right lung is a little shorter and wider than the left lung because diaphragmatic dome on the right is higher than on the left. Besides, the left lung is compressed by the heart, the apex of which is directed to the left. Each lung is covered by pleura consisting of the fibrous lamina and mesothelium like the other serous membranes. It is transparent, shiny, smooth, moistened by serous fluid. During inspiration, when the lung is quite filled with air, its lobular structure is clearly visible: the lung`s surface shows small polygonal areas, the size of which varies from 0,5 to 1,2 cm. Each of these areas corresponds to the pulmonary lobule, *lobulus pulmonis.* The boundaries between the individual lobules are formed by the connective-tissue septa, the blood vessels, spreading in the septa, and by pigmentation (in adults).

In children the lungs are pale pink, in adults they are dark grey and mottled. With age this maculation becomes black, due to the granules of inhaled carbonaceous material deposited in connective tissue of lungs.

The parenchyma of the lung is soft and gentle, like a sponge, due to contained air; therefore, the lungs do not sink in water. The lungs, which have never been functioned (e.g. the lungs of a stillborn fetus), sink in water. This fact is used in forensic medical examination. Owing to the abundance of elastic fibers in the stroma, the lungs possess a great elasticity that is important for their functioning.

**Lung capacity.** In maximal expansion of the thorax (during the deepest inspiration) the both lungs of an adult healthy man contain about 4000–5000 ml of air. After a maximal exhalation, about 1500 ml of air stays in the lungs: this is so called residual volume (it also remains in the lungs of a cadaver). The difference between these vol-

umes is 3500 ml: this is an average vital capacity of the lungs. The latter is composed of three values: tidal volume, inspiratory reserve volume and expiratory reserve volume. The tidal volume (400–500 ml) is the volume of air, inspired or expired during normal quiet breathing. The inspiratory reserve volume (1500–2000 ml) is the maximal volume of air that can be inhaled after a normal inspiration. The expiratory reserve volume (500–1000 ml) is the maximal volume of air that can be exhaled after a normal (not forced) expiration. The tidal volume directly correlates to the degree of the development of the thorax. Thus, the physical exercises and training of the respiratory musculature, especially in young age, contribute to the formation of high and wide thoracic cage with well-developed lungs. After 35–40 years of age the vital capacity of lungs gradually becomes to decrease.

The weight of the lungs is variable; it ranges not only individually but also depends on the content of blood in the lungs. In average, the weight of the lungs in adult men is ranges between 1000 g and 1300 g; in adult women it 200–300 g less. Thus, it correlates to the body weight as 1 : 50.

**External structure of lungs.** The lung has the form of an irregular cone, the flat side of which is directed to the mediastinum. The organ has a base, *basis pulmonis*, adjoining the diaphragm, and also a rounded end, apex of lung, *apex pulmonis*. The lung has four surfaces and three borders. The diaphragmatic surface, *facies diaphragmatica*, slightly concave, corresponds to the base of the lung. The widest surface of the lung is the costal surface, *facies costalis*; it is convex, adapted to the inner surface of the thoracic wall and carries the imprints of the ribs. Posteriorly, the costal surface has a vertebral part, *pars vertebralis*, which is in contact with the vertebral column. The surfaces of the lungs, facing each other, are termed the interlobular surfaces, *facies interlobares*. The surface of the lung, directed to the mediastinum, is the mediastinal surface, *facies mediastinalis*. Its inferior part is adapted to the heart as the cardiac impression, *impressio cardiaca*, which is deeper on the left lung. On the mediastinal surface, a little above its middle, there is an oval depression termed hilum, *hilum pulmonis*, where the principal bronchus, pulmonary artery and nerves enter the lung, and the pulmonary veins and lymphatic vessels leave the lung. These structures enveloped by connective-tissue form the root of the lung, *radix pulmonis*. At the hilum there are several bronchopulmonary lymph nodes, *nodi lymphoidei bronchopulmonales*. The hilum of the right lung is shorter and wider than that of the left lung; the height of the hila is 4–9 cm. The superior edges of the hila are at the level of the V thoracic vertebra posteriorly and the II rib or the II intercostal space anteriorly.

The components of the roots are arranged differently in the right and in the left lungs (fig. 1.14, 1.15). In the left root the pulmonary artery lies above all, the principal bronchus is below and somewhat behind it and two pulmonary veins are in front of and below the bronchus. In the right root the principal bronchus is above all, the pulmonary artery is in front of and below it and two pulmonary veins are in front of and below the artery. So, the rule of the arrangement of the structures in the hila is as follows: on the left, from above down, the sequence is artery, bronchus, veins ("ABV"); on the right: bronchus, artery, veins ("BAV").

The surfaces are separated by the borders. Each lung has three borders: anterior, inferior and posterior. The anterior border, *margo anterior*, sharp, is between the costal and mediastinal surfaces. On the right lung it passes almost vertically and then is continuous with the inferior border. On the left lung it shows the cardiac notch, *incisura cardiaca* (*pulmonis sinistri*), caused by the position of the heart. Below, the notch is bounded by the lingula of left lung, *lingula pulmonis sinistri*. The inferior border, *margo inferior*,

also sharp, separates the costal and mediastinal surfaces from the diaphragmatic. The posterior border corresponds to the heads of the ribs; it is rounded because the costal surface is continuous with the vertebral part gradually.

The mediastinal surfaces of the lungs have several grooves formed by the adjoining blood vessels: the subclavian groove passes on the apex of both lungs; in front of it on the right lung is the groove for the superior vena cava; a vertical groove, passing behind the hilum of the left lung, is adapted to the descending aorta; the azygos vein makes a groove behind the hilum of the right lung.

Each lung is divided into the lobes, *lobi pulmones*, by the fissures (fig. 1.13—1.15). The right lung has three lobes: superior, middle and inferior; the left lung has two lobes: superior and inferior. The oblique fissure, *fissura obliqua*, passes almost equally on the both lungs. It begins on the rounded posterior border of the lung, 6–7 cm below the

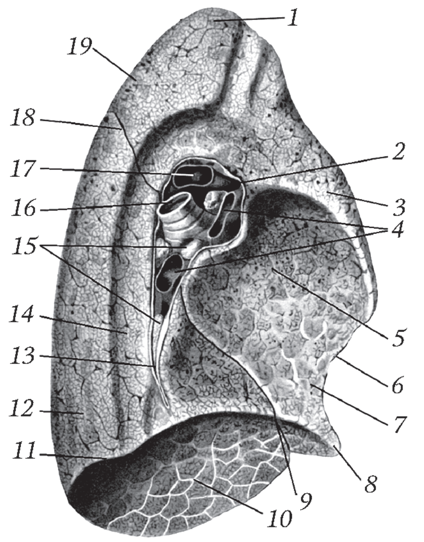


Fig. 1.14. Left lung (medial aspect):

*1* — apex of lung (*apex pulmonis*); *2* — hilum of lung (*hilum pulmonis*); *3* — mediastinal surface (*facies mediastinalis*); *4* — left pulmonary veins (*venae pulmonales sinistrae*); *5* — cardiac impression (impressio cardiaca); *6* — anterior border (*margo anterior*); *7* — superior lobe (*lobus superior*); *8* — lingula of the left lung (*lingula pulmonis sinistri*); *9* — oblique fissure (*fissura obliqua*); *10* — diaphragmatic surface (*facies diaphragmatica*); *11* — inferior border (*margo inferior*); *12* — inferior lobe (*lobus inferior*); *13* — pulmonary ligament (*ligamentum pulmonale*); *14* — aortic groove (*sulcus aorticus*); *15* — bronchopulmonary lymphatic node (nodus lymphoideus bronchopulmonalis); *16* — left principal bronchus (*bronchus principalis sinister*); *17* — left pulmonary artery (*arteria pulmonalis sinistra*); *18* — oblique fissure (*fissura obliqua*); *19* — vertebral part (*pars vertebralis*)

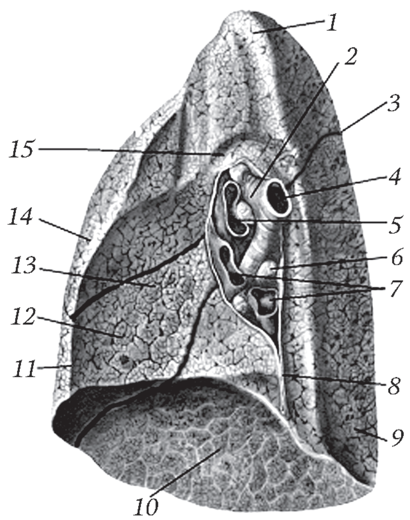


Fig. 1.15. Right lung (medial aspect):

*1* — apex of lung (*apex pulmonis*); *2* — hilum of lung (*hilum pulmonis*); *3* — oblique fissure (*fissura obliqua*); *4* — right principal bronchus (*bronchus principalis dexter*); *5* — right pulmonary artery (*arteria pulmonalis dextra*); *6* — bronchopulmonary lymphatic node (nodus lymphoideus bronchopulmonalis); *7* — right pulmonary veins (*venae pulmonales dextrae*); *8* — pulmonary ligament (*ligamentum pulmonale*); *9* — inferior lobe (*lobus inferior*); *10* — diaphragmatic surface (*facies diaphragmatica*); *11* — anterior border (*margo anterior*); *12* — middle lobe of the right lung (*lobus medius pulmonis dextri*); *13* — cardiac impression (impressio cardiaca); *14* — superior lobe (*lobus superior*); *15* — mediastinal surface (*facies mediastinalis*)

apex, approximately level with the III thoracic spinous process; it then descends forwards along the VI rib, reaching the inferior border of the lung opposite the junction of the shaft and cartilage of the VI rib. It then continues to the diaphragmatic surface and finally ascends posteriorly on the mediastinal surface to reach the hilum. Thus, the oblique fissure crosses all the surfaces of the lung, deeply penetrates into the organ up to the hilum and divides the lung into two lobes connecting only in the area of the hilum. The inferior lobe, *lobus inferior*, is a little bigger than the superior, *lobus superior*. Due to the course of the oblique fissure, the apex and much of the costal surface of the lung belong to the superior lobe, while the base, most of the posterior border and the rest of the costal surface comprise the inferior lobe.

Besides the oblique fissure, the right lung has the horizontal fissure, *fissura horizontalis pulmonis dextri* (fig. 1.13, 1.15). It begins on the costal surface from the oblique fissure, approximately level with the posterior axillary line; it then runs almost horizontally forwards, matching the position of the IV rib, reaches the anterior border of the lung, and then continues to the mediastinal surface to end in front of the hilum. So, the horizontal fissure separates from the superior lobe a small part, the middle lobe of the right lung, *lobus medius pulmonis dextri*, having a triangular shape on the costal surface.

Thus, the superior lobe of the left lung corresponds to both superior and middle lobes of the right lung in the volume and relations (fig. 1.13).

The posterior part of the costal surface is formed by the smaller superior lobe and larger inferior lobe.

The division of the lungs into the lobes is variable: sometimes the horizontal fissure is absent or poorly expressed, and in this case the right lung consists of two lobes. Rarely the lung has three lobes, and more rarely it is comprised of four lobes.

**Branching of bronchi in the lungs.** In the hilum the principal bronchus, *bronchus principalis*, divides into the lobar bronchi, *bronchi lobares*; the right lung has three lobar bronchi, and the left lung has two lobar bronchi. The bronchus, entering the superior lobe of the right lung, lies above the artery, while the bronchi, entering other lobes of the right and left lungs, are below the arteries. The lobar bronchi enter the lobes of the lungs and then divide into the segmental bronchi, *bronchi segmentales* (fig. 1.16, table 1).

The segmental bronchus enters the segment, which is a cone-shaped part of the pulmonary lobe, directed by its base to the surface of the lung and by its apex to the root of the lung and consisting of the pulmonary lobules. In the center of the segment there are the segmental bronchus and segmental artery, and at the boundary with the neighboring segment is the segmental vein. The segments are separated from each other by connective tissue containing few vessels. The names of the segments correspond to the names of the segmental bronchi. According to International Anatomical Terminology, each lung consists of 10 segments (table 1).

In the bronchial tree (fig. 1.17) the segmental bronchi are tertiary (bronchi of the III order), the lobar bronchi are secondary (bronchi of the II order) and the principal bronchi are primary (bronchi of the I order). The segmental bronchus branches into the 9–10 generations of the intersegmental bronchi, *bronchi intrasegmentales* (their branching is magistral-like). The bronchus of 1 mm in diameter enters the pulmonary lobule and is called the lobular bronchus, *bronchus lobularis*. The pulmonary lobule is a small pyramidal-shaped part of the lung parenchyma, having the diameter of 10–15 mm. The total number of the lobules in both lungs is about 1000. Inside the lobule the lobular bronchus divides into 12–18–24 terminal bronchioles, *bronchioli terminales*, the total number of which in both lungs is about 20 000. Their diameter is 0,3–0,5 mm. The bronchial tree, *arbor bronchialis*, which forms the conducting portion of the lung, ends by the terminal bronchioles.

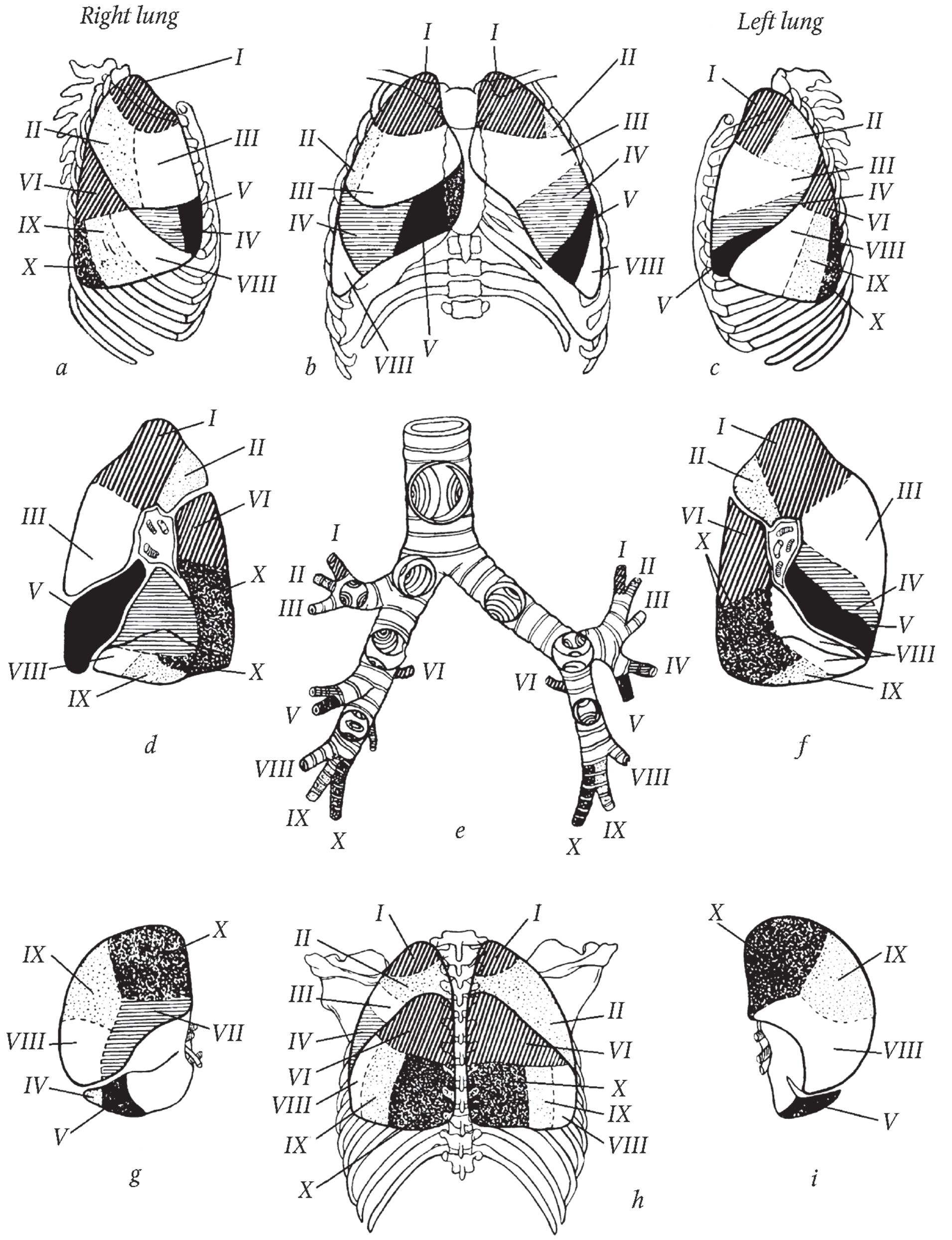


Fig. 1.16. Segments of lungs (scheme). The digits denote the segments which are given in table 1: *a* — lateral aspect; *b* — anterior aspect; *c* — lateral aspect; *d* — mediastinal surface; *e* — bronchial tree; *f* — mediastinal surface; *g* — diaphragmatic surface; *h* — posterior aspect; *i* — diaphragmatic surface

*Table 1*

**The bronchial tree and bronchopulmonary segments in relationship (in accordance with International Anatomical Terminology)**

| Principal bronchi | Lobar bronchi | Segmental bronchi | Bronchopulmonary segments |
|---|---|---|---|
| Right principal bronchus | Right superior lobar bronchus | Apical segmental bronchus (BI) | Apical segment (SI) |
| | | Posterior segmental bronchus (BII) | |
| | | Anterior segmental bronchus (BIII) | Posterior segment (SII) |
| | | Lateral segmental bronchus (BIV) | |
| | | Middle segmental bronchus (BV) | Anterior segment (SIII) |
| | | Superior segmental bronchus (BVI) | |
| | Right middle lobar bronchus | Medial basal segmental bronchus (cardiac) (BVII) | Lateral segment (SIV) |
| | | Anterior basal segmental bronchus (cardiac) (BVIII) | Middle segment (SV) |
| | Right inferior lobar bronchus | Lateral basal segmental bronchus (cardiac) (BIX) | Superior segment (SVI) |
| | | Posterior basal segmental bronchus (cardiac) (BX) | Medial basal segment (cardiac) (SVII) |
| | | Apicoposterior segmental bronchus (BI + II) | Anterior basal segment (SVIII) |
| | | Anterior segmental bronchus (BIII) | Lateral basal segment (SIX) |
| | | Superior lingular bronchus (BIV) | Posterior basal segment (SX) |
| | | Inferior lingular bronchus (BV) | Apicoposterior segment (SI + SII) |
| | | Superior segmental bronchus (BVI) | |
| Left principal bronchus | Left superior lobar bronchus | Medial basal segmental bronchus (cardiac) (BVII) | Anterior segment (SIII) |
| | | Anterior basal segmental bronchus (cardiac) (BVIII) | Superior lingular segment (SIV) |
| | | Lateral basal segmental bronchus (cardiac) (BIX) | Inferior lingular segment (SV) |
| | | Posterior basal segmental bronchus (cardiac) (BX) | Superior segment (SVI) |
| | Left inferior lobar bronchus | | Medial basal segment (cardiac) (SVII) |
| | | | Anterior basal segment (SVIII) |
| | | | Lateral basal segment (SIX) |
| | | | Posterior basal segment (SX) |

The different orders of the bronchi differ from each other in the structure of their walls. The cartilaginous semi-rings in the walls of the principal bronchus are replaced by the cartilaginous rings in the walls of the lobar bronchi, but beginning from the segmental bronchi the cartilages break into separate plates. The sizes of cartilaginous plates diminish together with the decrease of the bronchial diameter. The walls of the lobular bronchi still contain the pieces of the cartilages. The muscular layer is composed of the circular fibers of smooth muscles, situated internal to the cartilages. The abrupt contraction of these fibers may cause the bronchoconstriction (asthma attack).

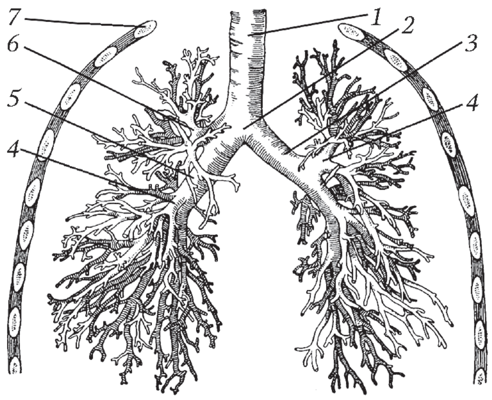


Fig. 1.17. Branching of bronchial tree (anterior aspect):

*1* — trachea; *2* — tracheal bifurcation; *3* — left principal bronchus; *4* — left superior lobar bronchus; *5* — right principal bronchus; *6* — apical segmental bronchus; *7* — the I rib

The mucosa contains the mucous glands and is covered by pseudostratified ciliated columnar epithelium. The decrease of the amount of cartilage in the bronchial wall is accompanied by the increase of the smooth muscle fibers. Thus, in the terminal bronchi the smooth muscles prevail, the cartilage is absent, the mucous glands also disappear, but the pseudostratified ciliated columnar epithelium remains.

The air passes through the terminal bronchioles into the respiratory parenchyma of the lung. The respiratory parenchyma consists of the respiratory bronchioles, alveolar ducts, alveolar sacs and alveoli.

Each terminal bronchus dichotomously subdivides into one to three generations of the respiratory bronchioles, *bronchioli respiratorii* (I, II, III orders); they are called 'respiratory' because their walls contain the alveoli. The number of these alveoli is 2 % of their total number. The respiratory bronchioles conduct air, and also are involved in the exchange of gases which starts in few alveoli located in the walls of these bronchioles.

The respiratory bronchioles of the III order have small expansions called the vestibules, the form and sizes of which are variable. Sometimes the vestibule divides into two-three wide cavities. From 3 to 17 alveolar ducts, *ductuli alveolares*, (more often 8) arise from each vestibule. The alveolar ducts, in their turn, branch one to three times. The walls of the ducts consist of the alveoli (about 80 in one duct). The alveolar ducts end by the alveolar sacs, *sacculi alveolares*, the walls of which also consist of the pulmonary alveoli, *alveoli pulmonales*. The diameter of the alveolar duct and alveolar sac is 0,2–0,6 mm, of the alveola is 0,25–0,3 mm. The wall of the alveola is formed by the finest epithelium, 0,3–0,4 mcm thick. The epithelium consists of large thin transparent anucleate cells forming a continuous layer.

Thus, the respiratory bronchioles arising from the terminal bronchiole and also the alveolar ducts, alveolar sacs and alveoli, surrounded by a thick capillary network, form the alveolar tree (pulmonary acinus), *arbor alveolaris* (*acinus pulmonis*), constituting the parenchyma of the lung. The acinus (bunch) is a structural and functional unit of the lung. The venous blood, passing into the pulmonary capillaries through the branches of the pulmonary artery, receives oxygen from air and gives carbon dioxide into the alveoli. The oxygen-enriched blood outflows from the capillaries through the pulmonary veins. The acinuses, connecting with each other by connective tissue, form the pulmonary lobule. Each lobule includes about 96 acinuses, and the both lungs contain several hundred thousand of acinuses. The number of the alveoli in both lungs is about 300–350 millions. All the alveoli form the respiratory surface, the square of which is 30–40 $m^2$ in quiet breathing; during deep breathing it increases to 80–100 $m^2$.

**Borders of lungs.** The surface projection of the lungs is determined by four borders: superior, anterior, inferior and posterior (fig. 1.18, 1.19, 1.20).

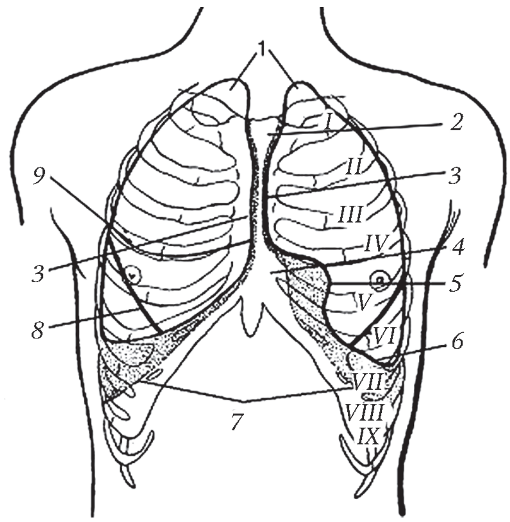


Fig. 1.18. Borders of lungs and parietal pleura (anterior aspect):

I—IX — ribs; *1* — apex of lung; *2* — superior interpleural area; *3* — anterior border of lung; *4* — inferior interpleural area; *5* — cardiac notch of the left lung; *6* — inferior border of lung; *7* — inferior border of parietal pleura; *8* — oblique fissure; *9* — horizontal fissure of the right lung

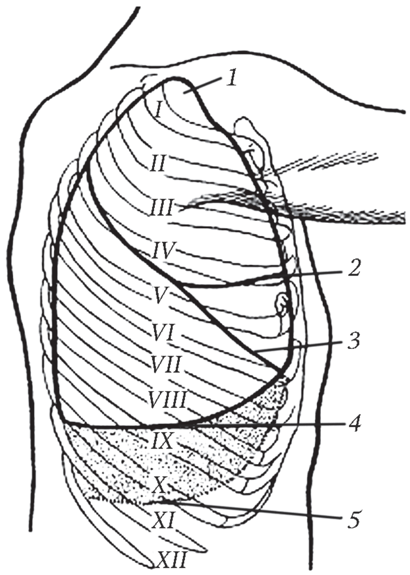


Fig. 1.19. Borders of lungs and parietal pleura (right-side view):

I—XII — ribs; *1* — apex of lung; *2* — horizontal fissure of the right lung; *3* — oblique fissure; *4* — inferior border of lung; *5* — inferior border of parietal pleura

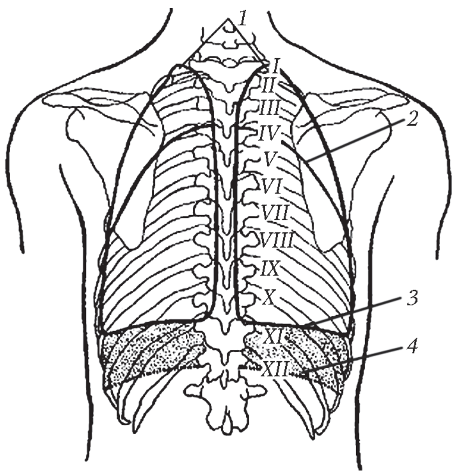


Fig. 1.20. Borders of lungs and parietal pleura (posterior aspect):

I—XII — ribs; *1* — apex of lung; *2* — oblique fissure; *3* — inferior border of lung; *4* — inferior border of parietal pleura

The superior border corresponds to the projection of lung`s apex. It is equal for both right and left lungs: anteriorly it protrudes 2 cm above the clavicle (and 3–4 cm above the I rib); posteriorly it is at the level of the VII vertebral spinous process.

The anterior border of the right lung descends from the apex to the right sternoclavicular joint, it then passes through the center of the sternal manubrium, and behind the sternal body it descends slightly to the left of the midline to the VI costal cartilage, where it is continuous with the inferior border.

The anterior border of the left lung passes similarly to that of right lung to the level of the IV rib, where it abruptly deflects to the left to approach the parasternal line and then turns down, crosses the IV intercostal space and reaches the VI costal cartilage approximately in the middle between the parasternal and midclavicular lines. From this point the inferior border starts.

The inferior border of the right lung crosses the VI rib at the midclavicular line, the VII rib at the anterior axillary line, the VIII rib at the mid-axillary line, the IX rib at the posterior axillary line, the X rib at the scapular line and ends opposite the neck of the XI rib at the paravertebral line. From here the inferior border of the lung abruptly turns up and is continuous with the posterior border.

The inferior border of the left lung starts from the level of the middle of the VI costal cartilage and passes mainly similarly to the inferior border of the right lung but approximately the width of one rib below (i.e. it passes along the intercostal spaces).

The posterior border of both lungs passes equally: along the vertebral column from the neck of the XI rib to the head of the II rib.

The anterior and inferior borders of the right and left lungs are different because the right lung is wider and shorter, and the left lung has the cardiac notch on its anterior border.

## TEST QUESTIONS

1. Describe the skeletotopy of the trachea; what is it length and diameter?
2. What is the tracheal bifurcation? Describe the skeletotopy of the tracheal bifurcation.
3. Describe the syntopy of the trachea`s cervical part.
4. Describe the syntopy of the trachea`s thoracic part.
5. Describe the structure of the tracheal walls.
6. Describe the right principal bronchus: length, diameter, structure.
7. Describe the left principal bronchus: length, diameter, structure.
8. Describe the syntopy of the right principal bronchus.
9. Describe the syntopy of the left principal bronchus.
10. Describe the differences between the left and the right principal bronchi and the left and right lungs.
11. Describe the lung capacity: the volume in maximal inspiration and expiration. What are the tidal volume, inspiratory reserve volume and expiratory reserve volume?
12. What surfaces do the lungs have? How will you differentiate the surfaces of the lung on the anatomical preparation?
13. What borders do the lungs have? How will you differentiate the borders of the lung on the anatomical preparation?
14. What is the hilum of the lung?
15. What is the root of the lung? Describe its components. Describe the skeletotopy and syntopy of the roots of the right and left lungs.

16. Describe the position of the elements in the right lung`s root.
17. Describe the position of the elements in the left lung`s root.
18. What is the lobe of the lung? How many lobes are in each lung?
19. What is the segment of the lung?
20. What is the lobule of the lung? How many lobules are in each lung?
21. List the subdivisions of the bronchi from the principal to respiratory ones. What bronchi are included into the bronchial tree? What are the differences in structure between the different types of the bronchi?
22. What parts does the acinus include? How many acinuses are there in each lobule? Describe the process of the exchange of gases in the acinus.
23. Describe the skeletotopy of the right lung`s apex.
24. Describe the skeletotopy of the left lung`s apex.
25. Describe the skeletotopy of the right lung`s anterior border.
26. Describe the skeletotopy of the left lung`s anterior border.
27. Describe the skeletotopy of the right lung`s posterior border.
28. Describe the skeletotopy of the left lung`s posterior border.
29. Describe the passage of the right lung`s inferior border along the topographical lines of the thorax.
30. Describe the passage of the left lung`s inferior border along the topographical lines of the thorax.

### CLINICOANATOMICAL PROBLEMS

1. An endoscopist is performing the bronchoscopy. At what level and at what angle should he direct the bronchoscope into each of the principal bronchi?
2. A doctor has to perform the tracheotomy to provide access of air into the lungs through the opening in the tracheal wall. The operation is performed in the cervical region. At what level should a doctor do the cut? What tissues in order will be dissected? The relationships with what organs should be taken into account obligatorily?
3. The radiological examination shows the tumor of the left principal bronchus. What neighboring anatomical structures can be involved in the pathological process?
4. In bronchial asthma exhaling is difficult. At which level of the bronchial tree will the passage of the inspired air be obstructed?
5. A knife wound was made on the right half of the chest along the midclavicular line in the fifth intercostal space: what lobe of the lung is injured?
6. The radiological examination shows the focus of darkness in the 9-th segment of the right lung. In what lobe is this segment located? What is its name?

## 1.7. Pleura. Pleural Cavity

The pleura, *pleura*, is a serous membrane covering the lung and lining the thoracic walls. It consists of two layers: visceral and parietal.

**Visceral pleura**, *pleura visceralis*, is adherent to the lung over all its surfaces, entering the fissures between the lobes. It is impossible to separate the visceral pleura from the lung parenchyma therefore it is also called the pulmonary pleura, *pleura pulmonalis*. Along the surface of the lung`s root the visceral pleura is continuous with the parietal pleura lining the walls of the thoracic cavity and limiting the mediastinum from the sides. Below the root, the pleura extends as a double layer in the frontal plane between the mediastinal surface of the lung (from the hilum to the base) and the mediastinal pleura;

this double layer is the pulmonary ligament, *ligamentum pulmonale*. The latter is paired, triangular-shaped; above, it blends with the serous covering of the lung`s root, below, its free border almost reaches the diaphragm (fig. 1.14, 1.15).

**Parietal pleura**, *pleura parietalis*, is adhered to the inner surface of the thoracic walls and is continuous with the visceral pleura thus forming a closed serous sac for each lung. The parietal pleura is divided into the diaphragmatic, costal and mediastinal parts (fig. 1.21, 1.22).

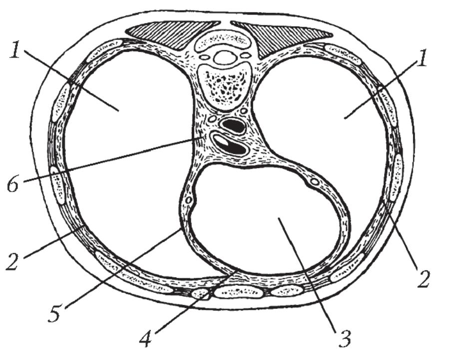


Fig. 1.21. Horizontal section of thorax; the heart and lungs have been removed (scheme):

*1* — pleural cavity; *2* — costal part of parietal pleura; *3* — pericardial cavity; *4* — parietal layer of pericardium; *5* — mediastinal part of parietal pleura; *6* — mediastinum

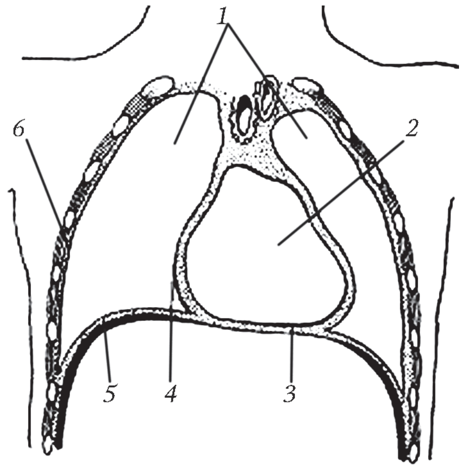


Fig. 1.22. Frontal section of thorax; the heart and lungs have been removed (scheme):

*1* — pleural cavity; *2* — pericardial cavity; *3* — parietal layer of pericardium; *4* — mediastinal part of parietal pleura; *5* — diaphragmatic part of parietal pleura; *6* — costal part of parietal pleura

The diaphragmatic part, *pars diaphragmatica*, lines the whole superior surface of the muscular part of the diaphragm and small part of the central tendon. The most part of the central tendon is lined by the pericardium.

The costal part, *pars costalis*, is the most extensive: it covers the ribs and the intercostal muscles from inside, immediately adjoining the endothoracic fascia.

The fat, visible through the serous covering, accumulates between the costal pleura and the ribs.

The line of the continuation of the costal pleura with the diaphragmatic is somewhat above the attachment of the diaphragm because an acute angle between the diaphragm and thoracic wall is filled with connective-tissue.

The mediastinal part, *pars mediastinalis*, adjoins the organs of the mediastinum; it is arranged in the sagittal plane, extending from the inner surface of the sternum to the lateral side of the vertebral column. The right and left mediastinal pleurae are asymmetric owing to the asymmetry of the mediastinal organs, especially heart, relatively to the median plane. The distance between the right and left mediastinal pleurae in the region of the vertebral column is quite considerable. Anteriorly, between the heart and sternum they converge to form a double layer of the serous membrane called the mediastinal

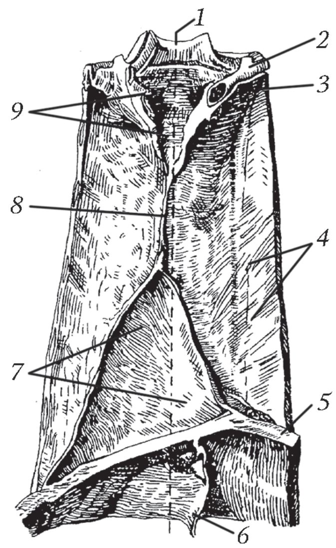


Fig. 1.23. Inner surface of the anterior thoracic wall (in the region of sternum):

*1* — anterior median line; *2* — right subclavian artery; *3* — costal part of parietal pleura; *4* — transversus thoracis muscle; *5* — diaphragm; *6* — falciform ligament of liver; *7* — pericardial area; *8* — mediastinal septum; *9* — thymic area

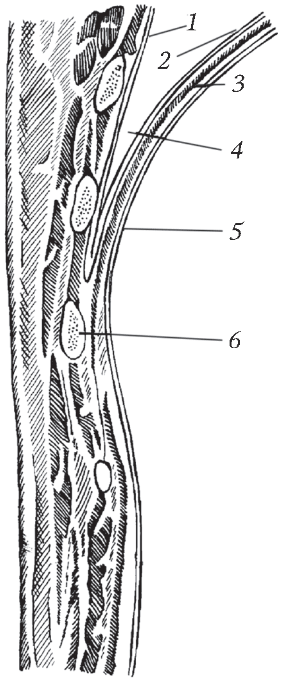


Fig. 1.24. Costodiaphragmatic recess (frontal section):

*1* — costal part of parietal pleura; *2* — diaphragmatic part of parietal pleura; *3* — diaphragm; *4* — costodiaphragmatic recess; *5* — parietal peritoneum; *6* — the IX rib

septum, *septum mediastinale*, which is attached to the posterior surface of the sternum (fig. 1.23). A large extent of the mediastinal part of the pleura is fused with the pericardium. On the right, it covers the superior vena cava, azygos vein and oesophagus; and on the left, the aortic arch. Enveloping the root of the lung, the mediastinal part of the parietal pleura is continuous with the visceral (pulmonary) pleura. Above, at the level of the superior thoracic aperture, the mediastinal and costal parts merge to form the pleural cupula, *cupula pleurae*, corresponding to the shape of the lung apex. The relations of the pleural cupula are: laterally the scalene muscles; medially and anteriorly the subclavian artery and vein; superiorly the brachial plexus; posteriorly the head and neck of the I rib. The pleural cupula is connected to all these structures by the fibers of fibrous tissue.

**Pleural cavity** (fig. 1.21, 1.22). Between the parietal and visceral pleurae there is a slit-like closed space, the pleural cavity, *cavitas pleuralis*. It contains a small volume of the serous fluid moistening the adjoining layers of the pleura to prevent the friction between them. During the breathing, the lung covered by the visceral pleura freely glides over the smooth wet surface of the parietal pleura.

The pleural cavity has several depressions termed the pleural recesses, *recessus pleurales*, which are formed in the places where one part of the pleura is continuous with another part. Hence, the pleural recess is a part of the pleural cavity bounded by two parts of the parietal pleura. Where the costal part is continuous with the diaphragmatic part the deepest costodiaphragmatic recess, *recessus costodiaphragmaticus*, is formed (fig. 1.24). Its greatest sizes are at the level of the mid-axillary line (here its depth reaches 9 cm). Be-

tween the mediastinal and diaphragmatic parts of the pleura there is a phrenicomediastinal recess, *recessus phrenicomediastinalis*. It is not very deep and arranged in the sagittal plane. A smaller recess is formed between the anterior portion of the costal part and the mediastinal part; this is the costomediastinal recess, *recessus costomediastinalis*. Where the mediastinal part of the pleura continues to cover the thoracic part of the vertebral column there is a vertebromediastinal recess, *recessus vertebromediastinalis*.

The pleural sinuses are reserve spaces of the right and left pleural cavities. When the pleura is inflamed, and the processes of the production and absorption of the serous fluid are disordered, the recesses may accumulate this fluid.

**Borders of pleura.** The borders of the pleura are the surface projections of the lines of the pleural reflexions from one part of the parietal pleura to another.

The superior border of the pleura corresponds to the pleural cupula. Behind, it reaches the neck of the I rib and level of the VII vertebral spinous process (equally on the right and on the left). Anteriorly, the pleural cupula rises 3—4 cm above the I rib and 1—2 cm above the clavicle (fig. 1.18, 1.19, 1.20).

The anterior border of the pleura corresponds to the line of the continuation of the costal pleura with the mediastinal. On the right and on the left it passes unequally.

On the right the anterior border descends from the pleural cupula behind the sternoclavicular joint, then behind the sternal manubrium to the level of the II sternocostal joint. It then descends behind the sternal body slightly to the left of the midline to the VI rib where it is continuous with the inferior border.

On the left the anterior border also descends from the pleural cupula to the sternoclavicular joint and reaches the level of the II sternocostal joint. Behind the sternal body it passes near the left edge of the sternum to the level of the IV costal cartilage. From here the anterior border deflects laterally and descends along the parasternal line to the level of the VI costal cartilage where it is continuous with the inferior border.

The inferior border of the pleura corresponds to the line of costodiaphragmatic reflexion (the continuation of the costal pleura with the diaphragmatic). To the right of the VI sternocostal joint the inferior border runs laterally and down, crossing the VII rib at the midclavicular line, the VIII rib at the anterior axillary line, the IX rib at the median axillary line, the X rib at the posterior axillary line, the XI at the scapular line and approaches the vertebral column at the level of the XII costal head, where it is continuous with the posterior border.

On the left the inferior border of the pleura is a little below than on the right, crossing the VII–XI intercostal spaces at the respective lines.

The posterior border of the pleura corresponds to the line of the costomediastinal reflection and passes along the vertebral column from the pleural cupula to the head of the XII rib, where it is continuous with the inferior border.

Thus, the anterior borders of the pleura on the right and on the left from the II to IV ribs pass closely to each other as two vertical parallel lines, but above and below they diverge and form two triangular spaces which are free from the pleura; they are the superior and inferior interpleural areas (fig. 1.18, 1.23).

The superior interpleural area, *area interpleurica superior*, is behind the sternal manubrium and has the shape of a triangle, the apex of which is directed down. It contains the thymus in children, and fat in adults. Therefore, this area is also called the thymic area, *area thymica*.

The inferior interpleural area, *area interpleurica inferior*, lies behind the lower half of the sternal body, adjacent anterior ends of the IV, V ribs and intercostal spaces of the left side. The inferior interpleural area has the shape of a triangle, the apex of which is

directed up. Here is the pericardium therefore this area is also called the pericardial area, *area pericardiaca*.

In practice it is important to remember that the anterior border of the left pleura from the IV to VI ribs passes along the parasternal line i.e. slightly lateral to the sternal edge. Due to the absence of the pleural covering here, it is possible to puncture the pericardial cavity without opening the pleural cavity.

The comparison of the borders of the lung and of the pleura shows that the superior, anterior on the right and posterior borders completely coincide. The greatest difference between the border of the pleura and of the lung on both sides is observed inferiorly. Here the difference between them reaches 2–3 cm (at the mid-axillary line even more). In the maximal inspiration the inferior borders of the lungs and of the pleura get closer to each other, but the inferior borders of the lungs never reach the inferior borders of the pleura.

## 1.8. Mediastinum

The mediastinum, *mediastinum*, is a complex of the organs situated between the right and left pleural cavities. The mediastinum is limited anteriorly by the sternum; posteriorly by thoracic vertebrae; laterally by the right and left mdiastinal parts of the parietal pleura; above it extends to the superior thoracic aperture, and below it reaches the diaphragm (fig. 1.25, 1.26). The mediastinum is oriented sagittally; it is displaced to the left because the asymmetry of the heart. The organs comprising the mediastinum are connected by areolar tissue.

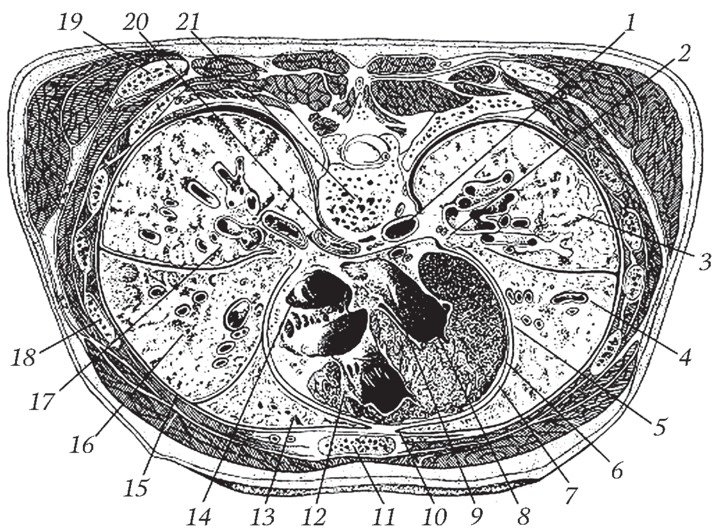


Fig. 1.25. Horizontal section of thorax at the level of the VI thoracic vertebra (superior aspect):

*1* — thoracic part of aorta; *2* — root of lung; *3* — inferior lobe of the left lung; *4* — superior lobe of the left lung; *5* — pleural cavity; *6* — pericardial cavity; *7* — pericardium; *8* — left ventricle; *9* — left atrium; *10* — costomediastinal recess; *11* — sternum; *12* — right ventricle; *13* — superior lobe of the right lung; *14* — right atrium; *15* — costal part of parietal pleura; *16* — middle lobe of the right lung; *17* — inferior lobe of the right lung; *18* — the IV rib; *19* — inferior angle of scapula; *20* — oesophagus; *21* — body of the VI thoracic vertebra

The division of the mediastinum into anterior and posterior, *mediastinum anterius et posterius*, is the most important in clinical practice. The boundary between these parts is the frontal plane passing through the trachea and the roots of the lungs (fig. 1.25).

The anterior mediastinum includes the heart with the pericardium and the roots of the great vessels, thymus (or fat replacing the thymus in adults), phrenic nerves, pericardiophrenic vessels, internal thoracic vessels and the parasternal, anterior mediastinal and superior diaphragmatic lymph nodes.

The posterior mediastinum contains the trachea and principal bronchi, oesophagus, thoracic part of the descending aorta, lymphatic thoracic duct, azygos and hemiazygos veins, right and left vagi and splanchnic nerves, sympathetic trunks and posterior mediastinal, prevertebral, paratracheal, tracheobronchial and bronchopulmonary lymph nodes.

The mediastinum also can be divided into superior and inferior. The boundary between them is the horizontal plane passing from the inferior edge of the sternal manubrium to the intervertebral disc between the IV and V thoracic vertebrae.

The superior mediastinum, *mediastinum superius*, contains the thymus, the roots of the great vessels, the vagus and phrenic nerves, sympathetic trunks, lymphatic thoracic duct and the upper portion of the thoracic part of the oesophagus.

The inferior mediastinum, *mediastinum inferius*, in its turn, is divided into anterior, middle and posterior.

The anterior mediastinum, *mediastinum anterius*, is between the sternal body anteriorly and the anterior part of the costal pleura posteriorly. It includes the internal thoracic vessels and the parasternal, anterior mediastinal and prepericardial lymph nodes.

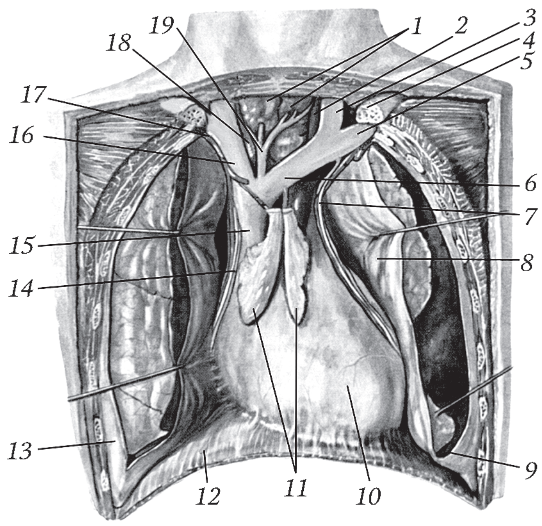


Fig. 1.26. Organs of thoracic cavity (anterior aspect):

*1* — thyroid gland; *2* — left common carotid artery; *3* — left internal jugular vein; *4* — clavicle; *5* — left subclavian vein; *6* — left brachiocephalic vein; *7* — left phrenic nerve and left pericardiophrenic artery; *8* — mediastinal part of parietal pleura; *9* — costodiaphragmatic recess; *10* — pericardium (parietal layer); *11* — thymus; *12* — diaphragm; *13* — costal part of parietal pleura; *14* — right phrenic nerve and right pericardiophrenic artery; *15* — superior vena cava; *16* — right brachiocephalic vein; *17* — internal thoracic artery; *18* — brachiocephalic trunk; *19* — inferior thyroid vein

The middle mediastinum, *mediastinum medius*, contains the heart with the pericardium, the roots of the great vessels, the roots of the lungs and the tracheobronchial lymph nodes. Also the phrenic nerves and pericardiophrenic vessels pass here.

The posterior mediastinum, *mediastinum posterius*, is bounded by the pericardium anteriorly; by the thoracic part of the vertebral column and ribs posteriorly. The organs of the posterior mediastinum are: the thoracic part of the descending aorta, azygos and hemiazygos veins, right and left sympathetic trunks, the vagus and splanchnic nerves, lymphatic thoracic duct, the middle and inferior portions of the thoracic part of the oesophagus, the posterior mediastinal and prevertebral lymph nodes.

## 1.9. Development of Respiratory Organs

The rudiments of the respiratory organs appear in the end of the third week as a longitudinal protrusion of the wall of the primitive gut at the junction between foregut and midgut. Firstly, this protrusion is like a groove but it grows ventrally and gradually converts into a tube. The tube is in front of the primitive gut and further it separates from the gut, except the cranial portion which develops into the larynx. Here the connection between the respiratory and alimentary tracts by means of the opening leading from the pharynx into the larynx remains throughout life. During the fourth week, the lower blind end of the tube divides into asymmetric protrusions, the lung buds, which further develop into the lungs.

In the early stages of the development the walls of the lung buds, primitive bronchi, trachea and of the larynx consist of only cells of entoderm, then the elements of mesenchyme join them. Thus, the entoderm gives rise to the epithelium lining the air ways and alveoli, and the mesenchyme gives rise to all other tissues forming the lungs and the walls of the respiratory tract (cartilages, ligaments, muscles, blood and lymphatic vessels).

At the end of the first month of embryonic development the cricoid cartilage is already developed. From the mesenchyme of the IV and V branchial arches the thyroid cartilage is developed; firstly it is paired cartilage but further its laminae are fused. Then the arytenoid and corniculate cartilages are formed, and finally epiglottis and cuneiform cartilages are developed.

A little later, during the eighth-ninth week the cartilages and muscles of the trachea are developed.

The development of the bronchial tree starts during the fifth week of embryogenesis. The primordia of the principal bronchi look like kidney-shaped protrusions: three on the right and two on the left. They grow into the lung buds.

The primary bronchial protrusions divide into the secondary, giving rise to the segmental bronchi (10 in each lung). On their ends new protrusions appear, and they divide again. This way during the 2d–4th months of embryogenesis the bronchial tree is formed. Further, from the 4th to 6th months the bronchioles appear, and from the 6th to 9th months the alveolar ducts and sacs are developed. By the time of birth, the branching of the bronchial and alveolar tree reaches 18 orders. After birth the bronchial tree continues to grow, and the structure of the alveolar tree becomes more complicated (new branches of the alveolar ducts appear and the number of the alveoli increases). As a result, the number of the ramification of the bronchial and alveolar ways in the human lungs reaches 23 orders.

The following defects and development abnormalities of the respiratory organs are observed most often:

1. Agenesia (total absence) of one or both lungs (newborn babies with this anomaly can not live).

2. Aplasia (underdevelopment) of one or both lungs.

3. Congenital bronchiectasis is excessive saccular extensions of the terminal bronchioles.

4. Tracheo-oesophageal fistula is a malformation which is in most of cases successfully correctable with the help of surgical treatment.

5. Inverse position of the organs of the thoracic cavity is a variant of the development of the respiratory organs, independent or frequently combined with the inverse position of the abdominal organs.

## TEST QUESTIONS

1. What is the pleura? What is its function? What layers does it consist of?
2. What is the pleural cavity? How many pleural cavities are in the thorax? What pressure exists in the pleural cavity? What is the role of such a pressure?
3. Describe the relations of the pleural cupula with surrounding organs.
4. Describe the skeletotopy of the pleural cupula.
5. Give the definition of the pleural sinus. Name the sinuses and describe their localization and function.
6. Describe the parts of the parietal pleura.
7. Describe the position of the mediastinal pleura anteriorly and posteriorly. What is the mediastinal septum? Where and how is it formed?
8. What are the superior and inferior interpleural areas? What is the practical importance of the inferior interpleural area?
9. Describe the anterior and posterior borders of the parietal pleura on the right.
10. Describe the anterior and posterior borders of the parietal pleura on the left.
11. Describe the passage of the inferior border of the parietal pleura on the right along the topographical lines of the thorax.
12. Describe the passage of the inferior border of the parietal pleura on the left along the topographical lines of the thorax.
13. Give the definition of the mediastinum.
14. Describe the walls of the mediastinum (anterior, posterior, laterals).
15. Name the organs of the mediastinum.
16. How can the mediastinum be classified? What lines divide the mediastinum into anterior and posterior; superior and inferior? How can the inferior mediastinum be classified? Describe the organs which are located in each part of the mediastinum.
17. Describe the development of the respiratory organs.
18. What developmental abnormalities of the respiratory system do you know?

## CLINICOANATOMICAL PROBLEMS

1. A patient has a gunshot wound immediately above the clavicle. The pneumothorax is observed on the side of the wound. Explain why the pneumothorax occured?
2. A knife wound was made on the right half of the chest along the posterior axillary line in the 10-th intercostal space: will it be accompanied with the pneumothorax?
3. The radiological examination of a patient with pleuritis shows the level of a fluid, reaching the site of the junction of the III costal cartilage to the sternum, in the right pleural cavity. What is the approximate size of the fluid column in the pleural cavity along the scapular, posterior axillary and midclavicular lines? What volume of fluid may be present in the pleural cavity? In what intercostal space and along which topographical line should the pleural puncture be done?

# 2. HEART

The heart, *cor* (in Greek *cardia*), is the central organ of the cardiovascular system. It pumps the blood through the vessels by means of the rhythmic contraction.

The heart together with the pericardium and the roots of the great vessels is an organ of the anterior mediastinum.

The average weight of the heart in men of 20—40 years of age is 300 g; in women it is 30–50 g less, 220–250 g. The largest transverse size of the heart ranges from 9 to 11 cm, the vertical size is from 12 to15 cm, the anteroposterior size is from 6 to 8 cm.

## 2.1. External Structure of Heart

The heart is a hollow muscular organ consisting of four chambers: right and left atria and right and left ventricles. It has an irregular conical form and is slightly flattened from front to back. The superior expanded part of the heart, base, *basis cordis*, is directed backwards and up and corresponds to both atria and to the roots of the great vessels (aorta, pulmonary trunk, superior and inferior venae cavae, pulmonary veins). The apex of the heart, *apex cordi*s, is a narrow rounded part; it is directed down, forwards and to the left. The atria have relatively thin walls, while the walls of the ventricles are thick.

Between the atria and ventricles there is a coronary groove, *sulcus coronarius*. The atria are above this groove, the ventricles are below it. The anterior part of the coronary groove is interrupted by the vessels arising from the ventricles, the pulmonary trunk and aorta. The coronary groove contains the coronary sinus which receives the venous blood from the proper cardiac veins.

The heart has three surfaces and two borders. The sternocostal surface of the heart, *facies sternocostalis,* (anterior surface, *facies anterior*), more convex, is behind the sternal body and cartilages of the III–VI ribs (fig. 2.1). The diaphragmatic surface, *facies diaphragmatica*, (inferior surface, *facies inferior*), flattened, adjoins the central tendon of the diaphragm in the cardiac impression (fig. 2.2). On the left and on the right there are lateral surfaces of the heart, directed to the lungs and therefore called the pulmonary surfaces, *facies pulmonales* (lateral surfaces, *facies laterales*).

The right border of the heart is sharp, while the left border is rounded. The right border corresponds to the right ventricle and right atrium and extends from the place where the superior vena cava opens into the heart to the cardiac apex. The left border is shorter than the right one, corresponds to the wall of the left ventricle and extends from the left auricle to the cardiac apex.

The cardiac division into four chambers is not always clearly distinct externally. The cardiac grooves show the borders of the chambers on the surface of the heart. The grooves contain the proper cardiac vessels covered by the epicardium and fat. The direction of the grooves depends on the position of the heart, which can be oblique, vertical or transverse, according to the body type and the level of the diaphragm. As usual in mesomorphic body type the heart has an oblique position; in dolichomorphic – vertical; in brachimorphic – transverse.

The boundary between the right and left ventricles corresponds to the interventricular grooves. The anterior interventricular groove, *sulcus interventricularis anterior*, passes along the sternocostal surface obliquely and down from the coronary groove to the cardiac apex. The posterior interventricular groove, *sulcus interventricularis posterior*, also passes obliquely and down from the coronary groove to the cardiac apex, but along the diaphragmatic surface. Both longitudinal grooves join to the right of the cardiac apex to form the apical notch, *incisura apicis cordis*.

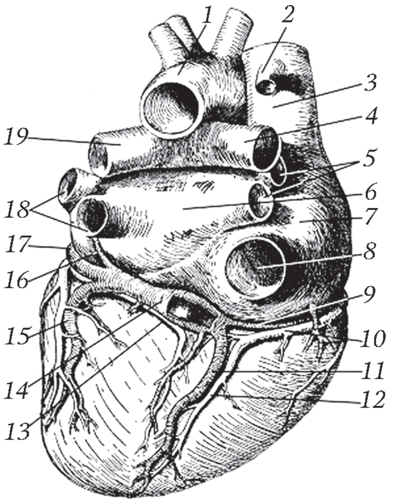


Fig. 2.1. Heart and great vessels (posterior aspect). The vessels of the heart are visible. The coronary sinus is opened:

*1* — aortic arch (*arcus aortae*); *2* — azygos vein (*vena azygos*); *3* — superior vena cava (*vena cava superior*); *4* — right pulmonary artery (*arteria pulmonalis dextra*); *5* — right pulmonary veins (*venae pulmonales dextrae*); *6* — left atrium (*atrium sinistrum*); *7* — right atrium (*atrium dextrum*); *8* — inferior vena cava (*vena cava inferior*); *9* — small cardiac vein (*vena cordis parva*); *10* — right coronary artery (*arteria coronaria dextra*); *11* — middle cardiac vein (*vena cordis media*); *12* — posterior interventriucular branch (*ramus interventricularis posterior*); *13* — circumflex branch of left coronary artery (*ramus circumflexus arteriae coronariae sisnistrae*); *14* — coronary sinus (*sinus coronarius*); *15* — posterior vein of left ventricle (*vena posterior ventriculi sinistri*); *16* — oblique vein of left atrium (*vena obliqua atrii sisnistri*); *17* — great cardiac vein (*vena cordis magna*); *18* — left pulmonary veins (*venae pulmonales sinistrae*); *19* — left pulmonary artery (*arteria pulmonalis sinistra*)

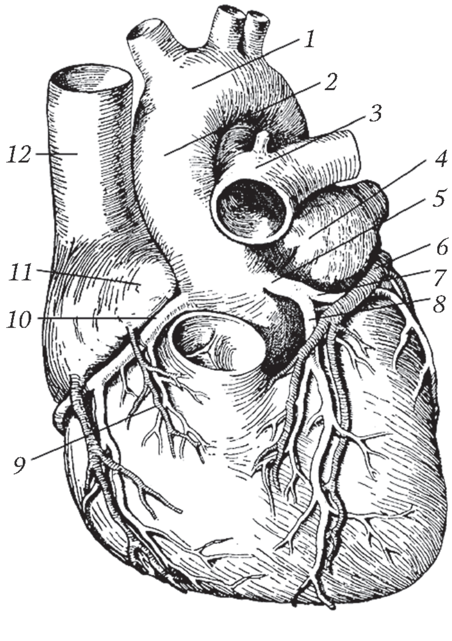


Fig. 2.2. Heart and great vessels (anterior aspect). The vessels of the heart are visible:

*1* — aortic arch (*arcus aortae*); *2* — ascending part of aorta (*pars ascendens aortae*); *3* — pulmonary trunk (*truncus pulmonalis*); *4* — left auricle (*auricula sinistra*); *5* — left coronary artery (*arteria coronaria sisnistra*); *6* — great cardiac vein (*vena cordis magna*); *7* — circumflex branch of left coronary artery (*ramus circumflexus arteriae coronariae sisnistrae*); *8* — anterior interventriucular branch (*ramus interventricularis anterior*); *9* — anterior cardiac veins (*venae cordis anteriores*); *10* — right coronary artery (*arteria coronaria dextra*); *11* — right auricle (*auricula dextra*); *12* — superior vena cava (*vena cava superior*)

The anterior interventricular groove divides the sternocostal surface into the wider right part, corresponding to the right ventricle, and smaller left part, corresponding to the right ventricle. The posterior interventricluar groove divides the diaphragmatic surface into the wider left part, corresponding to the left ventricle, and smaller right part, corresponding to the right ventricle.

The heart of an adult person is located asymmetrically: $^2/_3$ is to the left, $^1/_3$ is to the right of the midline. The longitudinal axis of the heart passes obliquely: from above to down, from the right to the left and from back to front. The right ventricle faces forwards, the left ventricle and atria are directed backwards.

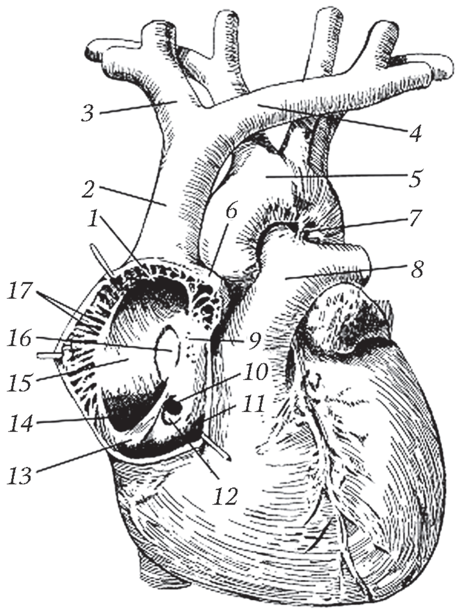


Fig. 2.3. Heart and great vessels (anterior aspect). The right atrium is opened:

*1* — opening of the superior vena cava (*ostium venae cavae superioris*); *2* — superior vena cava (*vena cava superior*); *3* — right brachiocephalic vein (*vena brachiocephalica dextra*); *4* — left brachiocephalic vein (*vena brachiocephalica sinistra*); *5* — aortic arch (*arcus aortae*); *6* — right auricle (*auricula dextra*); *7* — ligamentum arteriosum (*ligamentum arteriosum*); *8* — pulmonary trunk (*truncus pulmonalis*); *9* — openings of the smallest cardiac veins (*foramina venarum minimarum*); *10* — opening of coronary sinus (*ostium sinus coronarii*); *11* — right atrioventricular orifice (*ostium atrioventriculare dextrum*); *12* — valve of coronary sinus (*valvula sinus coronarii*); *13* — valve of inferior vena cava (valvula venae cavae inferioris); *14* — opening of inferior vena cava (ostium venae cavae inferioris); *15* — intervenous tubercle (*tuberculum intervenosum* ); *16* — fossa ovalis (*fossa ovalis*); *17* — pectinate muscle (*mm. pectinati*)

Superior and posterior to the coronary groove are the atria. In front of the atria there are the ascending aorta (on the right) and the pulmonary trunk (on the left). Each atrium has an auricle (atrial appendage). The right auricle, *auricula dextra*, is directed forwards and covers the commencement of the aorta. The left auricle, *auricula sinistra*, somewhat smaller than the right, is also directed forwards. On the left it adjoins the pulmonary trunk. To the right of the ascending aorta there is the superior vena cava. The inferior vena cava is visible just above the diaphragm, if the pericardial cavity is opened and the diaphragmatic surface of the heart is elevated. This is the intrapericardial part of the superior vena cava, which is 10–15 mm long. Thus, the heart is suspended by its base on the great vessels, while its apex is free and may be displaced relatively to the fixed base.

As mentioned above, the cardiac grooves indicate the position of the chambers. All the four cardiac chambers project to the diaphragmatic surface. The right and left ventricles, the auricles of the both atria, ascending aorta and pulmonary trunk project to the sternocostal surface. The left pulmonary surface is formed by the walls of the left ventricle and of the left atrium. The heart is divided by the internal partition into two not communicating halves: right (venous) and left (arterial).

Each half of the heart, in its turn, consists of one atrium, *atrium cordis*, and one ventricle, *ventriculus cordis.* The cardiac partition, separating the atria, is called the interatrial septum, *septum interatriale.* Between the ventricles there is an interventricular septum, *septum interventriculare.* Thus, the heart is comprised of four chambers: two atria and two ventricles.

**Right atrium**, *atrium dextrum* (fig. 2.3), resembles an irregular cube in shape. Anteriorly it is continuous with the additional cavity, the right auricle, *auricula dextra*. The atrium has superior, anterior, posterior, lateral and medial walls. The thickness of each wall does not exceed 2–3 mm. The volume of the atrium is 100–180 $cm^3$ (in the diastolic phase).

The superior vena cava opens into the right atrium superoposteriorly; the inferior vena cava opens into it inferiorly; the coronary sinus opens into it inferiorly and from the right. Between the opening of the superior vena cava, *ostium venae cavae superioris*,

and the opening of the inferior vena cava, *ostium venae cavae inferioris*, there is a small intervenous tubercle, *tuberculum intervenosum*. In a fetus it directs the blood flow from the superior vena cava immediately into the right atrium. At the opening of the inferior vena cava there is a semilunar fold of the endocardium, the valve of inferior vena cava, *valvula venae cavae inferioris*. In fetuses and children this valve is better expressed than in adults. During the fetal life it directs the blood flow from the right atrium into the left atrium through the foramen ovale.

The expanded posterior part of the right atrium cavity, taking both venae cavae, is called the sinus of venae cavae, *sinus venarum cavarum*.

The medial wall of the right atrium, oriented obliquely, is an interatrial septum, *septum interatriale*. It has an oval-shaped depression, 15—20 mm in diameter, the fossa ovalis, *fossa ovalis*, surrounded by a dense border, the limbus fossae ovalis, *limbus fossae ovalis*. In the area of the fossa ovalis the wall of the atrium is formed by two layers of the endocardium only that is why it is thin. The fossa ovalis is the site of the foramen ovale which communicates the right atrium with the left atrium during the fetal life.

The inner surface of the right atrium`s wall is smooth but in the area of the right auricle and of the anterior wall it is uneven due to the presence of the pectinate muscles, *mm. pectinati*, which end by the terminal crest, *crista terminalis*. On the outer surface of the heart the terminal crest is marked by the terminal sulcus, *sulcus terminalis*; it passes at the junction between the auricle and the atrium itself. The right atrium is communicated with the cavity of the right ventricle through the right atrioventricular orifice, *ostium atrioventriculare dextrum*. Near it there is an opening of the coronary sinus, *ostium sinus coronarii*; its lower part is covered by a thin semilunar valve of the coronary sinus, *valvula sinus coronarii*. Besides, the numerous openings of the smallest cardiac veins, *foramina venarum minimarum*, open into the right atrium.

**Right ventricle**, *ventriculus dexter*, consists of the ventricle proper and its funnel-shaped continuation, the conus arteriosus, *conus arteriosus*, or infundibulum, *infundibulum* (fig. 2.4). The shape of the right ventricle resembles a trihedral pyramid, the apex of which is directed down and the base

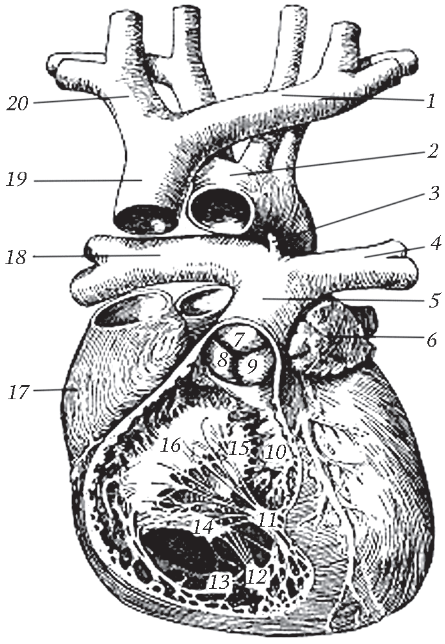


Fig. 2.4. Heart and great vessels (anterior aspect). The right ventricle has been opened. The aorta and superior vena cava have been partially removed:

1 — left brachiocephalic vein (*vena brachiocephalica sinistra*); 2 — aortic arch (*arcus aortae*); 3 — ligamentum arteriosum (*ligamentum arteriosum*); 4 — left pulmonary artery (*arteria pulmonalis sinistra*); 5 — pulmonary trunk (*truncus pulmonalis*); 6 — right auricle (*auricula dextra*); 7—9 — the semilunar cusps of the valve of pulmonary trunk (*valvula semilunaris valvae trunci pulmonalis*); 10—12 — papillary muscles (*mm. papillares*); 13 — trabeculae carneae (*trabeculae carneae*); 14—16 — cusps of the right atrioventricular valve (*cuspis valvae atrioventricularis dextra*); 17 — right atrium (*atrium dextrum*); 18 — right pulmonary artery (*arteria pulmonalis dextra*); 19 — superior vena cava (*vena cava superior*); 20 — right brachiocephalic vein (*vena brachiocephalica dextra*)

of which is directed up. In accordance with the shape, it has three walls: anterior, posterior and medial, the interventricular septum, *septum interventriculare*. The anterior wall is convex. The medial wall has two parts: inferior, muscular part, *pars muscularis*, (larger) and superior, membranous part, *pars membranacea*, (smaller). The posterior (inferior) wall, flattened, is in contact with the central tendon of the diaphragm. The thickness of the anterior and posterior walls is 5–7 mm. The base of the pyramid is directed to the atrium and has two openings: posterior, communicating the ventricular cavity with the right atrium, termed the right atrioventricular orifice, *ostium atrioventriculare dextrum*; and anterior, opening of the pulmonary trunk, *ostium trunci pulmonalis*.

The right atrioventricular orifice is oval-shaped with the diameter of 30–45 mm. The right atrioventricular valve, *valva atrioventricularis dextra,* (tricuspid valve, *valva tricuspidalis*) is attached to the orifice\`s margin. It consists of three cusps (leaflets). One of the cusps is attached to the interventricular septum and called the septal cusp, *cuspis septalis*; other, posterior cusp, *cuspis posterior*, is attached to the posterior wall; and the third, anterior cusp, *cuspis anterior*, is attached to the anterior wall. Each cusp is a reduplication of endocardium and represents a thin strong oval-shaped lamina, which is fused with the annulus fibrosus, *anulus fibrosus*, surrounding the atrioventricular orifice. The free margins of the cusps are directed into the ventricular cavity. The cusps are connected to the papillary muscles, *mm. papillares*, by means of the chordae tendineae (tendinous cords), *chordae tendineae*.

The inner surface of the conus arterious is smooth. The inner surface of the ventricle proper is roughened by the trabeculae carneae, *trabeculae carneae*, (irregular muscular ridges or columns). The trabeculae are less distinct on the interventricular septum. The cone-shaped papillary muscles freely protrude into the ventricular cavity. Their apices are connected to the valvar cusps by the chordae tendineae. The localization and degree of the development of the papillary muscles are greatly variable. They can be single and multiple, large and small. Usually the right ventricle has three main papillary muscles: anterior, posterior and septal, *mm. papillares anterior, posterior et septalis*, and small accessory papillary muscles. The chordae tendineae run from one muscle to two adjacent cusps, i.e. each papillary muscle is connected to two neighboring cusps. This provides the close contact of the cusps during the systole of the ventricle resulting in the complete closure of the atrioventricular orifice.

The right ventricle pumps the blood into the pulmonary trunk. Its opening, *ostium trunci pulmonalis*, 17–20 mm in diameter, is in the anterior part of the ventricular base. The pulmonary valve, *valva trunci pulmonalis*, is attached to the margin of the pulmonary trunk\`s opening; it prevents the back flow of the blood from the pulmonary trunk to the right ventricle during the diastole. The valve has three semilunar cusps (valvules): anteriorly is the anterior semilunar cusp, *valvula semilunaris anterior*, posteriorly are the right and left semilunar cusps, *valvula semilunaris dextra et valvula semilunaris sinistra*. Between each cusp and the wall of the pulmonary trunk the lunules, *lunulae valvularum semilunarium*, are present. Central in each cuspal free margin is a small thickening, the nodulus, *nodulus valvulae semilunaris*. During the diastole the blood fills the space between the cusps and the pulmonary trunk\`s wall (i.e. fills the lunules), the nodules get close to each other and contribute to more complete closure of the cusps.

**Left atrium**, *atrium sinistrum* (fig. 2.2), is behind the right atrium and adjoins the descending part of the aorta and oesophagus. Its shape resembles an irregular cube and, like the right atrium, it has superior, anterior, posterior, lateral and medial walls. Anteriorly it is continuous with the additional cavity, the left auricle, *auricula sinistra*, which turns forwards to the left of the pulmonary trunk. The four pulmonary veins, *vv. pulmo-*

*nales*, open into the left atrium posterosuperiorly. The openings of the pulmonary veins, *ostia venarum pulmonalium*, like the openings of the venae cavae, do not have the valves.

The medial wall of the left atrium is represented by the interatrial septum, *septum interatriale*. The inner surface of the atrium`s wall is smooth; the pectinate muscles are confined to the left auricle only. The left auricle is longer and narrower than the right one. It is constricted at its atrial junction. Below, the left atrium is communicated with the cavity of the left ventricle by means of the left atrioventricular orifice. The small circle of blood circulation ends in the left atrium. The capacity of the left atrium is 100–130 $cm^3$, the thickness of the wall is 2–3 mm.

**The left ventricle**, *ventriculus sinister* (fig. 2.5), has the shape of a cone, the base of which is directed upwards. It has anterior, posterior and medial walls. There is no a distinct boundary between the anterior and posterior walls. Their thickness reaches 10–15 mm. The base of the cone has two openings: left atrioventricular orifice, *ostium atrioventriculare sinistrum*, and aortic orifice, *ostium aortae*. The left atrioventricular orifice, oval-shaped, 25—40 mm in diameter, is posteriorly and to the left. The left atrioventricular valve, *valva atrioventricularis sinistra,* (bicuspid, mitral valve, *valva mitralis*) is attached along the orifice`s margin. The anterior cusp, *cuspis anterior*, is in front of and to the right; the posterior cusp, *cuspis posterior*, smaller, is behind and to the left. The free margins of the cusps are directed into the ventricular cavity; the chordae tendineae are attached to them. The two papillary muscles protrude into the ventricular cavity: anterior papillary muscle, *m. papillaris anterior*, and posterior papillary muscle, *m. papillaris posterior*. Besides, the accessory papillary muscles are present in the left ventricle, as well as in the right one. Each papillary muscle is connected to the both cusps of the mitral valve by the chordae tendineae. The numerous trabeculae carneae are well-developed on the wall of the left ventricle, especially in the cardiac apex.

The aortic orifice lies anteriorly; it is round. The structure of the aortic valve, *valva aortae*, is similar to the structure of the pulmonary trunk. It consists of three cusps: posterior semilunar cusp, *valvula semilunaris posterior*, located posteriorly; right and left semilunar cusps, *valvulae semilunares dextra et sinistra*, occupying the right and left sides of the aortic orifice. The nodules, *noduli val-*

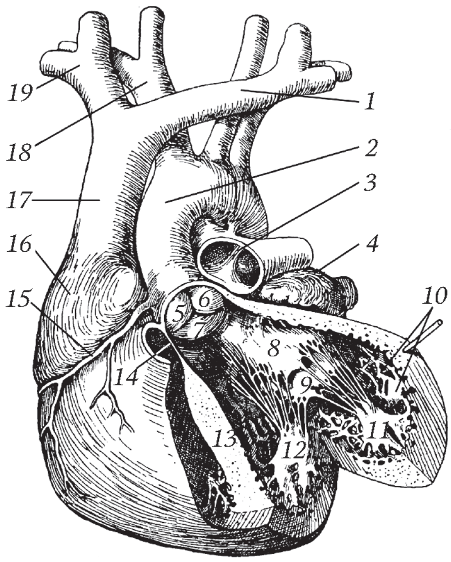


Fig. 2.5. Heart and great vessels (anterior aspect). The left ventricle has been opened.

1 — left brachiocephalic vein (*vena brachiocephalica sinistra*); 2 — ascending part of aorta (*pars ascendens aortae*); 3 — pulmonary trunk (*truncus pulmonalis*) (the place of its division into the right and left pulmonary arteries); 4 — left auricle (*auricula sinistra*); 5—7 — the semilunar cusps of the aortic valve (*valvula semilunaris valvae aortae*); 8, 9 — cusps of the left atrioventricular valve (*cuspis valvae atrioventricularis sinistra*); 10 — trabeculae carneae (*trabeculae carneae*); 11, 12 — papillary muscles (*mm. papillares*); 13 — muscular part of interventricular septum (*pars muscularis septi interventricularis*); 14 — membranous part of interventricular septum (*pars membranacea septi interventricularis*); 15 — right coronary artery (*arteria coronaria dextra*); 16 — right atrium (*atrium dextrum*); 17 — superior vena cava (*vena cava superior*); 18 — brachiocephalic trunk (truncus *brachiocephalicus*); 19 — right brachiocephalic vein (*vena brachiocephalica dextra*)

*vularum semilunarium aortae*, are on the free margins of the cusps; they are larger than those in the pulmonary valve. Between each cusp and the aortic wall there are the lunules, *lunulae valvularum semilunarium aortae* (aortic sinuses, *sinus aortae*). The right and left coronary arteries, *a. coronaria dextra et a. coronaria sinistra*, (these are the proper cardiac arteries), start in the areas of the right and left lunules. The commencement of the aorta is expanded; its diameter at the aortic valve reaches 30 mm.

## 2.2. Structure of Heart Wall

The cardiac wall is comprised of three layers: inner, the endocardium, middle, the myocardium, and outer, the epicardium.

**Endocardium**, *endocardium*, is relatively thin layer; it lines the cardiac chambers from inside. The endocardium consists of the endothelium, subendothelial layer (inner connective tissue), muscular-elastic layer and external connective tissue. The endothelium is formed by only single layer of flat cells. The endocardium of the heart is continuous with the endocardium of the great vessels without a distinct border. The cusps of the cardiac valves and of the semilunar valves of the vessels represent the reduplication of the endocardium.

**Myocardium**, *myocardium*, is the thickest layer of the heart, playing the most important role. The myocardium is comprised of striated muscle tissue (typical cardiomyocytes), loose and fibrous connective tissue, atypical cardiomyocytes (the cells of the conducting system), vessels and nerve elements. The collection of the contractile muscle cells (cardiomyocytes) constitutes the cardiac muscle. The latter has a specific structure, transitional between the striated (skeletal) and smooth muscle tissue. The fibers of the cardiac muscle are able to contract rapidly; they are interconnected by crosslinks, forming the network called the syncytium. The muscle fibers are almost devoid of the coat; their nuclei are located centrally. The contraction of the heart musculature occurs automatically. The musculature of the atria and of the ventricles is anatomically separated. They are connected only by the system of the conducting fibers. The myocardium of the atria consists of two layers: superficial, the fibers of which run transversely enveloping both atria, and deep, proper to each atrium. The deep layer is formed by the vertical fascicles arising from the annuli fibrosi surrounding the atrioventricular orifices, and from the circular bundles surrounding the openings of the venae cavae and pulmonary veins.

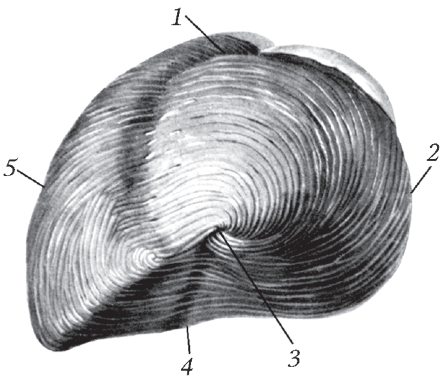


Fig. 2.6. Cardiac apex with vortex cordis:

1 — anterior interventricular groove; 2 — left ventricle; 3 — vortex cordis; 4 — diaphragmatic surface; 5 — right ventrcile

The myocardium of the ventricles is more complex than the myocardium of the atria. It has three layers: external (superficial), middle and internal (deep). The fibers of the superficial layer, common to both ventricles, arise from the annuli fibrosi, run obliquely from above to down, directing to the cardiac apex. At the apex they form the vortex of heart, *vortex cordis*, through which the superficial fascicles turn inwards to be continuous without interruption with the internal (deep) layer of the myocardium (fig. 2.6). The latter is made up of the longitudinal fibers and forms the trabeculae carneae and papillary muscles.

Between the superficial and deep layers there is a middle, circular, layer. It is proper to each ventricle and developed better in the left ventricle. Its fascicles also start from the annuli fibrosi and run almost horizontally. All the muscular layers are interconnected by the numerous connecting fibers.

Besides the muscular fibers, the cardiac wall has the connective tissue structures forming a "soft skeleton" of the heart (fig. 2.7). They are the maintaining structures providing the attachment of the muscle fibers and establishing a stable base for the attachment of the valvar cusps. The soft skeleton of the heart is formed by four annuli fibrosi, two fibrous trigones, *trigonum fibrosum*, and the membranous part of the interventricular septum.

The right and left annuli fibrosi, *anulus fibrosus dexter*, *anulus fibrosus sinister*, surround the right and left atrioventricular orifices and make the support to the tricuspid and bicuspid valves. The projection of these annuli to the heart surface corresponds to the coronary groove. The similar annuli surround the aortic orifice and opening of the pulmonary trunk.

The right fibrous trigone is larger than the left one. It lies centrally and connects the right and left annuli fibrosi and the fibrous annulus of the aorta to each other. Below, the right fibrous trigone is connected with the membranous part of the interventricular septum. The left fibrous trigone is much smaller and is connected to the left fibrous annulus.

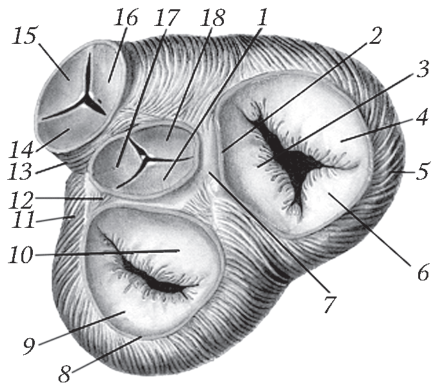


Fig. 2.7. Fibrous annuli (transverse section through the atria; the bicuspid valve, the semilunar valves of the aorta and pulmonary trunk are visible):

1 — posterior semilunar cusp of aortic valve; 2 — right fibrous annulus; 3 — septal cusp of tricuspid valve; 4 — anterior cusp of tricuspid valve; 5 — right ventricle; 6 — posterior cusp of tricuspid valve; 7 — right fibrous trigone; 8 — left fibrous annulus; 9 — posterior cusp of bicuspid valve; 10 — anterior cusp of bicuspid valve; 11 — left ventricle; 12 — left fibrous trigone; 13 — conus arteriosus; 14 — left semilunar cusp of the valve of pulmonary trunk; 15 — anterior semilunar cusp of the valve of pulmonary trunk; 16 — right semilunar cusp of the valve of pulmonary trunk; 17 — left semilunar cusp of aortic valve; 18 — right semilunar cusp of aortic valve

Atypical cells of the conducting system, generating and conducting the impulses, provide the automatic contraction of the typical cardiomyocytes. They constitute the conducting system of the heart.

Thus, the myocardium includes three functionally interrelated apparatuses:

1) contractile, represented by the typical cardiomyocytes;

2) supporting, formed by connective tissue structures surrounding the openings of the heart and penetrating into the myocardium and endocardium;

3) conducting, consisting of the atypical cardiomyocytes, the cells of the conducting system.

**Epicardium,** *epicardium*, covers the heart from outside; beneath it there are fat and proper vessels of the heart. It is a serous membrane consisting of a thin connective tissue lamina covered by mesothelium. The epicardium is also called the visceral layer of the serous pericardium, *lamina visceralis pericardii serosi*.

**Conducting system of heart.** The conducting system of the heart, *systema conducente cordis*, provides the rhythmic work of the musculature of the atria and ventricles

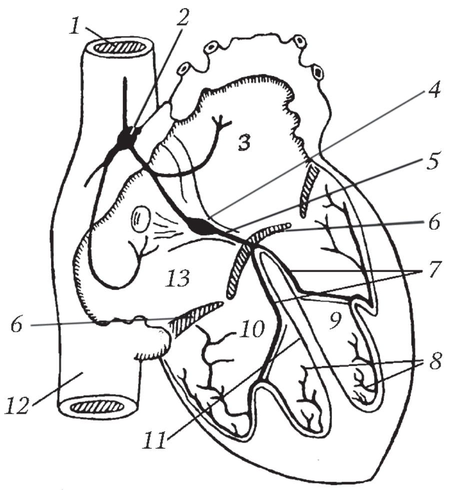


Fig. 2.8. Scheme of cardiac conducting system:

1 — superior vena cava; 2 — sinuatrial node; 3 — left atrium; 4 — atrioventricular node; 5 — trunk of the atrioventricular bundle; 6 — atrioventricular valves; 7 — right and left crura of the atrioventricular bundle; 8 — subendocardial branches; 9 — left ventricle; 10 — right ventricle; 11 — interventricular septum; 12 — inferior vena cava; 13 — right atrium

and coordinates its activity (fig. 2.8). It is constructed of the atypical cardiomyocytes included into the myocardium. They have more light color and larger diameter. The conducting system is constituted by the sinuatrial and atrioventricular nodes and the fiber fascicles.

The sinuatrial node, *nodus sinuatrialis* (Keith and Flack node), is located under the epicardium in the wall of the right atrium between the opening of inferior vena cava and the right auricle. The atrioventricular node, *nodus atrioventricularis* (Aschoff-Tawara node), is inside the lower part of the interatrial septum. The sinuatrial node gives rise to the fascicles of fibers, running to the myocardium of the atria as the right and left branches, *ramus dexter et ramus sinister nodi sinuatrialis*, and to the atrioventricular node. The sinuatrial and atrioventricular nodes are connected by the interatrial conducting tract (the bundle of Bachmann). From the atrioventricular node a large atrioventricular bundle (His bundle), *fasciculus atrioventricularis*, arises. The commencement of this bundle is called the trunk of the atrioventricular bundle, *truncus fasciculi atrioventricularis*. It passes in the upper (membranous) part of the interventricular septum and connects the myocardium of the atria with the myocardium of the ventricles. In the muscular part of the interventricular septum, the trunk divides into the right and left crura, *crus dextrum et crus sinistrum*, that firstly run along the corresponding sides of the septum and then they branch in the walls of both ventricles. The crura of His bundle end under the endocardium with thin fibers, subendocardial branches, *rami subendocardiales*, termed the Purkinje fibers.

## 2.3. Topography of Heart

The heart, enclosed into the pericardium, lies in the anterior mediastinum. Its long axis passes obliquely: from above to down, from the right to the left, from back to front, forming with the axis of the body an angle of 40°, opened upwards.

The sternocostal surface of the heart is formed by the anterior wall of the right atrium; by the right auricle situated in front of the ascending aorta and pulmonary trunk; the anterior wall of the right ventricle; the anterior wall of the left ventricle; and the left auricle. Near the base it is completed by the roots of the great vessels (superior vena cava, ascending part of the aorta and pulmonary trunk). The anterior interventricular groove, containing the proper cardiac vessels, passes along the strenocostal surface.

The diaphragmatic surface of the heart is formed by the posterior (inferior) walls of all the four cardiac chambers: left ventricle, right ventricle, left atrium and right atrium.

The inferior wall of the right atrium has a large opening of the inferior vena cava. Two grooves pass along the diaphragmatic surface: posterior interventricular and coronary. The first one transmits the proper cardiac vessels and the second one contains the coronary sinus. The left pulmonary surface of the heart is formed by the posterior wall of the left atrium with the four pulmonary veins, opening into it, and by the posterior wall of the left ventricle. The right pulmonary surface is formed by the right atrium.

**Skeletotopy of heart** is a projection of the heart borders to the anterior surface of the thorax.

The superior border of the heart passes horizontally along the superior borders of the third costal cartilages to the right and to the left of the sternal body. It corresponds to the superior walls of the atria.

The right border of the heart corresponds to the wall of the right atrium. It extends from the III to V right costal cartilages, passing 1–1,5 cm lateral to the right border of the sternum.

The left border of the heart corresponds to the wall of the left ventricle. It passes from the III costal cartilage along the left parasternal line to the cardiac apex.

The cardiac apex (corresponds to the apex beat) is palpated in the V intercostal space, 1–1,5 cm medial to the left midclavicular line.

The inferior border corresponds to the wall of the right ventricle. It passes horizontally from the right V costal cartilage through the base of the xiphoid process to the cardiac apex.

In clinical practice the heart borders are determined by percussion as the relative and absolute cardiac dullness. The borders of the relative cardiac dullness reflect the true borders of the heart (fig. 2.9).

The heart with the pericardium is partly covered by the lungs. The pericardium adjoins immediately only the sternal body and the cartilages of the V and VI left ribs. This area corresponds to the sternocostal surface of the heart, more precisely to the anterior wall of the right ventricle. It is determined by percussion as the absolute cardiac dullness. It shows

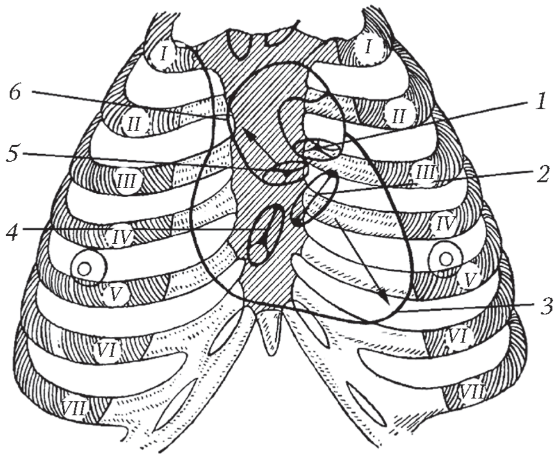


Fig. 2.9. Projection of the cardiac valves and the places of their auscultation to the anterior thoracic wall:

I—VII — ribs; 1 — opening of pulmonary trunk; 2 — left atrioventricular orifice; 3 — place of the auscultation of the bicuspid valve`s sounds; 4 — right atrioventricular orifice; 5 — aortic valve; 6 — of the auscultation of the aortic valve`s sounds

the size of the heart, its mobility, condition of the lungs and how much the lungs cover the heart. The borders of the absolute cardiac dullness: the superior border corresponds to the IV costal cartilage; the right border passes along the left edge of the sternum below the attachment of the IV costal cartilage; the left border corresponds to the left border of the heart from the IV costal cartilage along the parasternal line to the cardiac apex.

**Skeletotopy of the cardiac valves** is a projection of the valves to the anterior surface of the thorax.

The anterior atrioventricular orifice (tricuspid valve) projects to the anterior surface of the thorax behind the sternum, to the oblique line connecting the sternal edges of the IV left and V right costal cartilages.

The left atrioventricular orifice (bicuspid valve) projects at the left edge of the sternum in the site where the IV costal cartilage is connected to the sternum.

The aortic orifice (aortic valve) is behind the sternum at the level of the III intercostal space.

The opening of the pulmonary trunk (the valve of the pulmonary trunk) projects at the left edge of the sternum where the III costal cartilage is connected to the sternum.

## 2.4. Blood Circulations and Work of Heart

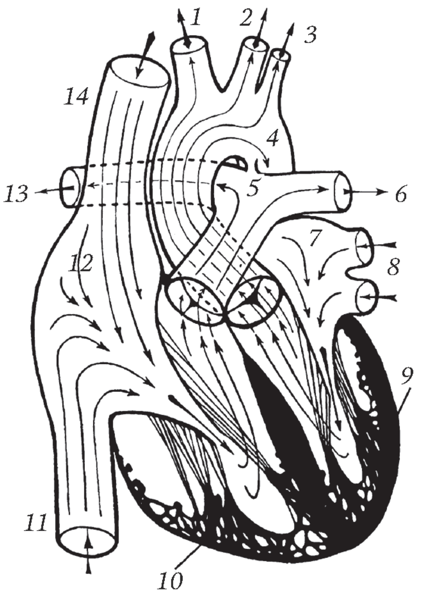


Fig. 2.10. Scheme of blood circulation in the cardiac chambers and great vessels (the arrows show the blood flow):

1 — brachiocephalic trunk; 2 — left common carotid artery; 3 — left subclavian artery; 4 — descending aorta; 5 — pulmonary trunk; 6 — left pulmonary artery; 7 — left atrium; 8 — pulmonary veins; 9 — left ventricle; 10 — right ventricle; 11 — inferior vena cava; 12 — right atrium; 13 — right pulmonary artery; 14 — superior vena cava

The movement of the blood occurs through circular courses called the big (systemic) and small (pulmonary) blood circulations, which start and end in the cardiac chambers (fig. 2.10).

The big circulation starts from the left ventricle which pumps the blood into the aorta. Through the aortic branches the blood reaches and supplies all parts of the body. The big circulation ends in the right atrium by the superior and inferior venae cavae. The blood, saturated with carbon dioxide, passes from the right atrium to the right ventricle, from where the small circulation starts. The blood is pumped to the pulmonary trunk originating from the right atrium and then dividing into the right and left pulmonary arteries which enter the lung and bring the blood to them. In the pulmonary capillaries, surrounding the alveoli, the blood enriches with oxygen, gives carbon dioxide and returns to the left atrium via the four pulmonary veins. In the left atrium the small circulation ends.

The left atrium pumps the blood into the left ventricle, i.e. the big circulation starts again. Hence, the heart connects both blood circulations.

The atria and ventricles contract separately but coordinately and rhythmically.

The heart work consists of three phases: the systole of the atria, the systole of the ventricles and the common diastole.

The I phase, the systole of the atria, lasts 0,1 s. The impulse is generated by the sinuatrial node. The blood presses the valvar cusps to the ventricular walls, the valves are opened and the blood is forced into the ventricles through the atrioventricular orifices. In the end of the atrial systole the cusps, the specific gravity of which is lesser than the specific gravity of the blood, "float" upward, completely separating the atria from ventricles.

The II phase, the systole of the ventricles, follows the atrial systole and lasts 0,3 s. The blood is propelled into the aorta and pulmonary trunk, and the cusps of the atrioventricular valves tightly close. In this moment the characteristic sound appears, known as the first heart sound. The I heart sound of the bicuspid valve is auscultated at the cardiac apex; the I heart sound of the tricuspid valve is auscultated at the base of the xiphoid process at the left edge of the sternum.

The blood, contained in the ventricles, presses the cusps but they do not prolapse into the atrial cavities due to the stretched chordae tendineae. The papillary muscles are shortened, and the atrioventricular orifices significantly narrow. All this creates such conditions in the ventricular cavities, under which the blood flows from the ventricles into only one direction, upwards into the aorta (on the left) and into the pulmonary trunk (on the right). The impulse is transmitted through the fibers of the conducting system from the cardiac apex to the base. Then the semilunar valves open, and the blood stream presses them to the walls of the aorta and pulmonary trunk. The semilunar valves remain in such a position until the blood pressure in the ventricles exceeds the blood pressure in the aorta and pulmonary trunk. When all the blood is pushed from the ventricles into the aorta, the ventricular systole ends and the ventricular wall relaxes. The back flow of the blood becomes impossible because the semilunar valves, having a form of pouches, are filled with blood and project into the lumen of the vessels. Their free margins with the nodules are closely pressed to each other resulting in the full seal of the aortic orifice and the opening of the pulmonary trunk. When the semilunar valves close, the second heart sound appears; it is auscultated in the second intercostal space to the right of the sternal edge (for the aortic valve) and to the left of the sternal edge (for the valve of the pulmonary trunk).

The III phase, the common diastole, lasts 0,4 s. The cardiac wall relaxes, and firstly the atria and then the ventricles are filled with the blood.

The rhythmic and coordinated work of the heart depends on the condition of the cardiac muscle, conducting system and the valvar apparatus which provides the sealing of the cardiac chambers during the systole.

## 2.5. Pericardium

The pericardium, *pericardium*, surrounds the heart, forming a closed slit-like serous cavity. In normal the pericardial cavity, *cavitas pericardiaca*, contains about 20 ml of the serous fluid. The pericardium has a specific structure and great density. It is non-transparent. It consists of two layers: inner, serous, *pericardium serosum*, and outer, fibrous, *pericardium fibrosum*.

The serous pericardium is constructed similarly to the peritoneum and pleura, i. e. it is a kind of the serous membrane. The visceral layer of the serous pericardium, *lamina visceralis pericardii serosi*, or epicardium, *epicardium*, immediately covers the heart. At the root of the great vessels the visceral layer is continuous with the parietal layer of the

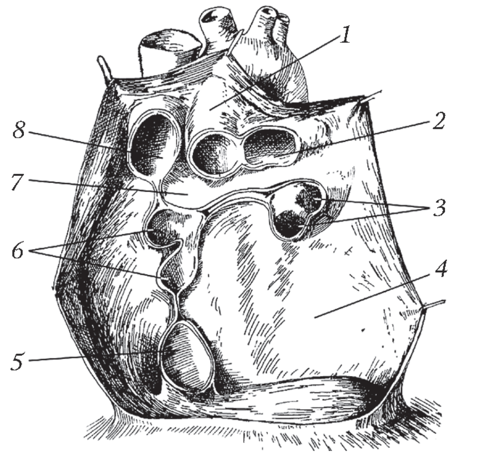


Fig. 2.11. Pericardium after removing the heart (anterior view, from the pericardial cavity); the openings of the great vessels are visible:

1 — ascending aorta; 2 — pulmonary trunk; 3 — left pulmonary veins; 4 — parietal layer of serous pericardium; 5 — inferior vena cava; 6 — right pulmonary veins; 7 — transverse pericardial sinus; 8 — superior vena cava

parietal pericardium, *lamina parietalis pericardii serosi*, which lines the fibrous pericardium.

The pericardium is connected with the surrounding organs by areolar tissue. Between the sternum and pericardium there are two ligaments. The superior sternopericardiac ligament, *ligamentum sternopericardiacum superius*, passes from the posterior surface of the sternal manubrium, and the inferior sternopericardiac ligament, *ligamentum sternopericardicum inferius*, starts from the xiphoid process. Posterior to the pericardium are the oesophagus and thoracic part of the aorta.

The pericardium has three parts: sternocostal, diaphragmatic and mediastinal (paired).

The sternocostal surface, *pars sternocostalis*, adjoins immediately the sternal body and the cartilages of the IV, V and VI ribs. This part of the pericardium is in the inferior interpleural area, *area interpleurica inferior*, *seu pericardiaca*. The diaphragmatic part of the pericardium, *pars diaphragmatica*, adheres to the central tendon of the diaphragm. The mediastinal surface, *pars mediastinalis*, is loosely connected with the mediastinal part of the pleura. In the duplication of these serous membranes there is a neurovascular bundle of the pericardium.

The pericardium fixates the heart to the great vessels (fig. 2.11). It protects the heart, decreases the friction and contributes to the passive expansions of the chambers during the diastole phase.

In the pericardial cavity there are the slit-like spaces between the roots of the great vessels and the atrial walls covered by the epicardium, termed the sinuses. The transverse sinus of pericardium, *sinus transversus pericardii*, is a narrow space between the aorta and pulmonary trunk anteriorly and the anterior wall of the right atrium posteriorly. This sinus freely admits the index finger. The oblique sinus of pericardium, *sinus obliquus pericardii*, is between the inferior vena cava inferiorly and on the right and the left pulmonary vein superiorly and on the left. Besides, the blind sac of the pericardium is distinguished; it is behind the left atrium and in front of the oesophagus.

## 2.6. Development of Heart

The paired rudiment of the heart appears during the second week of the embryonic life in the cervical region in front of the foregut as two tubes. The medial walls of the tubes are thickened. This is the rudiment of the cardiac muscle and outer covering of the heart (*epimiocardium*). Further the rudiments of the heart draw together to form a single cardiac tube fixed by two mesenteries (3 week). It is located centrally and has the cranial and caudal ends. It consists of the venous sinus (the largest part of the embryon-

ic heart), a single atrium, a single ventricle and the arterial trunk (cone). The cardiac tube grows unevenly. Firstly the ventricular loop is formed. The atria and venous sinus are displaced up and cranially. The arterial trunk (the cranial end of the tube) descends forwards (fig. 2.12).

During 5–8 weeks of the embryonic development the septa of the heart appear. The primary interatrial septum grows from inside, from the posterior wall of the atrium down to the endocardial tubers located between the atrium and ventricle. The primary septum exists not for long, it then breaks and remains as a "valve" directing the blood from the right atrium to the left. The secondary interatrial septum grows in the same direction but it deviates to the right and has a foramen ovale, through which the blood flows freely from the right to the left atrium. In normal after the birth, when the pulmonary blood circulation begins and the blood pressure in the left atrium increases, the upper edges of the primary and secondary septa converge to close the foramen ovale (as usual 2–3 after the birth). After the closure of the foramen ovale, the fossa ovalis, surrounded by a dense limbus, remains.

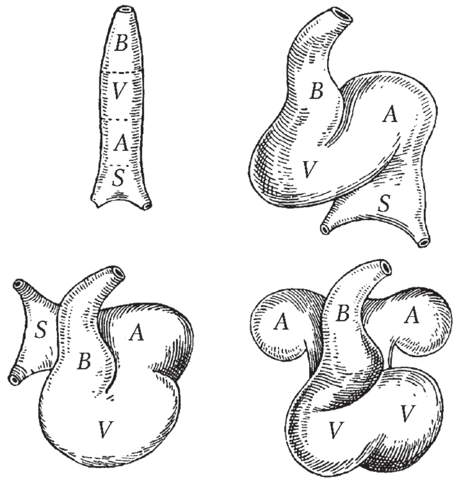


Fig. 2.12. Development of the heart of the human embryo:

*A* — atria; *B* — arterial trunk; *S* — venous sinus; *V* — ventricles

The arterial trunk is divided by the aorto-pulmonary septum into the aorta and the pulmonary trunk. It grows from down to up. During growth the trunk rotates along a spiral 225 ° at the clockwise direction. The four endocardial tubers at the border between the ventricle and arterial cone convert into the semilunar valves of the aorta and pulmonary trunk.

During the 8 week of the development a longitudinal groove appears on the top of the interventricular loop, and the semilunar fold appears from inside. Te fold grows inwards and up towards the endocardial tubers of the atrioventricular canal to connect the muscular and membranous parts of the interventricular septum. By the end of the 8 week the heart has four chambers. During the developmental process the heart gradually descends from the cervical region into the thoracic cavity.

## 2.7. Fetal Blood Circulation

The arterial blood enters the fetus from the placenta through an unpaired umbilical vein included into the umbilical cord. In the fetus body the umbilical vein passes along the edge of the falciform ligament and divides into two vessels: one flows into the portal vein and the other is fused with the parenchyma of the liver and as a ductus venosus (Arantius` duct), *ductus venosus (Arantii)*, flows into the inferior vena cava. Thus, the placental blood, partially directly, partially through the liver comes into the inferior vena cava and mixes with the venous blood, flowing from the lower part of the fetus body. This mixed blood comes into the right atrium (fig. 2.13).

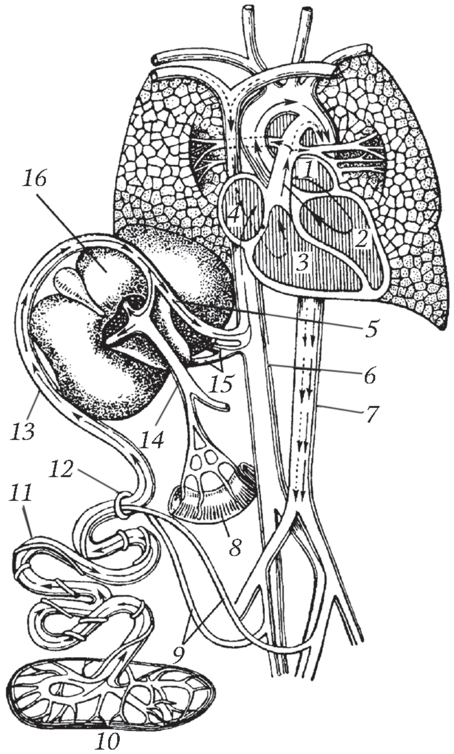


Fig. 2.13. Scheme of the fetal blood circulation:

1 — left atrium; 2 — left ventricle; 3 — right ventricle; 4 — right atrium; 5 — venous duct; 6 — inferior vena cava; 7 — aorta; 8 — intestine; 9 — umbilical arteries; 10 — placenta; 11 — umbilical cord; 12 — umbilical ring; 13 — umbilical vein; 14 — portal vein; 15 — hepatic veins; 16 — liver

The small volume of the blood is pumped from the right atrium into the right atrioventricular orifice and further into the right ventricle. The main volume of the blood flows, bypassing the small circle of the blood circulation, into the left atrium through the foramen ovale. The blood is directed from the right into the left atrium by the fold of the endocardium, the valve of the inferior vena cava.

The superior vena cava returns into the heart the blood from the head, neck and upper limbs. It flows by usual way: the right atrium, the right ventricle, the pulmonary trunk, but the blood from the pulmonary trunk actually does not pass into the lung because the pulmonary arteries are weakly developed and the small circle of blood circulation does not function. The pulmonary trunk is connected with the concave part of the aortic arch, lateral to the arteries, arising from the aortic arch and supplying the head, neck and upper limbs, by the ductus arteriosus (ductus Botalli), *ductus arteriosus* (*Botalli*), having a large diameter. It carries the venous blood from the upper part of the body into the aortic arch. After the flowing of the ductus Botalli the placental blood, passing through the aorta, is diluted by the venous blood once again.

Thus, in the fetus all the arteries and cardiac chambers contain the mixed blood (placental blood, rich in oxygen and nutrients, and venous blood).

Two immiscible blood streams exist in the right atrium. The pulmonary circle does not function. The blood from the fetus body outflows through the umbilical arteries, *aa. umbilicales*, included into the umbilical cord.

During the whole fetal life a constant balancing between the flow of the blood to the heart and outflow of the blood from the heart occurs. This is contributed firstly by the presence of the foramen ovale and ductus arteriosus.

At birth, when the umbilical vessels are ligated, the blood pressure in the right atrium abruptly decreases, the hypoxia of the respiratory center occurs, the newborn infant performs the first inspiration, the lungs expand and the blood flows to them from the right ventricle through the pulmonary trunk and pulmonary arteries. The small (pulmonary) circle of blood circulation starts to work. As a result, the ductus arteriosus reflectively narrows. In normal 1,5–2 months after birth the ductus arteriosus is completely obliterated, becoming the ligamentum arteriosum, *ligamentum arteriosum*.

After birth the pulmonary circulation intensifies, the blood pressure in the left atrium increases. The foramen ovale is closed by the remnant of the primary interatrial septum,

which becomes compacted and loses mobility. The foramen narrows, becoming slit-like, the atrial pressures become equal and the arterial and venous blood mixes no more. The foramen ovale is completely closed during 5–6th months after birth.

The umbilical vein, *v. umbilicalis*, after birth thromboses, obliterates and transforms into the ligamentum teres of liver, *ligamentum teres hepatis*; the ductus venosus, *ductus venosus*, transforms into the ligamentum venosum, *ligamentum venosum*; both umbilical arteries, *aa. umbilicales*, convert into the medial umbilical ligaments, *ligamenta umbilicalia medialia*, which are located on the inner surface of the anterior abdominal wall.

## 2.8. Developmental Abnormalities of Heart and Great Vessels

***Abnormalities of heart position*** appear during 4–6 weeks, if the development of the heart rudiments is stopped or delayed. The following abnormalities are distinguished:

1. Cervical ectopia: the heart stays in the neck, i.e. on the place of its rudiment.
2. Thoracic ectopia: the heart lies in front of the sternum; the sternum has malformations.
3. Abdominal ectopia: the heart is in the abdominal cavity because of the maldevelopment of the diaphragm. The abnormal position of the heart is often assotiated with the maldevelopment of the cardiac tube itself (the chambers are not differentiated, the septa are not developed).

Among ***the congenital abnormalities of the heart and great vessels*** the following are most often:

1. Arterial septal defect. The foramen ovale is not closed and not fused. During contraction of the heart the blood is propelled from the right to the left atrium, and the arterial blood mixes with the venous.
2. Ventricular septal defects. It occurs because the two parts of the intervenricular septum, the muscular and membranous, are not fused. During the contraction of the ventricles some amount of the blood is pumped from the left ventricle to the right. This abnormality may be independent or associated with other malformations.
3. Defects of aortopulmonary septum. It is incomplete division of the arterial cone into the ascending aorta and the pulmonary trunk or constriction of the pulmonary trunk to its full atresia.
4. The transposition of the vessels, when the aorta arises from the right ventricle and the pulmonary trunk arises from the left ventricle.
5. The patent ductus arteriosus. The ductus arteriosus connects the pulmonary trunk with the concave part of the aortic arch below the commencement of aortic arch`s branches supplying the head, neck and upper limbs. This duct is known as ductus Botalli because it was described by Italian doctor and anatomist Leonardo Botallo in 1564 year. If the ductus arteriosus is opened, the blood from the aorta, where the pressure is higher, returns to the pulmonary trunk and right ventricle, resulting in expansion of the right ventricle. As an independent malformation this defect is observed in 9–12 % of total number of heart abnormalities, most commonly in girls.
6. Complex combined abnormalities of the heart and great vessels development: triad, tetralogy, pentad of Fallot.

Fallot`s tetralogy: commom arterial trunk, arterial and ventricular septal defects. In this case the atrial and venous blood mix, the blood is pumped into the right half of the heart, the right ventricle hypertrophies.

Fallot`s triad: constriction of the pulmonary trunk, ventricular septal defect, right position of the aorta, hypertrophy of the right ventricle.

Fallot`s pentad: constriction of the pulmonary trunk, ventricular septal defect, right position of the aorta, hypertrophy of the right ventricle, atrial septal defect.

## TEST QUESTIONS

1. Describe the localization of the heart. Describe the sizes of the heart.
2. What surfaces does the heart have? How will you differentiate the anterior side of the heart from the posterior side on the anatomical preparation? How will you differentiate the left side of the heart from the right side on the anatomical preparation?
3. What chambers has the heart? Where are the outlines of the chambers on the external surface of the heart?
4. What are the atrioventricular orifices, where are they located? What diameter do they have?
5. Where can the fibrous rings be found?
6. What great vessels start from the right and left ventricles? What type of blood do they contain? Describe their function.
7. What great vessels open into the right and left atria? What type of blood do they contain? Describe their function.
8. Describe the structure of the ventricles. Describe the differences between the left and right ventricles. How many papillary muscles are distinguished in the right and in the left ventricles?
9. Describe the structure of the atria. Describe the differences between the left and right atria. What is the function of the auricles? Where can the pectinate muscles be found?
10. Describe the differences between the ventricles and atria.
11. Where is the oval fossa located? How does it appear?
12. Where can the opening of coronoid sinus be found? What is the function of the coronary sinus?
13. Where is the tricuspid valve located? What are the names of its cusps? Describe its functioning.
14. Where is the bicuspid valve located? What are the names of its cusps? Describe its functioning.
15. Describe the aortic valve. Name its cusps. Where are the lunulae and nodules located? What are their functions? Describe the functioning of the aortic valve.
16. Describe the valve of the pulmonary trunk. Name its cusps. Where are the lunulae and nodules located? What are their functions? Describe the functioning of the valve of the pulmonary trunk.
17. What is the purpose of the papillary muscles and tendinous cords? How do these muscles work?
18. Describe the phases of the work of the heart.
19. List the layers of the heart in order.
20. Describe the structure of the atria`s myocardium.
21. Describe the structure of the ventricles` myocardium.
22. What is the conducting system of the heart? What is its function? Describe its structure and its functioning.
23. Describe the surface projection of the superior, inferior, right and left borders of the heart.

24. Where is the projection of the tricuspid and bicuspid valves to the thorax?
25. Where is the projection of the valves of the aorta and pulmonary trunk to the thorax?
26. What layers does the pericardium consist of?
27. Where is the pericardial cavity located?
28. What parts of the pericardium do you know?
29. Where are the transverse and oblique pericardial sinuses located?
30. Describe the development of the heart.
31. Describe the fetal blood circulation.
32. What developmental anomalies of the heart do you know?

## CLINICOANATOMICAL PROBLEMS

1. The electric shock caused a cardiac arrest. Closed-cheat cardiac massage needs to be done. In what area of the chest will you do it?
2. The USI-examination of a patient with endocarditis shows that the diameter of the left atrioventricular orifice is 8-10 mm. What may a doctor say about stenosis of the left atrioventricular orifice in this case?
3. A doctor is performing a radiological examination with the injection of the contrast substance to a patient with mitral valve insufficiency. The catheter is inserted into the aorta through the brachial artery. Which chambers of the heart should be visible on the radiograph?
4. The electrocardiography of a patient with endocarditis shows the disorder of the conductivity in the left ventricle. What structures of the conducting system are damaged?

## 3. ENDOCRINE SYSTEM

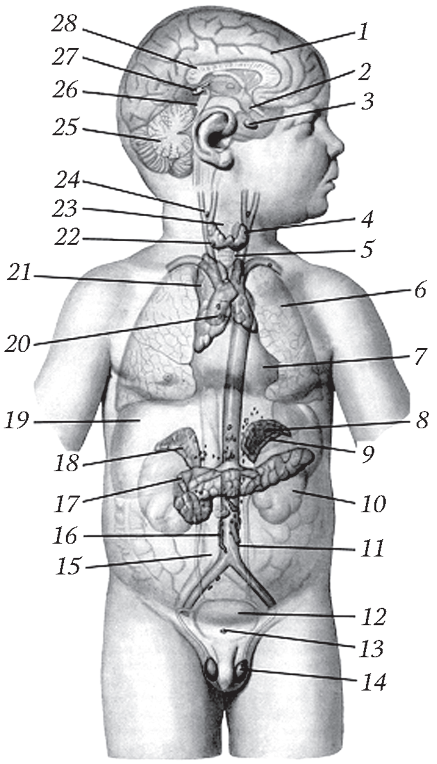


Fig. 3.1. Scheme of the disposition of the endocrine glands:

1 — cerebral hemispheres; 2 — infundibulum; 3 — hypophysis; 4 — thyroid gland; 5 — trachea; 6 — left lung; 7 — pericardium; 8 — medulla of suprarenal gland; 9 — medulla of suprarenal gland; 10 — kidney; 11 — aorta; 12 — urinary bladder; 13 — mons pubis; 14 — testis; 15 — inferior vena cava; 16 — para-aortic body; 17 — pancreas; 18 — suprarenal gland; 19 — liver; 20 — supracardial paraganglion; 21 — thymus; 22 — parathyroid glands; 23 — larynx; 24 — carotid body; 25 — cerebellum; 26 — tectum mesencephali; 27 — pineal body; 28 — corpus callosum

The endocrine glands, *glandulae endocrinae*, are the organs producing the biological active substances, the hormones (from Greek *hormao* — excite, arouse). Unlike the external secretory glands (the exocrine glands), they do not have excretory ducts and discharge their secreting products immediately into body`s internal environment (blood, lymph and other tissue fluids). This explains the term “endocrine glands” (from Greek *endo* — inside, *crino* — discharge).

The hormones selectively act on the cells of the certain organs. These cells are the target-cells for the hormone. The hormones reach the target-cells via blood or lymph thus they participate in the humoral regulation of the physiological functions of the organism. All the endocrine glands are highly vascularized thus the substances, which are necessary for the synthesis of the hormones, can rapidly reach the glands. The outflow of the blood, which transports the hormones to the corresponding organs, occurs also rapidly.

The endocrine glands (fig. 3.1) are functionally interrelated. The hypothalamus plays the chief role in the regulation of the activity of all the glands; it provides the close interrelationsip of the nervous system and endocrine glands. The neurons of some hypothalamic nuclei secrete the biological active substances called the releasing factors or hormone-regulating factors. These substances act on the cells of the anterior lobe of the hypophysis that produces so-called *tropic* hormones regulating the activity of the thyroid, adrenal and reproductive glands. Thus, the hypophysis is a specific intermediary between the brain (hypothalamus) and most endocrine glands. But this mechanism of the regulation of the endocrine glands activity is not single; the other mechanisms exist.

Due to the functional hierarchy, the morphologically separated glands are united into the endocrine system.

**The classification of the endocrine glands according to origin**:

I. Glands of entodermal origin:

1) the derivatives of the epithelium of the pharynx and pharyngeal pouches (branchiogenic group): thyroid gland, parathyroid glands and thymus;

2) the derivatives of the epithelium of the gut: the islets of the pancreas.

II. Glands of mesodermal origin: the suprarenal cortex, inter-renal system and reproductive glands.

III. Glands of ectodermal origin:

1) the derivatives of diencephalon (neurogenic group): the posterior lobe of the hypophysis (neurohypophysis), epiphysis;

2) the derivatives of the epithelium of the hypophysial pouch (Rathke`s pocket): the anterior lobe of the hypophysis (adenohypophysis);

3) the derivatives of the sympathetic part of the vegetative nervous system: the suprarenal medulla and paraganglia (chromaffin bodies).

Apart from the endocrine glands, the cells of the diffuse neuro-endocrine system (APUD cells), which are situated in most of the internal organs, produce the biological active substances, the polypeptide hormones.

## 3.1. Thyroid Gland

The thyroid gland, *glandula thyroidea*, is an unpaired dark red organ which consists of two lobes connected by the isthmus (fig. 3.2). It resembles a horseshoe in shape, but its form and sizes are variable and depend on the vascularization and functional condition of the gland. The length of each lobe is about 50 mm; the transverse extent is about 50—60 mm; the height of the isthmus is 5—15 mm. The weight is about 25—30 g (0,05 % of the total body weight).

The thyroid gland consists of the left and right lobes, *lobus sinister et lobus dexter*. Each lobe has a wide base and sharpened apex; also it has outer (or anterolateral) surface and inner (or posteromedial) surface. Anteriorly the lobes are connected by the isthmus, *isthmus glandulae thyroideae*. The isthmus is variable in structure: it may be narrow (5 mm), wide (15 mm), may be absent; in one third of cases it gives a long narrow process, the pyramidal lobe, *lobus pyramidalis*. The gland is placed anteriorly in the neck. The bases of the lobes cover 5–6 tracheal cartilages, while the apices reach the middle of the thyroid cartilage. Posteriorly, the lobes reach the oesophagus, covering the groove between the oesophagus and trachea, which transmits the recurrent laryngeal nerve. Laterally, the neurovascular bundle of the neck contacts the lobes. The isthmus is in front of the first two tracheal cartilages, often in front of the cricoid cartilage. The pyramidal lobe arises from the isthmus either at the midline or to the right or to the left of the midline. The apex of this inconstant lobe reaches the middle of the thyroid cartilage or may ascend to the hyoid bone and even

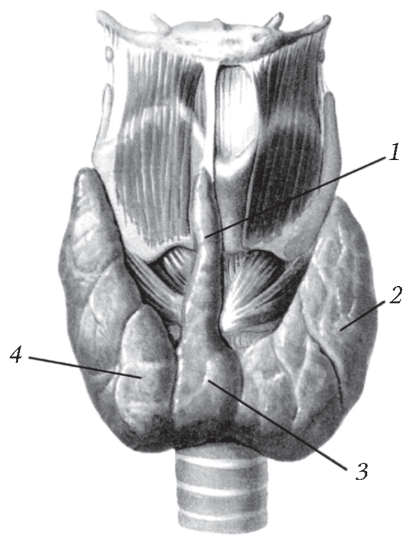


Fig. 3.2. Thyroid gland:
1 — pyramidal lobe; 2 — left lobe; 3 — isthmus of thyroid gland; 4 — right gland

higher. Anteriorly, the thyroid gland is covered by the infrahyoid muscles (sternohyoid, sternothyroid, thyrohyoid, omohyoid), and also by the superficial and pretracheal layers of the proper cervical fascia. The gland has an external fascial capsule, formed by the visceral layer of the endocervical fascia, and internal connective tissue capsule. The space between these two capsules contains areolar tissue, vessels and nerves; posteriorly, it contains the parathyroid glands. Thin fibro-elastic internal capsule, *capsula fibrosa*, gives the septa, trabeculae, into the gland. The septa containing the nerves, blood and lymphatic vessels form a stroma and divide the gland into the lobules, *lobuli*. The parenchyma consists of the follicles which are filled with viscid colloid possessing high hormonal activity. The follicle is a structural and functional unit of the thyroid gland. Their number is about 30 millions. The follicle is a rounded or oval cavity, whose walls are composed of a single layer of the epithelial cells. The collection of 20–40 follicles, surrounded by interfollicular connective tissue and plexuses of blood and lymphatic vessels, forms a lobule of the gland.

The chief hormones of the thyroid gland are thyroxine (tetra-iodthyroinine) and tri-iodthyronine; their specific feature is the content of iodine. The follicular cells of the gland have a unique ability to take iodine from the blood; iodine is necessary for the biosynthesis of these hormones. Normally the gland takes about 50 % of iodine entering the body and rapidly uses it for the synthesis of the thyroid hormones. In iodine insufficiency the glandular tissue grows, the weight of the gland abruptly increases (hypertrophia), and the goitre appears. It should be noted that if the thyroid gland hypertrophies, its function may not change or may even decrease. The other cells of the thyroid gland, parafollicular, produce the hormone thyrocalcitonin. The thyrocalcitonin lowers the concentration of calcium in the blood, when it rises above the normal value, and contribute to absorption of calcium by osseous tissue. The thyroid hormones are powerful regulators of the main body functions: they stimulate the growth, sexual development, basal metabolism and the activity of the central nervous system.

The thyroid dysfunctions manifest as the increase or decrease of the secretion of the hormones. The reduction of the thyroid function is called hypothyroidism. The increase of the thyroid function is termed hyperthyroidism. In children, hypothyroidism leads to cretinism (delay in growth, intellectual and sexual development). In adults, hypothyroidism causes myxedema (mucous swelling), which is characterized by the decrease of the basal metabolic rate, disorder of the protein metabolism and the swelling of tissues. The excessive production of the hormones (hyperthyroidism) is marked by the toxic effects, thyrotoxicosis (Graves-Basedow`s disease), causing exophthalmos (bulging eyeballs), weight loss, rapid heart beat, increased irritability.

**Embryogenesis.** The rudiment of the thyroid gland appears in embryo during the third week of embryonic life as a protrusion of the ventral wall of the pharynx between the first and second pairs of the pharyngeal pouches. From this protrusion, near the developing tongue, the epithelial cord termed the thyroglossal duct starts to grow into mesenchyme. The distal end of this duct bifurcates to form the paired thickenings, the primordia of the thyroid gland`s lobes. During the sixth week, the epithelial cord separates from the pharynx, its lumen closes but its distal end remains between the rapidly growing lateral thickenings (primordia of the lobes) as the isthmus which connects the lobes of the developing gland.

**Age changes**. In children, the thyroid gland lies higher than in adults. At puberty the gland increases, in old age it decreases without the disorder of the function.

## 3.2. Parathyroid Glands

In humans there are paired superior parathyroid gland, *glandula parathyroidea superior*, and paired inferior parathyroid gland, *glandula parathyroidea inferior* (fig. 3.3). They are small, yellowish-brown, rounded or ovoid structures. The glands vary in number: usually there are four parathyroid glands, in 30 % of cases more than four, occasionally (less than 1 %) 2–3 glands. Their average sizes are: the length is 4–5 mm, thickness is 2–3 mm, weight is 0,2–0,5 g. The inferior parathyroid glands are usually larger than superior.

Each of the parathyroids is covered by a thin connective tissue capsule which sends the septa into the gland. However, the gland does not have the lobules. The parathyroids lie in loose connective tissue separating the inner (proper) and outer (fascial) capsule of the thyroid gland. The superior glands adjoin the apices of the thyroid gland`s lobes, approximately level with the cricoid cartilage. The inferior glands are between the trachea and the thyroid gland`s lobes, near their bases. In 20% of cases one of the gland occupies atypical position (in the anterior or posterior mediastinum, behind the oesophagus, near the bifurcation of the common carotid artery). Rarely, the parathyroid glands lie immediately in the parenchyma of the thyroid gland.

Parathyroid hormone, parathormone, controls the level of calcium ions in blood. It selectively affects osteoclasts which destroy the osseous tissue, releasing calcium from bone into blood. The decrease of the level of calcium in blood (deficiency of calcium in eaten food, cancer of the parathyroid gland, rachitis) stimulates the secretion of parathormone which in its turn activates osteolysis. As a result, the level of calcium in blood is increased but the bones become fragile. The removal of the parathyroid glands in animals causes tetany (convulsive contraction of the skeletal musculature), the immediate cause of which is the decrease of the level of calcium in blood. In children (in case of the congenital insufficiency of the parathyroid glands), hypoparathyroidism leads to delayed growth of the bones and long convulsions of the certain group of the muscles. Hyperparathyroidism is caused by malignant tumors of the parathyroid glands.

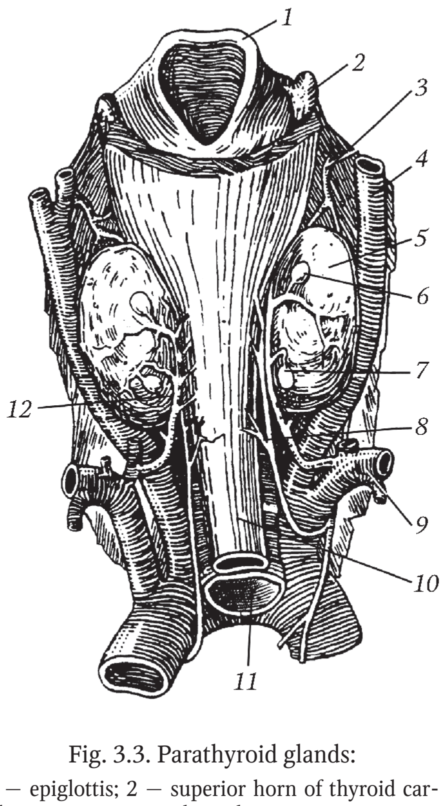


Fig. 3.3. Parathyroid glands:

1 — epiglottis; 2 — superior horn of thyroid cartilage; 3 — superior thyroid artery; 4 — common carotid artery; 5 — right lobe of thyroid gland; 6 — right superior parathyroid gland; 7 — right inferior parathyroid gland; 8 — inferior laryngeal nerve; 9 — right subclavian artery; 10 — oesophagus; 11 — trachea; 12 — inferior thyroid artery

**Embryogenesis.** The parathyroid glands develop from epithelium of the III and IV pharyngeal pouches. Their rudiments appear between the 3 and 4 weeks of embryonic life. Then they separate from the pharynx and migrate caudally: from the III pharyngeal pouch to the bases of the thyroid

gland`s lobes (the inferior parathyroids), and from the IV pharyngeal pouch to the apices of the thyroid gland`s lobes (the superior parathyroids).

**Age changes.** The parathyroid glands intensively grow after birth: during the first year of life their weight increases by 3—4 times. The weight of the glands increases during the entire period of the body growth. By 18—20 years of age they reach the maximum development, and their weight remains unchanged until old age.

## 3.3. Thymus

The thymus, *thymus*, an unpaired organ, consists of two lobes, the middle parts of which are connected by loose connective tissue (fig. 3.4). The lobes are elongated structures, slightly expanded inferiorly and narrow superiorly. The left lobe, *lobus sinister*, is more developed and usually longer than the right lobe, *lobus dexter*. The form of the gland resembles a leaf of thyme hence, it is called the thymus. Its surface is uneven, the color is pinkish-grey. Its weight in a newborn is 10–15 g, the length is 5 g; in the period of the maximum development (10–15 years of age) the gland is 7,5–16 cm long and weighs 30–40 g.

The thymus leis behind the sternum; it protrudes above the jugular notch and inferiorly reaches the level of the 3—4 ribs. The gland is mainly in the superior part of the anterior mediastinum, in the superior interpleural area. Above, the thymus bulges into the cervical region and may contact the thyroid gland. Below, the gland reaches the pericardium and covers it in different extent. Posterior to the gland is the trachea and great vessels: brachiocephalic veins, superior vena cava, aortic arch with its branches. The most part of the anterior and lateral surfaces of the thymus is covered by the pleura.

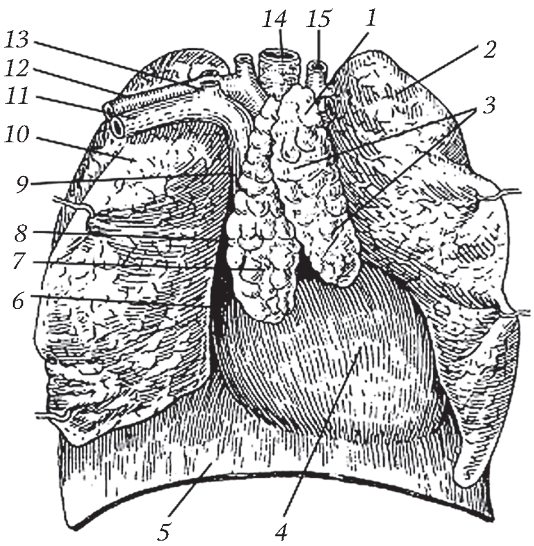


Fig. 3.4. Thymus:

1 — thymic lobule; 2 — mediastinal surface of the left lung; 3 — left lobe of thymus; 4 — pericardium; 5 — diaphragm; 6 — anterior border of the left lung; 7 — right lobe of thymus; 8 — mediastinal part of pleura; 9 — superior vena cava; 10 — right lung; 11 — subclavian vein; 12 — subclavian artery; 13 — internal jugular vein; 14 — trachea; 15 — left common carotid artery

The thymic lobes are enclosed in connective tissue capsule which sends the incomplete interlobular septa, *septa interlobularia*, into the lobes; the septa divide the gland into the lobules, *lobuli thymi*. Each lobe consists of a peripheral cortex, *cortex thymi*, and central medulla, *medulla thymi*. The cortex is composed of a framework of interconnected epithelial cells, which contains lymphocytes. The epithelial cells of the medulla are strongly flattened and form so-called thymic (Hassal`s) corpuscles, *corpuscula thymi*.

The thymus is the central organ of the immune system. In the cortex the primary differentiation of T-lymphocytes, providing an effective immune response, occurs. The differentiation of T-lymphocytes occurs

only under the effect of the thymic hormone, which is produced by the epithelial cells of the thymic medulla. The recent researches showed that the thymic hormone consists of thymogen, thymosin, T-activin, thymarin and several other biological active substances. The thymic hormone is especially important for the normal development of lymphoid tissue during neonatal and early postnatal life.

**Embriogenesis.** The thymus develops as a paired protrusion of the epithelium of the IV pharyngeal pouch at the beginning of the 2d month of embryonic life. During the 5th month the formation of the cortex and medulla ends, and the structure of the gland becomes lobular.

**Age changes.** The sizes and structure of the thymus considerably change with age. In relation to body weight, the thymus is largest in fetal life and during first two years of life. Then the thymus continues to increase in absolute size up to the period of puberty. After this period the gland undergoes gradual involution, and the glandular tissue is mainly replaced by adipose tissue but often keeps the initial form.

## 3.4. Endocrine Part of Pancreas

The endocrine part of the pancreas, *pars endocrina pancreatis*, consists of pancreatic islets, *insulae pancreaticae*, (of Langerhans). These are the compact cell groups, lighter than the main parenchyma of the pancreas. They greatly vary in form, sizes and number. More often the islets are round, 100–200 mkm in diameter; their total number is from 500 000 to 1 500 000. The islets are dispersed throughout the pancreas but mainly concentrate in its tail. The weight of the endocrine part is about 1–2% of the total weight of the pancreas.

The specific cells of the islets include two types: A (alpha), which tend to be peripheral in islets, and B (beta), more central. These cells secrete two main hormones of the pancreas, regulating the level of the glucose in blood but antagonistic. B cells produce insulin which decrease the level of carbohydrates in blood, facilitating the transport of glucose into cells, and stimulate the synthesis of glycogen in the liver and muscles. A cells produce glucagon which transforms glycogen into glucose and raises the concentration of glucose in blood. The ratio between A and B cells is important for the regulation of the carbohydrate metabolism; normally, the number of B cells 3—4 times exceeds the number of A cells in an islet. The insufficient production of insulin by the pancreas causes diabetes; the clinical manifestation of diabetes is accompanied by hyperglycemia (the increased level of glucose in blood). Conversely, if the concentration of insulin in blood is increased (in case of the overdose of insulin to a patient with diabetes or tumor of the pancreas), hypoglycemia (the abrupt decrease of the level of glucose) occurs .

Apart from A and B cells, the islets have C, D, E, PP-insulocytes producing somatostatin, pancreatic polypeptides etc. They act on the production of insulin, glucagon and pancreatic juice.

**Embriogenesis.** Both the endocrine and exocrine parts of the pancreas develop from entoderm of the middle part of the primitive gut. In early stages of the embriogenesis there is no differentiation into the endo- and exocrine parts. The first islets appear during 10th week of embryonic life from the epithelium of the pancreatic excretory ducts.

## 3.5. Suprarenal Glands

The suprarenal (adrenal) gland, *glandula suprarenalis (adrenalis)*, is a paired organ situated in the paranephric fat, in immediate vicinity to the superior pole of the kidney (fig. 3.5).

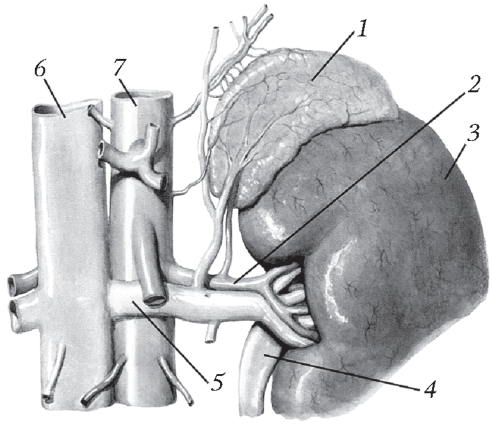


Fig. 3.5. Left suprarenal gland:

1 — left suprarenal gland; 2 — left renal artery; 3 — left kidney; 4 — ureter; 5 — left renal vein; 6 — inferior vena cava; 7 — abdominal part of aorta

The right and left suprarenal glands differ in shape: the right gland is like a trihedral pyramid, the left gland is semilunar. Each suprarenal gland has three surfaces: anterior, *facies anterior*, posterior, *facies posterior*, and renal, *facies renalis*. Free borders of the glands, which do not adjoin the kidneys, are called superior and medial, *margo superior et margo medialis*. The medial border of the right gland is in contact with the superior pole of the kidney, while the medial border of the left kidney adjoins the medial border of the left kidney, from the renal superior pole to hilum. The suprarenal glands are yellow, their surfaces are slightly uneven. They measure about 5 cm vertically, 3—4 cm transversely and 1 cm in the anteroposterior dimension.

Each gland is covered by the fibrous capsule connected with the renal capsule by the numerous cords. The parenchyma of the glands consists of an outer cortex, forming the main mass (about 90 % of the total weight of the gland), and central medulla. The cortex is adherent to the fibrous capsule that sends the septa, trabeculae, into the gland.

On the medial side of the suprarenal gland there is a suprarenal hilum, *hilum suprarenalis*, through which the vessels (the central suprarenal vein, middle suprarenal artery) and nerves pass.

The suprarenal glands lie at the level of the XI and XII thoracic vertebrae, the right gland is slightly below than the left. Their posterior surfaces are related to the lumbar part of the diaphragm, the renal surfaces adjoin the kidneys (vide supra). The syntopy of the anterior surfaces is different. The anterior surface of the left suprarenal gland is in contact with the cardiac part of the stomach and the tail of the pancreas; the medial border adjoins the aorta. The anterior surface of the right suprarenal gland adjoins the liver and duodenum; the medial border contacts the inferior vena cava. Both glands are located retroperitoneally, their superior surfaces are partially covered by the peritoneum. The suprarenal glands together with kidneys are surrounded by the sheaths providing their fixation: perinephic fat and renal fascia.

**Internal structure.** The suprarenal glands consist of two independent endocrine glands, the cortex and medulla, which unite into a single organ. The cortex and medulla have different origin, cell composition and functions.

The cortex is divided into three zones associated with the synthesis of the certain hormones. The most superficial and thin layer of the cortex is the zona glomeruloza, *zona glomerulosa*. The middle layer is the zona fasciculata, *zona fasciculata*. The innermost layer, adjoining the medulla, forms the zona reticularis, *zona reticularis*. The hormones of the suprarenal glands (corticosteroids) are essential to life because they regulate the metabolic processes in the whole body. They are divided into three groups, and each of them is produced in the certain cortical zone. The first group is called mineralocorticoids; they are produced in the zona glomeruloza. The second group is glucocorticoids; they are produced in the zona fasciculata. The third group includes the reproductive hormones which are synthesized in the zona reticularis.

Mineralocorticoids regulate the mineral metabolism in the body: first of all they maintain the balance between sodium and potassium. The most active hormone, aldosterone, increases the reabsorption of sodium and water in the renal tubules, resulting in the increase of the level of sodium in blood, lymph and tissue fluid and simultaneous decrease of the reabsorption of potassium. When the production of mineralocrticoids by the suprarenal glands is insufficient, the reabsorption of sodium decreases, and it is excreted with urine in large quantity. The loss of sodium leads to the lethal changes of the internal environment therefore, the mineralocortocoids are vital.

Glucocorticoids (cortisol, hydrocortisone) greatly affect the metabolism of proteins, carbohydrates and lipids.

Reproductive hormones (androgens and estrogens) regulate the development of the reproductive organs in children, and largely determine gender-specific behavior in adults.

The medulla, *medulla*, is composed of chromaffin cells. These cells give an intense yellow-brown coloration, when treated with potassium dichromate. They secrete catecholamines (adrenalin and noradrenalin). In normal state both hormones are produced in small quantity and do not give pronounced physiological effects. But in extreme situations (emotional and physical stress) these hormones are released by the cells of the medulla in larger quantity and cause the emergency reconstruction of physiological functions: the increase of heartbeat, the increase of the concentration of glucose in blood, the increase of excitability of the receptors of the retina, acoustic and vestibular apparatuses, the increase of the efficiency of the skeletal muscles and so on. The effects of noradrenalin is almost similar to the effects of adrenalin but some of them may be even opposite.

**Embryogenesis.** The suprarenal cortex and medulla develop independently from each other. Firstly (during the 8th week of embryonic life) the cortex is formed; it appears as a thickening of mesoderm near the root of the dorsal mesentery of the developing kidneys. Further (during 12—16 weeks), from the embryonic sympathetic trunk the sympathochromaffin cells migrate; they grow into the rudiment of the suprarenal cortex and form the medulla. Thus, the cortex develops from mesoderm (from coelomic epithelium), while the medulla develops from the embryonic nerve cells, chromaffinoblasts.

According to the localization of the primordium (between the primary kidneys) the cortex is considered to be a part of the inter-renal system. The accessory suprarenal glands, *glandulae suprarenales accessoriae*, (so-called intra-renal bodies) also belong to the inter-renal system. They may appear in humans as the small structures consisting mainly of the cells of the zona fasciculata. In 16–20 % of cases they are observed in different organs: in the uterine broad ligament, in epoophoron, on the inferior vena cava, near the coelic plexus and also on the surfaces of the suprarenal glands in the form of nodules. «True» accessory suprarenal glands, consisting of the cortex and medulla, are observed extremely rarely.

Besides the chromaffin cells of the suprarenal medulla, the adrenal system includes the paraganglia (chromaffin bodies) composed of the small aggregation of the chromaffin cells. The para-aortic bodies, *corpora paraaortica*, lie to the right and to the left of the aorta above its bifurcation; the coccygeal body, *glomus coccygeum*, is below the bifurcation; the sympathetic paraganglia, *paraganglia sympathica*, are in the ganglia of the sympathetic trunk; the carotid body, *glomus caroticum*, is at the bifurcation of the common carotid artery.

**Age changes.** The thickness and structure of the suprarenal gland change with age. In a newborn the suprarenal cortex consists of two parts: the primordial cortex (X-zone) and thin layer of the true cortex. After birth the suprarenal glands decrease due to degeneration of X-zone. The growth of the suprarenal glands accelerates during puberty. By old age the suprarenal glands begin to atrophy.

## 3.6. Pineal Gland (Epiphysis)

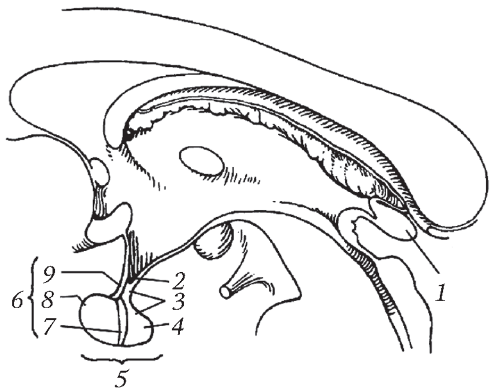


Fig. 3.6. Hypophysis and epiphysis. Median section of brain:

1 — pineal gland; 2 — infundibulum; 3 — neurohypophysis; 4 — nervous lobe; 5 — hypophysis; 6 — adenohypophysis; 7 — intermediate part; 8 — distal part; 9 — tuberal part

The pineal gland, *glandula pinealis*, (epiphysis, *epiphysis*), is an unpaired structure, also called *appendix cerebri superior*, is a part of the epithalamus of the diencephalon (fig. 3.6). It lies along the median plane deeply between the cerebral hemispheres. It resembles a pine cone (hence, the name), has a slightly uneven surface and reddish-grey color. The gland is about 8–10 mm in length, and 6 mm in breadth; its weight is about 0,2 g. The base of the pineal gland adjoins the posterior wall of the III ventricle, connecting by *habenulae* with the superior colliculi of mesencephalon. The sharpened apex of the gland is in the groove between the superior colliculi.

The pineal gland is covered by a thin connective tissue capsule which gives into the gland the incomplete septa dividing the glandular parenchyma into the lobules. The pineal parenchyma consists of the secretory cells, pinealocytes, and glial cells. The pinealocytes secrete melatonin and serotonin in blood; they are the humoral regulators which presumably inhibit the secretion of gonadotropic hormones of the hypophysis.

There are enough evidences to consider the pineal gland to be an endocrine gland which regulates the activity of the reproductive glands. It inhibits the development of the reproductive system until puberty.

**Embryogenesis.** The pineal gland appears during the 2d month of embryonic life as a protrusion (diverticulum) of the caudal end of the roof of the III ventricle. The walls of the diverticulum thicken, and its lumen is obstructed.

**Age changes.** The pineal gland reaches the maximum development in children. With age it undergoes the gradual involution: the increase of the layers of the stroma and the decrease of the number of the parenchymal cells. After the age of 10 years the gland starts to calcify; the granules of calcium and magnesium salts (so called "*acervulus cerebri*") appear in the pineal gland. Most authors consider this process to be a physiological process. However, in spite of the age structural changes, the specific parenchyma of the pineal gland remains until old age.

## 3.7. Reproductive Glands

The reproductive glands produce the germ cells and also work as endocrine glands, secreting the reproductive hormones into blood. The structure of these glands is described in the corresponding chapters.

The reproductive hormones have many biological effects aimed at the providing of normal reproductive function. The reproductive hormones are divided into male reproductive hormones, androgens, and female, estrogens and gestogens. The male and female hormones are produced by both male and female reproductive glands.

The reproductive hormones are necessary for puberty, i.e. for the gamete maturation, preservation of their viability, for the transport in the reproductive tract; in females they create the conditions for the fertilization of ovum and its implantation in the uterus. The male reproductive hormone, testosterone, is produced in the interstitial tissue of the testis by Leydig cells. The female reproductive hormones, estrogens, are produced in the ovaries, in the membrana granulosa of the follicles and Graafian vesicles, and also in the theca interna.

The corpus luteum, which develops from the broken Graafian vesicle, secrets the hormone progesteron (it belongs to gestagens), which prepares the uterus for the implantation a fertilized ovum and maintains pregnancy.

## 3.8. Hypophysis

The hypophysis, *hypophysis*, or appendix cerebri inferior, is a part of the hypothalamus of the diencephalon (fig. 3.6). It is an unpaired reddish-grey ovoid body, about 12-15 mm in transverse and 10 mm in anteroposterior diameter and weighing about 0,5–0,6 g. It lies in the hypophysial fossa of the sella turcica, covered superiorly by the diaphragma sellae, *diaphragma sellae*. The diaphragma sellae is a piece of dura mater, stretched between the anterior clinoid processes and posterior clinoid processes of the sphenoid bone and pierced centrally by an aperture for the infundibulum, *infundibulum*, connecting the hypophysis with the tuber cinereum, *tuber cinereum*.

The hypophysis consists of two parts, which are different in structure and origin but are in close interrelationship, the adenohypophysis and neurohypophysis. In children, they are separated from each other by a distinct fissure; in adult, by cystic cavities filled with a colloid.

The adenohypophysis, *adenohypophysis*, forms a larger anterior lobe, *lobus anterior*; the neurohypophysis, *neurohypophysis*, forms a narrow posterior lobe, or nervous part, *lobus posterior (lobus nervosus)*.

The adenohypophysis consists of three parts: 1) distal, *pars distalis*, forming the main mass of the anterior lobe (70–80 % of the total weight of the gland); 2) tuberal, *pars tuberalis*, forming the superior part of the anterior lobe and spreading to the anterior and lateral parts of the infundibulum, and 3) intermediate, *pars intermedia*, adjoining the posterior lobe. The anterior lobe produces several hormones (each by the cells of the specific type). These are so-called tropic hormones; each hormone stimulates the activity of the certain target-gland: thyroid gland (TTH, thyreotropic hormone); suprarenal cortex (ACTH, adrenocrticotropic hormone); pancreas (PTH, pancreatotropic hormone); reproductive glands: male and female (GTH, gonadotropic hormone: FSH, folliculostimulating hormone; LH, luteinizing hormone; LTH, lactotropic hormone); STH, somatotropin involved in the control of body growth.

Insufficient or excessive secretion of the hormones of the adenohypophysis causes the various and very serious disorders in the body.

The intermediate part of the hypophysis produces melanocyte-stimulating hormone (MSH), regulating the quantity of the pigment (melanin) in the body, and lipotropic hormone (LTH), stimulating the lipid metabolism.

The neurohypophysis includes, besides the posterior lobe of the hypophysis, the infundibulum and the median eminence of the tuber cinereum. The posterior lobe of the hypophysis is an extraordinary component of the endocrine system because it does not have the cells producing the hormones into blood. The posterior lobe is closely associated with the hypothalamus (with the supraoptic and paraventricular hypothalamic nuclei) by the hypotalamo-hypophysial tract. The latter is formed by the axons of these

nuclei, which end in immediate vicinity to the capillaries of the posterior lobe of the hypophysis. In fact, the hormones contained in the posterior lobe are secreted by the neurosecretory cells of the hypothalamus: the cells of the supraoptic nuclei produce the hormone vasopressin (also called antidiuretic hormone, ADG); the cells of the paraventricular nuclei produce oxytocin. Through the fibers of the hypothalamo-hypophysial tract the hormones are delivered into the posterior lobe of the hypophysis and then into the capillary bed. Vasopressin increases the blood pressure (in artificial introduction), and normally works as antidiuretic hormone reducing diuresis. The hypofunction of the posterior lobe leads to the diabetes insipidus. Oxytocin stimulates the contraction of smooth musculature of the hollow organs, especially of the uterus; it is necessary for the normal parturition.

The hypothalamus and hypophysis have a particular blood supply that provides their functioning. The adenohypophysis and neurohypophysis are vascularized independently from each other.

The vascular bed of the adenohypophysis is represented by so-called portal system which is arranged as follows. The superior hypophysial arteries form the primary capillary network in the hypothalamus. The capillaries of this network unite to form the portal venules which descend to the adenohypophysis where branch again into wide capillaries (sinusoids); the sinusoids form the secondary capillary network. The primary capillary network absorbs hormone-releasing factors, elaborated in the hypothalamic nuclei. The hormone-releasing factors may either stimulate the production of the tropic hormones by the hypophysis or inhibit it. The factors stimulating the secretion of the tropic hormones are called liberins: corticoliberin, thyroliberin, gonadoliberin, somatoliberin etc. The inhibiting factors are named statins: prolactostatins, somatostatin etc. Via the portal venules these peptides are delivered into the secondary capillary network where they regulate the secretion of the tropic hypophysial hormones.

The neurohypophysis is supplied by the inferior hypophysial arteries.

**Embryogenesis.** The hypophysis develops from two rudiments. The adenohypophysis appears as a protrusion of the epithelium of the stomatodeum (Rathke`s pouch) during the 4th week of embryonic life. Simultaneously from the developing diencephalon a protrusion grows, the rudiment of the infundibulum. Both protrusions grow towards each other. The growth of neuroglia on the end of the infundibulum results in the formation of the neurohypophysis, and the expansion of the Rathke`s pouch gives rise to the adenohypophysis. Thus, the adenohypophysis develops from epithelium (like most of the endocrine glands), while the neurohypophysis is a derivative of the diencephalon.

**Age changes.** The weight of the hypophysis in a newborn is 0,10–0,12 g. In childhood and adolescence the gland intensively grows and reaches the maximum development by 20 years of age, having a weight 0,5–0,6 g. Further the weight of the gland does not change.

## TEST QUESTIONS

1. Give the definition of the endocrine system.
2. What is the function of the endocrine system?
3. Give the definition of the hormones.
4. Give the definition of an endocrine gland.
5. Classify the hormones.
6. Describe the properties of the hormones.
7. Describe the components of the endocrine system.
8. Describe the principles of the organization of the endocrine system.
9. Classify the endocrine glands according to the origin.

10. Describe the components and localization of the hypothalamus. What is the hypothalamo-hypophysial system?
11. Describe the structure of the hypophysis. What are the sizes of the hypophysis?
12. Describe the relations between the hypothalamus and hypophysis? What hormones of the hypothalamus affect the hypophysis and how do they affect?
13. Name the hormones of the adenohypophysis and of the neurohypophysis.
14. Describe the effects of STH, TSH, ACSH, GSH (in males and females).
15. Describe the effects of the hormones of the neurohypophysis (ADH and oxytocine).
16. Describe the development of the hypophysis.
17. Describe the localization of the epiphysis. What are the sizes of the epiphysis? What hormones does it produce? What are their effects?
18. Describe the development of the epiphysis.
19. Describe the localization and structure of the thymus. What age changes occur with the thymus? What hormone and BAS does the thymus produce? Describe the function of the thymus.
20. Describe the development of the thymus.
21. Describe the localization, external structure and normal sizes of the thyroid gland. Describe the internal structure of the thyroid gland.
22. Which hormones does the thyroid gland produce? Describe their effects.
23. Describe the symptoms of the disorder of the thyroid gland`s hormones production in childhood and in adults.
24. Describe the development of the thyroid gland.
25. Describe the localization and normal sizes of the parathyroid glands. Describe their structure. What hormone do the parathyroid glands produce?
26. Describe the function of parathyroid hormones and the symptoms of the disorder of their production.
27. Describe the development of the parathyroid glands.
28. Describe the structure of the endocrine part of the pancreas. What hormones are produced by the cells of the endocrine part of the pancreas? Describe their effects.
29. Describe the symptoms of the insufficient and excessive production of insulin.
30. Describe the development of the endocrine part of the pancreas.
31. Describe the localization and sizes of the suprarenal glands. Describe their internal structure.
32. Which hormones are produced by the cortex of the suprarenal glands and by the medulla? Describe their effects.
33. Describe the development of the suprarenal glands.
34. Describe the localization of the reproductive glands in males and females. What hormones do they produce?
35. Describe the effects of the reproductive hormones. Describe the symptoms of the disorder of the production of these hormones.

## CLINICOANATOMICAL PROBLEMS

1. A doctor observed the increase of the thyroid gland in a patient. The doctor has to determine the degree of the increase. What sizes of the thyroid gland are considered as normal?
2. A doctor is performing the operation for the tumor of the trachea at the level of the I-II thoracic vertebrae. Is there a risk of the damage of the thymus?
3. In a patient with hypertonic disease and atherosclerosis, the hemorrhage in the suprarenal gland occurred. Which functions of the suprarenal gland can be disordered?