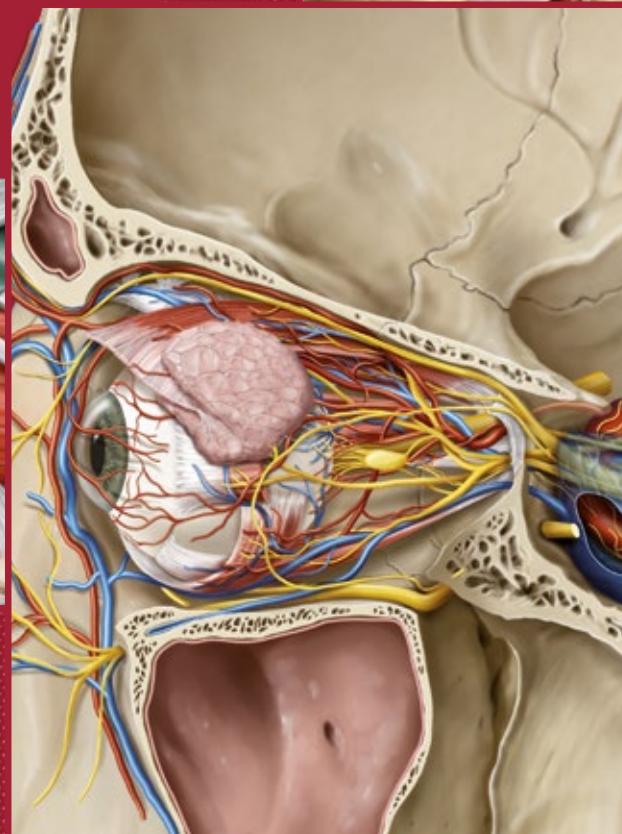
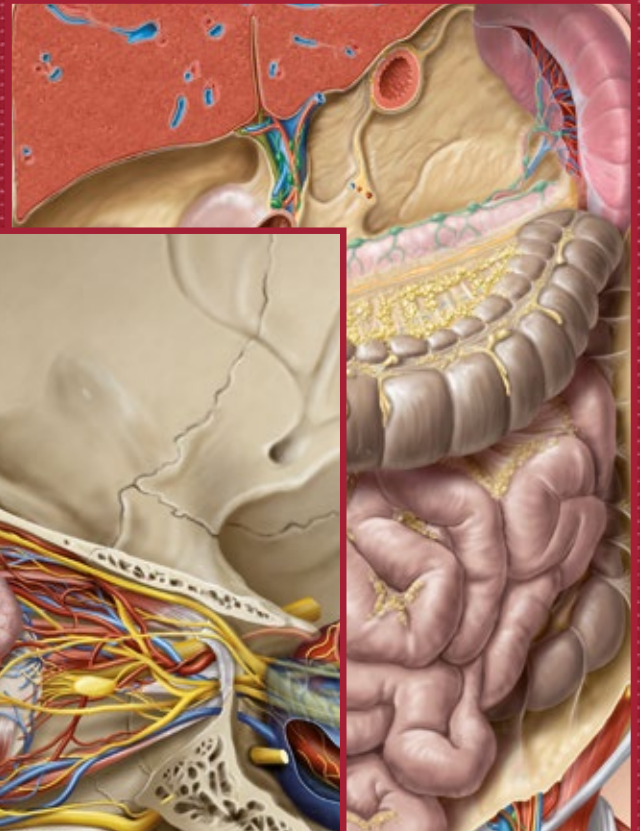
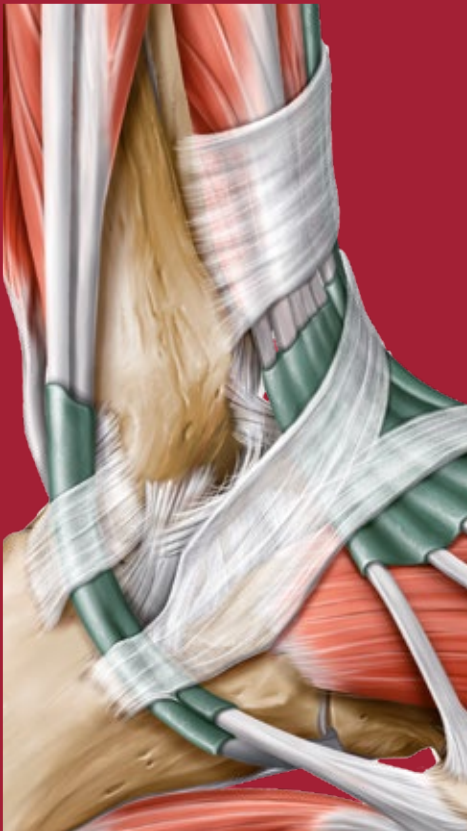


# HUMAN ANATOMY

THREE-VOLUME SET

THE INTEGUMENT  
MUSCULOSKELETAL SYSTEM  
CIRCULATORY SYSTEM  
LYMPHOID AND  
HEMATOPOIETIC ORGANS

ALIMENTARY SYSTEM  
RESPIRATORY SYSTEM  
URINARY SYSTEM  
GENITAL SYSTEM  
ENDOCRINE SYSTEM



NERVOUS SYSTEM  
SENSE ORGANS

*edi-ermes*





TREATISE ON  
**systemic and functional**  
**HUMAN ANATOMY**

**Estomih Mtui**  
*Editor English Edition*

***edi·ermes***

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<b>VOLUME 2</b>	Alimentary system Respiratory system Urinary system Male genital system Female genital system Endocrine system
<b>VOLUME 3</b>	Central nervous system Sense organs Peripheral nervous system

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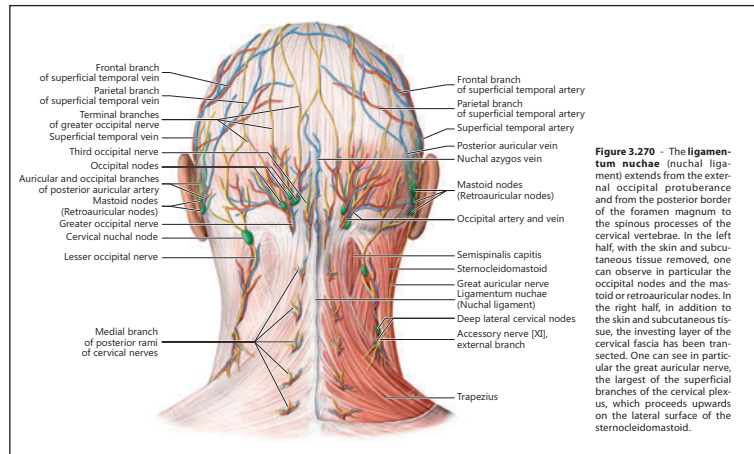
Scuola di Scienze della Salute Umana, Università degli Studi, Firenze

# Organization of the contents

While maintaining a systemic approach, the fifth edition of the Treatise on Human Anatomy has been enriched on the functional, clinical and radiological approach, as evidenced by the particularly accurate and updated iconography.

## Basic competence

The text provides useful elements for understanding the general organization. The large body text describes the essential notions for understand the subject, while the small body text deals with more insights related to the part being described.



### Sternoclavicular joint

The **sternoclavicular joint** connects the sternal or medial extremity of the clavicle to the manubrium of sternum and the first costal cartilage (Fig. 3.145). It is a saddle-shaped joint which must be considered double because of the interposition between the articular heads of an **articular disc**.

The **articular surfaces**, represented by the sternal extremity of clavicle and the clavicular notch of sternum, are not concordant. The articular surface of clavicle at right angles shows a marked convexity in vertical direction and modest in horizontal direction, whereas the articular surface of sternum continues downward and frontward with the superior surface of the first costal cartilage. A fibrocartilaginous articular disc, convex at the bottom and concave at the top, dividing the articular cavity into two portions, is situated between the two articular surfaces.

## Visualization

The extensive iconographic apparatus, including images, drawings and graphs, enriches the text and helps the student through a visual learning.

## Functional and clinical aspects

Functional and clinical aspects have been included in order to illustrate the anatomical basics in a logical manner.

### Popliteal pulse

The popliteal pulse is important to establish the vascularization state of the lower limb in presence of peripheral vascular lesions. It can be perceived more easily if the knee is slightly flexed, in a way to release the popliteal fascia and compress the artery against the central wall of the popliteal surface of the distal extremity of femur, exerting a slight pressure with the tip of the finger of both of the hands on the popliteal fossa and with the thumbs on both of the sides of the patella. A **popliteal aneurism** causes edema and pain in the popliteal fossa.



4.129; see Figs. 4.127, 4.128).

**Terminal branches** - The anterior and posterior tibial arteries provide for the arterial need for the vascularization of leg and foot. They participate with the recurrent branches to the formation of the genicular anastomosis, forming the **medial and lateral malleolar networks** and the **calcaneal network**, whereas the anastomoses between their distal branches form the **dorsal** (arcuate artery, branch of the dorsal artery of foot) and **plantar arterial arcades** (deep plantar arch).

**Collateral branches of the popliteal artery**

**Sural arteries**

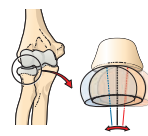
They are two rather large arteries originating at the level of the popliteal fossa.



### Simple joint movements

#### Sliding movement

It is the simplest movement of a joint and consists in the sliding of an articular surface over another one.

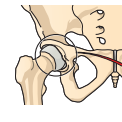


It consists in the reduction or increase of the space between the articular surfaces of the joint, during which the axis remains fixed in one point. The result is the biomechanics of the simple movements.

### JOINT MOVEMENTS

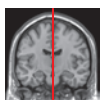
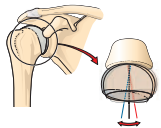
#### Rotation

The rotation movement makes a bone, or a body part, to rotate around its axis and is typical of the spheroidal joint. Examples: head movement to say "no" or to look to the right and to the left staying in upright position.



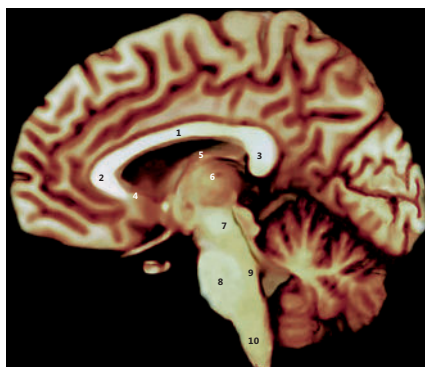
#### Oscillation

It consists in the oscillatory movement of a bone or a body part, during which the axis remains fixed in one point. The result is the biomechanics of the simple movements.



**Figure 13.154 - Location and relations of the thalamus**, a three-dimensional image of a living human body, obtained by NMR using a 3D volume rendering technique, showing the configuration of the telencephalon in median sagittal section.

1. Trunk of corpus callosum
2. Genu of corpus callosum
3. Splenium of corpus callosum
4. Rostrum of corpus callosum
5. Fornix
6. Thalamus
7. Tegmentum of midbrain
8. Pons
9. Tegmentum of pons
10. Medulla oblongata.

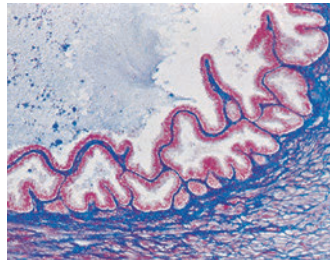


## Live three-dimensional images

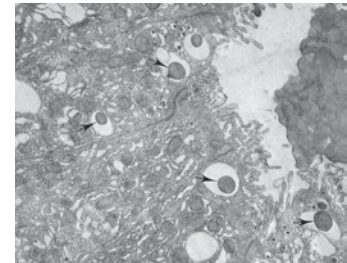
The three-dimensional images of the living obtained with 3D volume rendering technique, of CT or MR image sequences help to understand the most refined anatomic details.

## Microscopic and ultramicroscopic images

A large amount of new data on the microscopic and ultramicroscopic level have been included.



**Figure 10.37 - Seminal glands (or vesicles).** Note the reticular aspect of the mucosa and the moderate thickness of the muscular layer. A homogeneous material, formed by the secretion product of the epithelial cells, is present in the lumen.



**Figure 10.38 - Seminal gland (or vesicle)** observed under electron microscope. The apical portion of the columnar cells with numerous secretion granules (indicated by arrows) is visible. 15,000x.

**Table 3.5 - Bones of the neurocranium and the viscerocranium, their joints and main canals, canaliculi, fissures, foramina, hiatuses and meatuses**

Bone	Joints	Canals, canaliculi, fissures, foramina, hiatuses, meatuses
Neurocranium		
Ethmoid	Ethmoidoconchal, lacrimoethmoidal, maxilloethmoidal, vomeroethmoidal, frontoethmoidal, ethmoidopalatine, sphenothmoidal, with the nasal bone	Cribiform foramina, anterior ethmoidal foramen, posterior ethmoidal foramen; superior nasal, middle nasal, common nasal, nasopharyngeal meatuses
Frontal	Coronal, frontal (inconstant), frontoethmoidal, frontolacrimal, frontomaxillary, frontonasal, frontozygomatic, sphenofrontal	Diploic canals; foramen cecum, frontal notch/foramen, supraorbital notch/foramen
Occipital	Atlanto-occipital, anterior intraoccipital (inconstant), posterior intraoccipital (inconstant), lambdoid, transverse occipital, occipitomastoid, petro-occipital, sphenoccipital	Condylar, hypoglossal, diploic canals; petro-occipital fissure; foramen magnum
Parietal	Coronal, lambdoid, parietomastoid, sagittal, sphenoparietal, squamous	Diploic canals; parietal foramen

## Summary tables

Numerous tables summarize the boundaries and content of anatomical regions, arteries, veins, nerves, lymph nodes, muscles, joints and bones, providing and organizing the most relevant information for each item schematically.

## Insight boxes

By proposing particular aspects and topics of Human Anatomy, the insight boxes analyze specific aspects of this discipline in detail.

### VOMERONASAL ORGAN

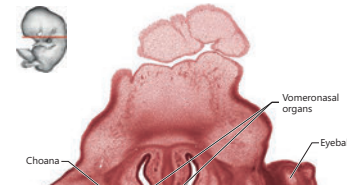
The vomeronasal organ is a tubular structure situated in the context of the nasal septum, equipped with a duct that opens into the nasal cavity.

First observed in a child by Frederick Ruysch (1638-1731), its formal description dates back to 1811 when Ludwig Jacobson (1783-1843) studied the vomeronasal organ in a variety of mammals, denying, however, its existence in humans.

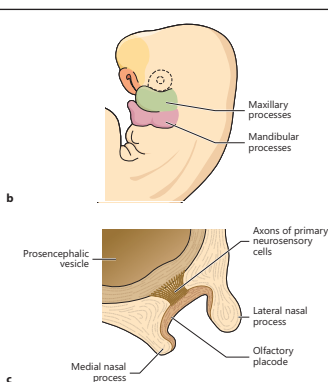
It is part of the *accessory olfactory system* and is connected to the accessory olfactory bulb, which is a separated region of the olfactory bulb, through the **vomeronasal nerves**, where the so-called **vomeronasal glomeruli** are present. In turn, the accessory olfactory bulb projects to the vomeronasal amygdala through the olfactory tract. The vomeronasal amygdala projects to the hypothalamus involved in the modulation of numerous physiological and behavioral functions. It is believed that the vomeronasal organ is a specific structure to detect the presence of *pheromones*, substances that influence the behavior and physiological state of other members of the same species, modulating the levels of reproductive hormones and stimulating sexual behavior, as well as aggressive behavior.

The first to discuss the vomeronasal organ as a histologically defined structure in humans was Rudolf Albert von Kölliker (1817-1905) in 1877, who identified it in both fetuses and adults. In humans, the vomeronasal organ is situated bilaterally in the antero-inferior part of the nasal septum, superiorly to the palate, dorsally to the paraseptal cartilages. Nowadays, it is possible to state that the vomeronasal organ is **inconstantly present** in humans: it is present in human fetuses (**Figure**) but undergoes a regression

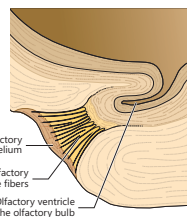
observations have shown, in some individuals, the presence of a blind-ended cavity and provided with a duct, of very variable size and shape, identifiable as vestige of the vomeronasal organ. The vomeronasal organ in humans is devoid of neurons and nerve fibers, being also absent the accessory olfactory bulb, receiving all the afferences from the vomeronasal organ. In humans, the genes encoding the receptor proteins and the specific ion channels essential for transduction processes present in mammals, where it is functional, are silenced. Although recent literature denies the sensory function of the vomeronasal organ in humans, particular connections between the cells of its wall and the underlying capillaries, together with the expression of some calcium-binding proteins, have been recently observed, suggesting its possible endocrine function.



**Figure 14.15 - Development of the olfactory system in a 25 mm human embryo:** schematic representation of the relationships between the axons of primitive olfactory cells and the primordium of the olfactory ventricle protruding from the telencephalic cavity.



**Figure 14.13 - Cephalic end of human embryo at 5th week of development (6.5 mm)** seen from the front (a) and from the left side (b) and in coronal section (c): schematic representation. In c the migration towards the telencephalic vesicle of axons of primitive nerve cells is observed.



**Figure 14.16 - Development of the olfactory system in a 45 mm human embryo:** schematic representation showing the progression of the olfactory ventricle towards the vault of the nasal cavity.

## Embryology and organogenesis

These topics are clearly explained using appropriate schematic representations in order to understand the development of organs and systems during the embryonic period and fetal life.

### Icons used in the text



Movements



Embryology



Clinical anatomy notes



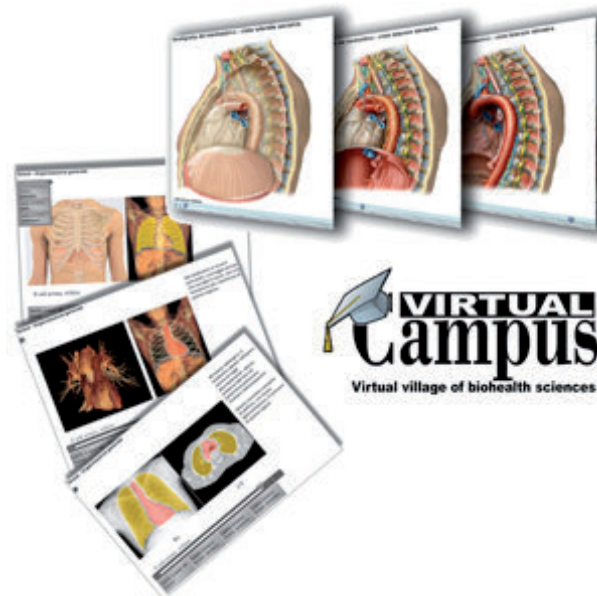
Relations



Notes referring to the cardiovascular system



# Digital contents



The volume is enriched by an online platform (Virtual Campus), accessible through the code provided at the beginning of the book. Some of the resources available in this virtual area are video lectures, interactive 3D reconstructions of organs or anatomical regions based on CT or MRI examinations, interactive stratigraphic animations, elements of microscopic anatomy and self-assessment test.

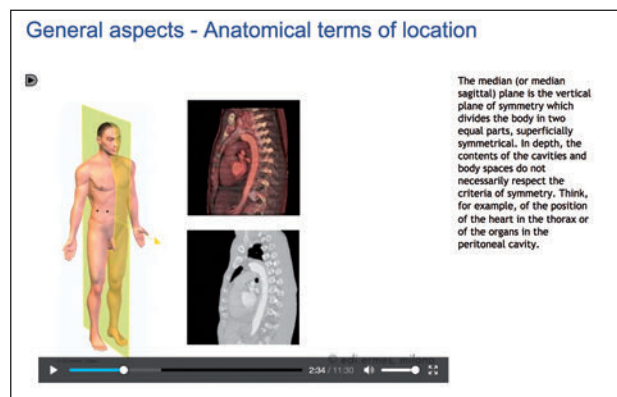
The code also enables the download of the digital version of the book. Instructions are available on the platform.

Both access to the platform and the digital book are available for a limited period starting from the registration of the code.



## Lectures

Each online lecture consists of a series of animations accompanied by audio comments; it provides a complete and engaging exposition of a specific topic and is usable in a totally independent mode. The online lectures allow an effective visual approach, making more immediate the learning and study processes.



## Commented surgical videos

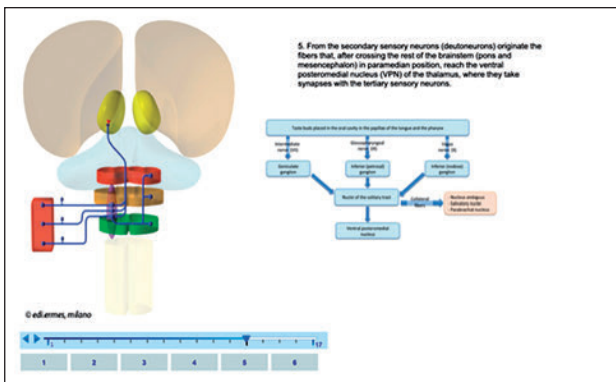
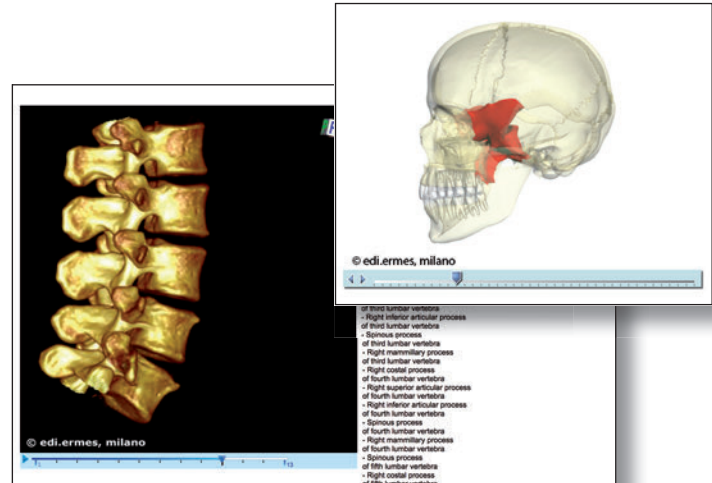


There are videos of dissections, endoscopies, ultrasound scans and other, which makes it easily accessible information available in places expressly dedicated or acquired with special equipment.



### 3D reconstructions

The three-dimensional reconstructions from CT and MR or 3D models become extremely dynamic tools in the web: it is possible to move the object by observing it from every direction and angle and there are interactive areas that, to the passage of the mouse, show details and indications of the structure observed.



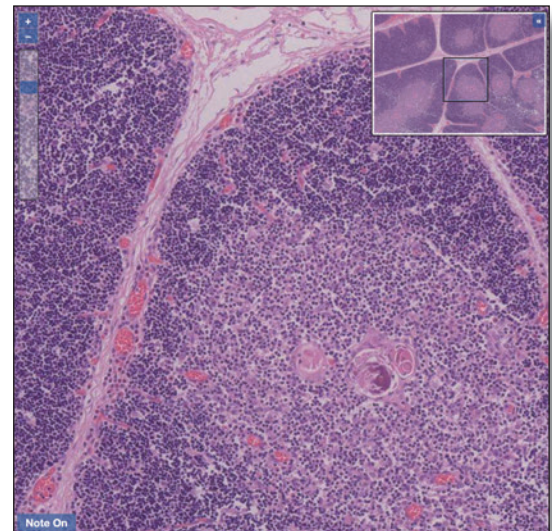
### Nerve pathways

Interactive anatomical diagrams show the course of the signals along the nerve pathways, highlighting the main structures of origin, destination and passage. A flow chart summarizes the major phases of the nerve pathway and, to complete, a schematic image of the nerve pathway allows analyzing in detail the anatomical structures involved.



### Microscopic anatomy

Visualization of histological preparations that can be enlarged and observed as in a real microscope.



Which of the following statements are accurate

Select one or more:

- ☒ a. the platysma is located in the subcutaneous tissue ✔ Correct answer
- ☐ b. the subclavius lies between the clavicle and the first rib
- ☒ c. the buccinator is a masticatory muscle ✘ Incorrect answer
- ☐ d. (Bichat's) buccal fat pad is not well-developed in children
- ☐ e. the subclavius raises the clavicle

### Self-assessment test

Students can use the questions to assess their level of preparation, helping them to fill any gaps. Furthermore, once the exercise has been completed, the system provides a differentiated score based on the degree of difficulty and the topic. There are many types of tests, including true-false, multiple choice, completion, recognition and drag and drop.





### **Digital edition of the books**

The digital edition of the book allows you to read wherever you are, on multiple devices (tablet, computer or with a simple web browser), also when you are offline, personalizing your learning through useful interactive tools. The “fluid” format version gives the opportunity to change the body text size; in addition, the text can be read by the system device.



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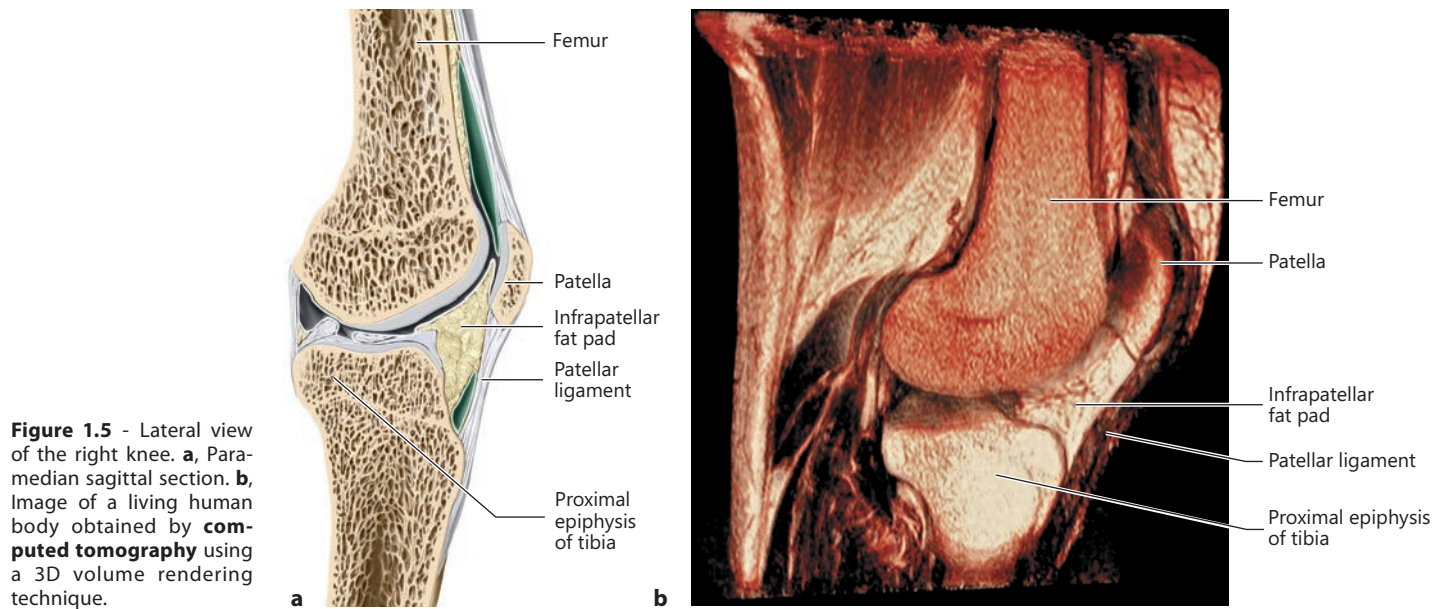
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# SAMPLE PAGES







the observation of muscles, tendons and fasciae, in addition to bone segments (typical of radiology). It is also possible to perform *in vivo* observations of structures, cavities and spaces, which can be compared to classic sections, as shown in **Fig. 1.5 a-b**, displaying, respectively, a sagittal section of the right knee and the corresponding image obtained with **computed tomography**.

**Positron emission tomography (PET)** is a technique which belongs to the field of nuclear medicine. It can provide physiological information, in contrast to CT and MR, which give morphological details of the anatomical area under examination (**Fig. 1.6**).

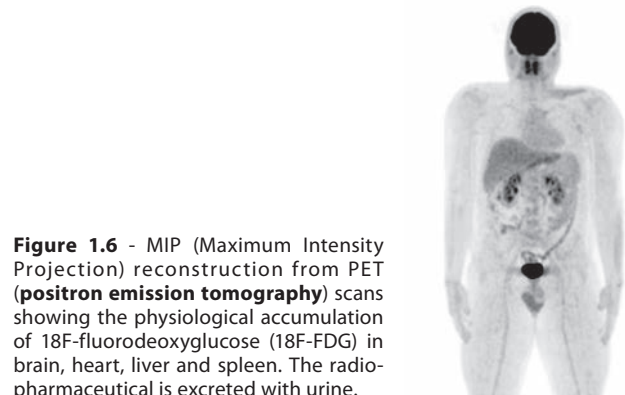
A more sophisticated version, called **single photon emission computed tomography (SPECT)**, allows to obtain single sections of an organ.

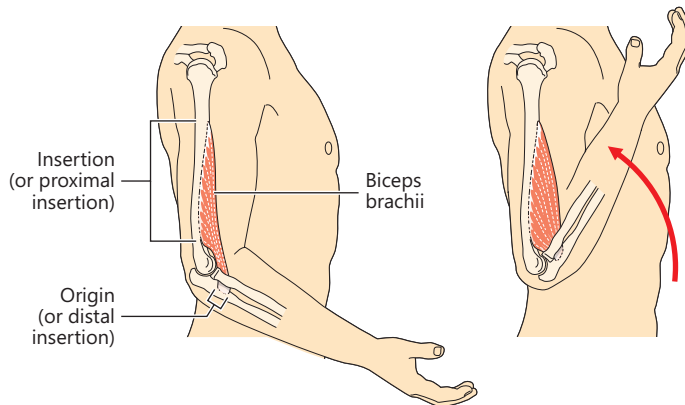
The **methods of injection** allow injecting several liquids, fixatives or dyes into the lumen of blood or lymphatic vessels or, in general, into hollow organs, such as the excretory system of glands or the respiratory tree; in case of a cadaver, the procedure continues with the destruction of the parenchyma of the organ and the visualization of the mold of the injected organ (**Fig. 1.7**).

These techniques have been historically very used and take advantage of contrast agents in living subject under different conditions.

## ORGANIZATION OF THE HUMAN BODY —

**Normal human anatomy** defines the general organization of the human body, thanks to appropriate investigation methods, both at macroscopic, microscopic and submicroscopic levels; it focuses on the healthy body at all ages, even in presence of anomalies (hereditary or congenital deviations in the constitution of the organism) compatible with life.





**Figure 1.13 - Contraction** of the biceps brachii.

Before listing the main terms of movement, it is important to clearly explain the basic principles of the skeletal muscle activity, without which any other reasoning becomes abstract and not easy to understand (**Fig. 1.13**).

- Muscles can only actively shorten (contract, then pull) and passively lengthen: they cannot push.
- All muscles have at least two insertions on two or more bones, called origin (or proximal insertion) and insertion (or distal insertion).
- All muscles pass over at least one joint.
- Muscle mass is usually proximal to the joint.
- When the muscle contracts, the insertion gets closer to the origin.

In order to better understand the logic underlying the description of a movement, it is useful to think of a door that closes a gap on a wall: the door can either open or close. The movement that the door makes as it moves away from the gap and the wall is defined as “opening”. The wall represents the plane respect to which the movement is done. The opposite situation, which is the antagonist movement, is the “closing” of the door, defined as the movement that brings the door closer to the wall in which the gap is.

In order to open or close, the door must be inserted into hinges, which represent, in this example, the joint along which the movement happens. The hinges are oriented in such a way that the door can only open in one direction. In other words, if the hinges have a vertical orientation, the door can open as a common door. On the contrary, if they have a horizontal orientation, the door will open either upward or downward. Therefore, the axis along which the movement occurs, established by the orientation of the joint, is another parameter used to define the movement in a correct way. A movement occurs getting far or close to a specific reference plane and along a defined axis.

The movements and the terms described below will be further clarified after the description of the joints. The terms indicating the most common movements (for example, the everyday movements of the body and its parts, but also the exercises that we perform at the gym or training for a sport competition) are listed and exemplified by a figure in the following box (➡ Joint movements).

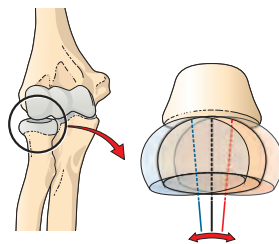


## JOINT MOVEMENTS

### Simple joint movements

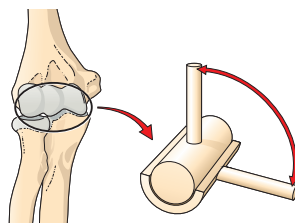
#### Sliding movement

It is the simplest movement of a joint and consists in the sliding of an articular surface over another one, without any rotational component or angular change, and is typical of plane, spheroidal and condylar joints. *Examples:* movements of the carpal and tarsal joints, combining with angular and rotational movements; movements of the costotransverse joints; movements of the sternocostal joints.



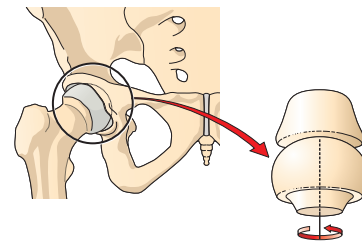
#### Angular movement

It determines the reduction or widening of the angle between the two bones forming the joint and it is typical of the hinge and condylar joints. *Examples:* the angular movements typically executed by humans are flexion-extension and abduction-adduction.



#### Rotation

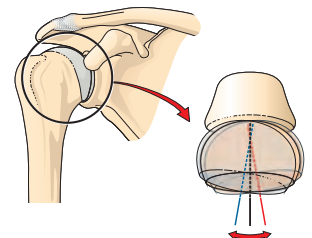
The rotation movement makes a bone, or a body part, to rotate around its axis and is typical of the spheroidal joint. *Examples:* head movement to say “no” or to look to the right and to the left staying in upright position.

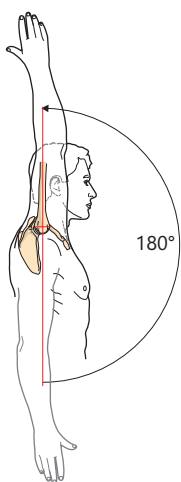


#### Oscillation

It consists in the oscillatory movement of a bone or a body part, during which the axis remains fixed in one point.

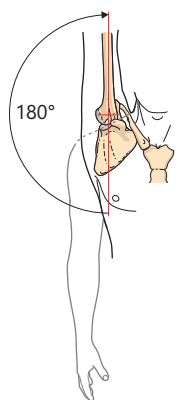
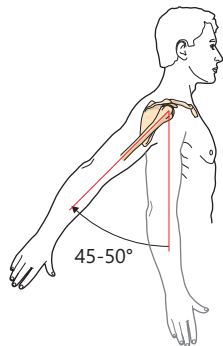
The result is the biomechanics of the simple movements.





**Flexion** - Movement usually occurring on the sagittal plane, reducing the distance between two body parts, with the reduction of the angle between them. *Examples:* flexion of the head (the chin gets closer to the thorax); flexion of the leg (the foot rises and moves backwards); flexion of the forearm (the forearm goes towards the shoulder); flexion with anterosuperior elevation of the shoulder joint.

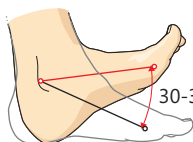
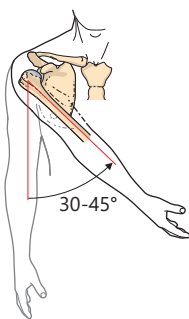
**Extension** - It is the opposite of flexion. It occurs on the sagittal plane and allows increasing the distance between two body parts and the angle between them. It is called hyperextension when the angle is larger than 180°. *Examples:* extension of the head raising the chin upwards; extension of the leg, when the football player kicks the ball; extension of the forearm, when the hand moves forward or downward from the shoulder; extension of the shoulder joint.



**Abduction** - It is a movement usually occurring on the frontal plane and allows increasing the distance between two body parts. *Examples:* starting from the anatomical position, the upper limb moves increasing the distance from the trunk with an amplitude of 180°; the fingers or the toes make a fan-like movement. The abduction movement of the foot is the one that brings the forefoot outward.

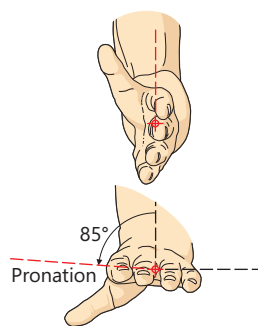
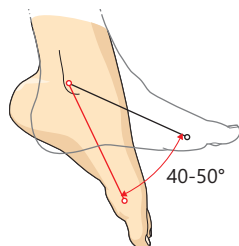
**Adduction** - It is the opposite of abduction. It also occurs on the frontal plane and causes a reduction of the distance between two

body parts. *Examples:* the limb gets closer to the sagittal plane; the fingers or the toes get closer to each other from a fan-like position. The adduction movement in the foot is the inward movement of the forefoot.



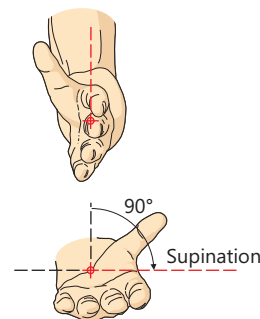
**Dorsiflexion** - Flexion of the foot on the sagittal plane, occurring when the dorsum of the foot gets closer to the anterior region of the leg. It allows standing on the heels.

**Plantar flexion** - Movement of the foot opposite of dorsal flexion, occurring when the sole of the foot moves backward and the toes downward. It consists in an extension of the foot, therefore the muscles involved are called extensor muscles. It allows standing on tiptoes.

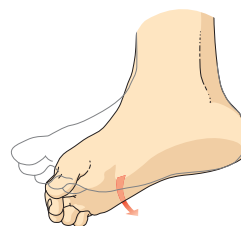


**Pronation** - It occurs in forearm and hand when the palm rotates from an anterior plane (as in the anatomical position) to a posterior plane or from a superior to an inferior plane. Regarding the foot, it occurs when its external side is lifted.

**Supination** - It is the opposite of pronation, occurring when the palm of the hand moves from posterior to anterior position or from inferior to superior position. Regarding the foot, it occurs when its internal side is lifted.



### Composite joint movements

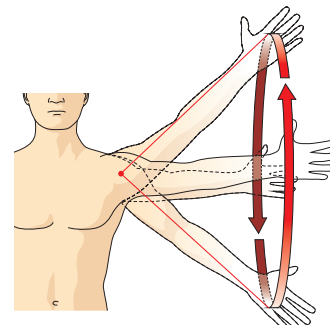


**Inversion** - It is a movement involving only the feet. It is the sum of adduction, plantar flexion and supination of the foot, causing the inward exposure of the plant of the foot.

**Eversion** - It is a movement involving only the feet and it is opposite to the inversion. It is the sum of abduction, dorsal flexion and pronation of the foot, causing the outward exposure of the plant of the foot.



**Circumduction** - It is the most complex movement, typical of the joints of shoulder and hip. It is obtained by summing, in sequence, flexion, extension, abduction and adduction. The graphical representation of the sequence of these movements of the upper limb is a cone with the tip on the head of humerus.





cal viscera, delimiting the **visceral compartment of the neck** (➔ Figs. 3.266 and 3.267).

## THORAX

The *thorax* is the part of the trunk located between neck and abdomen, where the upper limbs attach.

### BOUNDARIES

A *thoracic wall* and a *thoracic cavity* are identified in the thorax.

The boundaries of the **thoracic wall** (Fig. 1.21) are the *inferior border of the neck*, previously described, and the *thoracoabdominal line*, which begins at the base of the xiphoid process of the sternum and follows, on each side, the costal margin and the inferior border of the last rib, reaching the spinous process of the twelfth thoracic vertebra. This line divides the thorax from the abdomen. Moreover, it is possible

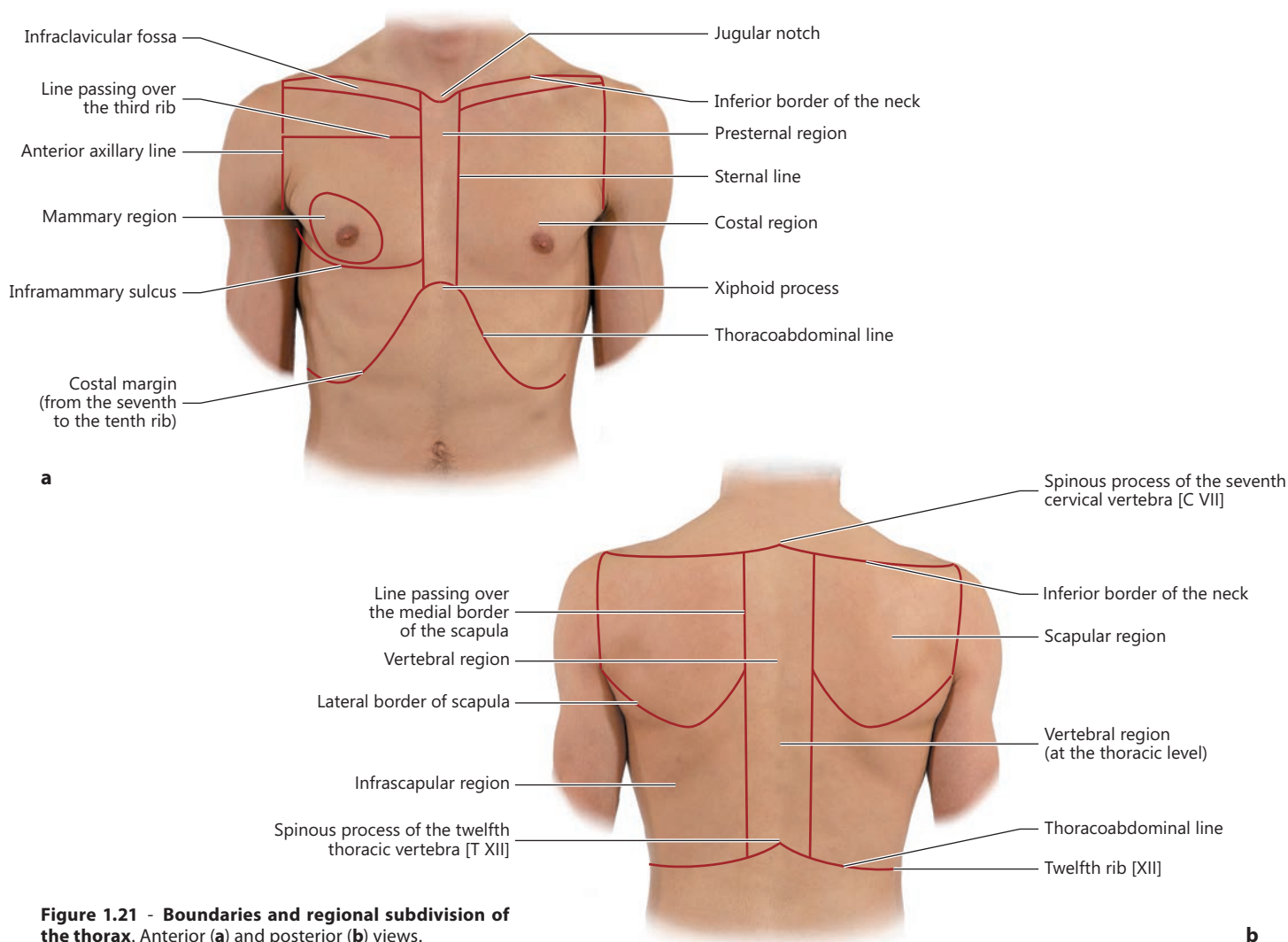
to identify the *thoracoappendicular lines* marked on the anterior and posterior axillary lines.

The thorax is separated from the upper limb by a line that passes medially through the glenohumeral joint or shoulder joint, along the lateral surface of the thorax. Therefore, this plane divides the thorax from the axilla, located between the regions of the upper limb.

The **thoracic cavity** has different boundaries from those of the wall (Fig. 1.22): indeed, superiorly, it goes beyond the inferior border of the neck reaching the supraclavicular fossae with the cervical pleurae and the apex of the lungs, whereas, inferiorly, corresponds to the diaphragmatic cupula, located above the thoracoabdominal line, therefore some abdominal viscera are situated in a region that, superficially, corresponds to the thorax.

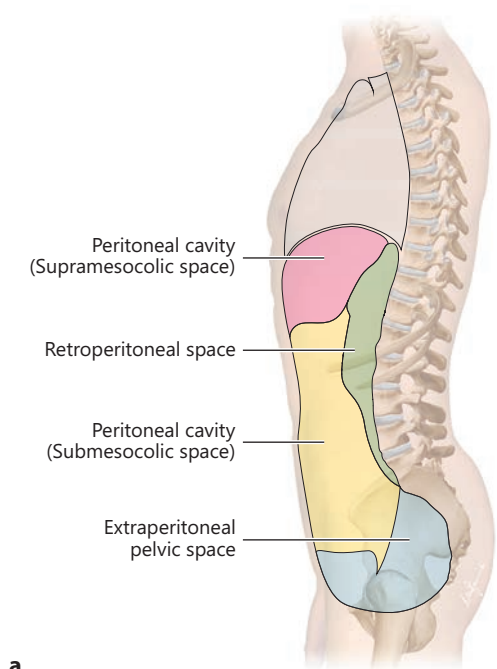
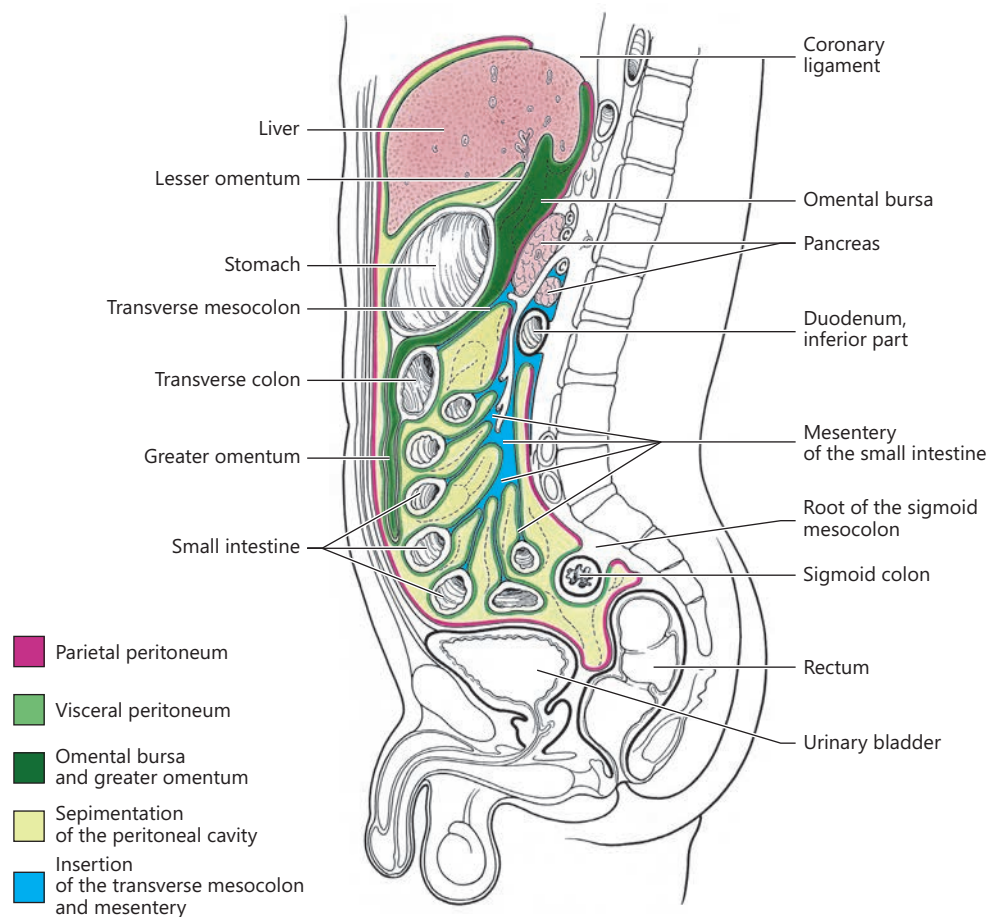
### GENERAL ORGANIZATION

The thorax is formed by a *thoracic wall* and a *thoracic cavity*.

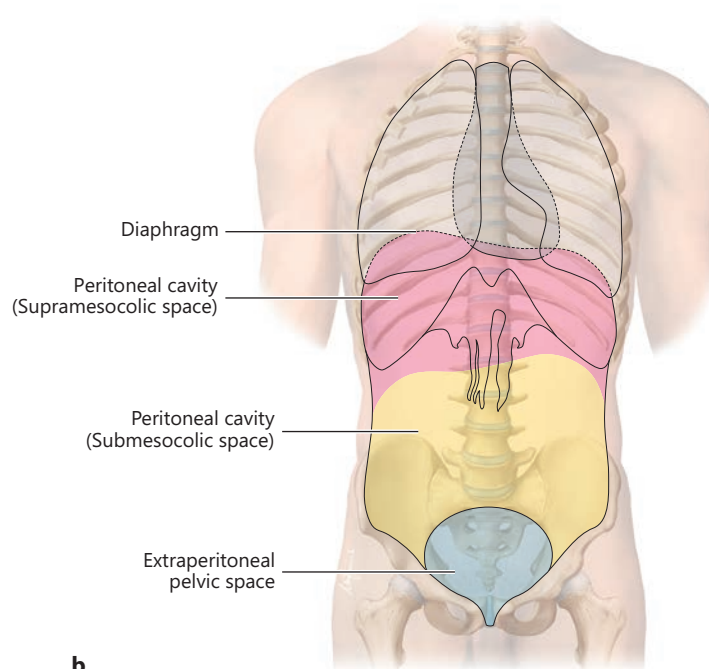


**Figure 1.21 - Boundaries and regional subdivision of the thorax.** Anterior (a) and posterior (b) views.

**Figure 1.26** - Sagittal section of the trunk showing the location of the **parietal peritoneum** (red) and **visceral peritoneum** (green) in the abdominal and pelvic cavities. The **dark green** area comprises the omental bursa, or lesser sac, and the greater omentum. Outlined in **light green** is the septimentation of the peritoneal cavity into pouches, recesses, excavations, fossae and diverticula by peritoneal compartments, ligaments, omenta or epiploon, and mesenteries. The **light blue** area displays the insertion of the transverse mesocolon and mesentery to the posterior abdominal wall. The transverse mesocolon divides the supramesocolic from the submesocolic spaces. The omental bursa extends posterior to the stomach and to the lesser omentum. The small intestine lies extensively in the submesocolic space.



a



b

**Figure 1.27** - **a**, Lateral projection of the trunk. The **peritoneal cavity** (also defining the supramesocolic and submesocolic spaces) and the **connective tissue spaces** (retroperitoneal space, in **green**, and extraperitoneal or subperitoneal pelvic space, in **light blue**) are indicated. **b**, Front projection.





**Figure 2.2 - Dermatoglyphics** (fingerprints) detected from the palmar surface of a distal phalanx with the inking method. Triradius ("Y" shape pattern) image of a loop print (arrow).

The **muscular folds** are sulci formed by the repetitive traction exerted by mimic muscles; they are present on the areas of skin corresponding to the insertion points of the muscles, such as facial and frontal regions (*mimic folds*) and

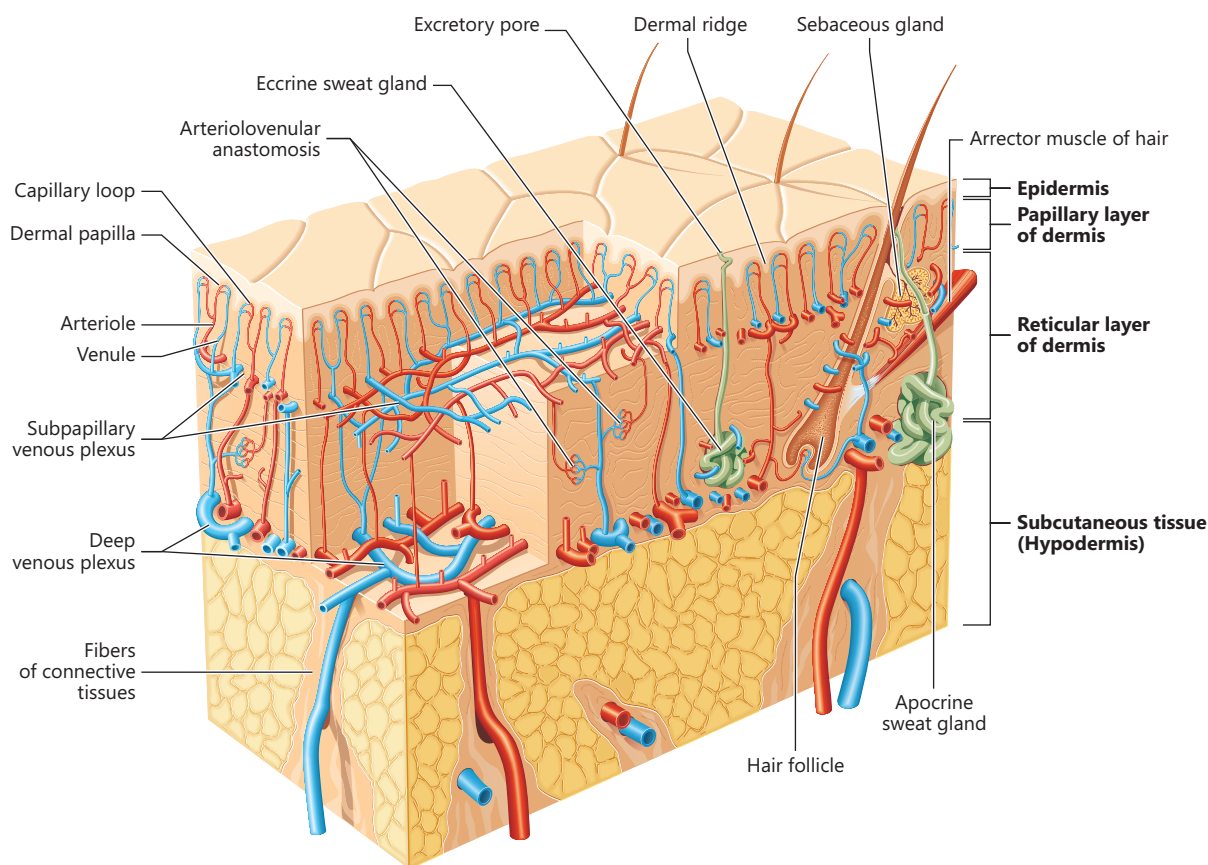
are arranged perpendicularly to the direction of the underlying muscle fibers. The folds become progressively deeper, and then permanent, with age.

The **articular folds** are related to the movement of joints and can be divided into: *permanent*, such as the ones on the surface of the palm of hand, or *temporary*, delineated during movement and initially reversible; these types of folds, as the muscular ones, tend to progressively become permanent.

The **senile folds** or *wrinkles* are permanent skin sulci of variable depth, due to skin aging, particularly of the connective tissue of the dermis. They are folds of cutaneomuscular laxity that are determined due to alterations in the elastic fibers and collagen fibers of the dermis that no longer balance the force of gravity. They are folds due to cutaneomuscular looseness formed by alterations of elastic and collagen fibers of the dermis that no longer balance the force of gravity.

## MICROSCOPIC ANATOMY

The skin is formed by layers presenting different localization, structure, properties and embryological origin (Fig. 2.3).



**Figure 2.3 - Three-dimensional schematic graphic of the skin.** The surface of the body is covered with layers of tissue, the outermost of which is the epidermis. Proceeding deeper from the surface, various layers are found in the skin: epidermis, dermis (the papillary layer, containing capillaries and tactile corpuscles, and the reticular layer, containing collagen fibers arranged in courses that define the tension or Langer lines, blood vessels, lymphatic vessels, hair follicles and sweat glands), the subcutaneous tissue or hypodermis, which is constituted by loose connective tissue (areolar layer) and by membranous (or lamellar) or fatty layer.

The **epidermis** is the outermost layer. It has ectodermal origin and is formed by a stratified squamous epithelium.

The **dermis** is a connective layer with mesodermal origin. It is composed by two layers: the *papillary layer*, more external, and the *reticular layer*, more internal.

A complex structure called **dermal-epidermal junction** is located between papillary layer of the dermis and epidermis.

## Epidermis

The *epidermis* is a stratified squamous keratinized epithelium, with a thickness that varies from 50  $\mu\text{m}$  to 1.5 mm (Fig. 2.4). The **epidermal stratification** reflects the different stages of maturation of the *keratinocytes*, the most abundant cell type.

Proceeding from the deepest to the superficial layers of the epidermis, there are five **maturation stages of keratinocytes**. Each stage characterizes one of the layers of the epidermis, containing also different cells: *stratum basale* or *germinativum*, *stratum spinosum* or *Malpighian* (formed by several layers of cells), *stratum granulosum*, *stratum lucidum* (not evident in all cutaneous regions), *stratum corneum* (Fig. 2.5).

The maturation of the keratinocytes starts in the deepest

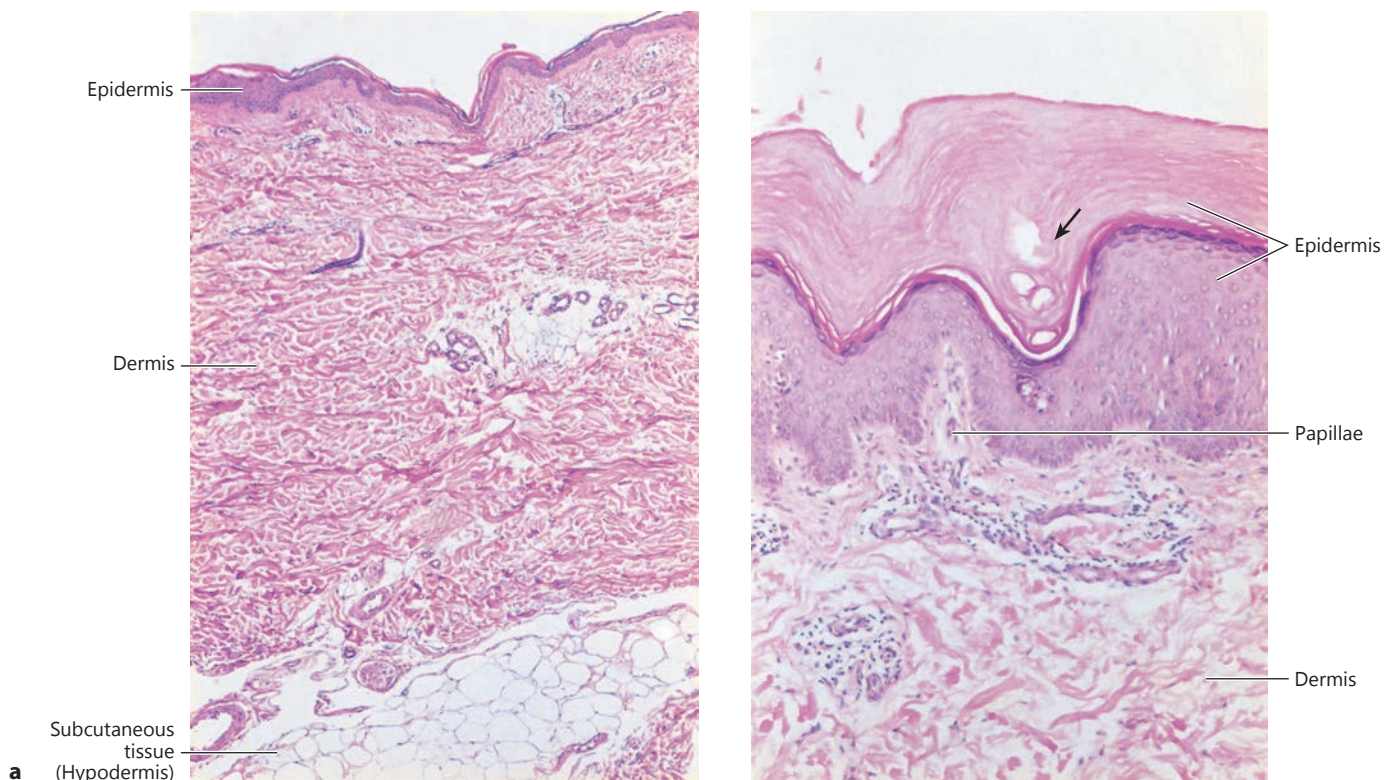
layer (*stratum basale*), formed by proliferating cells, and ends in the most superficial layer (*stratum corneum*), formed by dead cells assuming the aspect of thin corneal lamellae.

The epidermis contains other cell types in addition to the keratinocytes: *melanocytes*, responsible for the pigmentation, *dendritic cells*, immunocompetent cells acting as antigen presenting cells, *tactile epithelial cells*, associated with nerve endings and acting as mechanoreceptors (see Fig. 2.5).

## Keratinocytes

*Keratinocytes* undergo a progressive maturation (**cornea cytomorphosis**) lasting about two weeks, passing from elements with intense mitotic and metabolic activity (basal cells) to inert keratinized laminae (corneocytes). During the maturation, there is a progressive upward movement of the cells towards the cutaneous surface. Cells undergo death in the *stratum granulosum*, followed by (in the *stratum lucidum* and *stratum corneum*) the permanent transformation in corneocytes, corneous lamellae full of keratin that will get lost in the process of superficial flaking (Fig. 2.6).

Keratinocytes acquire different morphologies in each layer of epidermis.



**Figure 2.4 - Structure of the epidermis: thin (a) and thick (b) epidermis.** **a**, The central part of the dermis shows sections of the tubules of a sweat gland. The subcutaneous tissue appears rich in adipose tissue. **b**, The epidermis is characterized by a remarkable thickness and a very developed stratum corneum, showing the sinuous course of the excretory duct of a sweat gland (arrow). Protrusions of the dermis forming the papillae are situated in correspondence to the dermal-epidermal junction.



## PSORIASIS

*Psoriasis* is a chronic pathology affecting epidermis and dermis. At macroscopic level, its manifestation is represented by reddish and rounded patches on the skin, with well-delimited borders and covered by white-silvery overlapping scales (Figs. a, b).

At microscopic level, it is characterized by an accelerated maturation of the keratinocytes in the epidermis, going from the stratum basale to the stratum corneum in about 3-5 days, versus the two weeks of time that it takes under physiological conditions. The permanence of the cells in the stratum corneum is also reduced to a few days. The rapid exfoliation of the corneocytes is responsible for the scaly aspect of the lesion.

The stratum granulosum is often absent. Another feature is the increased number of dendritic cells and other epidermal cells (Fig. c).

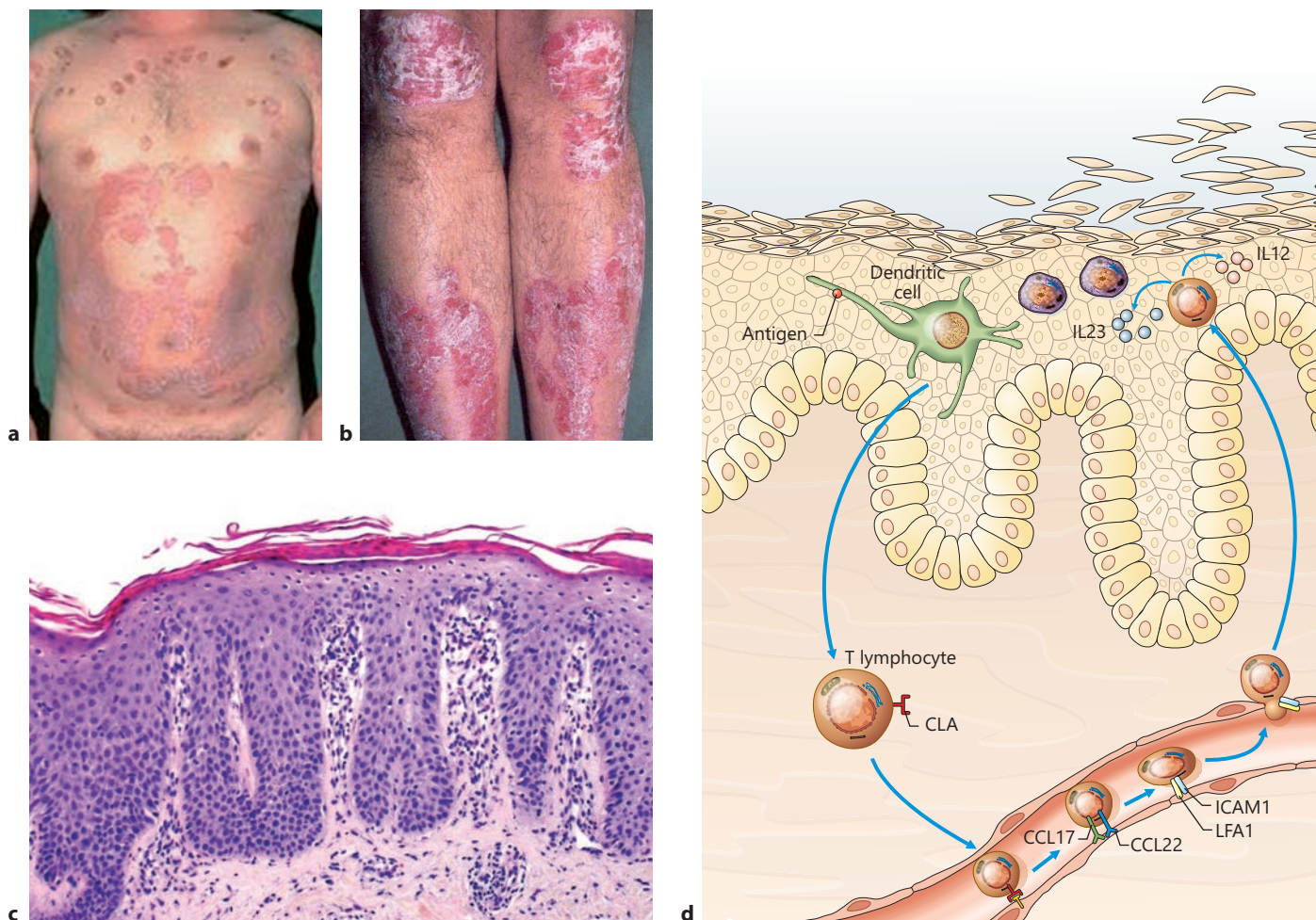
The capillary plexus in the dermis is dilated and convoluted, with signs of active neovascularization. There is also an evident inflammatory infiltration in the dermis, with neutrophils and activated T lymphocytes which migrate into the epidermis and form microabscesses.

Dendritic cells play a key role in the pathogenesis of psoriasis. After taking up the antigens from the epidermis, dendritic cells

migrate to the paracortical zone of the regional lymph nodes, where they activate the **T lymphocytes**.

Following their activation, T lymphocytes express a *homing receptor* (➔ **Chapter 6 Lymphoid and hematopoietic organs**) for the skin (*Cutaneous Lymphocyte-associated Antigen, CLA*). This receptor guides the T lymphocytes, mainly CD4<sup>+</sup> (Th1) and CD8<sup>+</sup>, which reach the skin through the circulation. The first ones locate themselves in the dermis, the second ones in the epidermis. The production of proinflammatory cytokines attracts to the areas of psoriasis neutrophils and monocytes, which are responsible for the formation of **microabscesses**, together with the CD8<sup>+</sup> T lymphocytes. Some of the cytokines produced by monocytes and T lymphocytes stimulate the proliferation of the keratinocytes, causing the **scaly phenotype**. At the same time, other cytokines cause vasodilation and neoangiogenesis. The inflammatory process is self-perpetuating and determines a continuous afflux of immune cells and consequent damage. It is possible that the presentation of a self-antigen to the T lymphocytes by the dendritic cells is at the base of this process.

Figures a, b, c, courtesy of Prof. F. Rongioletti, University of Genoa.



### Myoepithelial cells

*Myoepithelial cells* distribute throughout the basement membrane with which they make contact alternating with the extensions of clear glandular cells; there are numerous myofilaments in the cytoplasm.

### Excretory duct

The excretory duct, in the intradermal tract, is covered by two layers of **epithelial cells**.

Cells of the deep layer, in contact with the basement membrane, have a structure similar to the clear glandular cells and delimit intercellular secretory capillaries.

Cells reaching the lumen present, at their apical pole, brush borders formed by dense series of microvilli, responsible for the selective reabsorption of electrolytes, making in this way the sweat hypotonic respect to the plasma.

The orifices of the excretory ducts of the eccrine sweat glands, on the epidermal ridges, are often provided with a tilting horny plate that masks and protects them from the entry of microorganisms and foreign material. Sweat or excretory pores become evident during the sweating by the presence of small drops of secreted substance.

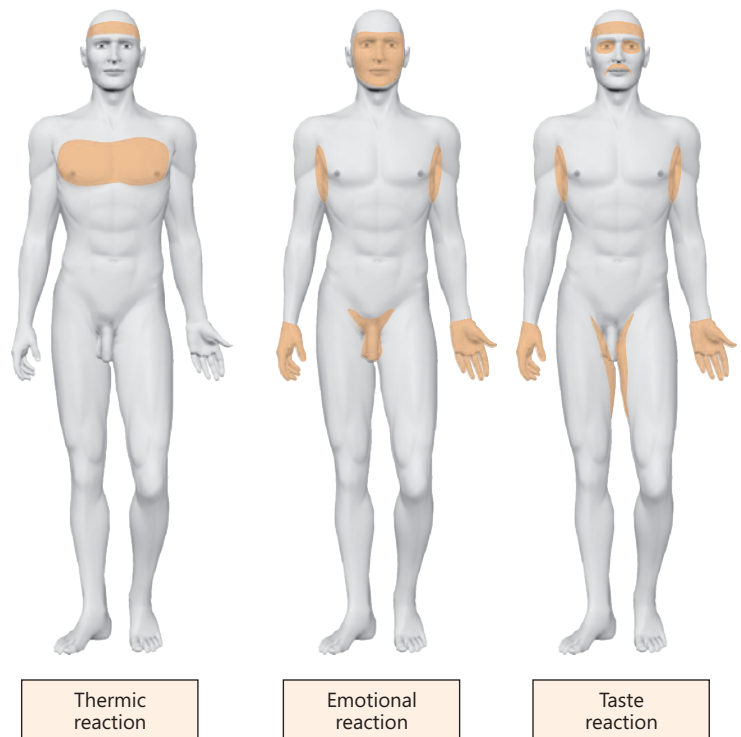
## FUNCTIONAL ANATOMY

Unlike in the sebaceous glands, which are holocrine, the production of secretion in the eccrine sweat glands occurs without cell destruction or loss of cytoplasm.

**Eccrine sweat** is an odorless, colorless, clear liquid, mostly formed by water (98-99%) and variable composition of solutes (1-2%) depending on the site. Among them, three quarters are formed by inorganic substances (mostly sodium chloride) and one fourth by organic substances (urea, uric acid, creatinine, lactic acid, epidermal growth factor). Sweat density varies between 1002-1006 g/mL and the pH from 5 to 7.5.

Sweat secretion is discontinuous, with alternated periodic rhythm in different groups of glands, induced by different types of stimuli. For example, the heat stimulates the sweating of forehead, neck, back, thorax and dorsum of the hand; emotional stimuli determine intense sweating of the sides of the trunk, axillae, palm of the hand, sole of the foot (**Fig. 2.29**).

At room temperature, the activity of the eccrine sweat glands occurs in an unapparent way (*perspiratio insensibilis*), becoming evident through the action of several physical, chemical, metabolic and psychic factors.



**Figure 2.29 - Activity of the eccrine sweat glands.** Distribution areas of sweating subsequent to various stimuli.

The main nerve centers for the control of sweat are located in the hypothalamus and the efferent nerve fibers are cholinergic for the secreting cells and adrenergic for the myoepithelial cells. The contraction of these latter ones entails a squeezing of the glandular glomeruli with emission of already secreted sweat. The amount of sweat secreted in 24 hours is variable, reaching in extreme cases even 10-12 liters.

Among the functions recognized to the eccrine sweat glands, the main one is to provide to thermoregulation through the evaporation of sweat which makes the body to cool down by subtracting heat from it. The passage of the water from a liquid to a gaseous phase, with the evaporation of the sweat on the cutaneous surface, causes a decrease of the temperature on the cutaneous surface and consequently of the blood circulating on the most superficial capillaries.

The process of sweating also plays a role in the regulation of the hydric balance in the organism and promotes, thanks to the participation of the aqueous component, the formation of the cutaneous hydrolipidic film. Lastly, it represents an important excretion pathway for the organism, helping in this way the renal emunctory.



## APOCRINE SWEAT GLANDS

The *apocrine sweat glands* are not much represented in humans, being located only in some sites such as axilla, groin, mammary areola, mons pubis, subumbilical region, labia majora, scrotum and perineum. Their body distribution, respect to the eccrine sweat glands, is shown in **figure 2.25**. They are more numerous in women than men and they are three times more numerous in black subjects than in Caucasian people. Mammary gland, perianal glands, ceruminous glands of the external acoustic meatus and ciliary glands (glands of Moll) of the palpebral margin are modified apocrine sweat glands. The secretory activity of the glands is influenced by the emotional states (adrenaline and noradrenaline) and decreases between birth and puberty, when it starts again and increases under hormonal stimulation (androgens).

### MICROSCOPIC ANATOMY

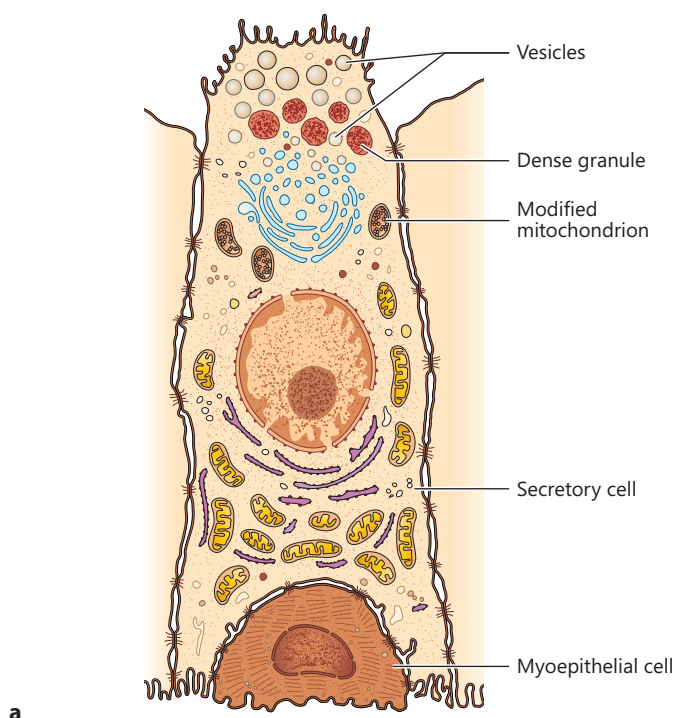
The apocrine sweat glands, as the eccrine ones, are **tubuloglomerular glands**, formed by a convoluted and deep part, the glomerulus, and a straight part, the terminal excretory duct, which opens up on the surface (**Fig. 2.30**). The **glomer-**

**ulus** is situated deeply at the level of the reticular layer of the dermis and is formed by tubular loops that can reach the subcutaneous tissue. The **terminal excretory duct** is wide and often opens into a hair follicle, in the isthmus or neck above the sebaceous gland opening.

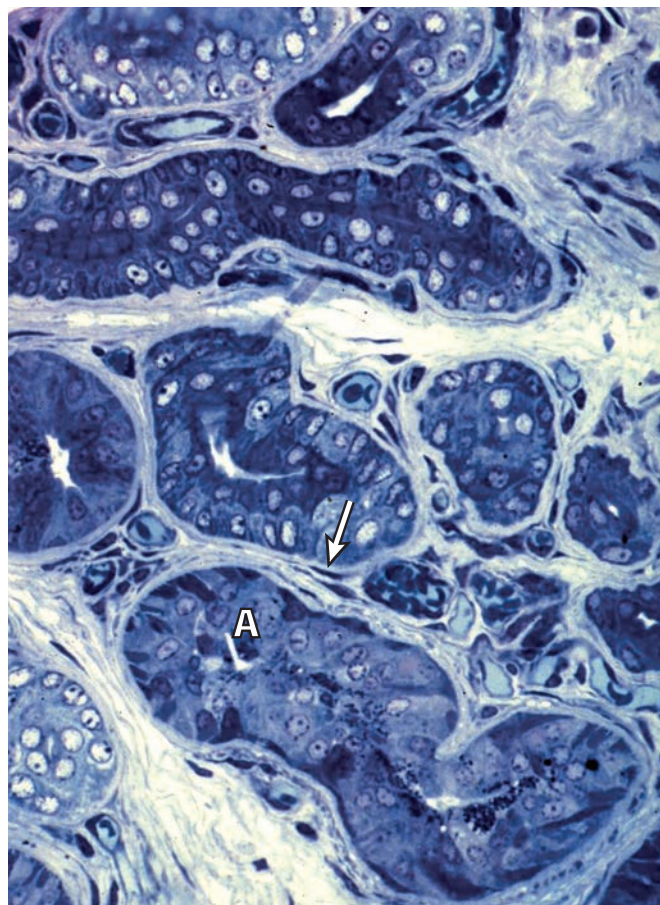
The tubule is formed by *cubic cells* (at rest) or *batiprismatic* (during activity) in the convoluted part of the gland, according to the secretory phase; these cells are externally related to the *myoepithelial cells* which, in turn, lean on a thick basement membrane. On its external side there is a connective sheath rich in vessels and nerves.

The cytoplasm of actively secreting cells is packed with small granules of secretion containing lipids, pigments, iron and are also rich in sulfhydryl groups; they move into the apical cytoplasm to be released into the glandular lumen together with cytoplasmic flaps (**apocrine secretion**).

Myoepithelial cells are elements rich in actin and myosin filaments oriented along the length of the tubule, below the secreting cells, leaning on a basement membrane on which they attach via short digitiform extroversions of the plasma membrane.



**Figure 2.30 - a, Glomerular portion of the apocrine sweat gland:** schematic representation. The secretory cell shows several cytoplasmic organelles and in particular drops of secretion in the apical region, numerous smooth vesicles and modified mitochondria. **b, Microphotograph of a portion of apocrine sweat gland.** The convoluted aspect of the glomerular adenomere (**A**) (densely colored in the image) is observed. Myoepithelial cells are present outside the adenomere (arrow).





# LOCOMOTOR SYSTEM

In general, all animals are able to move through space. Vertebrates, humans included, are provided with several body formations which allow these movements. These formations are part of the *locomotor system*, including bones and joints (**skeletal system**) and skeletal muscles (**muscular system**), guided and controlled by central and peripheral nervous formations (*nervous system*), supplied by arteries and drained by veins and lymphatic vessels (*cardiovascular system* and *lymphatic circulatory system*).

tem), guided and controlled by central and peripheral nervous formations (*nervous system*), supplied by arteries and drained by veins and lymphatic vessels (*cardiovascular system* and *lymphatic circulatory system*).

## SKELETAL SYSTEM

### BONE CLASSIFICATION

The *bones* as a whole form the skeleton; they are connected to each other by joints and represent the passive part of the locomotor system, whose motion is guaranteed by the active part, the *musculature*.

A bone observed under the microscope appears formed

by one external and one internal structure; the *cortical substance* (cortical bone) is the most superficial part and is formed by **compact bone tissue** (compact bone), whereas the *spongy or trabecular substance* (spongy or trabecular bone) is situated in the deepest part and is formed by **spongy bone tissue** (Fig. 3.1). The internal or medullary structure contains trabeculae delimiting areolae which contain red bone

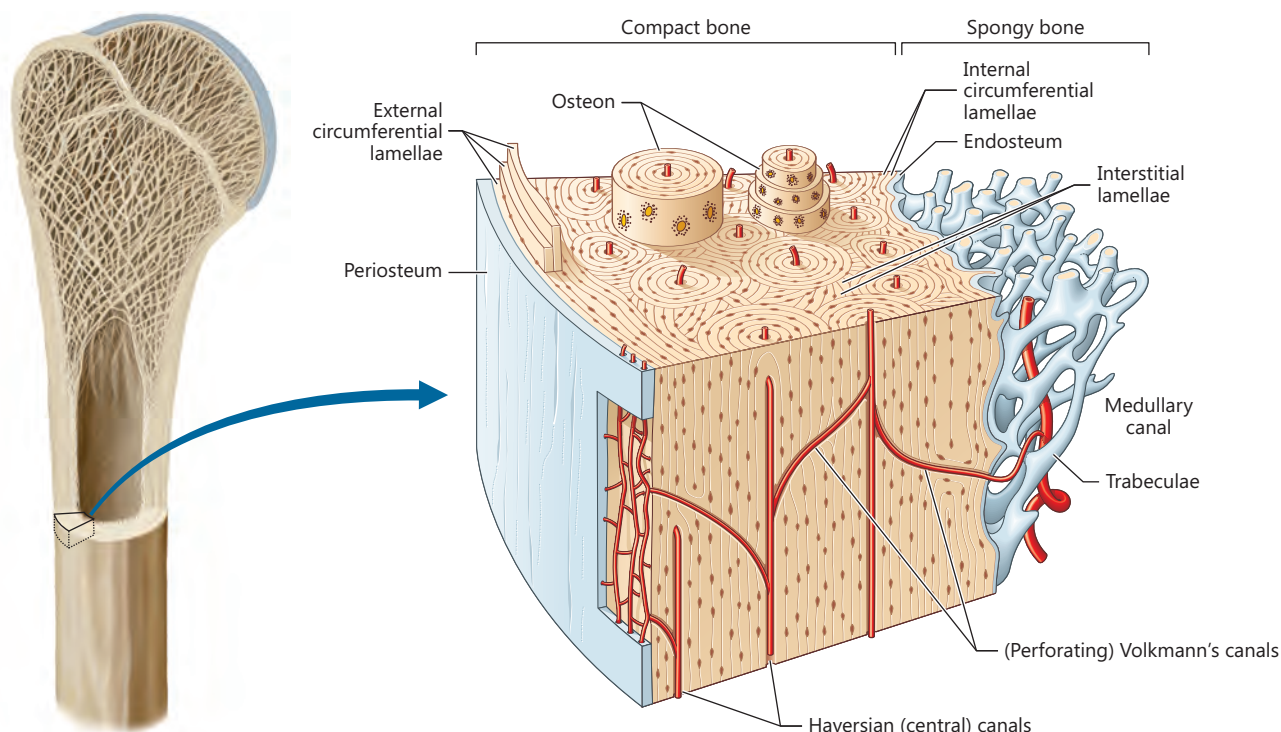
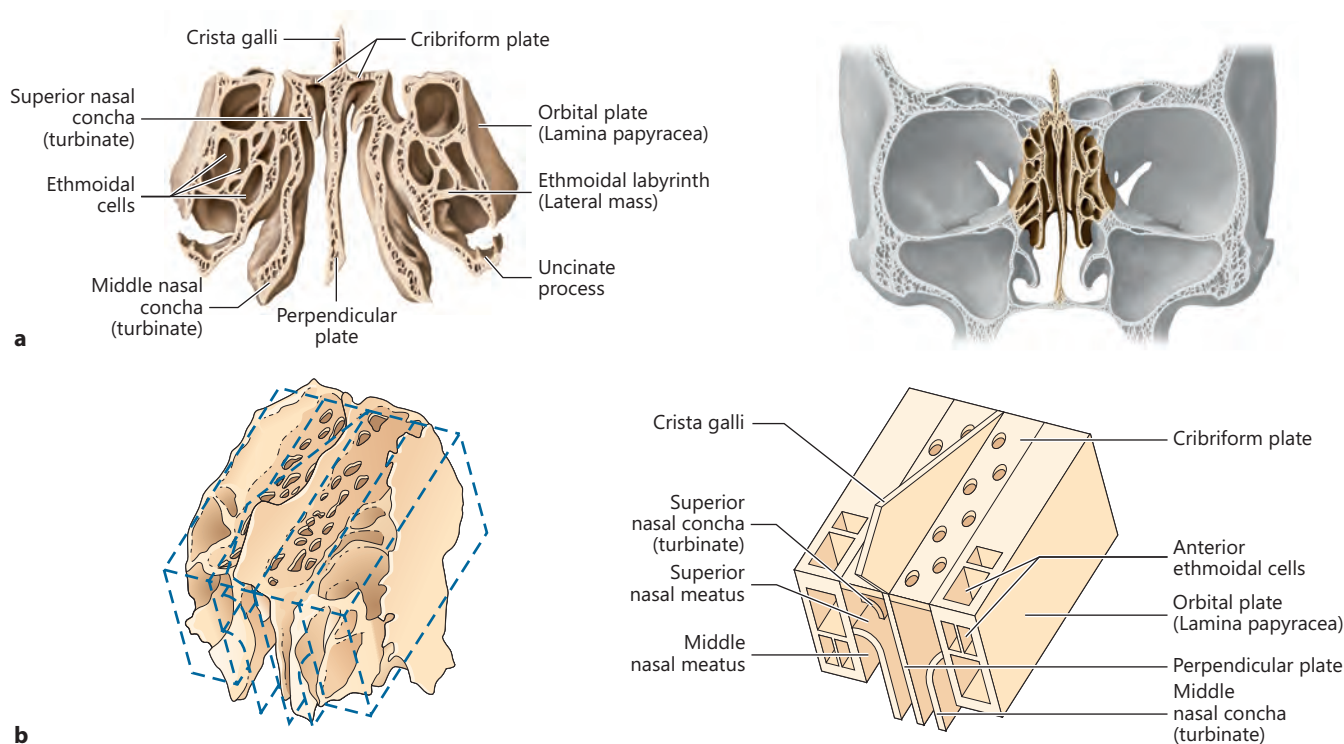


Figure 3.1 - Lamellar bone tissue: structure.



**Figure 3.27 - Ethmoid. a,** Frontal section, anterior view. Ethmoidal labyrinths or masses are excavated by small cavities presenting thin walls, the ethmoidal cells, which can be divided into anterior, middle and posterior. **b, Geometric schematization;** the ethmoid can be compared to a parallelepiped surmounted by the crista galli and with the three plates constituting it, viewed from above, from the front and medially.

**Perpendicular plate** - It has a superior portion (*crista galli*) protruding into the anterior cranial fossa and representing the attachment point for the anterior extremity of the falx cerebri; the base of the crista galli articulates anteriorly with the frontal bone. The inferior portion of the perpendicular plate forms the anterior and superior part of the *bony nasal septum*, articulating forward and upward with the frontal and nasal bones, forward and downward with the septal nasal cartilage, backward and upward with the body of the sphenoid, backward and downward with the vomer (Fig. 3.27).

**Cribriform plate** - It forms a right angle with the crista galli and the perpendicular plate and articulates with the ethmoidal notch of the frontal bone; it has an intracranial superior surface (anterior cranial fossa) that receives the olfactory bulbs and is perforated by numerous small holes crossed by the olfactory nerve. The inferior surface forms part of the roof of the nasal cavities.

**Ethmoidal labyrinths** - The ethmoidal labyrinths develop laterally and inferiorly to the cribriform plate and appear as two parallelepipeds with six surfaces. The **anterior surface** articulates with the lacrimal bone and reaches the frontal process of the maxilla, whereas the **posterior surface** articulates with the body of the sphenoid and the orbital process of the perpendicular plate of the palatine bone. The **superior surface** hosts a group of incomplete ethmoidal cells that oppose to those of the frontal bone in correspondence with the ethmoidal notch. There are also two transverse grooves which delimit the *anterior* and *posterior ethmoidal foramina* (which connect the orbital cavity with the anterior cranial fossa), together with similar grooves present on the inferior surface of the ethmoidal notch of the frontal bone.

The **inferior surface** articulates with the maxilla; the *uncinate process* is located on this surface and appears as a long and thin bony plate heading downward, backward and sideward, reaching the inferior nasal concha. The *ethmoidal bulla*, a protrusion with a thin wall, is situated posteriorly to the uncinate process. The *hiatus semilunaris* is situated anteriorly to the ethmoidal bulla and represents the inferior opening of the ethmoidal infundibulum, a canal draining the frontal sinus.

The **lateral surface**, thin and smooth, is called **orbital plate** (or lamina papyracea) and forms part of the medial wall of the orbital cavity, articulating with the lacrimal bone on the front part and with the sphenoid and palatine bone on the back. The **medial surface** forms part of the lateral wall of the nasal cavity and appears irregular for the presence of the *superior* and *middle nasal conchae* (turbinates). These are two thin bony laminae, which fold up heading downward and medially and delimiting the *superior* and *middle nasal meatuses*. The superior nasal concha is situated superiorly and posteriorly and is smaller, whereas the middle one is bigger and articulates with the palatine bone on the back side. A *supreme nasal concha* may sometimes be identified in the uppermost portion of the nasal cavities.

## Sphenoid

The *sphenoid*, located between ethmoid, temporal and occipital bones, contributes to the formation of the anterior and middle cranial fossae, the lateral wall of cranium, the orbital and nasal cavities, and the temporal, infratemporal and pterygopalatine fossae. It is an unpaired and median bone in which a body and three paired processes are recognized: the

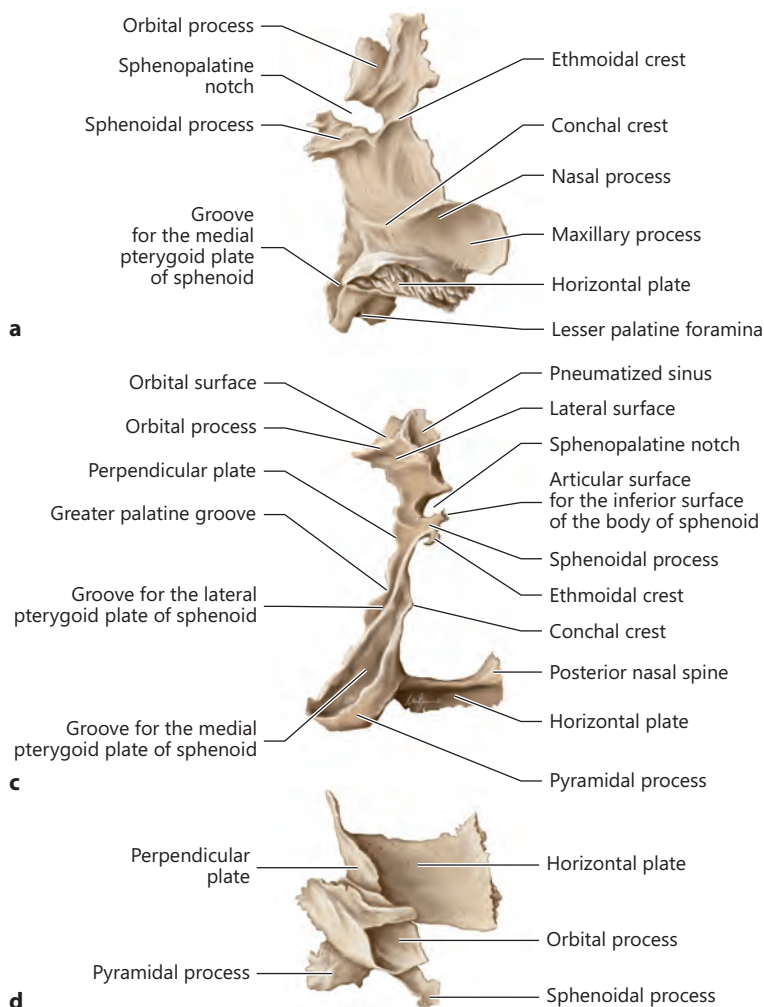
labyrinth, inferiorly to the frontal bone and superiorly to the body of the maxilla, articulating with these bones and with the inferior nasal concha (turbinate). It is a paired, thin and quadrangular bone (Fig. 3.42).

On the **lateral** or **orbital surface**, the *posterior lacrimal crest* is found, a vertical relief that continues, inferiorly, with the *lacrimal hamulus*, articulated with the maxilla. The posterior portion of the lateral surface is smooth and plane; the anterior portion houses the *lacrimal groove*. The latter joins the lacrimal notch of the frontal process of the maxilla, forming the *fossa for the lacrimal sac*.

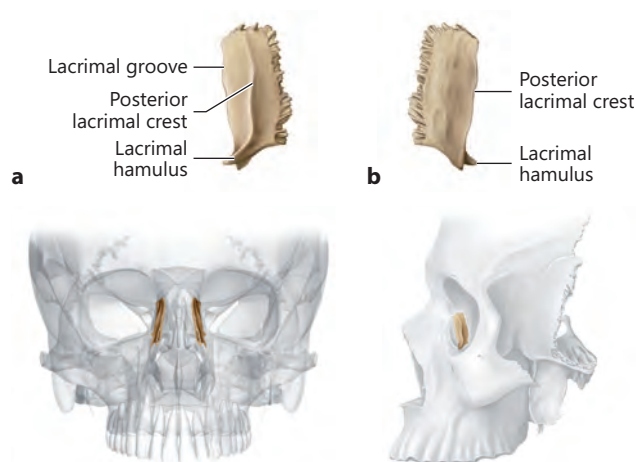
The **medial surface** articulates with the ethmoidal labyrinth, completing some ethmoidal cells, and, inferiorly, contributes to the formation of the lateral wall of the nasal cavity.

### Palatine bone

The *palatine bone* is part of the nasal, oral and orbital cavities, as well as of the pterygopalatine fossa. It is included between the ethmoid and maxilla, placed anteriorly, and the sphenoid, with which it articulates posteriorly (Fig. 3.43).

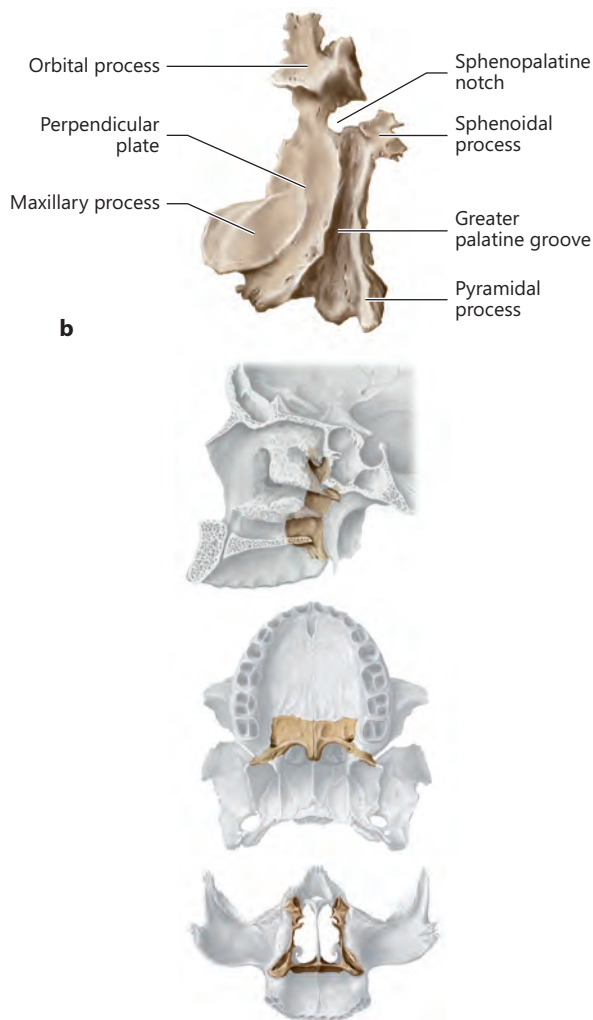


**Figure 3.43** - Right **palatine bone**. **a**, Nasal surface; **b**, maxillary surface; **c**, posterior view; **d**, superior view. The horizontal and perpendicular plates meet at a right angle.



**Figure 3.42** - Left **lacrimal bone**. Lateral (**a**) and medial (**b**) surfaces.

It is a paired bone, formed by two flattened **plates**, one **perpendicular**, sagittal, slightly oblique from top to bottom and from medial to lateral, and one **horizontal**. The two



**Table 3.5 - Bones of the neurocranium and the viscerocranium, their joints and main canals, canaliculi, fissures, foramina, hiatuses and meatuses**

<i>Bone</i>	<i>Joints</i>	<i>Canals, canaliculi, fissures, foramina, hiatuses, meatuses</i>
<b>Neurocranium</b>		
Ethmoid	Ethmoidoconchal, lacrimoethmoidal, maxilloethmoidal, vomeroethmoidal, frontoethmoidal, ethmoidopalatine, sphenothmoidal, with the nasal bone	Cribiform foramina, anterior ethmoidal foramen, posterior ethmoidal foramen; superior nasal, middle nasal, common nasal, nasopharyngeal meatuses
Frontal	Coronal, frontal (inconstant), frontoethmoidal, frontolacrimal, frontomaxillary, frontonasal, frontozygomatic, sphenofrontal	Diploic canals; foramen cecum, frontal notch/foramen, supraorbital notch/foramen
Occipital	Atlanto-occipital, anterior intraoccipital (inconstant), posterior intraoccipital (inconstant), lambdoid, trasverse occipital, occipitomastoid, petro-occipital, sphenoccipital	Condylar, hypoglossal, diploic canals; petro-occipital fissure; foramen magnum
Parietal	Coronal, lambdoid, parietomastoid, sagittal, sphenoparietal, squamous	Diploic canals; parietal foramen
Sphenoid	Sphenothmoidal, sphenofrontal, sphenomaxillary, sphenoccipital, sphenoparietal, sphenopetrosal, sphenosquamous, sphenozygomatic, with the vomer	Optic, palatovaginal, pterygoid, vomerorostral, vomerovaginal canals; inferior orbital, superior orbital, petrosphenoidal, pterygomaxillary fissures; foramen lacerum, optic foramen, foramen ovale, foramen petrosum (inconstant), foramen rotundum, foramen spinosum, sphenoidal emissary foramen (inconstant); nasopharyngeal meatus
Temporal	Occipitomastoid, parietomastoid, petro-occipital, sphenopetrosal, sphenosquamous, squamomastoid (inconstant), squamous, squamotympanic, temporomandibular, zygomaticotemporal	Carotid canal, canal for tensor tympani, facial canal, canal for auditory tube, diploic canals, longitudinal canals of modiolus, musculotubal canal, semicircular canals, spiral canal of modiolus, spiral canal of cochlea; caroticotympanic canaliculi, cochlear canaliculus, canaliculus for tympanic nerve, vestibular canaliculus, canaliculus for chorda tympani, mastoid canaliculus; petro-occipital, petrosphenoidal, petrosquamous, petrotympanic, tympanomastoid, tympanosquamous fissures; external acoustic opening, internal acoustic opening, jugular foramen, foramen lacerum, mastoid foramen, foramina nervosa, foramen singulare, stylomastoid foramen; hiatus for greater petrosal nerve, hiatus for lesser petrosal nerve; external acoustic, internal acoustic meatuses
<b>Viscerocranium</b>		
Inferior nasal concha (turbinate)	Ethmoidoconchal, lacrimoconchal, maxilloconchal, palatoconchal	Nasolacrimal canal; middle nasal, inferior nasal, common nasal meatuses
Lacrimal	Lacrimoethmoidal, frontolacrimal, lacrimoconchal, maxillolacrima	Nasolacrimal canal
Mandible	Dentoalveolar, temporomandibular	Mandibular canal; mandibular, mental foramina
Maxilla	Dentoalveolar, maxilloethmoidal, frontomaxillary, incisive (inconstant), intermaxillary, maxillolacrima, maxilloconchal, maxillonasal, median palatine, transverse palatine, maxillopalatine, sphenomaxillary, zygomaticomaxillary, with the vomer	Alveolar, incisive, infraorbital, nasolacrimal, greater palatine canals; inferior orbital, pterygomaxillary fissures; alveolar, incisive, infraorbital, lesser palatine foramina; inferior nasal meatus
Nasal	Frontonasal, internasal, maxillonasal, with the ethmoid	Nasal foramina
Palatine	Interpalatine, median palatine, transverse palatine, palatoconchal, ethmoidopalatine, maxillopalatine, vomeropalatine	Lesser palatine, greater palatine, palatovaginal canals; lesser palatine, greater palatine, sphenopalatine foramina; nasopharyngeal meatus
Vomer	Vomeroethmoidal, vomeropalatine, with the maxilla and with the sphenoid	Vomerorostral, vomerovaginal canals; nasopharyngeal meatus
Zygomatic	Frontozygomatic, sphenozygomatic, zygomaticotemporal, zygomaticomaxillary	Zygomatic canal; zygomaticofacial, zygomatico-orbital, zygomaticotemporal foramina



the *trochlea of the phalanx*, for the joint with the base of the corresponding middle and distal phalanges. The head of the *distal phalanx* has the tuberosity of the distal phalanx.



**Development** - The **proximal** and **middle phalanges** develop from ossification centers that correspond, in chronology and development mode, to the diaphysal ossification centers of the metacarpals. The bases of these phalanges form from epiphysal centers that appear later. In the **distal phalanges**, the proximal part develops by endochondral ossification, while the distal part undergoes membranous ossification. ■

## JOINTS AND LIGAMENTS OF THE UPPER LIMB

The *joints of the upper limb* include the **joints of the pectoral (shoulder) girdle** and the **joints of the free part of the upper limb**.

The pectoral (shoulder) girdle includes the *sternoclavicular* and *acromioclavicular synovial joints* and the syndesmoses represented by the *coracoacromial*, *superior transverse scapular* and *inferior transverse scapular ligaments*.

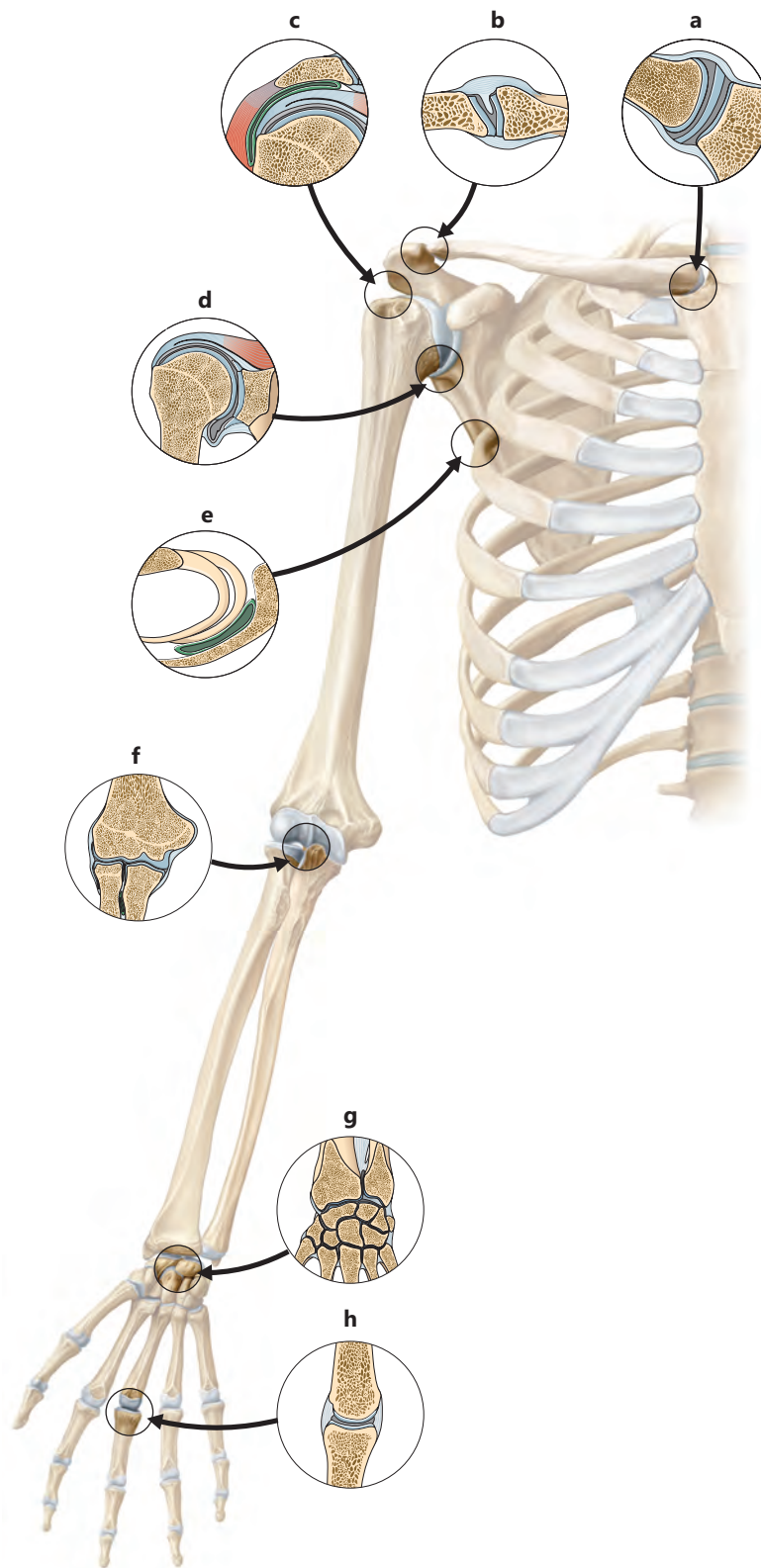
The joints of the free part of the upper limb include the *glenohumeral* (shoulder), *elbow*, *distal radioulnar* and *hand joints* and the subacromial and scapulothoracic functional joints (**Fig. 3.144**).

### Sternoclavicular joint

The *sternoclavicular joint* joins the sternal or medial end of the clavicle to the manubrium of the sternum and the first costal cartilage (**Fig. 3.145**). It is a saddle joint that must be considered double due to the interposition of an **articular disc** between the articular heads.

The **articular surfaces**, represented by the sternal end of the clavicle and the clavicular notch of the sternum, are not concordant. The articular surface of the clavicle at right angle shows a pronounced convexity in vertical direction and a modest convexity in horizontal direction, while the articular surface of the sternum continues downward and forward with the superior surface of the first costal cartilage. A fibrocartilaginous articular disc, convex at the bottom and concave at the top, which divides the articular cavity into two portions, is located between the two articular surfaces.

The **joint capsule**, which inserts in proximity to the articular surfaces, is reinforced by the bundles of the *anterior* (which inserts above the anterosuperior surface of the sternal end of the clavicle) and *posterior* (between the posterior part of the sternal end of the clavicle and the posterior part of the superior surface of the manubrium of the sternum) **sternoclavicular ligaments** (**Fig. 3.146**). The superior part of the joint capsule is also reinforced by the bundles of the **interclavicular ligament**, which pass above the jugular notch of the sternum and reach the contralateral joint. The sternoclavicular joint also presents a distant ligament, the **costoclavicular ligament**, which is shaped like an inverted cone, short and flattened. It consists of two parts (anterior and posterior) attached to the superior surface of the first rib and the first costal cartilage, from where they ascend leading to the inferior surface of the clavicle in correspondence to its medial end.



**Figure 3.144 - Joints of the upper limb:** a, sternoclavicular joint; b, acromioclavicular joint; c, subacromial joint; d, glenohumeral (or shoulder) joint; e, scapulothoracic joint; f, elbow joint; g, distal radioulnar joint, wrist (or radiocarpal) joint, carpal (or intercarpal) joints, carpo-metacarpal joints and intermetacarpal joints; h, metacarpophalangeal joints.



## FUNCTIONAL ASPECTS OF THE MUSCLES OF THE HEAD AND NECK

The rectus capitis anterior, longus capitis, longus colli and sternocleidomastoid act in the movements of **flexion of the head** involve, with the cervical column fixed. The movement of **extension of the head** involve the rectus capitis posterior major, rectus capitis posterior minor, obliquus capitis superior, obliquus capitis inferior, splenius capitis and sternocleidomastoid, with the cervical column not fixed, and the descending (superior) part of the trapezius. In the movement of **rotation of the head**, the obliquus capitis inferior, rectus capitis posterior major and the contralateral sternocleidomastoid contract. The **lateral inclination** of the head occurs by unilateral contraction of the rectus capitis lateralis and obliquus capitis superior, longus capitis and longus colli, scaleni and sternocleidomastoid.

The **movements of the neck** can be symmetrical (flexion, extension), with bilateral contraction of the muscles, or asymmetrical (lateral inclination, rotation), with unilateral contraction of the muscles. The **flexor muscles** of the cervical column are the longus colli, longus capitis and sternocleidomastoid, with the cervical column fixed. The **extensor muscles** of the cervical column are the rectus capitis posterior major, the rectus capitis posterior minor, the obliquus capitis superior, obliquus capitis inferior, splenius capitis and sternocleidomastoid, with the cervical column not fixed, the descending (superior) part of the trapezius, as well as all the muscles of the back proper at cervical level.

The movement of **rotation** of the neck is produced by the contraction of the obliquus capitis inferior, rectus capitis posterior major and the contralateral sternocleidomastoid. The unilateral contraction of the rectus capitis lateralis and obliquus capitis superior, longus capitis and longus colli, scalene muscles and sternocleidomastoid tilts the neck laterally.

The muscles of the back proper give an important contribution to these two asymmetric movements. With the thoracic cage fixed, the scalene muscles tilt the cervical column laterally. If the cervical column is fixed, the scalene muscles elevate the first two ribs (auxiliary inspiratory muscles). The sternocleidomastoid can

also act as an auxiliary inspiratory muscle, elevating the thorax with the head fixed.

### Extensor muscles of the head and neck

The *trapezius* has an extensor action, contracting bilaterally, through the superior and middle fascicles (descending and transverse fibers), maintaining its insertion on the clavicle and spine of the scapula as a fixed point (**Fig. a**).

The *sternocleidomastoid* extends the head by contracting bilaterally when the mastoid insertion is located posteriorly to the origin on the clavicle and on the sternum, rather than anteriorly (**Fig. b**).

The *levator scapulae* extends the neck by contracting bilaterally with a fixed point on the scapula; in unilateral contraction with a fixed point on the scapula it tilts and rotates the neck ipsilaterally (**Fig. c**).

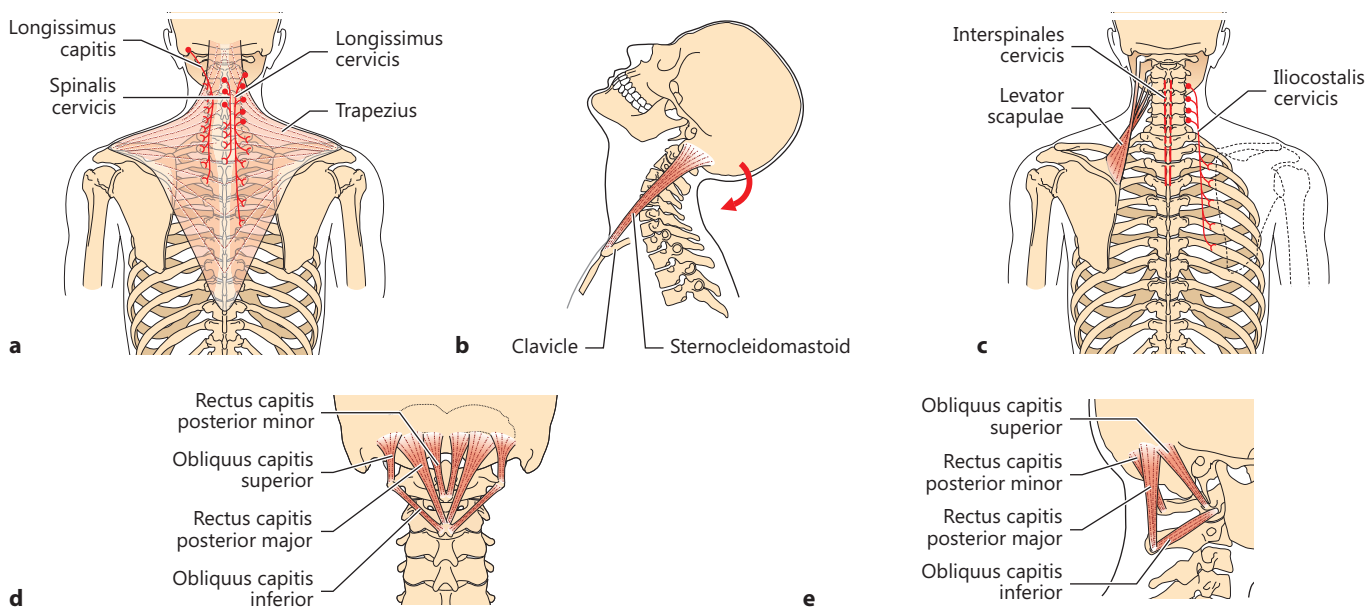
The *rectus capitis posterior minor*, *rectus capitis posterior major*, *obliquus capitis superior* and *obliquus capitis inferior* extend the head by contracting bilaterally. The unilateral contraction of these muscles tilts the head laterally (**Figs. d and e**).

The *rectus capitis posterior major* and *rectus capitis posterior minor* (which replace the interspinales between the occipital bone and the atlas, and between the atlas and the axis), and the *obliquus capitis inferior* rotate the head ipsilaterally (**Fig. f**).

The *obliquus capitis superior* (which replaces the intertransversarii between C II and C I) rotates the head contralaterally (see **Figs. d and e**).

The *splenius capitis* and *splenius cervicis* extend the head and neck by contracting bilaterally, while their unilateral contraction rotates the neck and head ipsilaterally (**Fig. g**).

The *iliocostalis cervicis* (see **Fig. c**), *interspinales cervicis*, *cervical intertransversarii*, *longissimus cervicis*, *longissimus capitis*, *spinalis cervicis*, *spinalis capitis*, *rotatores*, *multifidus*, *semispinalis capitis* and *semispinalis cervicis* are extensors when they contract bilaterally



## FASCIAE OF THE NECK

The neck is the part of the trunk located between the head and the thorax and borders laterally on the upper limbs. It contains both structures that pass through it to reach neighboring regions, such as viscera, large arterial and venous vessels and lymphatic vessels, and structures that remain contained exclusively in this region.

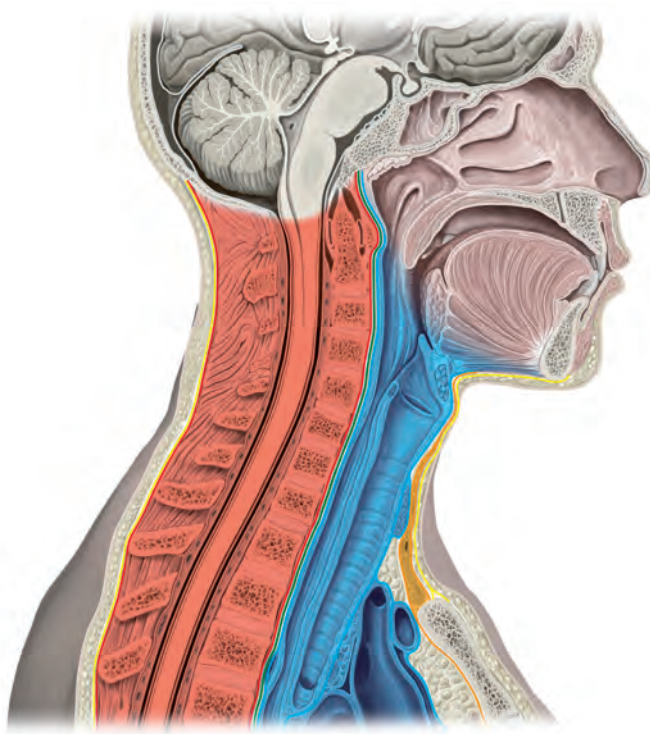
The structures of the neck are wrapped by a layer of superficial subcutaneous connective tissue, reinforced anteriorly by a layer of striated musculature, represented by the platysma, and by fasciae formed by dense connective tissue. These connective tissue structures divide the neck into spaces or compartments. Basically, they segment and divide the contents of the neck by wrapping the muscles, or by provid-

ing support and anchorage to the viscera, or to the vessels and deep lymph nodes. For example, by wrapping the common carotid arteries, internal jugular veins and vagus nerves, these connective systems form the carotid sheath that circumscribe the neurovascular bundle of the neck (Fig. 3.266).

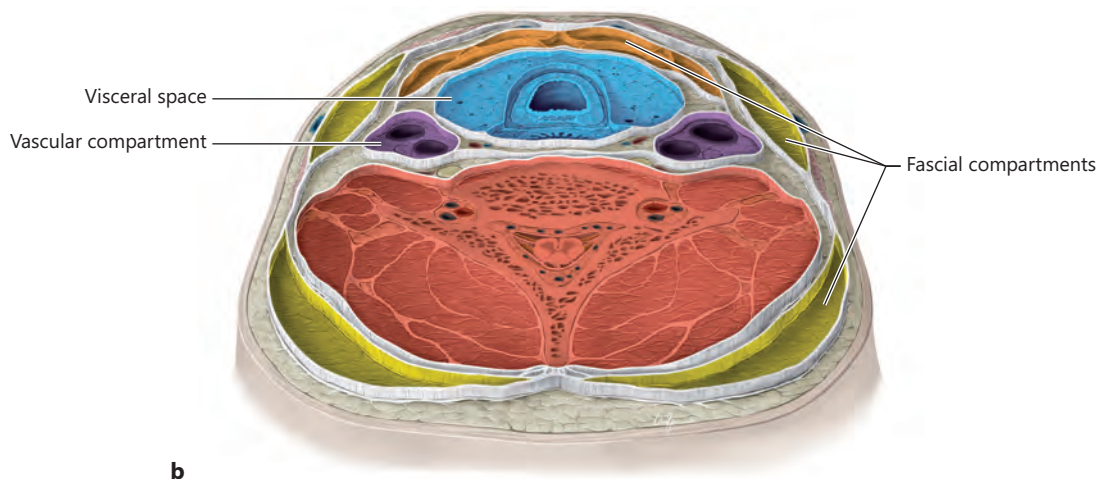
It is obvious that the various fascial planes that divide the neck do not only perform a function of covering or division, but, for example, can facilitate the sliding of the various structures of the neck during the movements of the head or during processes such as swallowing. At the same time, they can also represent pathways for the propagation of abscesses or hematomas, whose extension is determined by the course of the fasciae. The knowledge of the detachment planes of the fasciae is also important for the surgical access to the various structures of the neck.

**Figure 3.266** - **a**, Sagittal section of the neck: the compartments are indicated by different colors. **b**, Transverse section of the neck passing through the seventh cervical vertebra, showing: the **visceral space** or **visceral compartment of the neck**, bounded, anteriorly, by the pretracheal layer of the cervical fascia investing the infrahyoid muscles and, posteriorly, by the same layer on the posterior wall of the esophagus and around the trachea; the **vascular compartment** within the carotid sheath, which collects the neurovascular bundle of the neck; the **fascial compartments** formed by splits of the investing layer of the cervical fascia to enclose the sternocleidomastoid and trapezius; the **platysma**, which occupies the subcutaneous tissue, between the superficial fascia of the skin and the investing layer of the cervical fascia; the **fascial compartments** formed by splits of the pretracheal layer of the cervical fascia that envelop the infrahyoid muscles.

- Fascial compartments (of sternocleidomastoid and trapezius)
- Fascial compartment (of infrahyoid muscles)
- Visceral space
- Vascular compartment (Carotid compartment)
- Posterior cervical region (Nuchal region)

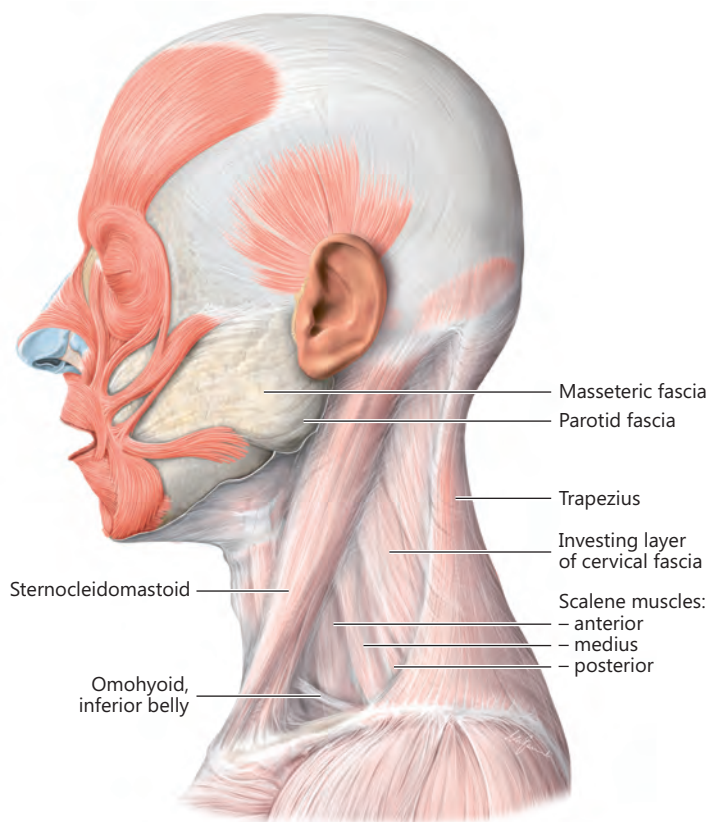


**a**



**b**





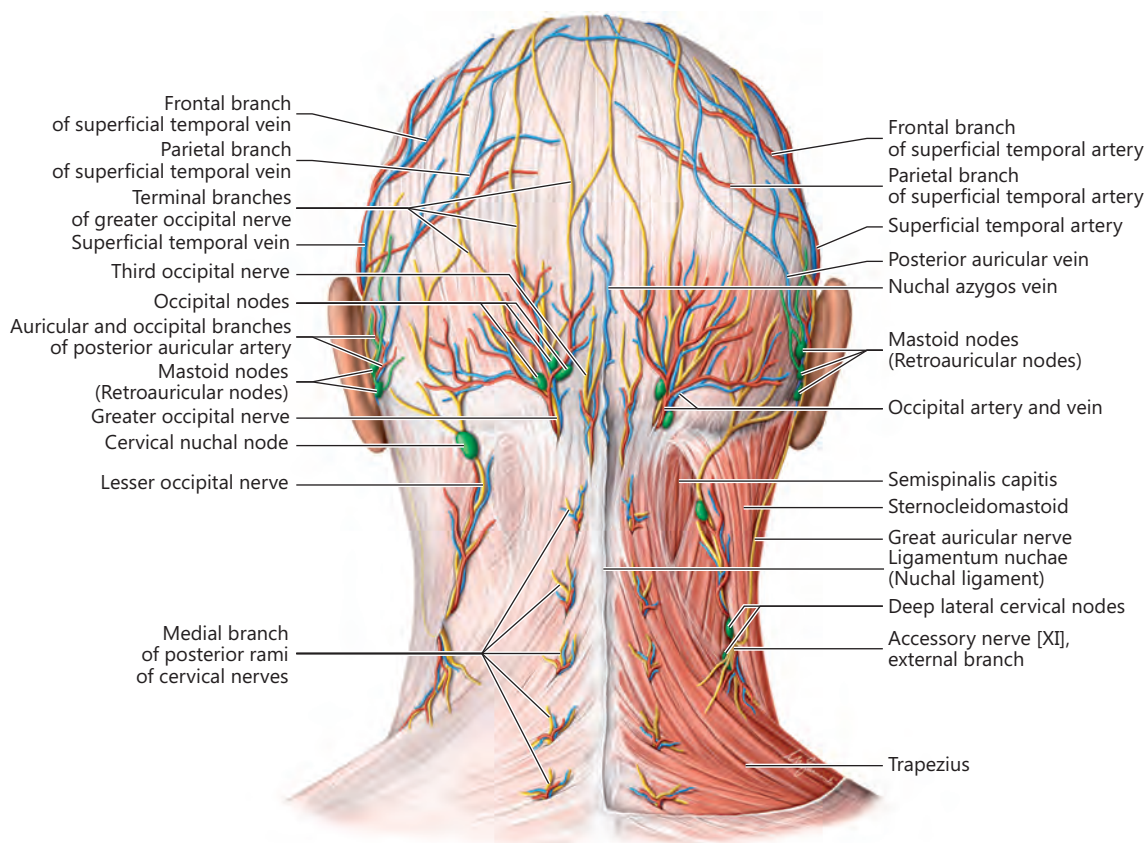
**Figure 3.269** - Investing layer of the cervical fascia after removal of the platysma.

The superior and inferior insertions of the investing (superficial) layer of the cervical fascia and its dependencies roughly follow the pericraniocervical line and the inferior border of the neck, which delimit the neck with respect to the head, at the top, and the thorax, at the bottom.

In detail, the cranial insertion follows the superior nuchal line up to the external occipital protuberance of the occipital bone and from here leads to the spinous processes of the cervical vertebrae, where it inserts and forms, deeply reinforced by the pretracheal and prevertebral layers of the cervical fascia, the ligamentum nuchae. Forward, it continues by inserting on the mastoid process of temporal bones, the inferior border of the zygomatic arches and the base of the mandible.

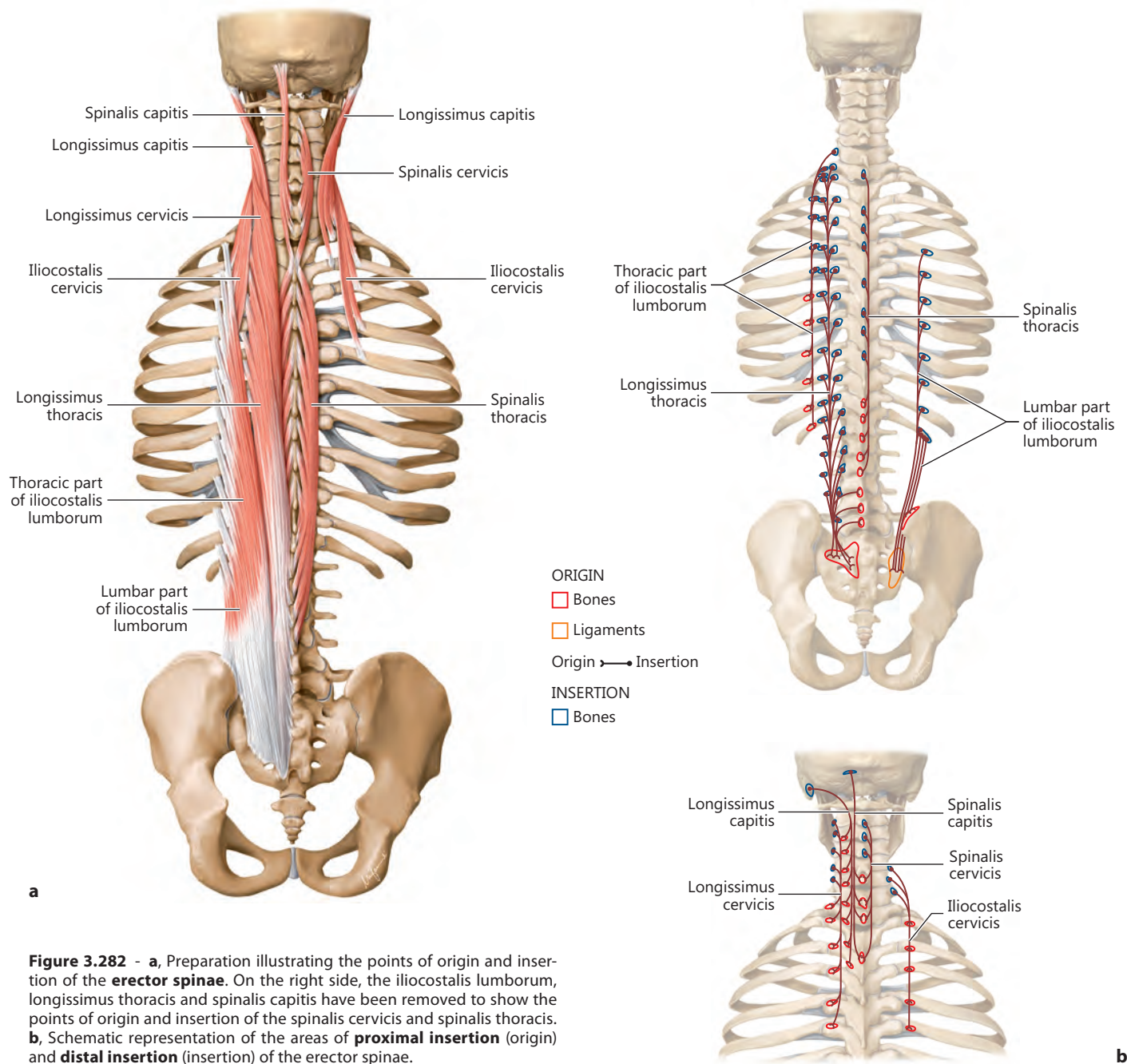
At the bottom, the investing (superficial) layer of the cervical fascia inserts on the superior margin of the manubrium of the sternum and the anterior margin of the clavicle, until it reaches the acromion and the spine of the scapula. At the level of the manubrium of the sternum, the insertion is double, leading to both the anterior and posterior surfaces of the bone, thus creating a canal that gives passage of the **jugular venous arch**, which joins the lower ends of the anterior jugular veins and accommodates some deep lymph nodes (**Fig. 3.271**).

At the level of the anterior margin of the trapezius, an extension called **vertebral extension** originates from the investing (superficial) layer of the cervical fascia, which, running on a frontal plane, attaches to the anterior tubercles of the transverse processes of the cervical vertebrae, forming two muscular sheaths, one wrapping the scalenus anterior and the other the scalenus medius and scalenus posterior, so that at the level of the supraclavicular triangle, in the space forming between the two sheaths, a sort of passageway is created through which the subclavian artery and the nerve trunks of brachial plexus run. The subclavian vein runs in front of the insertion of the scalenus anterior (**Fig. 3.272**).



**Figure 3.270** - The **ligamentum nuchae** (nuchal ligament) extends from the external occipital protuberance and from the posterior border of the foramen magnum to the spinous processes of the cervical vertebrae. In the left half, with the skin and subcutaneous tissue removed, one can observe in particular the occipital nodes and the mastoid or retroauricular nodes. In the right half, in addition to the skin and subcutaneous tissue, the investing layer of the cervical fascia has been transected. One can see in particular the great auricular nerve, the largest of the superficial branches of the cervical plexus, which proceeds upwards on the lateral surface of the sternocleidomastoid.





**Figure 3.282 - a,** Preparation illustrating the points of origin and insertion of the **erector spinae**. On the right side, the iliocostalis lumborum, longissimus thoracis and spinalis capitis have been removed to show the points of origin and insertion of the spinalis cervicis and spinalis thoracis. **b,** Schematic representation of the areas of **proximal insertion** (origin) and **distal insertion** (insertion) of the erector spinae.

#### Thoracic part of the iliocostalis lumborum

- **Insertions:** it originates from the external surface of the last six ribs and inserts at the costal angles of the first seven ribs and the transverse process of the seventh cervical vertebra.

#### Lumbar part of the iliocostalis lumborum, also called *lateral division of the lumbar erector spinae*

- **Insertions:** it originates from the iliac tuberosity, the iliac crest and the posterior layer of thoracolumbar fascia and inserts at the costal angles of the last eight ribs.
- **Innervation:** it is innervated by the posterior rami of the cervical, thoracic and lumbar nerves.
- **Action:** the *iliocostalis* extends the vertebral column and, by con-

tracting unilaterally, tilts it ipsilaterally. It can also elevate or lower the ribs.

**Longissimus** - It is formed by three parts, the *longissimus capitis*, the *longissimus cervicis* and the *longissimus thoracis* (see Fig. 3.282).

#### Longissimus capitis

- **Insertions:** it originates from the superior articular processes of the last four or five cervical vertebrae and the transverse processes of the first five thoracic vertebrae and inserts at the apex and the posterior surface of the mastoid process of the temporal bone.

**Table 3.14 - Muscles of the thorax**

<i>Muscle</i>	<i>Proximal insertion</i>	<i>Distal insertion</i>	<i>Innervation</i>	<i>Action</i>
Serratus anterior	Lateral surface of the first ten ribs	Medial (vertebral) border of the scapula	Long thoracic nerve [C5-C7]	Forward and lateral traction of the scapula and its rotation when the arm is raised. When the scapula is fixed, elevation of the ribs (inspiratory muscle)
Diaphragm		Central tendon of the diaphragm	Phrenic nerve [C3-C5] (the peripheral part of the muscle receives sensory fibers from the last six or seven intercostal nerves, T6-T12)	The initial contraction of the muscle pushes the central tendon downwards, which, once the movement has ceased, becomes a fixed point for the successive contraction of the fibers, with elevation of the second to tenth ribs and increase of the transverse and anteroposterior diameters of the thorax. This increase in thoracic capacity, which occurs during inspiration, confers the role of primary inspiratory muscle to the diaphragm
• Sternal part	Posterior surface of the xiphoid process			
• Costal part	Internal surface of the last six costal cartilages and of the adjacent ribs on both sides			
• Lumbar part	Medial and lateral arcuate ligaments and lumbar vertebrae through two crura (right and left)			
Levatores costarum	Transverse processes of the seventh cervical vertebra and first eleven thoracic vertebrae	Superior border and external surface of the underlying rib between the tubercle and the costal angle	Posterior rami of the thoracic nerves [T1-T12]	Elevation of the ribs (inspiratory muscles)
External intercostal	Inferior border of the ribs	Superior border of the underlying rib	Intercostal nerves [T1-T12]	Contraction of the ribs (inspiratory muscles)
Internal intercostal	Medial lip of costal groove	Superior border of the underlying rib and cartilage	Intercostal nerves [T1-T12]	Contraction of the ribs (expiratory muscles)
Innermost intercostal	Inferior border of the ribs	Superior border of the underlying rib	Intercostal nerves [T1-T12]	Contraction of the ribs (expiratory muscles)
Pectoralis major		Crest of the greater tubercle of the humerus	Medial and lateral pectoral nerves (C5-C8 and T1)	Flexion, adduction and internal rotation of the arm. With a fixed point on the humerus, elevation of the trunk (inspiratory muscle)
• Clavicular head	Medial half of the anterior border of the clavicle			
• Sternocostal head	Anterior surface of the sternum and from the second to the sixth costal cartilage			
• Abdominal part	Superior part of the anterior layer of the rectus sheath			
Pectoralis minor	Superior border and external surface of the third, fourth and fifth ribs (often of the second, third, and fourth ribs)	Coracoid process of the scapula	Medial and lateral pectoral nerves (C5-C8 and T1)	Downward traction of the scapula. With a fixed point on the scapula, elevation of the ribs (inspiratory muscle)
Subcostales	Internal surface of the rib near the costal angle	Internal surface of the underlying rib or the one next to it	Intercostal nerves [T1-T12]	Depression of the ribs (expiratory muscles)
Sternalis	Small muscular bundle, the presence of which is inconstant, located superficially to the sternocostal head of the pectoralis major (parallel to the border of the sternum)			
Subclavius	Superior surface of the first rib and adjacent costal cartilage	Inferior surface of the clavicle (subclavian groove)	Subclavian nerve [C5, C6]	Depression of the clavicle
Transversus thoracis	Posterior surface of the xiphoid body and process of the sternum	Internal surface and inferior border of the costal cartilages, (from the second to the sixth)	Intercostal nerves [T2-T6]	Downward traction of the costal cartilages (expiratory muscle)

Note: other muscles located in the thorax or with an origin or insertion in the thorax. The pleuroesophageus and trachealis are bundles of smooth muscle fibers that extend, respectively, from the left mediastinal pleura to the muscular layer of the esophagus, and as a bridge between the free ends of the C-shaped tracheal cartilages. The scalene muscles, which insert at the first two ribs, and the sternocleidomastoid, which originates from the sternum and clavicle, are considered among the muscles of the neck.

The serratus posterior superior and inferior (spinocostal muscles), which insert respectively at the second to fifth ribs and at the last four ribs, originating at the thorax level from the spinous processes T I and T II, and T XI and T XII, and the latissimus dorsi and trapezius (spinoappendicular muscles), originating at the thorax level, respectively, from the spinous processes from T VI or T VII to T XII and from T I to T XII, which line the thorax posterolaterally and posterosuperiorly, are considered among the muscles of the back. The quadratus lumborum, which inserts at the twelfth rib, is considered among the muscles of the abdomen.

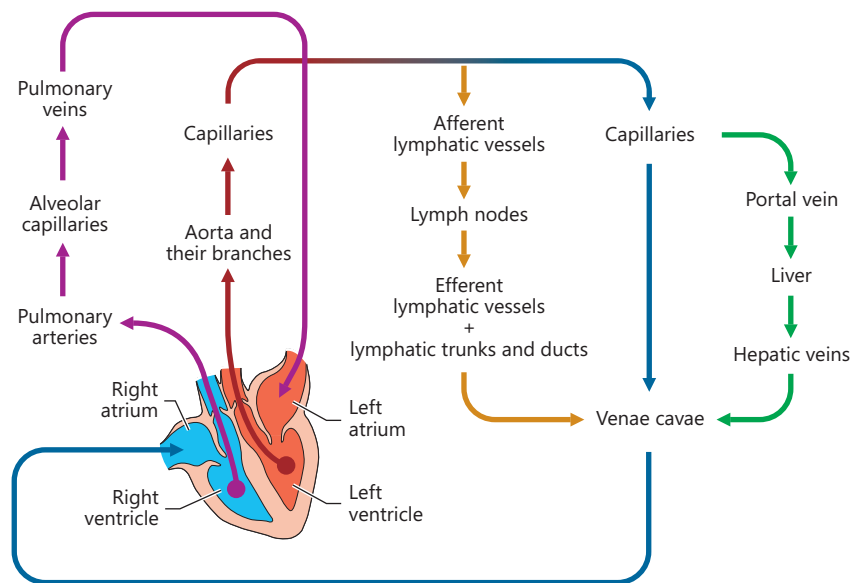
# CARDIOVASCULAR SYSTEM

The **circulatory system** is formed by *blood* and *lymphatic vessels*, which are a set of variably ramified ducts distributing throughout the whole body and containing *blood* and *lymph*. There is a **cardiovascular system** (or *blood circulatory system*), which contains blood, and a **lymphatic circulatory system** (*lymphatic trunks and ducts*), responsible for the lymph transport (Fig. 4.1).

The cardiovascular system includes the *heart*, an organ which works as a pump and ensures the blood circulation

into the vessels, whereas the lymphatic circulatory system is provided with lymphoid and hemopoietic organs of the *lymphatic* or lymphoid system (thymus, bone marrow, spleen, lymph nodes, tonsils), which represent the production site of the lymphocytes, the cells responsible for the immune response. The *bone marrow* has not only a lymphocytopoietic function, but also produces the other figurative elements of blood: erythrocytes (red blood cells or haematids), granulocytes, monocytes, platelets.

**Figure 4.1 - Overview of the circulatory system.** Blood pumped by the left ventricle of the heart is distributed by the branches of the aorta. Gaseous and metabolic exchanges take place at the level of **microcirculation** between the blood and the extracellular fluid that permeates the tissues. Following microcirculation, blood is drained towards the superior (supradiaphragmatic areas) and inferior (subdiaphragmatic areas) **venae cavae** and from these to the right atrium of the heart. Before reaching the inferior vena cava, reflux blood from the gastrointestinal tract, collected in the abdominal cavity from the pancreas, biliary tracts and spleen, is drained through the hepatic portal system by the portal vein. Extracellular fluids are drained by lymphatic capillaries, which originate in blind-ended vessels in the body's periphery. This fluid (lymph) is conducted through lymphatic ducts, which gradually increase in size, and passes through lymph node stations before being discharged into the superior vena cava (jugulosubclavian junction).



## FUNCTIONS

- The cardiovascular system presents numerous functions:
- **transport of nutrients and oxygen** and their distribution to the whole body
- **elimination of the products of cellular catabolism** from their production site
- **thermoregulation**
- **regulation of body fluids homeostasis**
- **intervenes during immune responses**, transporting cells with phagocytic activity, immune competent cells and antibodies.

## ORGANIZATION

The cardiovascular system includes *heart* and *blood vessels*, which can be divided into *arteries*, *veins* and *capillaries*, forming a closed system completely coated in its inner side by endothelium, whose wholeness is essential for the maintenance of the fluid state of the blood (Fig. 4.2).

The **heart** works as a pump and is provided with a valve system able to direct the blood flow in only one direction; it pumps the blood into the arteries thanks to its rhythmical contractions. These latter ones progressively ramify while getting further from the heart, increasing in number and reducing their diameter. The main function of the **arteries** is to transport the blood which they contain. The **capillary vessels** (with an average diameter of 10  $\mu\text{m}$ ), originate from the terminal segment of the **arterioles**, formed by the metarterioles; they are permeable and allow the passage of water and substances dissolved in it from the blood to the neighboring tissues and vice versa. The capillaries form nets which in turn, by confluence, form **venules**; these latter ones connect to each other, form small and middle caliber **veins** and lastly bigger veins which travel back to the heart. The veins also have only transport function (Fig. 4.3).

Humans are provided by a double and complete circulation: there is a **systemic circulation** or greater circulation, destined to the vascularization of all body segments (nutritional loop) and a **pulmonary circulation** or lesser circulation, with the function of re-establishing a correct oxygen

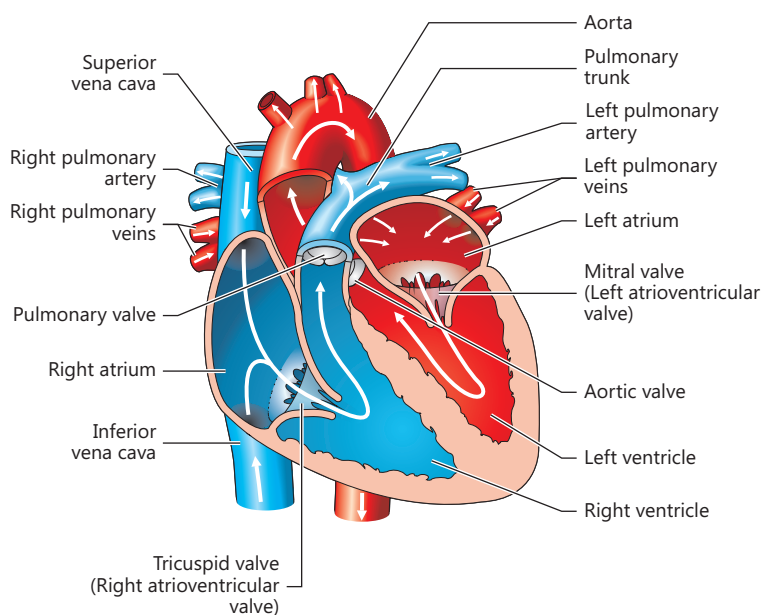
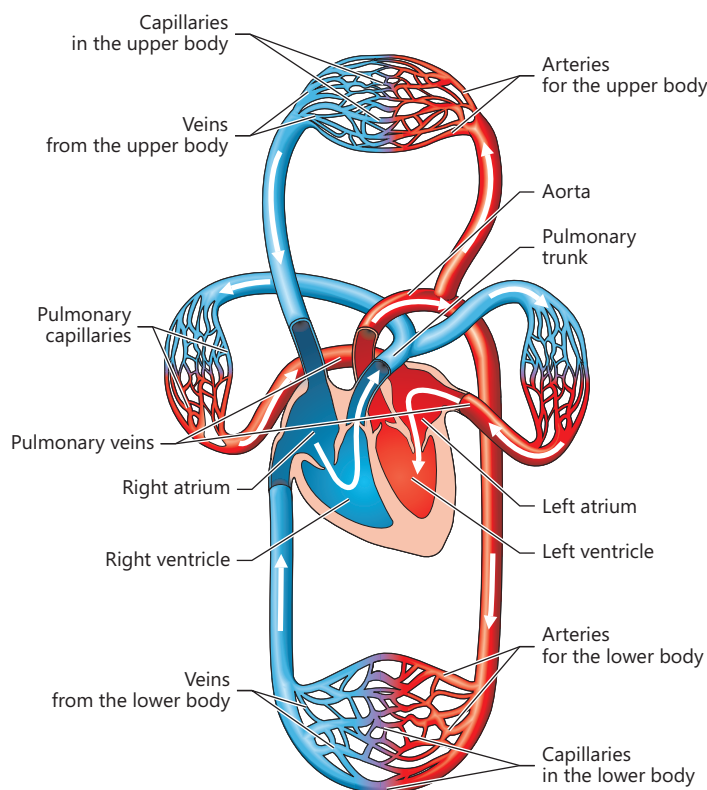
and carbon dioxide content in the blood (functional loop). Greater and lesser circulations start and end at the level of the heart, which presents a suitable conformation for their functional organization (Fig. 4.4).

The heart is formed by four cavities, two posterosuperior ones, which are the **right** and **left atrium**, separated by the *interatrial septum*, and two inferior ones, which are **right** and **left ventricle**, separated by the *interventricular septum*.

Each atrium is connected to the ventricle below through the **right** and **left atrioventricular orifices**, provided with valves (*right atrioventricular valve* or *tricuspid valve* and *left atrioventricular valve* or *bicuspid valve*) which allow the blood flow to direct only from the atrium to the respective ventricle.

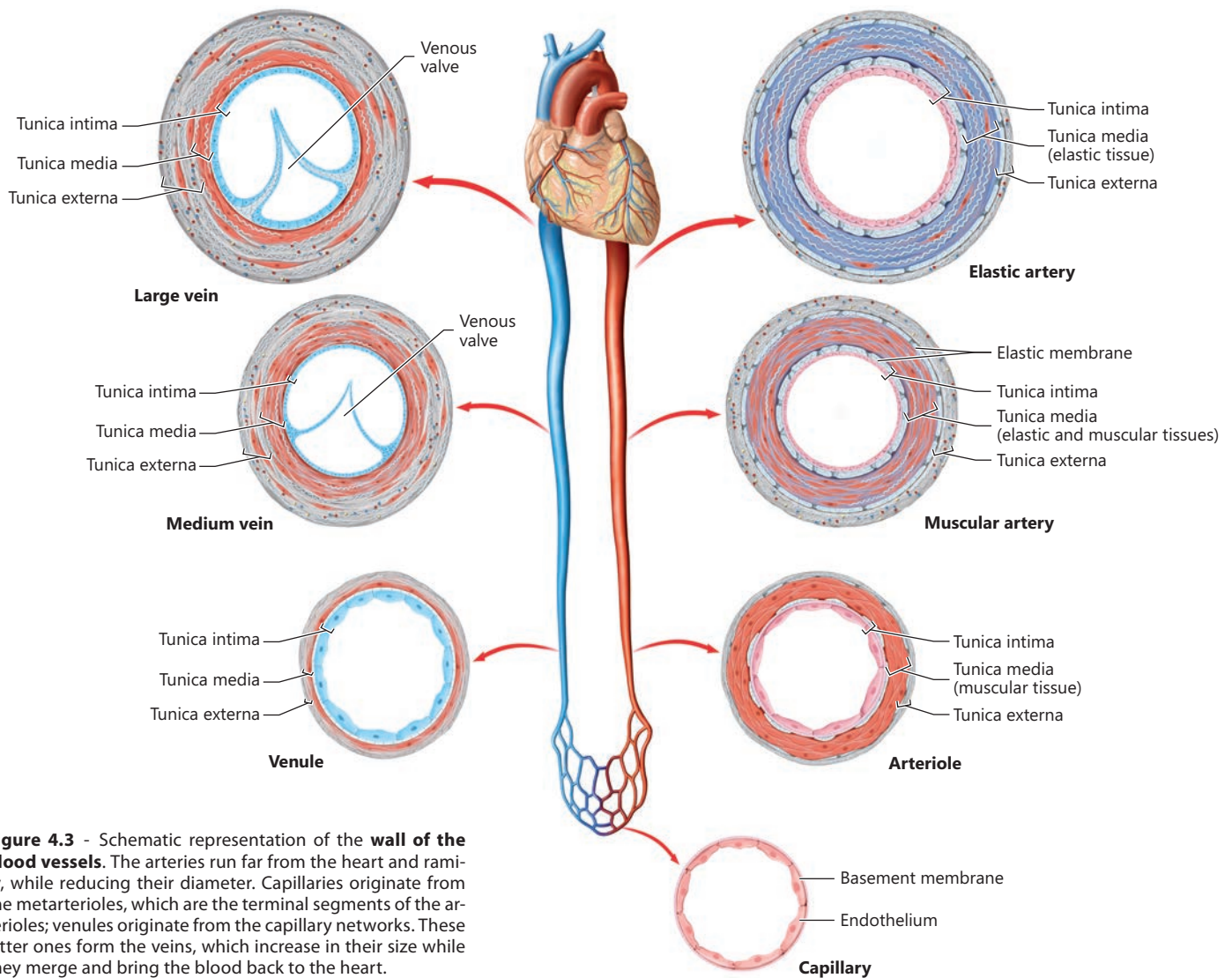
Veins emerge into the atria, through the **opening** of *superior* and *inferior vena cava* (right atrium) and the **openings of pulmonary veins** (left atrium); arteries start from the ventricles and present the *aortic* and *pulmonary valves* at their origin, allowing the unidirectional passage of blood from left and right ventricles to the aorta and the pulmonary trunk.

The **greater circulation** starts from the left ventricle via the *aorta*, which progressively ramifies and distributes to the whole body. The blood goes back to the right atrium from the capillary networks through the venous system; the *superior vena cava*, the *inferior vena cava* and the *coronary sinus* emerge into the right atrium; then, the blood goes from the atrium to the ventricle below.



**Figure 4.2 - Cardiovascular system.** The heart exerts the function of a pump and directs the blood flow into the valve through a system of valves and from these into the microcirculation, formed by arterioles, capillaries and venules, which give rise to the veins, responsible to bring the blood back to the heart.

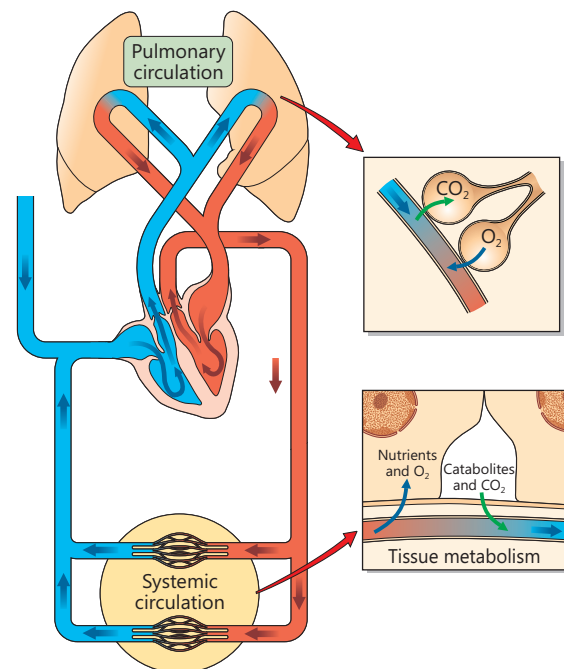




**Figure 4.3** - Schematic representation of the **wall of the blood vessels**. The arteries run far from the heart and ramify, while reducing their diameter. Capillaries originate from the metarterioles, which are the terminal segments of the arterioles; venules originate from the capillary networks. These latter ones form the veins, which increase in their size while they merge and bring the blood back to the heart.

The **lesser circulation** starts from the right ventricle with the *pulmonary trunk* which bifurcates into the two *right* and *left pulmonary arteries* and transports the venous blood to the lungs. The last branches of the pulmonary arteries form a network of capillaries leaning against the wall of the pulmonary alveoli. The venous blood traversing this network gives carbon dioxide to the air contained into the alveoli and takes up oxygen; in this way, it becomes arterial blood and goes back to the heart through four *pulmonary veins*, which are the *right superior pulmonary vein*, *left superior pulmonary vein*, *right inferior pulmonary vein* and *left inferior pulmonary vein*, emerging into the left atrium. It passes from here into the left ventricle, from which it starts the greater circulation via the aorta (**Fig. 4.5**).

**Figure 4.4** - Schematic representation of the **greater circulation** (systemic circulation) and the **lesser circulation** (pulmonary circulation), which derive from the left and right ventricle, respectively. Arrows indicate the direction of the blood flow. The main functions of the lesser and greater circulations are reported in the squares.



per minute in resting conditions); each beat corresponds to a contraction phase (*systole*) and a relaxation phase (*diastole*).

## EXTERNAL MORPHOLOGY

The heart presents the shape of a cone, flattened in anteroposterior direction, with the base corresponding to the atrial portion (**base of heart**), facing upward, to the right and backward, and the apex formed by the ventricular component (**apex of heart**), heading downward, to the left and to the front (**Fig. 4.8**).

Taking the median sagittal plane as a reference, about one third of the organ is situated on the right side, whereas two thirds are situated on the left side. Its major axis (**longitudinal diameter**), which connects the center of the base to the apex, measures in average about 13 cm in adults and is directed obliquely to the bottom, to the left and forward, forming an angle of about 45° with respect to the longitudinal axis of the body. The **transversal diameter** is perpendicular to the axis mentioned above and measures about 10 cm in adults when calculated in measuring from the base; the anteroposterior diameter can measure up to 5-6 cm in thickness.

The heart in long-limbed persons and asthenic subjects is situated in a more vertical position (*teardrop-shaped heart*), whereas the heart in short-limbed persons is usually situated in a horizontal position.

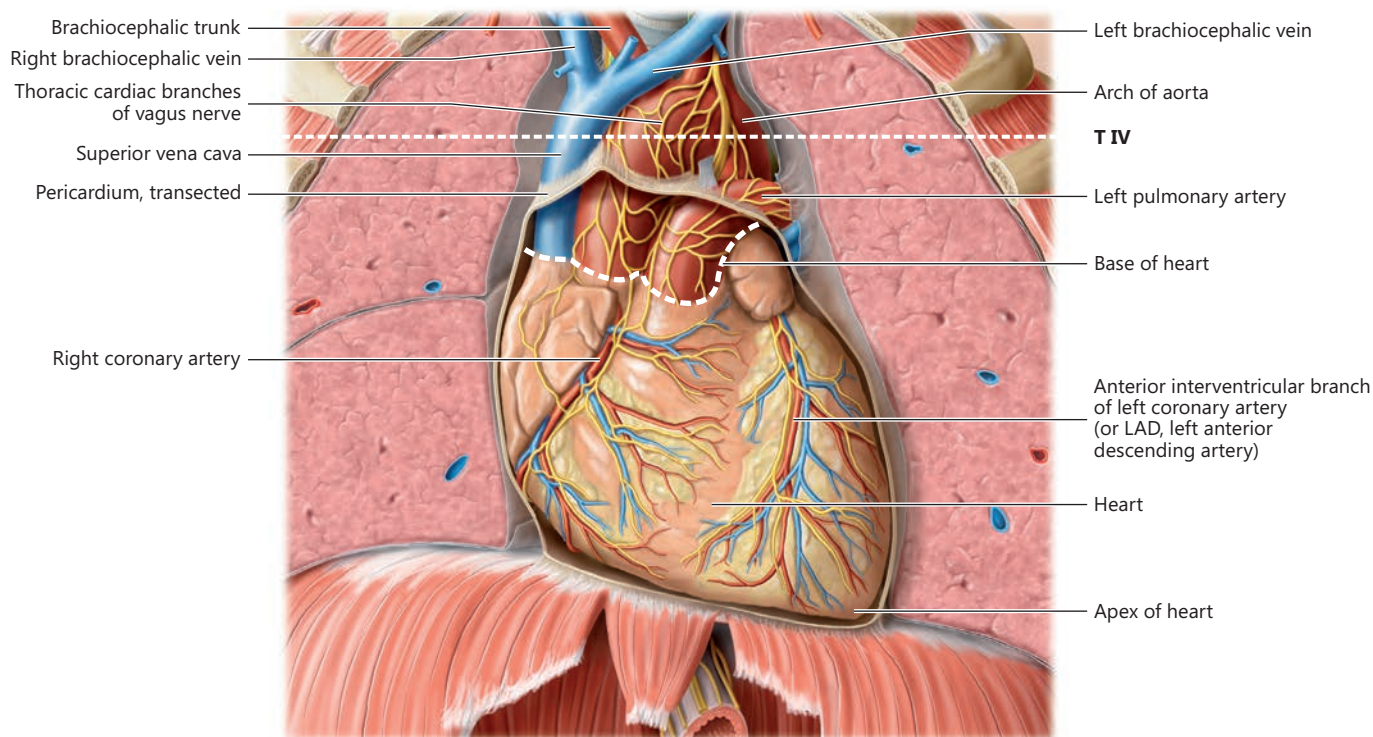
During deep inhalation, the major axis of the heart tends to become vertical because of the lowering of the diaphragm, and then goes back to normal position at the end of the exhalation process. The heart of newborns and children presents a more globular shape.

The heart is slightly rotated in clockwise direction with respect to the longitudinal axis (if observed from the tip), in a way that the most posterior part of the base of heart appears as the left part, corresponding to the left atrium, which gets in tight contact with the organs situated in the posterior mediastinum, in particular with the esophagus.

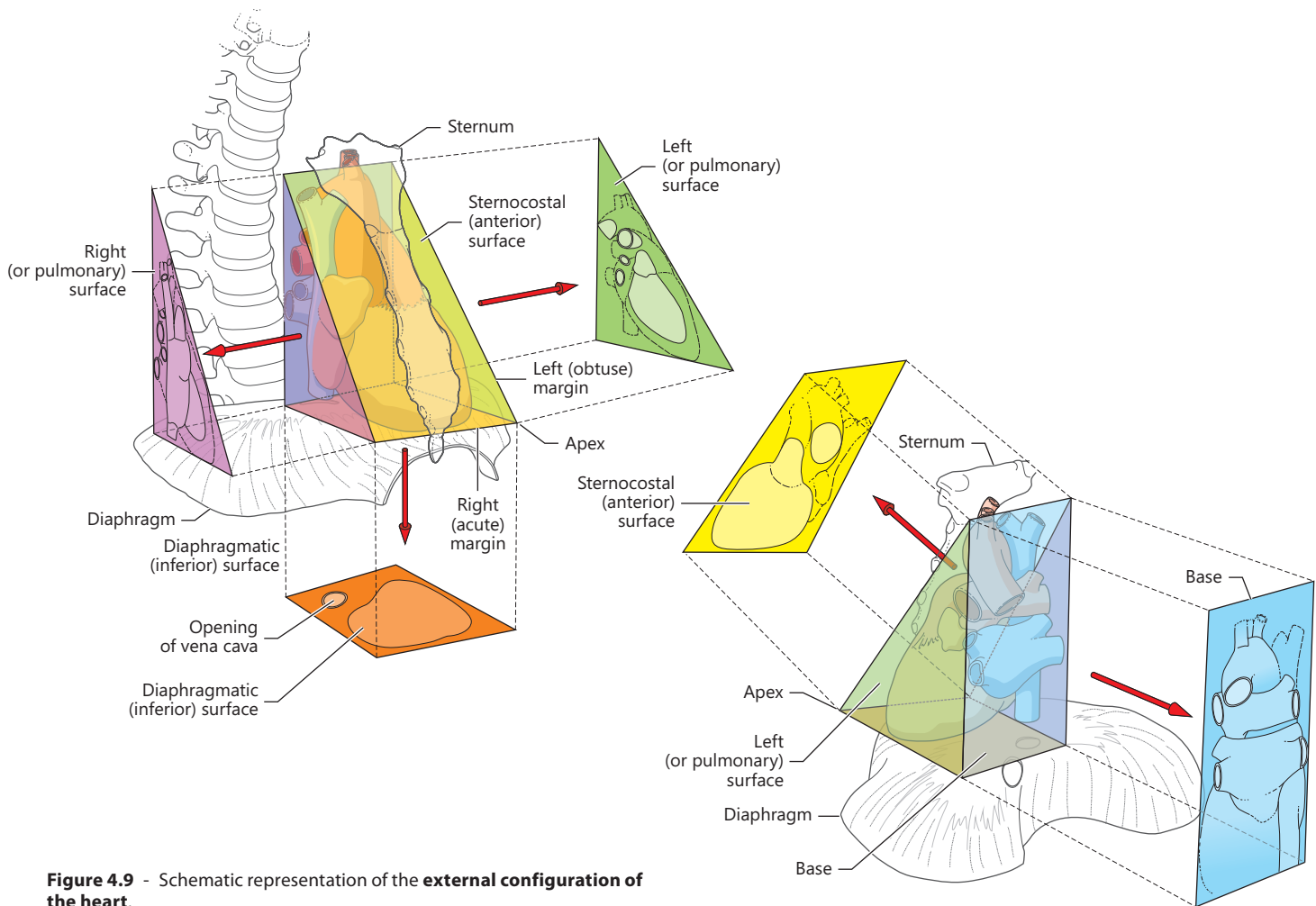
The heart presents a reddish color similar to the one of the skeletal muscles, but it presents yellowish spots with variable size, due to fat accumulations; they are mainly situated along the course of the coronary vessels, are scarcely developed in children and are more and more present with age progression.

The size of the heart varies with gender, age and conditions of the subject and is at least comparable to the size of the subject's fist. Its weight in adults (corresponding to 0.4-0.45% of the body weight) is included between 280 and 340 g in males and between 230 and 280 g in females; higher weights, up to 350 g in men and 300 g in women, are indicators of pathological conditions (cardiac hypertrophy). The heart weights in average 20 g at birth, corresponding to 0.7% of the body weight.

The external surface of the heart, surrounded by the *visceral layer (epicardium)* of the serous membrane of the heart (*serous pericardium*), presents a *sternocostal* or *anterior sur-*



**Figure 4.8 - Shape of the heart.** It is similar to a cone, flattened in anteroposterior direction, with the base facing upward, to the right and backward, and the apex facing downward, to the left and forward. About one third of the organ is situated on the right side with respect to the median sagittal plane, whereas two thirds are situated on the left side.



**Figure 4.9** - Schematic representation of the **external configuration of the heart**.

face, a *diaphragmatic* or *inferior* (or *posteroinferior*) surface, a *base*, an *apex* or tip and two *margins*, a *right* one (acute) and a *left* one, obtuse. There are also a *right surface* and a *left surface*, or *pulmonary surfaces* (**Fig. 4.9**).



#### Position of the heart in the thoracic cavity

From a clinical and diagnostic-instrumental points of view, it is more useful to consider the heart in the real position in the thoracic cavity, with the obliquity and rotation characterizing it and conditioning the connections with the neighboring organs. The projection of the heart onto the anterior surface of the thorax forms a trapezium (**cardiac aia**, see **Fig. 4.30**; § *Projection of the heart onto the anterior wall of thorax: cardiac aia*) whose inferior major base corresponds to the acute margin, the left side mainly to the obtuse margin, the right side to the margin of the corresponding atrium and the superior minor base is undefined, since it continues into the vascular pedicle. In case of **dextrocardia**, which can be associated or not to *situs viscerum inversus* (very rare condition), the heart assumes a symmetrical position in the thorax compared to normal conditions. ■

**Sternocostal or anterior surface (Fig. 4.10)** - It is moderately convex, facing frontward and to the left. It extends from the right margin, neatly separating it from the diaphragmat-

ic surface, to the left margin, where the two surfaces continue into each other. It is traversed by the **anterior interventricular sulcus** (or **anterior longitudinal sulcus**), which starts at the top, by the left margin and descends in almost vertical direction passing to the right of the apex of heart; it touches the right margin (**notch of cardiac apex**), merging with the posterior interventricular sulcus situated on the diaphragmatic surface. This sulcus, hosting the branches of the coronary vessels, surrounded by accumulations of fat, marks the limit between right and left ventricle on the sternocostal surface, and corresponds in the deepest areas to the interventricular septum. The part of the right ventricle is wider (about two thirds of the entire surface) than the one belonging to the left ventricle (about one third) and lifts up at the top forming a conical protrusion (**conus arteriosus** or **infundibulum**) which continues into the pulmonary trunk. This latter one heads upward and to the left, hiding the initial tract of aorta, which starts from the base of the left ventricle, goes up to the right and then curves at the top, to the left and backward, forming an arch (*arch of aorta*).

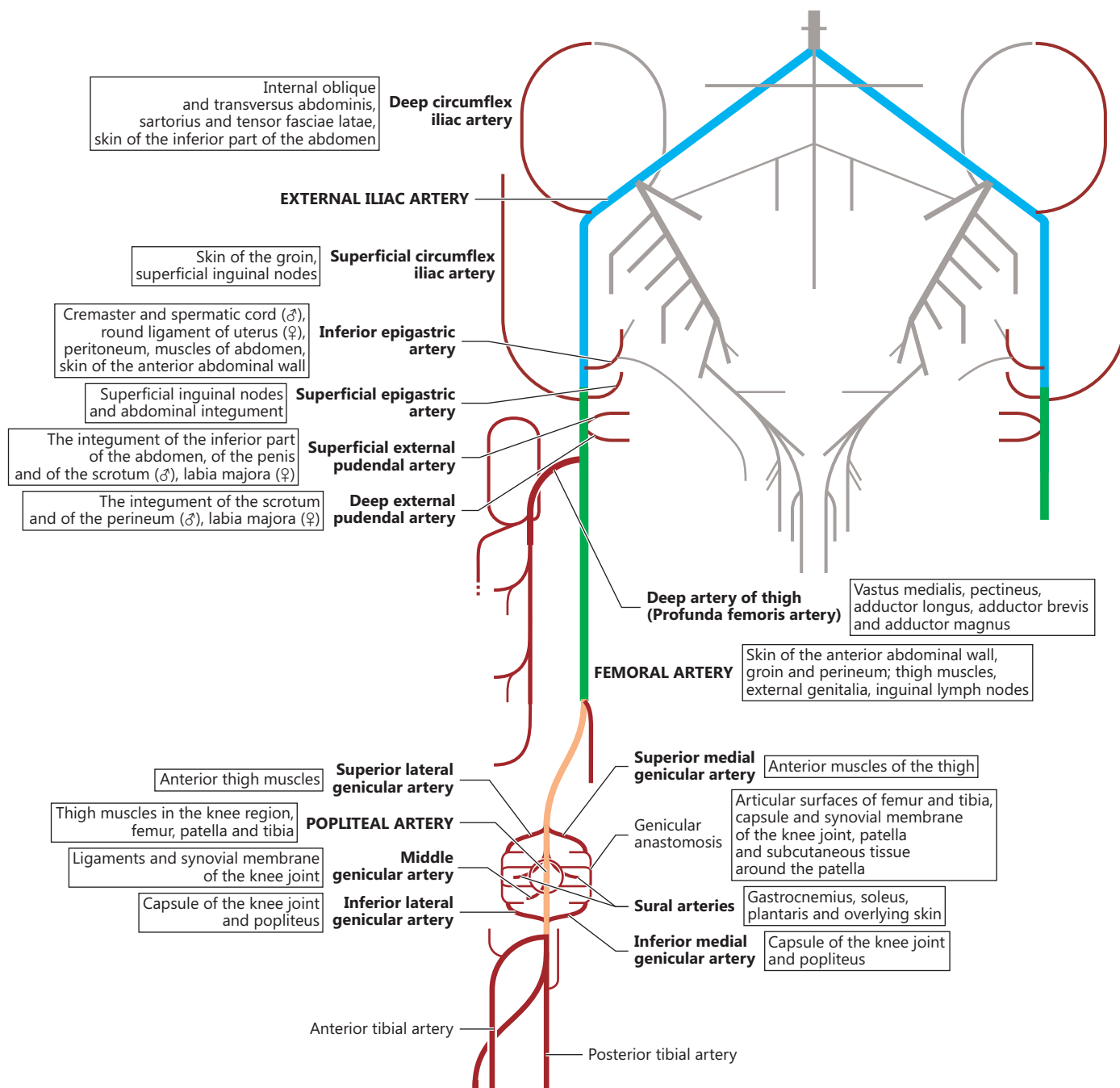
Pulmonary trunk and aorta communicate with each other thanks to the pattern of the **aortopulmonary septum** (septum of common



## EXTERNAL ILIAC ARTERY ■, FEMORAL ARTERY ■ AND POPLITEAL ARTERY ■

### Territory of supply

Abdominal wall, lower limb

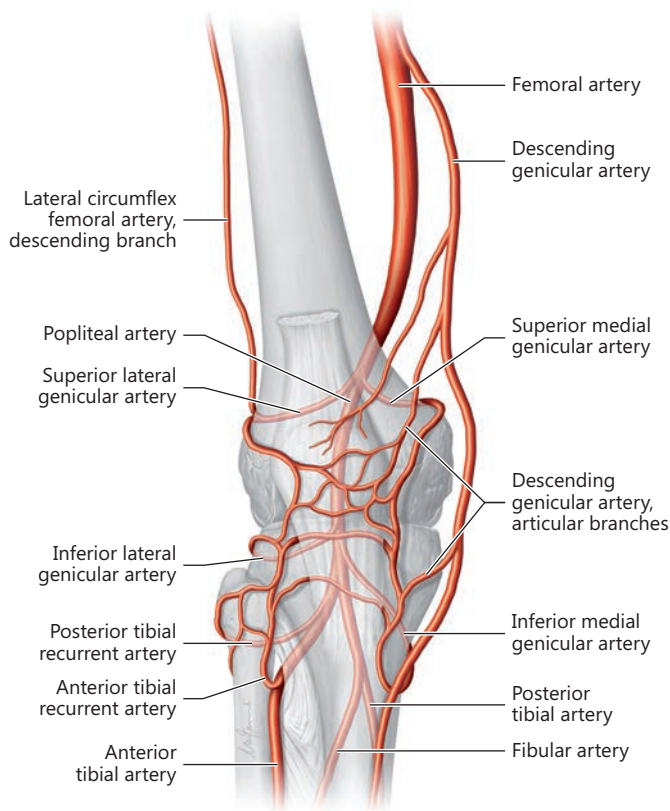


neum and the peritoneal tissue, which divide it on the right side from the last tract of ilium and on the left side from the sigmoid colon. It is crossed in the initial tract at the front by the ureter and, in females by the ovarian vessels; in the final tract, the testicular vessels the genital branch of the genitofemoral nerve, the deep iliac

circumflex vein and the deferent duct in males or the round ligament of uterus in females are situated anteriorly

- posteriorly and laterally, it is in relationship with the psoas major. The external iliac vein is firstly situated posteriorly and then in medial position. ■





**Figure 4.127** - Right **genicular anastomosis**. The numerous anastomoses between the branches of the femoral, popliteal, anterior tibial and posterior tibial arteries, offer a good alternative of collateral circuits.

the base of the collateral circle forming when the femoral artery obliterates. The *first perforating artery* is the most voluminous, perforates the adductor muscles at the level of the inferior margin of the pectineus. It vascularizes the adductor brevis, the adductor magnus, biceps femoris and gluteus maximus and forms the **superior femoral nutritive artery**. The *second perforating artery* is the thinnest, originates below the adductor brevis, distributes to the muscles of the posterior region of thigh and forms the **inferior femoral nutritive artery**. The *third perforating artery* is the terminal branch of the deep femoral artery. It traverses the adductor magnus and anastomoses with the superior branches of the genicular anastomosis formed by the popliteal artery.

#### Descending genicular artery

It distributes to the knee joint and the skin of the superomedial part of the leg (see **Fig. 4.127**). It is a voluminous collateral branch originating in the adductor canal and divides into a *saphenous* or *superficial branch*, perforating the anterior wall of the adductor canal, together with the saphenous nerve and distributes to the skin of the anterior surface of the knee, and *articular* or *deep branches* which descend along the medial condyle of femur and end anastomosing with the su-

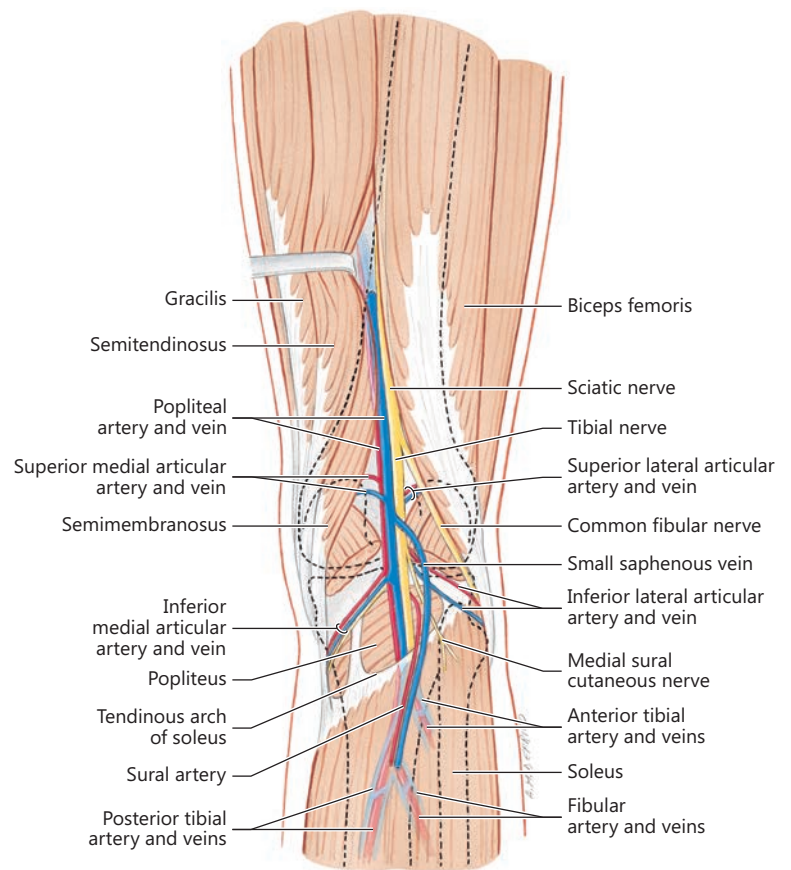
perior medial genicular artery, branch of the popliteal artery, participating to the formation of the genicular anastomosis.

#### Popliteal artery

- **Origin:** it is the continuation of the femoral artery.
- **Course and ending:** it extends from the adductor hiatus to the tendinous arch of soleus, where it divides into the terminal branches represented by the *anterior* and *posterior tibial arteries* (**Fig. 4.128**).



**Relationships** - The popliteal artery is in relationships with the popliteal surface of femur on the anterior side, from which it is separated by the interposition of adipose tissue, and with the articular genicular capsule. Distally, it runs between the gastrocnemius and the plantaris, from one side, and the popliteus, from the other. It has a winding course when the knee is flexed; on the contrary, its course is straight when the knee is extended. The popliteal vein runs by the popliteal artery; at its origin, it is situated behind and outside of the artery, whereas distally it is situated on its inner side. The tibial nerve is situated in a more superficial position, together with the vascular bundle; at proximal level, it is separated by the vessels thanks to the interposition of adipose tissue, where afterward it leans on them. The neurovascular bundle is coated by a thick connective sheath around which there are some lymph nodes (popliteal lymph nodes).



**Figure 4.128** - **Relationships of the popliteal artery and its branches:** schematic representation. The dotted line highlights the profile of the skeletal segments.

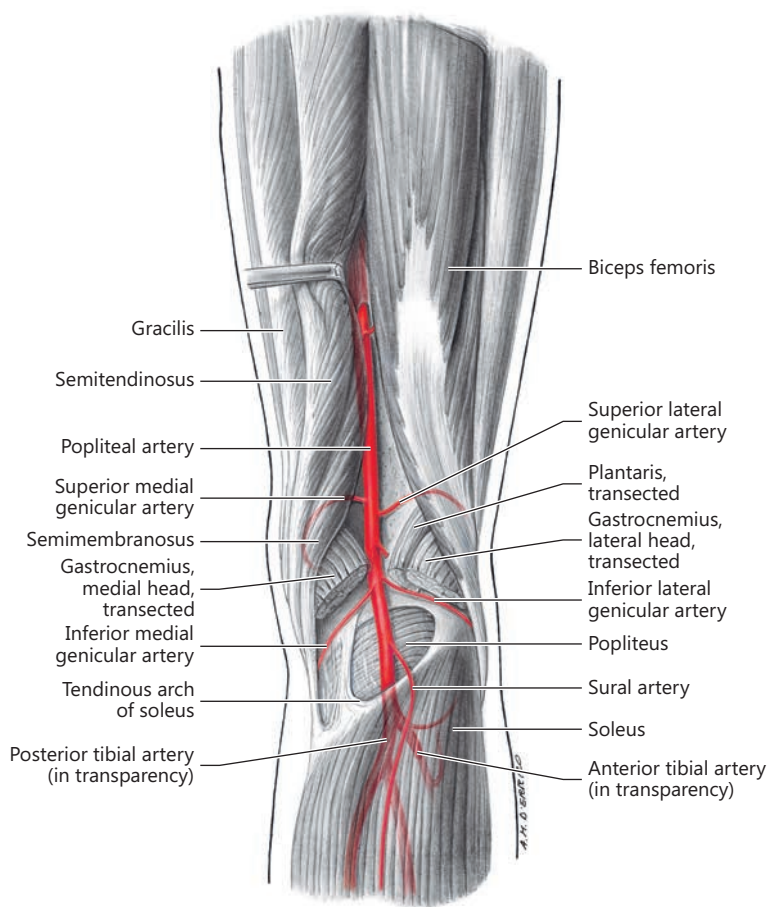


**Territory of supply** - Medial and lateral heads of gastrocnemius, skin and knee joint. It participates to the formation of the *genicular anastomosis*, whose superficial part is called *patellar anastomosis*. ■



### Popliteal pulse

The popliteal pulse is important to establish the vascularization state of the lower limb in presence of peripheral vascular lesions. It can be perceived more easily if the knee is slightly flexed, in a way to release the popliteal fascia and compress the artery against the central wall of the popliteal surface of the distal extremity of femur, exerting a slight pressure with the tip of the finger of both of the hands on the popliteal fossa and with the thumbs on both of the sides of the patella. A **popliteal aneurism** causes edema and pain in the popliteal fossa. ■



**Figure 4.129 - Course and branches of the right popliteal artery.** The gastrocnemius has been transected and removed in order to show the tendinous arch of the soleus below to which the popliteal artery passes.

**Collateral branches** - They are the *sural arteries* and the *articular arteries*, divided into *superior lateral* and *superior medial* of the genicular artery, the *middle genicular artery*, the *inferior lateral* and *inferior medial genicular arteries* (Fig. 4.129; see Figs. 4.127, 4.128).

**Terminal branches** - The *anterior* and *posterior tibial arteries* provide for the arterial need for the vascularization of leg and foot. They participate with the recurrent branches to the formation of the genicular anastomosis, forming the *medial* and *lateral malleolar networks* and the **calcaneal network**, whereas the anastomoses between their distal branches form the **dorsal** (arcuate artery, branch of the dorsal artery of foot) and **plantar arterial arcades** (*deep plantar arch*).

## Collateral branches of the popliteal artery

### Sural arteries

They are two rather large arteries originating at the level of the popliteal fossa.



**Territory of supply** - They vascularize the gastrocnemius, soleus and plantaris. ■

### Superior medial and superior lateral genicular arteries

- **Origin:** from the anterior surface of the popliteal artery.
- **Course and ending:** they head to the sides and coat the lateral and medial condyles of femur, respectively.



**Territory of supply** - They participate to the formation of the genicular anastomosis, in addition to distributing to the anterior muscles of thigh. ■

### Middle genicular artery

It is a small vessel which can also start from the superior lateral genicular artery; it perforates the capsule of the knee joint above the oblique popliteal ligament to vascularize the anterior and posterior cruciate ligaments and the synovial membrane of the knee joint.



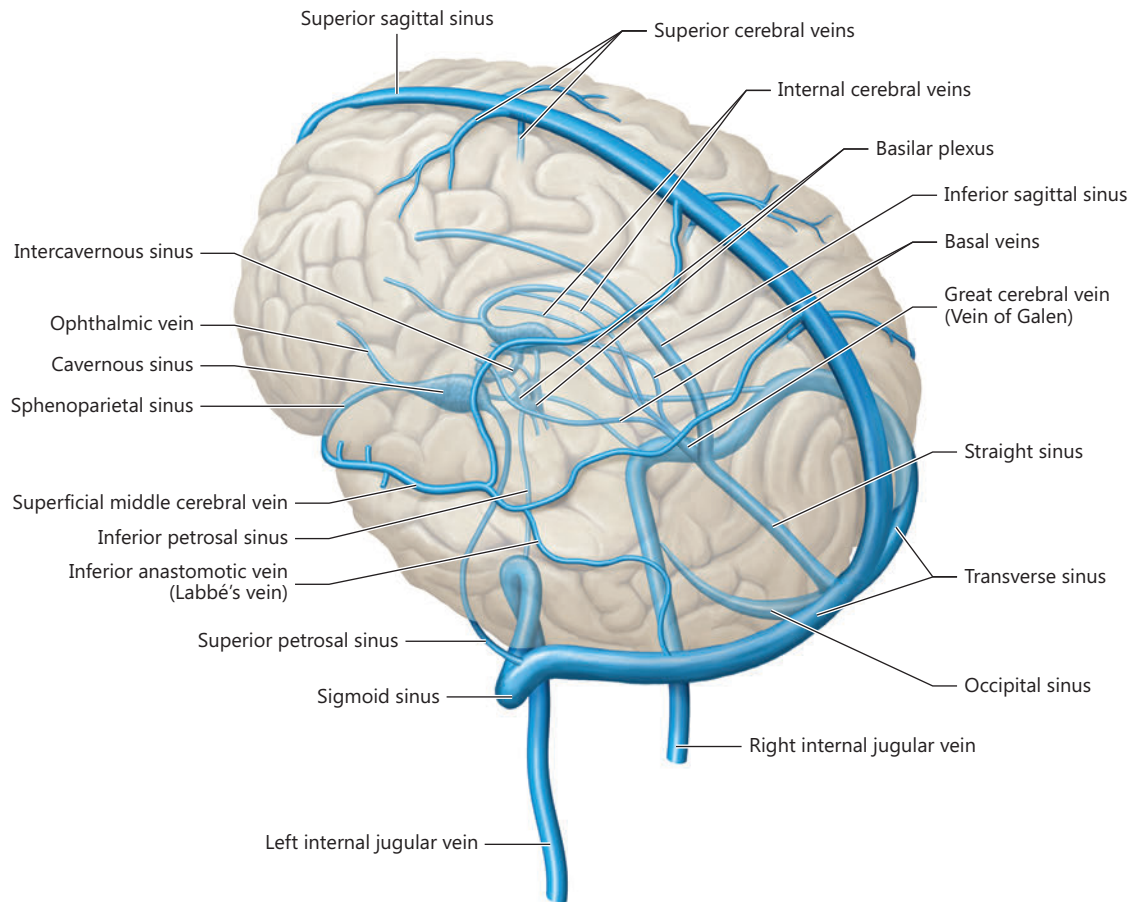
**Territory of supply** - Articular structures of knee (cruciate ligaments and synovial membrane). ■

### Lateral and medial inferior genicular arteries

As the superior arteries, they surround the respective medial and lateral tibial condyles.



**Territory of supply** - They participate to the formation of the genicular anastomosis. They also vascularize the capsule of the knee joint and the popliteus. ■



**Figure 4.170 - Deep cerebral veins:** schematic representation.

brane, from its apex to the base, where they end merging with the contralateral vein to form the great cerebral vein (vein of Galen). It drains the deep regions of the cerebral hemisphere. The *lateral direct veins* end into the *internal cerebral vein* and run in subependymal position in a coronal plane above the thalamus.

- **Superior thalamostriate vein** - It is a long vein which runs frontward in the sulcus between the thalamus and the caudate nucleus, covered by the *lamina affixa*, receiving laterally the *veins of the caudate nucleus* and merging, at the level of the caudal part of the interventricular foramen, with the *superior choroid vein* and the *anterior and posterior veins of septum pellucidum* to form the *internal cerebral vein*. In the *superior thalamostriate vein* also joins the *lateral vein of the lateral ventricle*, which drains the deep regions of the temporal and parietal lobes and runs in the lateral wall of lateral ventricle.
- **Great cerebral vein (vein of Galen)** - It is an unpaired and median venous trunk, about 1 cm long, which originates from the union of the *internal cerebral veins* and runs in the longitudinal cerebral fissure, between the cerebellum and the splenium of corpus callosum, which heads upward ending in the *straight sinus* (see Fig. 4.170). It re-

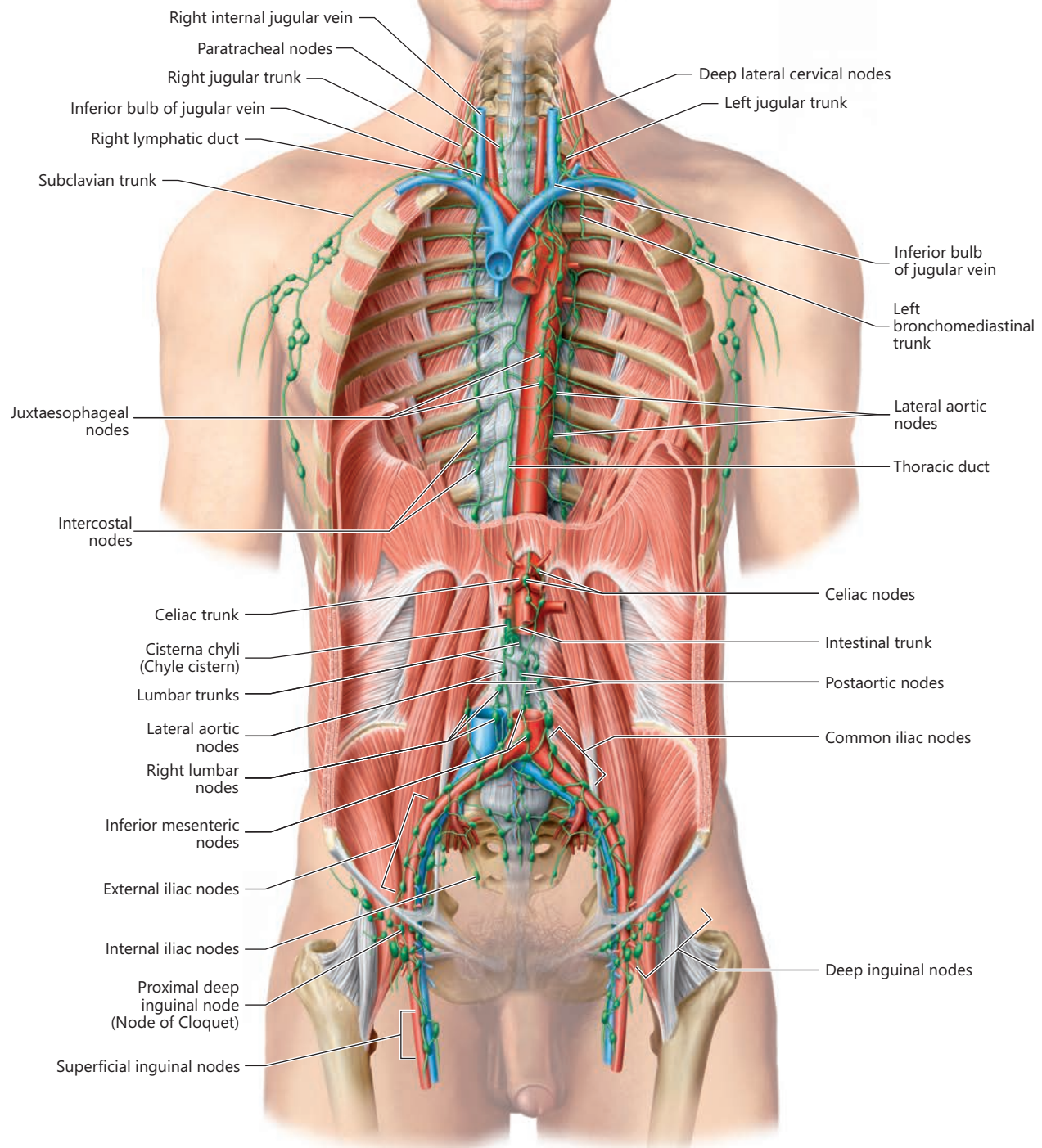
ceives numerous affluents among which the **medial vein of the lateral ventricle**, which drains the deep regions of the parietal and occipital lobes and runs in the medial wall of the lateral ventricle; the **vein of the corpus callosum**, which originates from the superior surface of corpus callosum and presents a posterior course; the **basal vein** (of basal vein of Rosenthal). The basal vein is a large vein (see Fig. 4.170) which originates from the confluence of the veins of the orbital cortex (*anterior cerebral veins*) and of the veins of the insular cortex (*deep middle cerebral vein* and *insular veins*, which present a course in the deep part of the lateral sulcus, together with the middle cerebral artery, and can also emerge into the superficial middle cerebral vein) and runs caudally and dorsally along the medial surface of the temporal lobe, receiving numerous affluents during its course:

- *vein of the olfactory gyrus*, which drains the medial olfactory stria
- *inferior thalamostriate veins*, which drain the thalamus and the corpus striatum and leave from the anterior perforated substance
- *inferior ventricular vein*, which drains the white matter of the superior and lateral regions of temporal lobe,







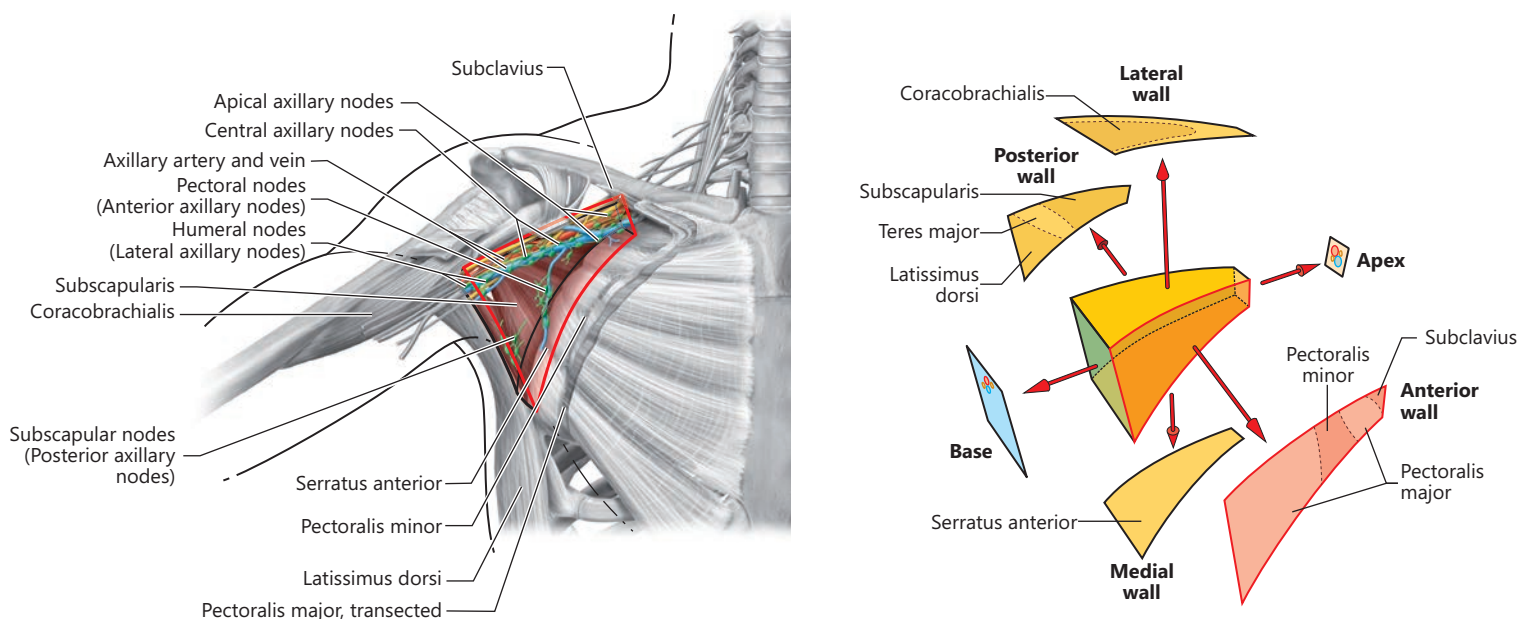


**Figure 5.6 - Course of thoracic duct and lymphatic trunks in the thorax, abdomen and pelvis.**

trunk and the right bronchomediastinal trunk, forming the right lymphatic duct.

The **bronchomediastinal trunks**, right and left, are situated in the posterior mediastinum and originate from the confluence from the lymphatic collectors and come from the anterosuperior (brachiocephalic) and tracheobronchial mediasti-

nal lymph nodal groups (see **Tab. 5.1** and **5.7**; § *Lymphatic drainage of the thoracic visceral organs*). They drain the lymph from the visceral organs and the deep portions of the thoracic walls, from the diaphragm and in part, indirectly, also from the liver. They culminate in correspondence to the confluence of the internal jugular vein with the subclavian vein or at the



**Figure 5.12** - The **axilla** is included between the medial surface of the superior part of the arm and the lateral surface of the superior part of the thorax. Its **shape** varies from the one of a sagittal fissure in anatomical position, when the arm hangs along the trunk, to the one of a quadrangular pyramid when the arm is abducted.

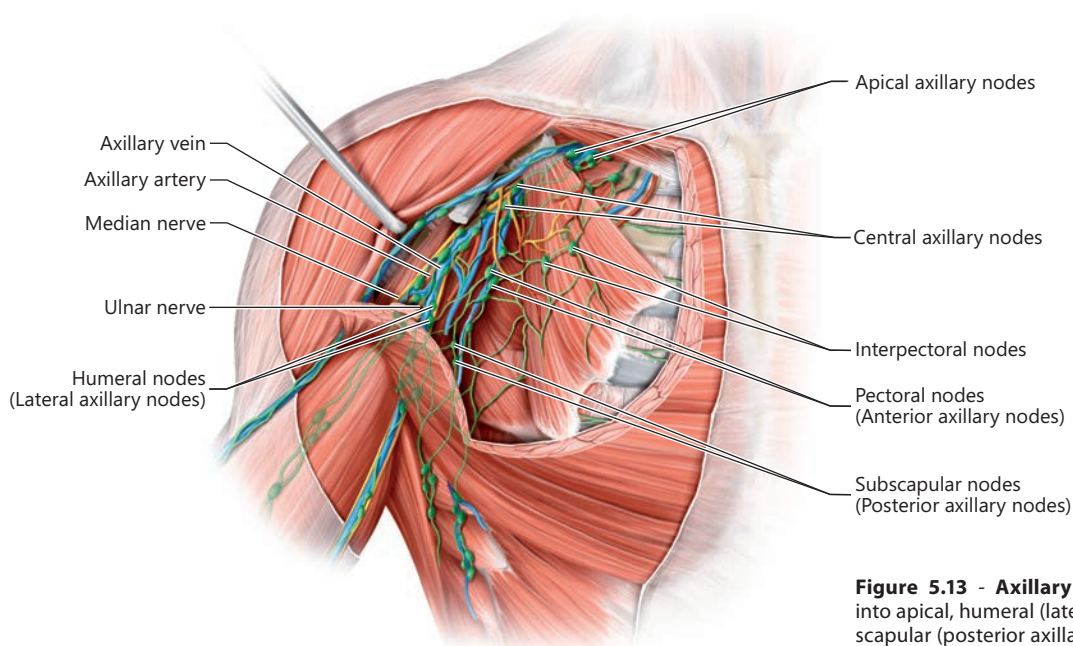
## LYMPH NODES OF THE UPPER LIMB

They are mainly collected in the axillary lymph center. Others are variable and in a lower number, mostly isolated and distributed along the course of the collectors which start from hand, forearm and arm and reach the axillary lymph nodes (see Fig. 5.7).

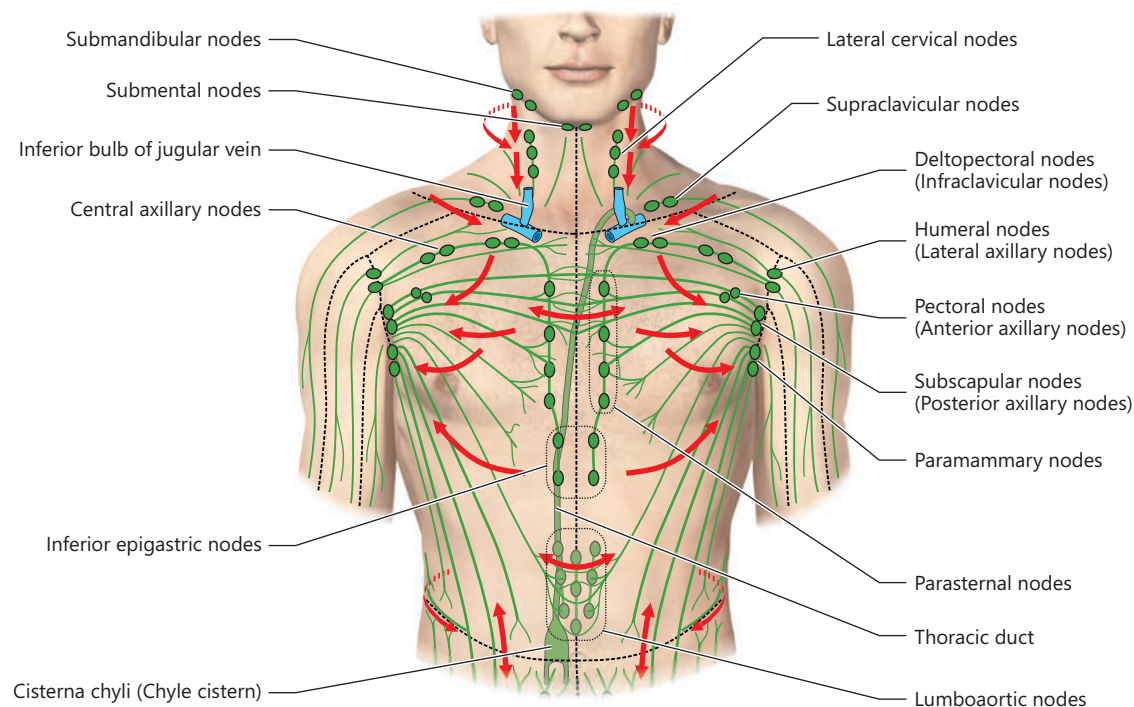
**Lymph nodes of the palm of hand and supratrochlear lymph nodes** (from 1 to 3) have a superficial location and

receive the collectors coming from the last three fingers, the ulnar side of hand and forearm and their efferent collectors are satellites of the basilic vein. They emerge into the brachial lymphatic collectors.

**Radial** (from 1 to 4), **anterior** and **posterior interosseus**, **cubital** (up to 6), **brachial** (from 2 to 6) **lymph nodes**, are situated deeply and are satellites along the deep vessels (see Fig. 5.7).



**Figure 5.13** - **Axillary nodes**, divided into apical, humeral (lateral axillary), subscapular (posterior axillary), pectoral (anterior axillary) and central.

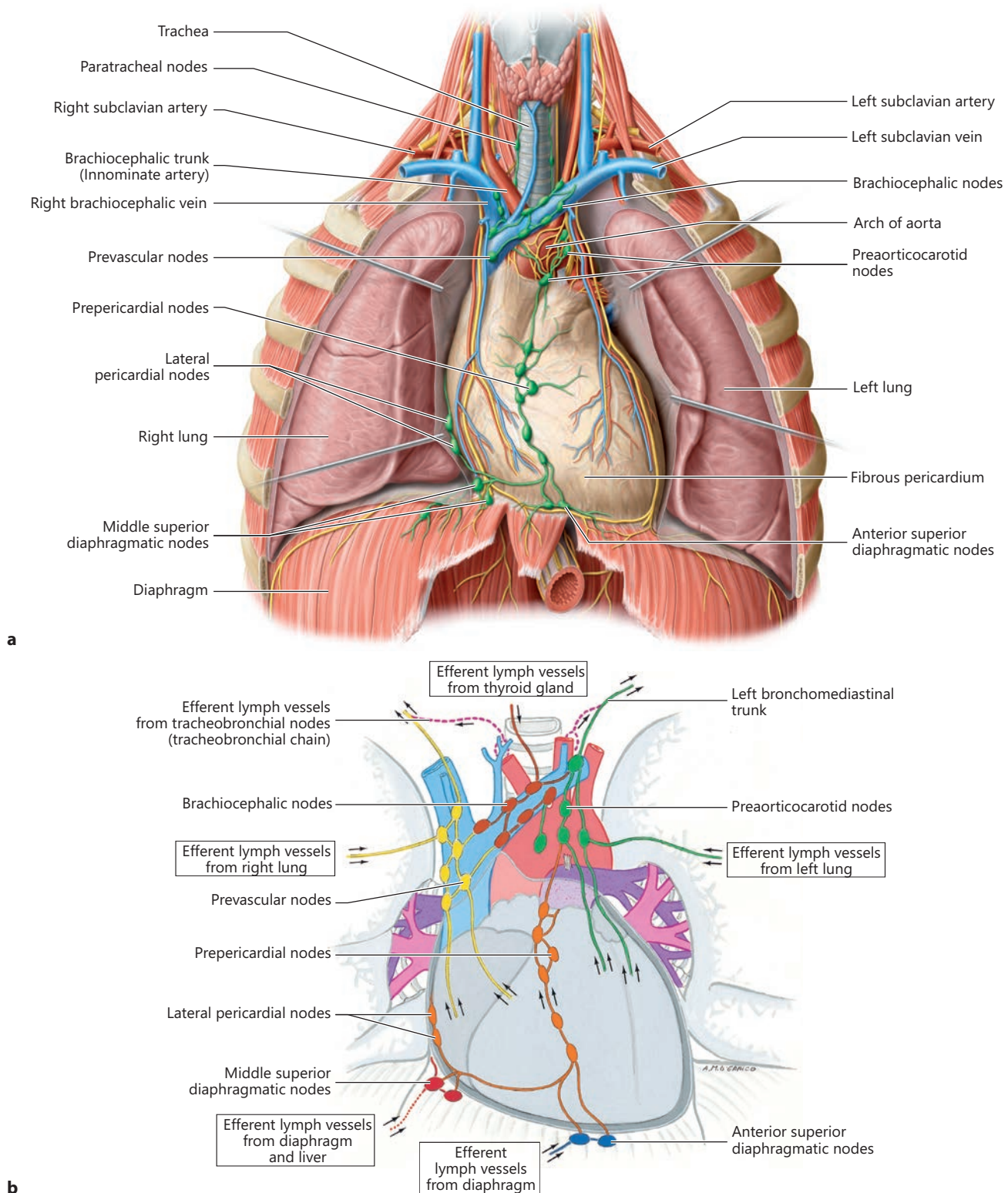


**Figure 5.14** - Main lymph node groups of the axilla and the thoracic wall. Arrows show the direction of lymphatic flow.

**Table 5.4** - Axillary lymph node groups

Group	Site	Afferences	Efferences
Lateral (or humeral nodes)	4-7 lymph nodes connected to the medial and posterior sides of the axillary vein	Almost all the superficial and deep lymphatic collectors of the upper limb	To the axillary lymph nodes of central and apical groups
Anterior (or pectoral/thoracic nodes)	3-6 lymph nodes distributed throughout the medial wall of the axilla, from the second to the sixth intercostal space, leaning against the serratus anterior along the course of the lateral thoracic artery (or external mammary artery)	The majority of the lymphatic collectors coming from the integument and the muscles of the anterolateral wall of the thorax, from the central and lateral regions of the breast, from the skin and the muscles of the supraumbilical region of the abdominal wall	To the axillary lymph nodes of central and apical groups
Posterior (or subscapular nodes)	2-6 lymph nodes distributed in the posterior wall of the axilla along the course of the subscapular artery	It receives lymphatic collectors draining the lymph from the skin and the superficial muscles of the posterior thoracic wall, the scapular region and the posteroinferior part of the neck; it receives some collectors from the upper limb	To the axillary lymph nodes of central and apical groups
Central	3-5 lymph nodes situated in the adipose tissue at the base of the axilla	It receives efferent collectors of other axillary lymph node groups	To the axillary lymph nodes of apical groups
Apical (or subclavicular nodes)	6-12 lymph nodes in the superior wall of the axilla, behind the superior portion of the pectoralis minor, in a medial position respect to the axillary vein	Lymph collected by the other axillary lymph node groups	The subclavian trunk originates from the plexus formed by the efferent collectors of this lymph node group and goes to the jugulo-subclavian venous confluence



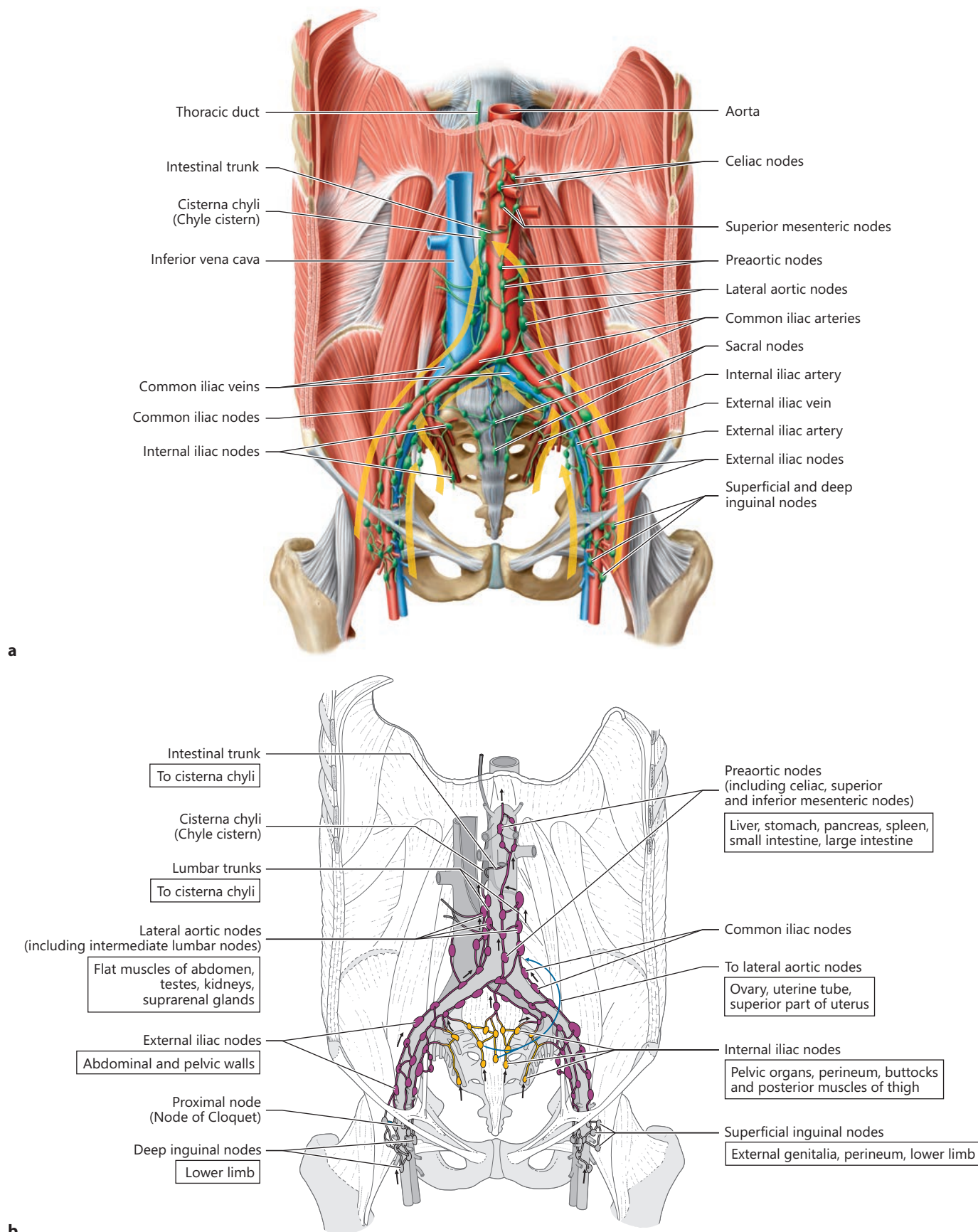


**Figure 5.17 - Lymphatic groups of the mediastinum. a, Anterior view. b, Flow paths of lymphatic drainage. Arrows indicate the direction of lymphatic flow.**

creates the efferent lymphatic vessels which go mainly backwards and emerge into the paratracheal and superior or inferior tracheobronchial nodes, depending on the level (see Fig. 5.18).

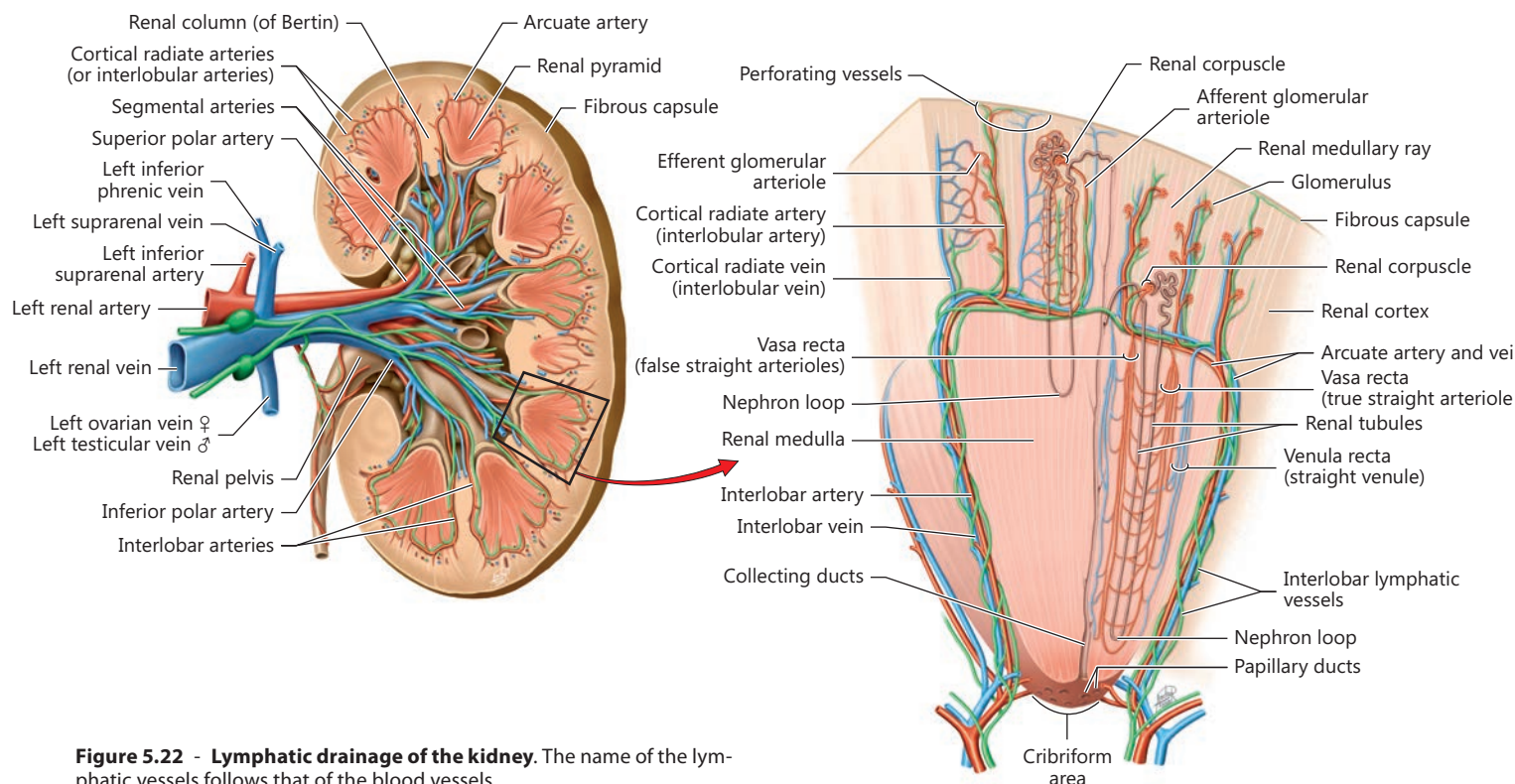
**Lymphatic drainage of lungs and pleurae** - Lymphatic vessels of the **lung** are situated both superficially and in depth into the parenchyma of the organ.

The **superficial lymphatic vessels** form a subpleural net-



**Figure 5.19** - Main lymphatic groups of the abdomen and pelvis. **a**, Anterior view. **b**, Flow paths of lymphatic drainage.





**Figure 5.22 - Lymphatic drainage of the kidney.** The name of the lymphatic vessels follows that of the blood vessels.

us and posterior abdominal wall, directly reach the lateral aortic nodes.

Lymphatic vessels of the majority of the pelvic viscera and anterolateral abdominal wall drain to the lateral aortic lymph nodes passing through the iliac lymph nodes.

Inguinal lymph nodes, which have the lymphatic vessels of the lower limb as afferents, are tributaries of the external iliac lymph nodes, which merge into the common iliac lymph nodes and then into the lateral aortic nodes (see **Fig. 5.19**).

**External iliac nodes** - They are spread out in a number from 6 to 10 along the external iliac vessels, from the femoral ring up to the level of the fifth lumbar vertebra. They are connected to each other via numerous collector vessels and form the **external iliac plexus**. They receive the efferent collectors of the inguinal nodes and the deep collectors from the abdominal and pelvic walls (satellites of the obturator artery, inferior epigastric artery and deep circumflex iliac artery), from organs of genital and urinary systems, from abductor muscles of thigh. The efferent collectors go to the common iliac nodes (see **Fig. 5.19**).

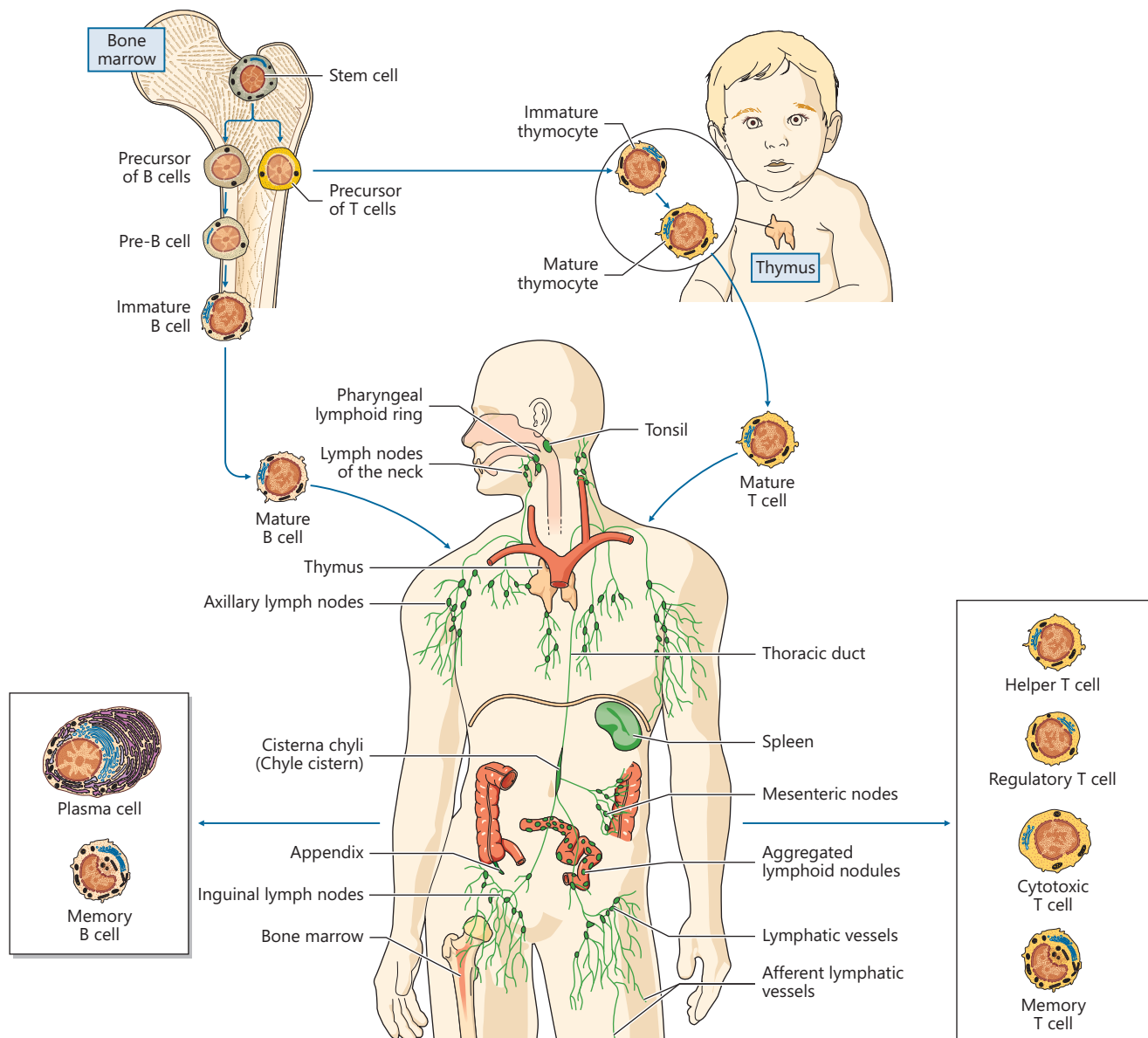
**Internal iliac nodes** - They vary between 10 and 12 and are situated along the course of the **internal iliac vessels**, forming the internal iliac plexus together with the afferent and efferent collectors. They receive lymphatic collectors which reach the plexus following the branches of the internal iliac

artery and come from the urinary pathways (bladder, urethra), genital organs (seminal vesicles, prostate, deferent duct, uterus, vagina), perineum, rectum, pelvic cavity, muscles of the posterior region of thigh and buttock (see **Fig. 5.19**).

**Common iliac nodes** - They are present in a number from 8 to 10 and form, together with their collector vessels, by the promontory of sacrum and along the course of the common iliac vessels, the **common iliac plexus**, which connects external and internal iliac plexuses with the lateral aortic nodes. They receive the afferent collectors from the pelvic viscera (see **Fig. 5.19**).

**Lymphatic drainage of the urinary system** - The general scheme of the lymphatic drainage of the **kidney** is reported in **figure 5.22**. The classification of the lymphatic vessels is the one of the blood vessels. The lymphatic capillaries start in the lobules of the cortical zone, hosted in the different parts of the nephrons. They merge then into the *interlobular lymphatic vessels* directed towards the corticomedullary junction; *arcuated*, along the base of the renal pyramids; *interlobar*, which then converge into the renal sinus, continuing through the renal hilum divided into 4-5 trunks. In parallel to this system of parenchymal drainage, there is a system of superficial subcapsular lymphatic vessels which converge into the renal hilum with the deep lymphatic vessels. They are tributaries of the *lateral aortic nodes*.





**Figure 6.2 - The B and T lymphocytes** derive from **stem cells present in the hematopoietic bone marrow**. The B cells, like the other leukocytes, also mature in the bone marrow and then migrate to the secondary lymphoid organs (in green). The precursors of the T lymphocytes migrate first from the thymus, reaching the secondary lymphoid organs after their intrathymic maturation.

cise vascular and cellular organization. The probability of a correct presentation of the antigen to cells expressing specific receptors for those antigens is also increased by an active re-introduction of the lymphocytes in blood and lymphatic circulation. Therefore, the organization of organs and secondary lymphoid tissues must be considered in a dynamic perspective, with cellular populations in continuous circulation and able to rapidly renew.

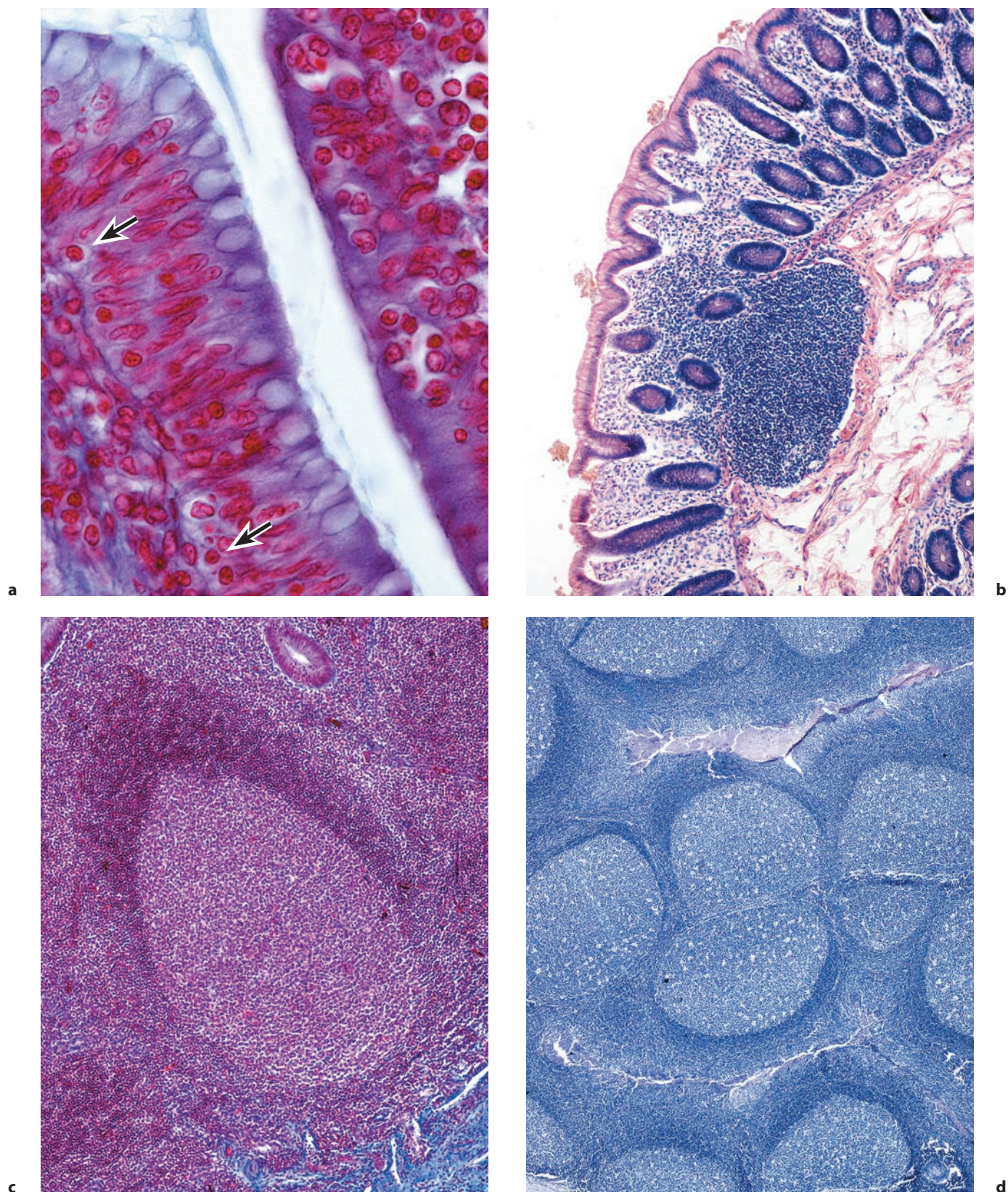
In addition to the **lymphocytes**, representing the main cellular component of the lymphoid tissue, also monocyte-macrophages and other **antigen presenting cells** (APC) belonging to the same lineage (*interdigitated* or *dendritic cells*, *veil cells*) play an essential role in the initiation and pro-

gression of the immune responses. These accessory cells have the ability to actively migrate, carrying out the dual function of transporters and antigen presenting cells.

Mature B and T lymphocytes migrate from the primary organs to distinct areas of the secondary lymphoid tissues, called **B-dependent** and **T-dependent zones** (☞ § *Lymph nodes*).

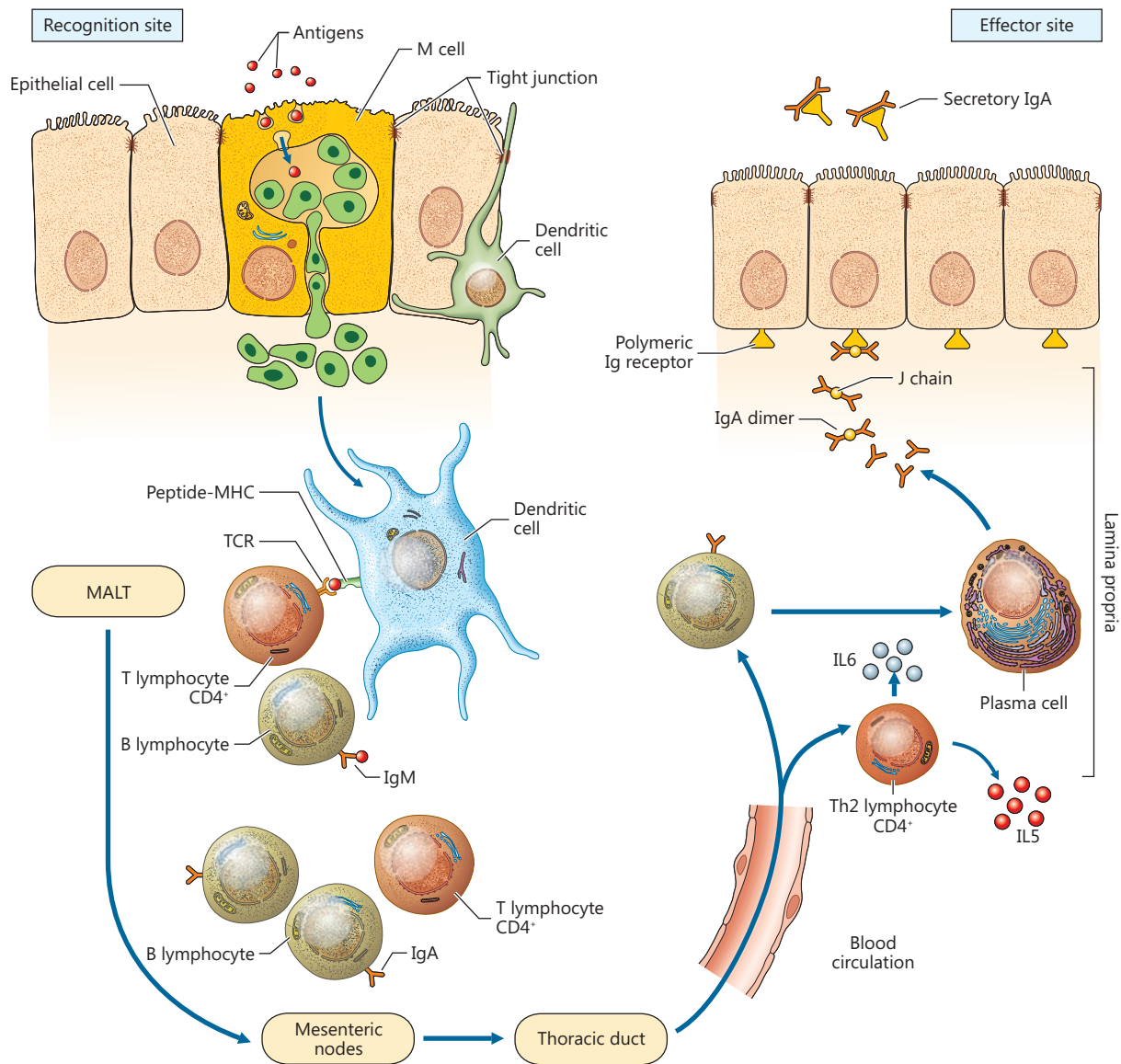
The antigen presentation triggers proliferation, activation and cellular differentiation phenomena leading to the generation of **effector cells** and **memory cells**. The effector cells of the humoral immune responses are the *plasma cells*, deriving from the B lymphocytes and having the ability to secrete antibodies. *T helper* and *T cytotoxic cells* are effector cells of





**Figure 6.30** - The MALT shows different organization levels: single **intraepithelial lymphocytes** (a; arrows indicate the nuclei of the intraepithelial lymphocytes in the mucous membrane of ileum); **lymphoid aggregates** (b; an intensely stained lymphoid aggregate in the lamina propria of the mucous membrane of colon); **isolated lymphoid nodules** (c; in the lamina propria of the mucous membrane of duodenum); **aggregated lymphoid nodules** (d; in a palatine tonsil).





**Figure 6.31** - The MALT can be divided into a recognition site, where there is the recognition of the luminal antigen by the CD4<sup>+</sup> T lymphocytes and virgin or *naïve* B lymphocytes, and an effector site, where these cells activate an immune response.

The antigens present in the lumen of the organ are transported to the mucosa-associated lymphoid tissue (MALT) via the M cells present in the FAE (*Follicle-Associated Epithelium*). The invaginations of the M cells contain one or more lymphocytes and occasional macrophages. The huge amount of B lymphocytes present in the MALT suggests that the B lymphocytes in these sites can act as “semi-professional” antigen presenting cells or modulate the tolerance of the T lymphocytes towards some antigens present in the diet. The FAE hosts also some specialized dendritic cells able to capture and present luminal antigens. The interposition of these cells between the epithelial cells does not alter the integrity of the epithelial barrier, thanks to the presence of *tight junction*.

Antigens that are taken up and processed by the dendritic cells (both the ones in the epithelium and the ones in the lamina propria of the recognition site) are presented to the CD4<sup>+</sup> T lymphocytes. At the same time, antigens coming in contact with virgin B lymphocytes present in the lamina propria induce the formation of germinal centers.

CD4<sup>+</sup> T lymphocytes and B lymphocytes specific for the same antigen migrate through efferent lymphatic vessels, regional lymph nodes, thoracic duct and circulatory blood stream, reaching effector sites. The final maturation of the B lymphocytes into plasma cells secreting IgA will occur in these sites, thanks to the secretion of cytokines (for example interleukin 5, IL5, and interleukin 6, IL6) by the T *helper* 2 lymphocytes (Th2).

The IgA are endocytosed by the epithelial cells thanks to a receptor (a secretory component or transport component) and secreted into the luminal side via a process called transcytosis. The production of the *Vasoactive Intestinal Peptide* (VIP) in the intestine by the epithelial cells promotes the synthesis of the secretory component, modulating the secretion efficiency of the IgA in the lumen of the organ.

and in particular in the ileum) and in the NALT (*Nasopharynx-Associated Lymphoid Tissue*), in particular at the bottom of the *tonsillar crypt*).

The M cells pick up antigens and pathogens, even the

multicellular ones (as the parasite larvae), from the lumen of the organ and transfer them to the deep cytoplasmic pockets, favoring their recognition by the lymphocytes hosted in them (see Fig. 6.31 and [M cells](#)).



(submandibular and sublingual parotid), *adnexa of the mouth*; liver and pancreas, *adnexa of the duodenum*.

The digestive system communicates with the external environment thanks to its two extremities (cephalic and caudal extremity) through the **oral fissure** and the **anus**, respectively. The organization of the digestive system is shown in **figure 7.1**.

From a **topographical point of view**, the alimentary canal occupies different parts of the body, such as head, neck and all the portions of the trunk (thorax, abdomen, pelvis and perineum).

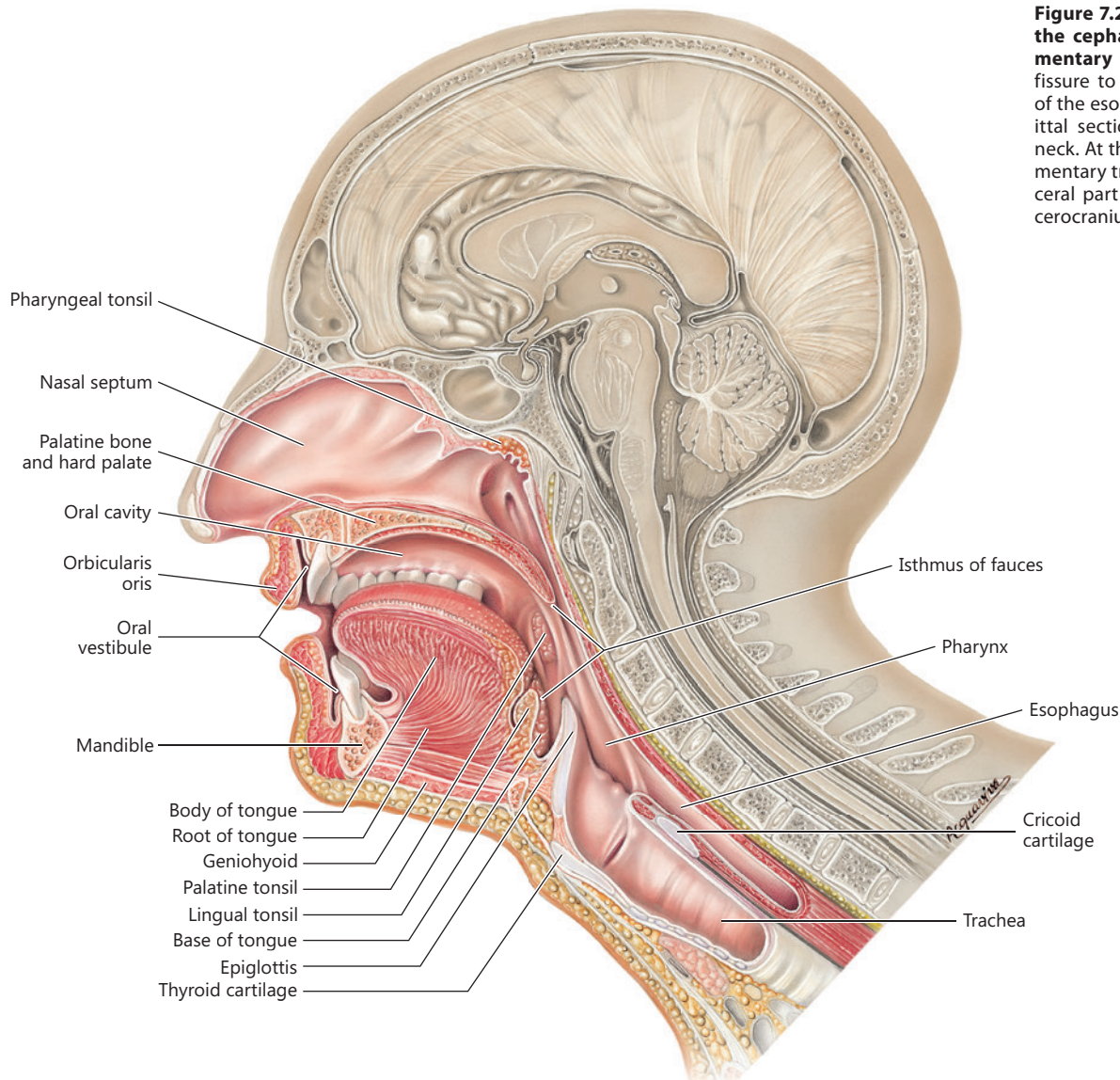
The *head* contains mouth, isthmus of fauces and part of the pharynx, the *neck* contains part of the pharynx and of the esophagus, the *thorax* contains part of the esophagus, the *abdomen* contains part of the esophagus, the stomach, the small intestine and most of the colon, the *pelvis* contains part of the colon and the rectum. This latter one traverses the perineum and opens to the external environment with the anus.

The organs of the digestive system present in the abdominal cavity, excluded pancreas and duodenum, are completely coated by tunica serosa called **peritoneum** (➔ § *Peritoneum*).

## MOUTH

The *mouth* must not be considered as a simple cavity, as it appears at a first sight (*oral cavity*), but as a real and complex system of organs developing from the initial tract of the ali-

mentary canal (**Fig. 7.2**). Indeed, the mouth includes organs exerting an essential role in the mastication process, the **teeth**; for speech articulation, the **tongue**, which is also es-



**Figure 7.2 - Organization of the cephalic part of the alimentary canal**, from the oral fissure to the cervical portion of the esophagus. Median sagittal section of the head and neck. At the head level, the alimentary tract occupies the visceral part of the cranium (viscerocranium).

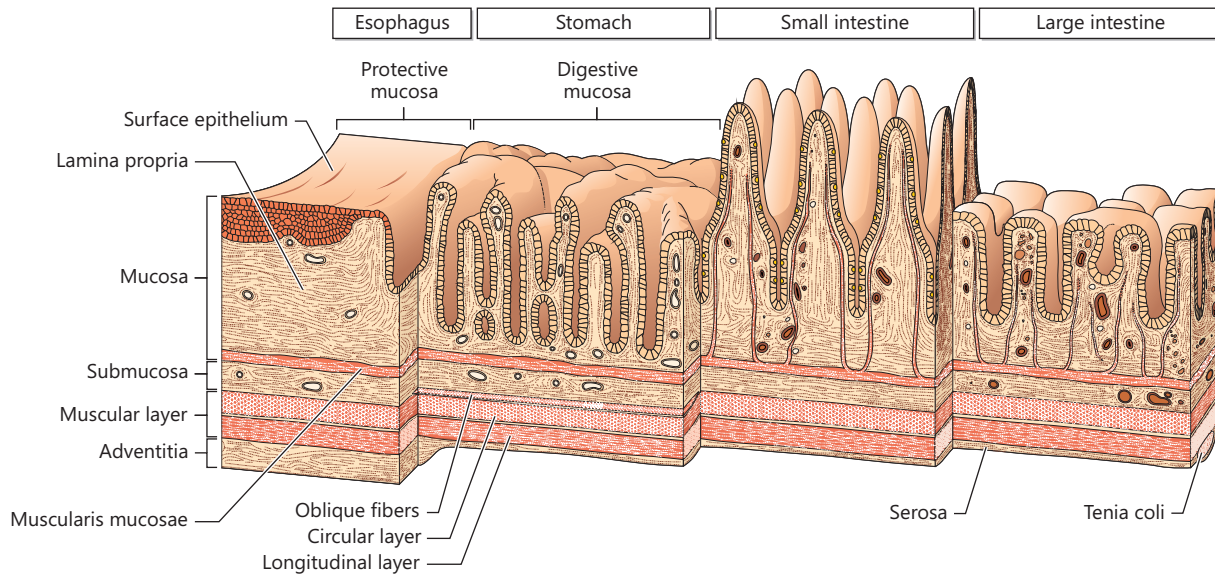


Figure 7.86 - Microscopic morphology from the esophagus to the large intestine.

### Submucosa

It is formed by loose connective tissue (see Fig. 7.87). It hosts branched tubular **esophageal mucous glands**. They are glands presenting a remarkable similarity with the salivary glands present in the oral cavity and produce a substance which protects the mucous membrane.

### Muscular layer

It is formed by striated muscle fibers in the cranial third of the organ and by smooth muscle cells in the remaining two thirds. The striated muscle is a continuation of the striated muscle of pharynx and is therefore a voluntary musculature.

As the involuntary smooth musculature present in the two distal thirds, it is organized into an internal layer presenting a circular organization of the fiber bundles and an external layer in which the fiber bundles are organized longitudinally (see Fig. 7.83).

### Adventitia

It is formed by connective tissue presenting a rich amount of elastic fibers.

### Serosa

It is situated in the abdominal part of the esophagus, where the anterior and the lateral wall are coated by peritoneum.

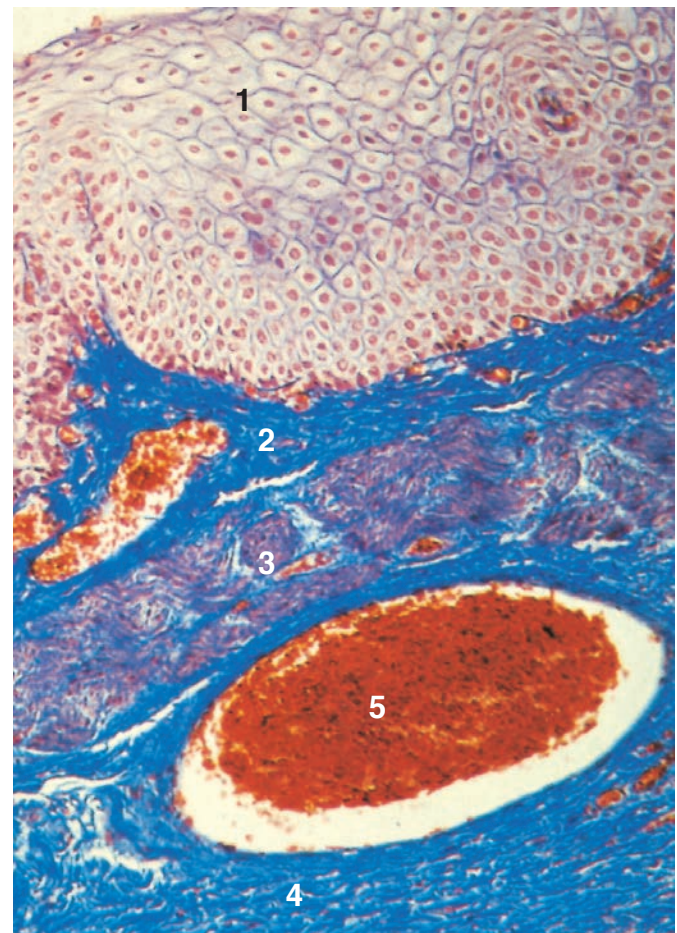
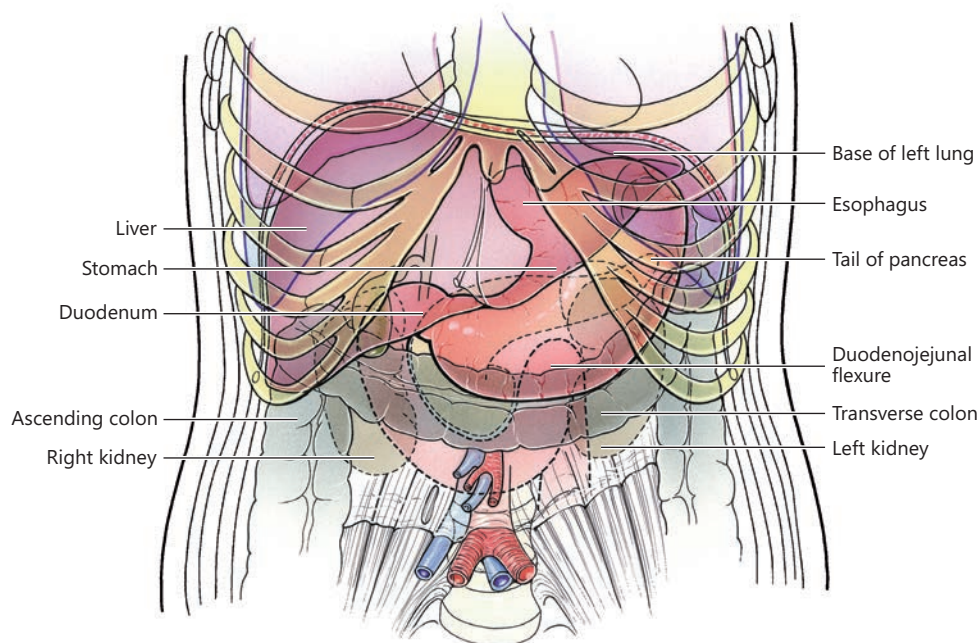


Figure 7.87 - Structure of the mucosa of esophagus. 1, Epithelium; 2, lamina propria; 3, muscularis mucosae; 4, submucosa; 5, venous vessel (from *Medicina e Salute*, Edi.Ermes).



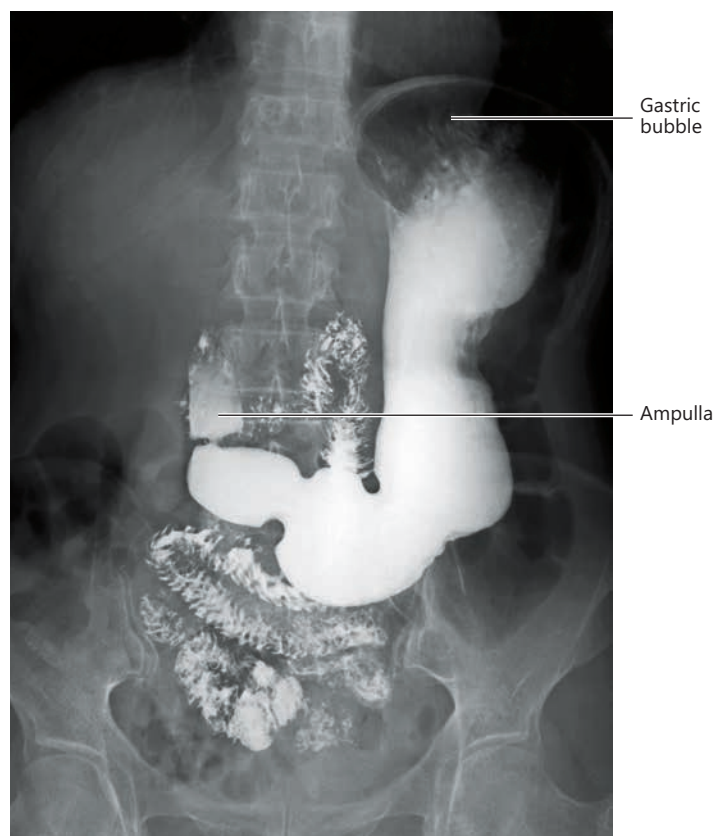


**Figure 7.89 - Position and relations of the stomach.** The figure highlights the relations of the anterior surface of the stomach with the thoracic cage and liver. The relations of the stomach with the pancreas, the left kidney and the transverse colon are also shown in transparency.

## RADIOLOGICAL ANATOMY OF THE STOMACH

The radiological observation of the stomach (**figure**) allows distinguishing three main areas with a different anatomo-functional meaning: a *superior part*, corresponding to the **fundus of the stomach**, usually occupied by gas (**gastric bubble**), whose presence exerts at the same time a regulatory function for the intra-gastric pressure and a restraint function, impeding the reflux from the stomach into the esophagus; a *middle part*, corresponding to the **body of the stomach**, characterized by a peristaltic activity, with a conveyor function in the direction of the pyloric antrum and of the pyloric canal; an *antropyloric part*, corresponding to the **pyloric part of the stomach**, which has an evacuator function in the direction of the duodenum and is characterized by concentric contractions of the musculature with a temporary formation of the preantral functional sphincter, impeding the reflux of the content (chyme) into the body of stomach during the phase of expulsion. The **pyloric orifice** is radiologically visible only during the emptying phases of the organ, appearing as a thin and short opaque tract connecting the stomach to the duodenum (see **figure**); when the pylorus is closed, the stomach has a dead-end, separated from the superior part of the duodenum (**ampulla**) via a radiotransparent septum corresponding to the endoluminal protrusion of the pyloric sphincter.

**Radiography of stomach and small intestine after oral administration of contrast medium (barium).** The stomach, as also the superior part of the duodenum (duodenal bulb) appears evenly filled by the contrast medium. On the contrary, the radiological image of the small intestine shows flaky opacity for the presence of circular folds causing numerous interruptions of the opaque column. The fundus of stomach is not occupied by the contrast medium because of the presence of the gastric bubble.





part is marked by an oblique line which reaches the greater curvature from the angular incisure (see Figs. 7.88 and 7.98).

**Pyloric part** - It presents a conical shape and is directed upward and to the right side; in normotypes, it forms an angle of about 90° with the body, creating a notch on the lesser curvature, called **angular incisure**. The *pyloric part* can be in turn divided into two portions which are sometimes divided by a sulcus. The proximal portion is called **pyloric antrum** and is slightly dilated, forming the small tuberosity. The distal portion is formed by a cylindrical canal about 3 cm long (**pyloric canal**) (see Fig. 7.102) which ends with the **pylorus** (see Fig. 7.98). It heads to the right, upward and backward and is separated from the duodenum by the **pyloric sulcus**.

### Relations

The stomach is almost completely lined by peritoneum and forms relations with numerous organs.

The **fundus of the stomach** touches the dome of diaphragm. Considering this relationship, it is easy to understand how the stomach modifies its position during the respiratory movements. During exhalation, it moves upward and reaches the level of the fifth rib on the midclavicular line. It forms relationships with pericardium, heart, pleura and the base of the left lung via to the diaphragm (see Fig. 7.89). It is covered on the front and medial parts by the left lobe of liver. For this reason, only one part of the stomach is visible when opening of the abdominal cavity, corresponding to the pyloric part and the inferior portion of the body, since the biggest part of the organ is hosted deeply into the diaphragmatic concavity and is covered on the front part by the left costal arch and by the liver.

The **anterior wall** is in relationship with the anterior thoracic wall and with the anterior abdominal wall. It is covered

on the right side by the left lobe of liver, whereas it is in relationship on the left side with the diaphragm and with the transversus abdominis (Fig. 7.90 a).

The *thoracic part* of the anterior wall of stomach corresponds to an area called **Traube's semilunar space**, for its lunate shape with the convexity facing upward and to the left. This space is delimited inferiorly by the left costal arch, between the sixth and the ninth rib; it corresponds superiorly to the left sixth rib; laterally, its limit is marked by a vertical line descending from the left sixth rib to the left ninth rib, a few centimeter externally with respect to the midclavicular line (Fig. 7.91). Traube's semilunar space presents a semiological importance, since it corresponds to the *gastric bubble*, which can be examined via percussion and auscultation.

The *inferior (abdominal) portion* of the stomach includes the inferior third of the *body of stomach* and the *pyloric part* and is situated in the epigastrium, being in this way accessible to palpation. It is covered at the top and for a short extension by the liver and is in direct contact with the anterior abdominal wall via a triangular projection area (**Labbé triangle**), delimited at the bottom by a horizontal line touching the inferior margin of the ninth costal cartilage (transpyloric line), on the left side by the costal arch and on the right side by the inferior (or anterior) margin of the liver (see Fig. 7.91). The extension of this area varies with the orientation of the major axis of the stomach and with the filling state of the organ, in addition to depend on the sizes of the left lobe of liver.

The **posterior wall** is in relationship with diaphragm, spleen, left adrenal gland and left kidney, pancreas and transverse colon. Thanks to the interposition of the transverse mesocolon, it forms relationships also with the ascending part or distal portion of the duodenum, with the duodenojejunal flexure and with the jejunal loops (see Fig. 7.90 b).

The **lesser curvature** is covered by the left lobe of liver

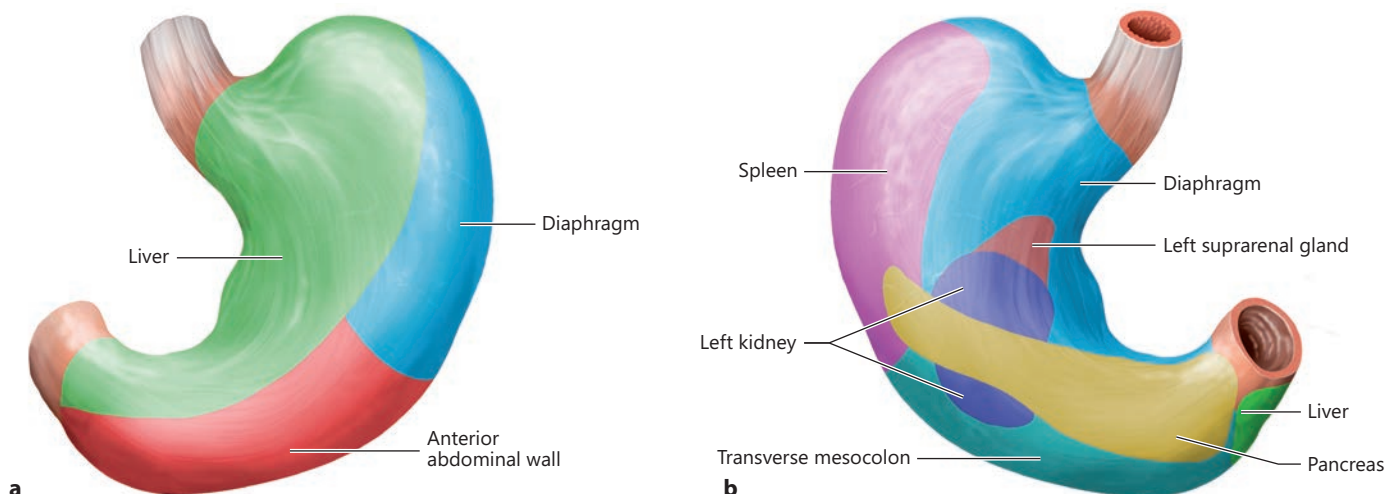
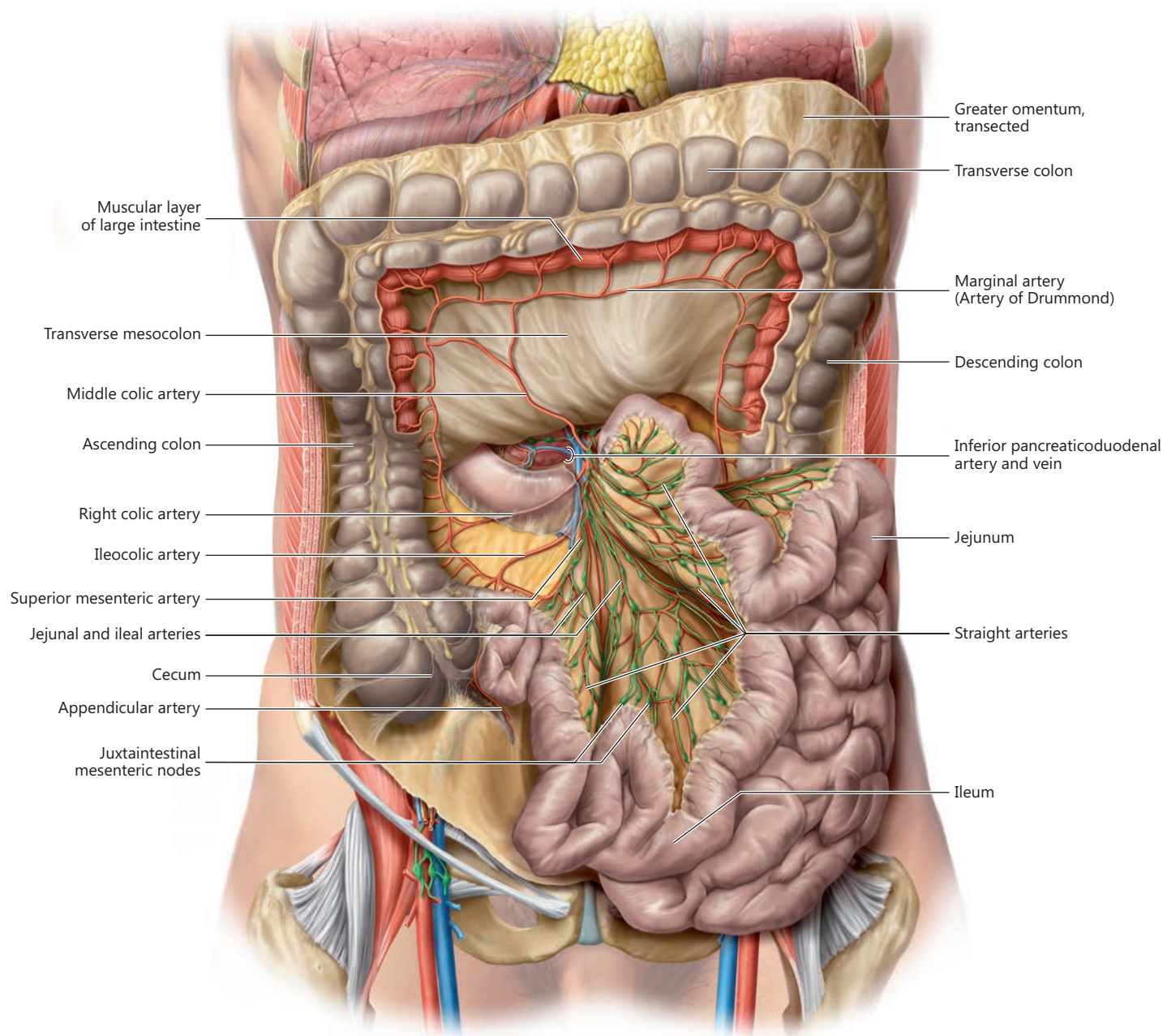


Figure 7.90 - Relations of the anterior (a) and posterior (b) walls of the stomach.



**Figure 7.138** - Distribution of the **lymphatic vessels** and **lymph nodes** within the **mesentery**.

way for lipid absorption, particularly of the triglycerides, which form most of the chylomicrons. On the contrary, hydrosoluble substances deriving by the digestion of sugar and protein (monosaccharides and amino acids) follow the hematic pathway (blood capillaries, postcapillary venules, axial venules of the villi).

**Nerves** - The small intestine receives visceral effector parasympathetic nerve fibers from the vagus nerve and visceral effector sympathetic nerve fibers from the thoracic segments or neuromeres of the spinal cord, from the fifth to the eight.

Two contingents of fibers initially converge into a voluminous prevertebral formation situated in front of the aorta, in the tract included between the celiac trunk and the superior mesenteric artery, called **celiac plexus** (Fig. 7.139). The efferences of the celiac plexus follow as perivascular branches the course of the arteries which originate from the abdominal aorta, forming the same number of plexuses, among which the **superior mesenteric plexus**. The nerve fibers are associated to a remarkable number of neurons, both isolated and collected into small ganglia, such as the **celiac ganglia** and the **superior mesenteric ganglion**. Fibers originating from

The wide intestinal surface causes a remarkable contact with the external substances and therefore the small intestine must be also considered an essential organ in the processes of **immune defense**. However, the absorption function is much more complex than a simple transport through the membrane. The different substances are transported into the enterocytes both in molecular form and via micropinocytosis. Then, these substances accumulate in the vesicles situated in

the apical portions of the enterocytes. The metabolic transformations of the absorbed substances occur into these vesicles. In particular, among them there is the synthesis of triglycerides starting from the fatty acids and the monoglycerides absorbed by the alimentary canal. These smooth vesicles open into the intercellular space, where the triglycerides are released in form of lipid droplets coated by a protein sheath, called **chylomicrons**.

## LARGE INTESTINE

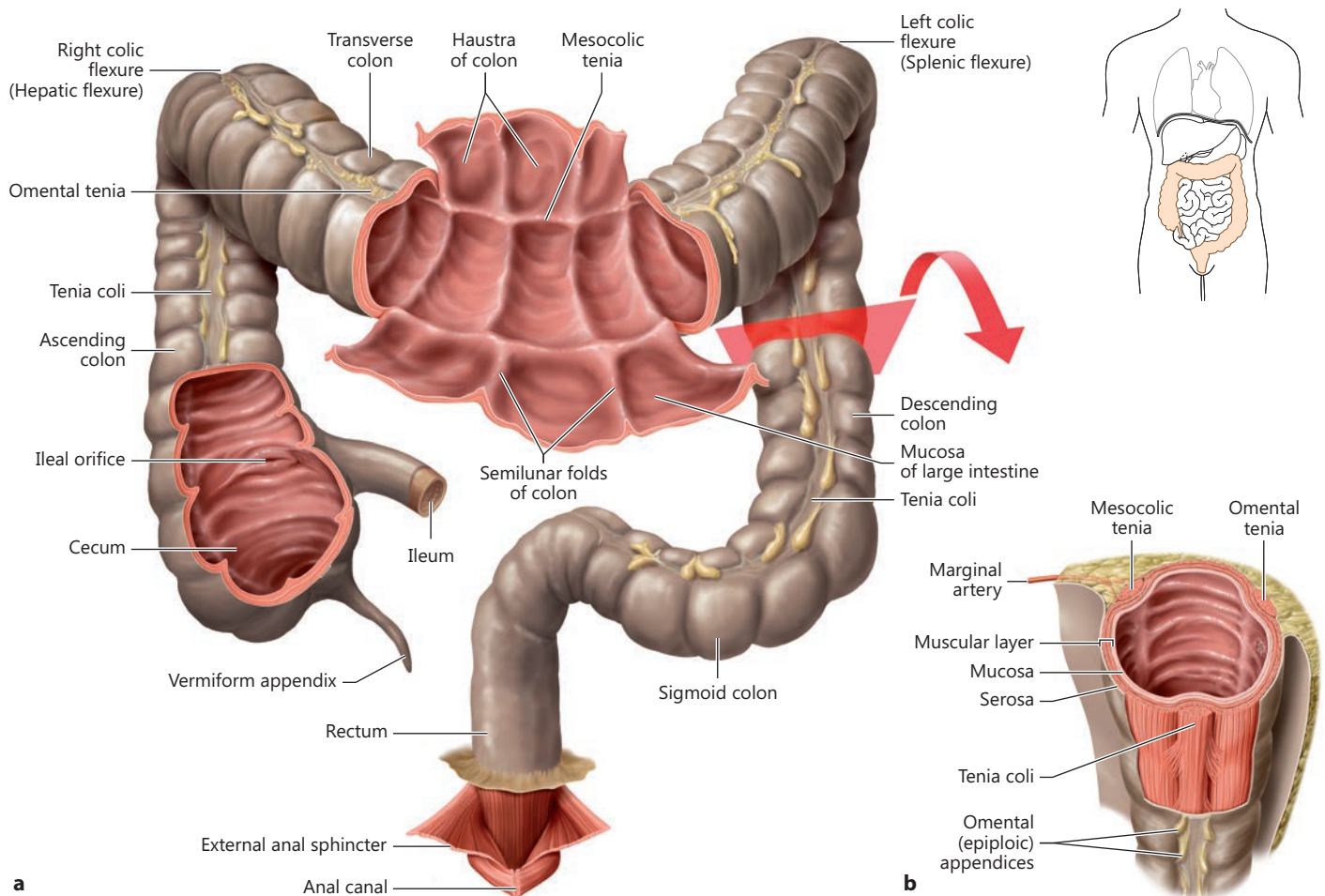
It is the portion of the digestive tract situated after the ileum, ending with the anus (see Fig. 7.129). The name derives from the Latin *crassus*, which means “thick”.

The large intestine can be divided into three portions: *cecum*, *colon* and *rectum* (Fig. 7.153 a).

The **cecum**, connected to the *vermiform appendix*, is situated in the right iliac fossa.

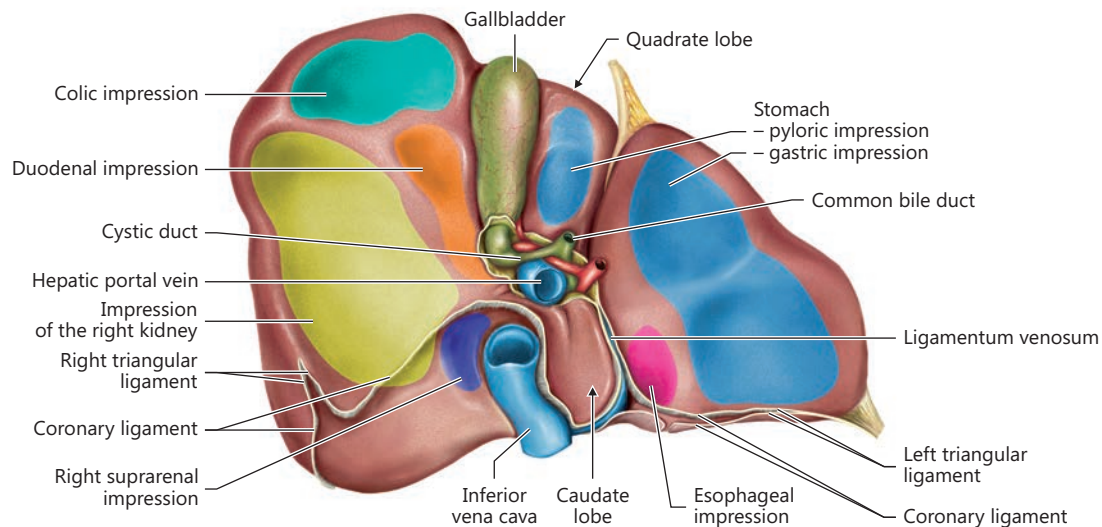
The **ascending colon** follows the cecum and heads upward, reaches the inferior surface of the liver in the right hypochondrium and then curves to the left, forming the *right colic* or *hepatic flexure*.

The following tract is called **transverse colon**, which, once it reaches the inferior pole of spleen in the left hypochondrium, curves downward at the level of the *left colic* or



**Figure 7.153 - Large intestine:** internal and external conformation. **a**, The large intestine extends between the terminal loop of the ileum and the anal canal. **b**, Detail showing the characteristic conformation of the organ, divided into haustra and crossed by the teniae.



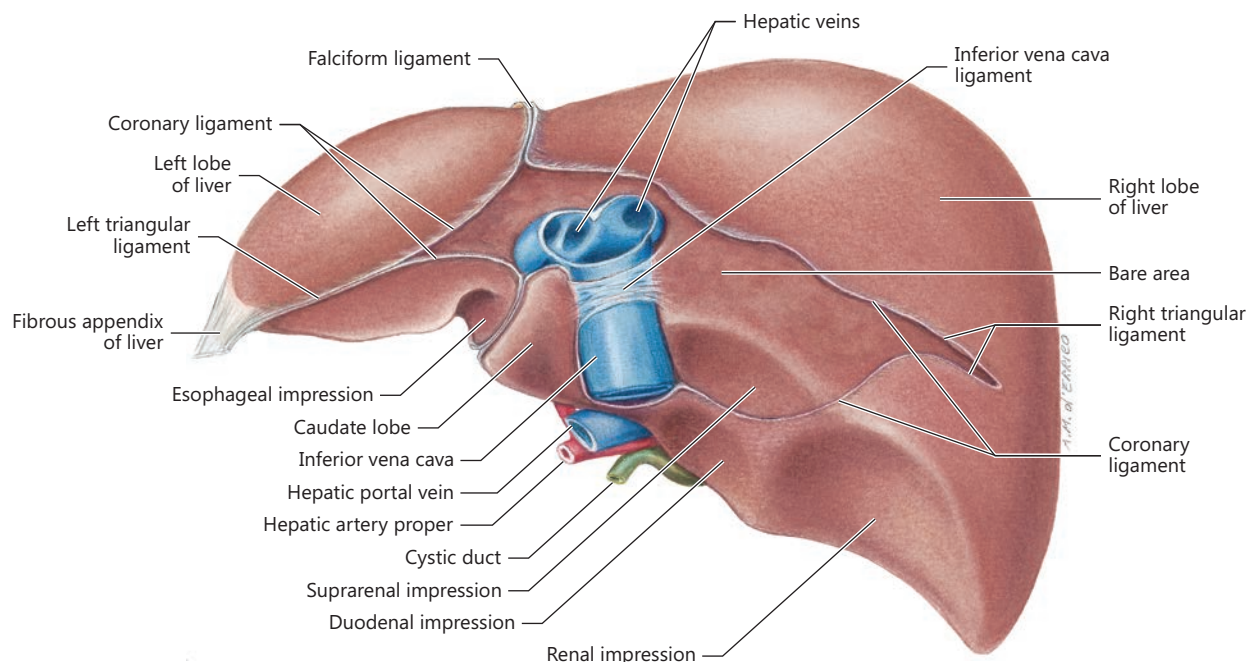


**Figure 7.193 - Impressions of the visceral surface of the liver.** The visceral surface of the right lobe of the liver is marked by a number of impressions, formed by related underlying organs: anteriorly, the **colic impression**, formed by contact with the right colic flexure; posteriorly, the **renal** and **suprarenal impressions**, formed by the right kidney and the right suprarenal gland, as well as the **duodenal impression**, formed by contact with the supramesocolic tract of the descending part of the duodenum. The **gastric impression** is caused by the relation with the lesser curvature and part of the anterior surface of the stomach on the visceral surface of the left lobe of the liver, while the relation with the abdominal part of the esophagus causes the **esophageal impression**. The quadrate lobe has a depression on its surface, the **pyloric impression**, caused by the relation with the anterior surface of the pyloric part of the stomach.

and is situated more in proximity to the posterior margin than to the anterior margin, with a length measuring 6-7 cm and a width measuring about 1 cm. It hosts the structures of the hepatic pedicle: from the front to the back, the right and left hepatic ducts, the lymphatic vessels of the liver and the

nervous branches of the hepatic plexus and of the biliary plexus, the division branches of the hepatic artery proper and of the hepatic portal vein.

Overall, the sagittal and the transverse fissure of liver delimit four lobes: the *right* and *left lobes*, on the right side and



**Figure 7.194 - Obtuse posterior border of the liver.** The visceral peritoneum reflects onto the diaphragmatic and posterior parietal peritoneum, leaving (on this surface) a large rhomboidal area devoid of serous covering (**bare area**). The inferior vena cava, which receives the hepatic veins, is found at the center of this area. At the lateral angles of the bare area, the superior visceral peritoneum adheres to the inferior layer, hence forming the left and right triangular ligaments.

The **hepatogastric ligament** is situated between the porta hepatis and the lesser curvature of the stomach. It is formed by two peritoneal layers leaning against each other, between which lymphatic vessels and hepatic and anterior gastric branches of the anterior vagal trunk of the vagus nerve, known as gastrohepatic nerve, run.

The **hepatoduodenal ligament** is situated between the porta hepatis and the superior border of the superior (intra-peritoneal part) of the duodenum. It is also formed by two peritoneal layers, between which there are elements of the hepatic pedicle. Indeed, it contains the hepatic artery proper, the hepatic portal vein, the extrahepatic bile ducts, the lymphatic vessels and the nerves for the liver.

Overall, the lesser omentum participates to the formation of the omental bursa or lesser sac. In particular, the hepatogastric ligament forms the anterior wall of the vestibule of omental bursa. Moreover, the right border of the hepatoduodenal ligament delimits anteriorly the *omental foramen* (of Winslow) (see **Fig. 7.198**), which represents the access to the omental bursa. Sometimes, the right border of the hepatoduodenal ligament can extend inferiorly, reaching the gallbladder, the duodenum and the transverse colon, forming the so-called **cholecysto-duodeno-colic ligament**.

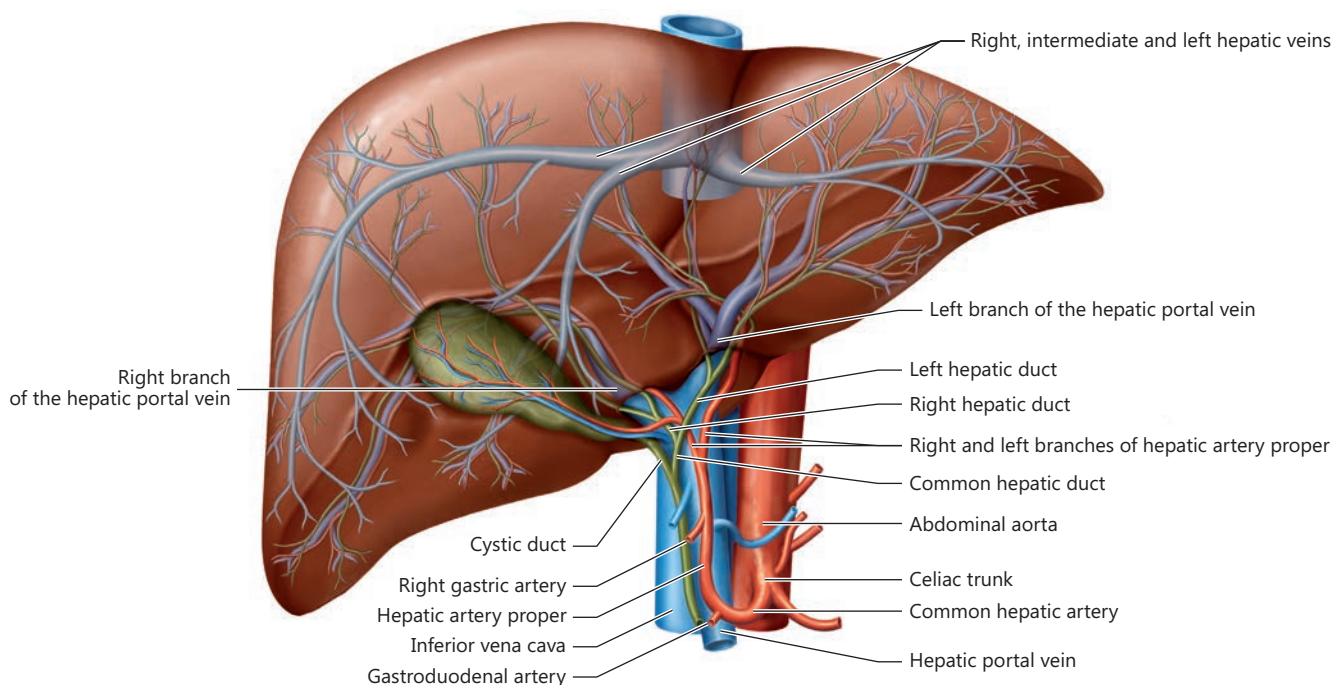
## VESSELS AND NERVES

The liver receives blood from two large afferent vessels (the *hepatic portal vein* and the *hepatic artery proper*) and has one single efferent system (the *hepatic veins*), which brings

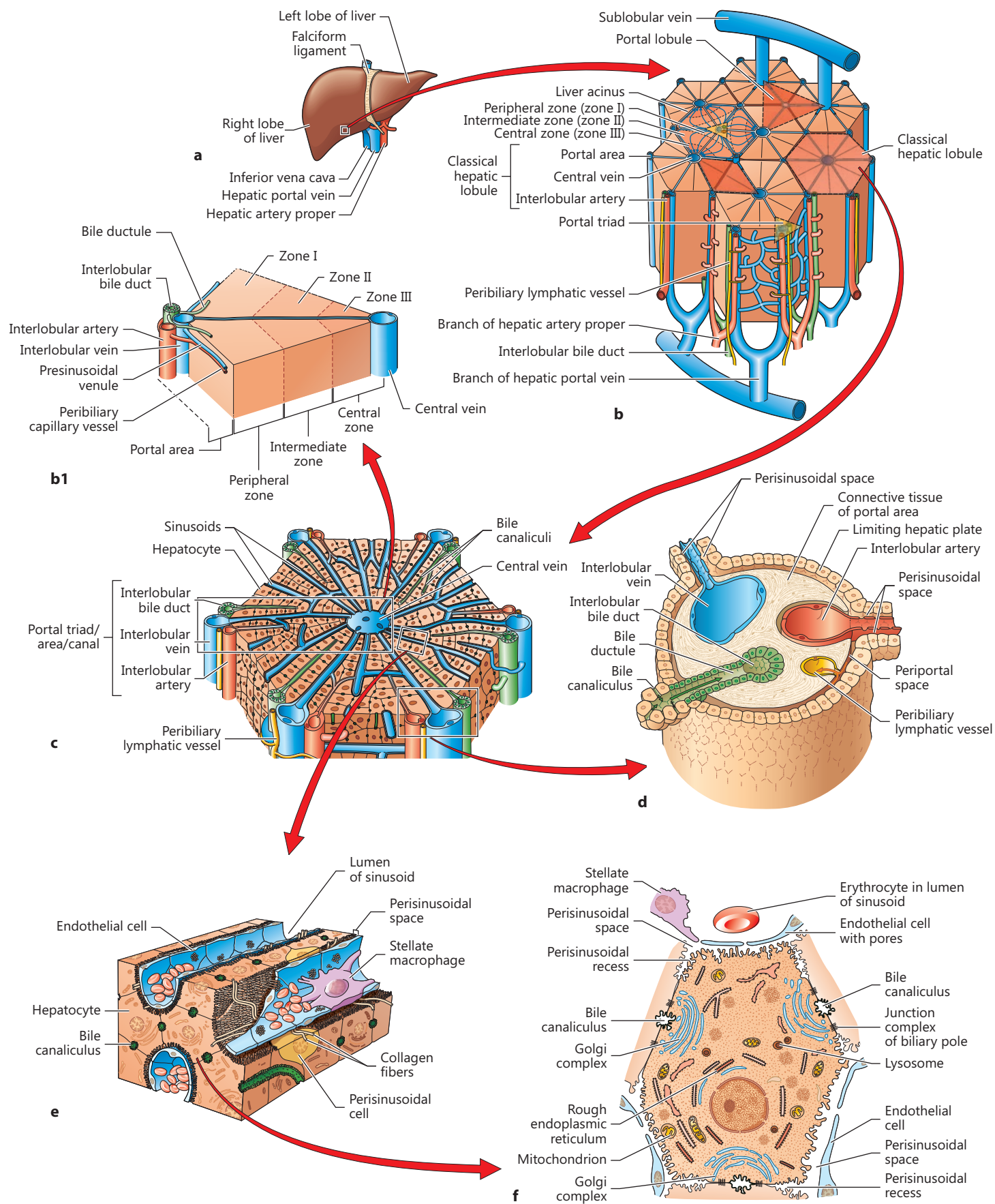
the blood into the inferior vena cava. The porta hepatis is the site through which the hepatic vena porta and the hepatic artery proper enter the liver (see **Fig. 7.196**); on the contrary, the hepatic veins leave the liver in correspondence to its posterior border, emerging into the inferior vena cava. The hepatic portal vein and the hepatic artery proper are contained in the hepatic pedicle together with the extrahepatic bile ducts, the lymphatic vessels and the lymphatic nerves. The elements of the hepatic pedicle are contained between the layers of the hepatoduodenal ligament and present a typical organization: the hepatic portal vein is situated posteriorly, the hepatic artery proper is situated anteriorly and medially (on the left side) (see **Fig. 7.103**); lastly, the extrahepatic bile duct (common hepatic duct and common bile duct) are situated anteriorly and laterally (on the right side).

**Hepatic artery proper** - It is the continuation of the common hepatic artery or gastrohepatic artery after the latter gives rise to the gastroduodenal artery. The common hepatic artery originates from the celiac trunk and runs from the back to the front and from the left to the right, providing for the right gastric artery as collateral branch, in addition to the gastroduodenal artery. Proceeding as hepatic artery proper, it is part of the structure of the hepatic pedicle. At the level of the porta hepatis, it bifurcates into a *right branch* and a *left branch*, anteriorly to the division branches of the hepatic portal vein (**Fig. 7.199**).

The right branch of the hepatic artery (or right hepatic artery) presents a larger caliber and in most of the cases gives



**Figure 7.199 - Vascularization of the liver.** The afferent vessels, the **hepatic portal vein** and the **hepatic artery proper**, and the efferent vessels, the **hepatic veins**, with their branches, are illustrated.

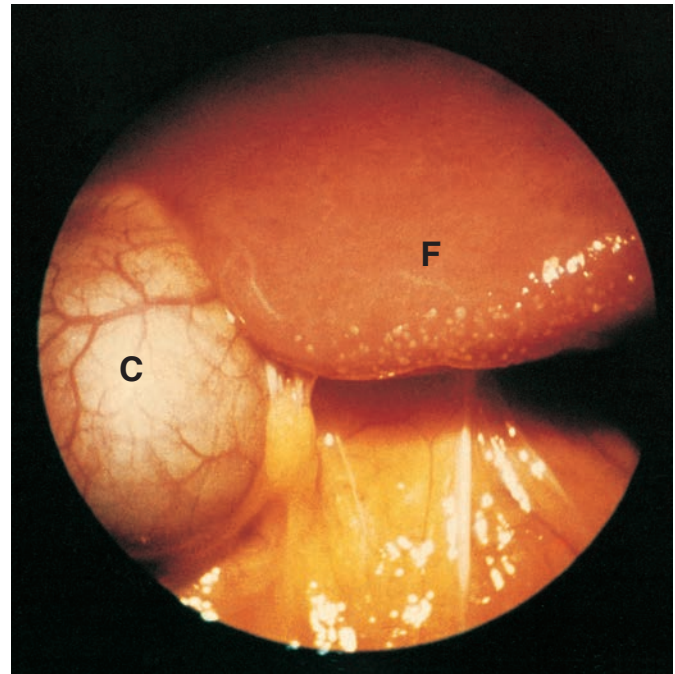




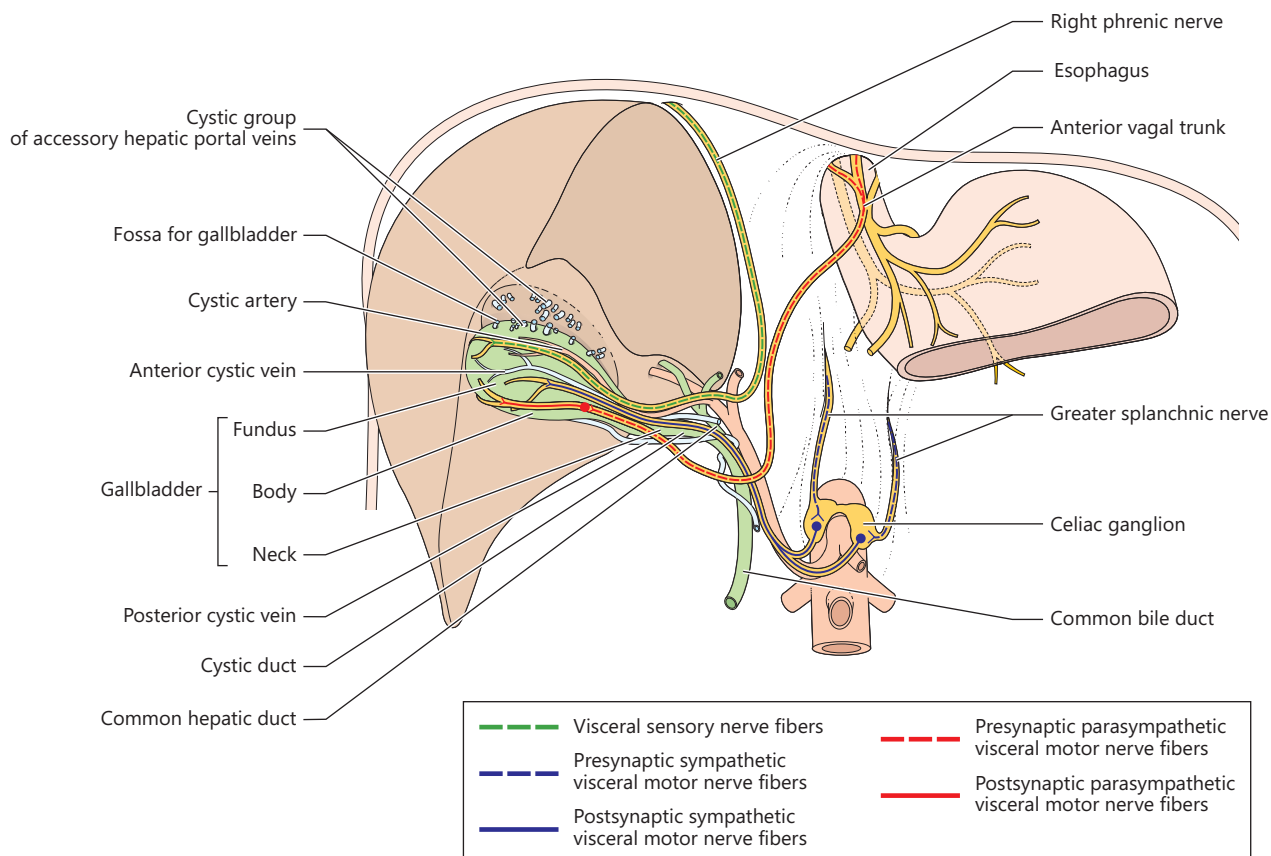
and to which it is connected by series of vessels which run from the wall of the gallbladder directly to the liver, forming the *cystic group of accessory hepatic portal veins* (Fig. 7.231). The visceral peritoneum lines the inferior surface of the body, which is in relationship with the anterior surface of the descending part of the duodenum, with the transverse colon and in some cases also with the anterior surface of the pyloric canal. It is possible to find at this level a peritoneal fold which connects the gallbladder to the duodenum and to the right colic flexure (*cholecysto-duodeno-colic ligament*).

The **infundibulum of the gallbladder** is the tapered portion of the body, which continues with the neck of gallbladder.

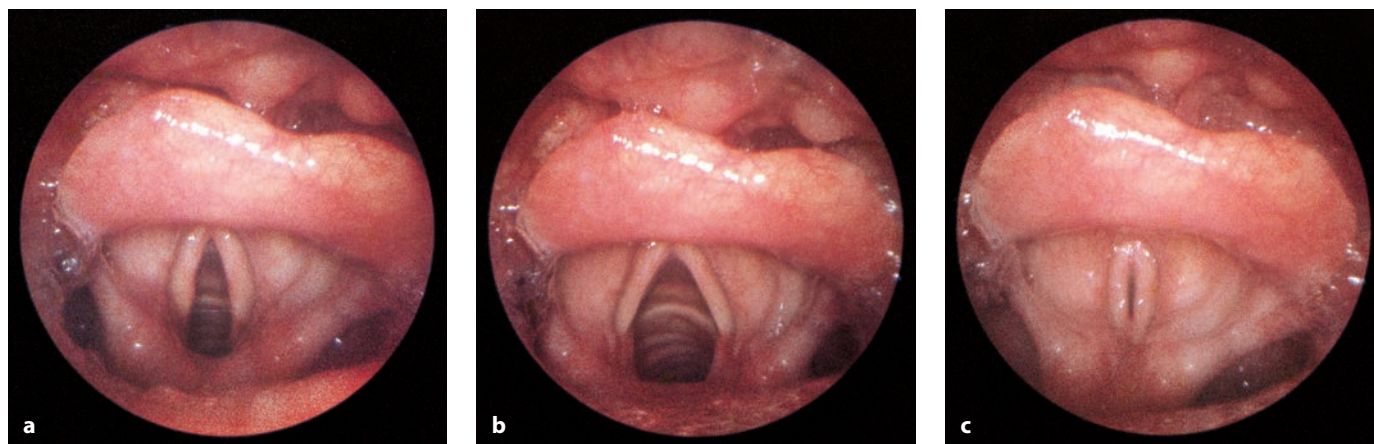
The **neck of the gallbladder** presents a sinuous course with an italic S-shape, rather enlarged, which ends continuing with the cystic duct (see Fig. 7.226); it is in relationship medially and on the left side with elements of the hepatic pedicle and inferoposteriorly with the superior part of the duodenum. The neck of the gallbladder forms an acute angle opened forward, where mostly the *cystic lymph node* is present. The external surface of the neck of the gallbladder appears protruding to the right side and depressed on the left side. The protruding part of the gallbladder corresponds to an ampullary cavity or bowl; on the contrary, the depression corresponds to an elevation or promontory. With respect to the cavity of the body of the gallbladder, the cavity is delim-



**Figure 7.230 - Gallbladder.** Laparoscopic image highlighting the fundus and body. Numerous branch vessels run into the subserosa. C, gallbladder; F, liver (inferior margin) (from *Medicina e Salute*, Edi.Ermes).



**Figure 7.231 - Vascularization and innervation of the gallbladder.**



**Figure 8.57 - Functional aspects of the rima glottidis** observed with the laryngoscope. **a**, Open during respiration; **b**, open to maximum extent during a forced inspiration; **c**, closed during phonation.

The vocal cords are essential for the phonation, whereas the vestibular folds are accessory organs; indeed, these latter ones can be excised with no alteration in the phonation. The vocal folds get closer to each other depending on the respiration phase (Fig. 8.57) and a sudden, intense physical work closes the glottis.

**Glottis** - It is a space which is elongated in anteroposterior direction, laterally delimited by the free margin of the vocal cords and the internal surface of the arytenoid cartilages. This space is formed by an anterior part, corresponding to the vocal ligaments and a posterior part situated between the arytenoid cartilages. The first one is the *intermembranous part of the rima glottidis* (or rima glottidis proper), whereas the second one is the *intercartilaginous part of the rima glottidis* (or intercartilaginous rima glottidis or interarytenoid space) (Fig. 8.58).

The **intermembranous part of the rima glottidis** pres-

ents the shape of isosceles triangle, whose apex is situated in correspondence with the angle of the thyroid cartilage and whose base corresponds to a transversal line passing through the vocal processes (or internal apophyses) of the arytenoid cartilages (see Fig. 8.58).

The **intercartilaginous part of the rima glottidis** is laterally delimited by the medial surface of the arytenoid cartilages and posteriorly by the oblique arytenoid and transverse arytenoid. It does not have a defined shape, since the arytenoid cartilages are rather movable during respiration (see Fig. 8.58).



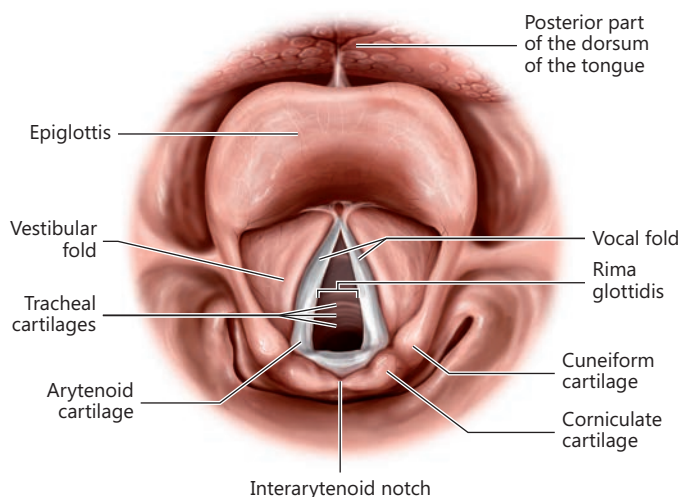
### Cricotomy

The *cricotomy* is an emergency intervention performed following obstruction of the rima glottidis. Firstly, the inferior margin of thyroid cartilage and the median cricothyroid ligament are detected. Then, a large needle is introduced into the skin and the median cricothyroid ligament, reaching in this way the laryngeal lumen, below the vocal cord, and restoring the pulmonary ventilation. Cricotomy can be performed in adults, but not in children, presenting a cricothyroid space with limited size. ■

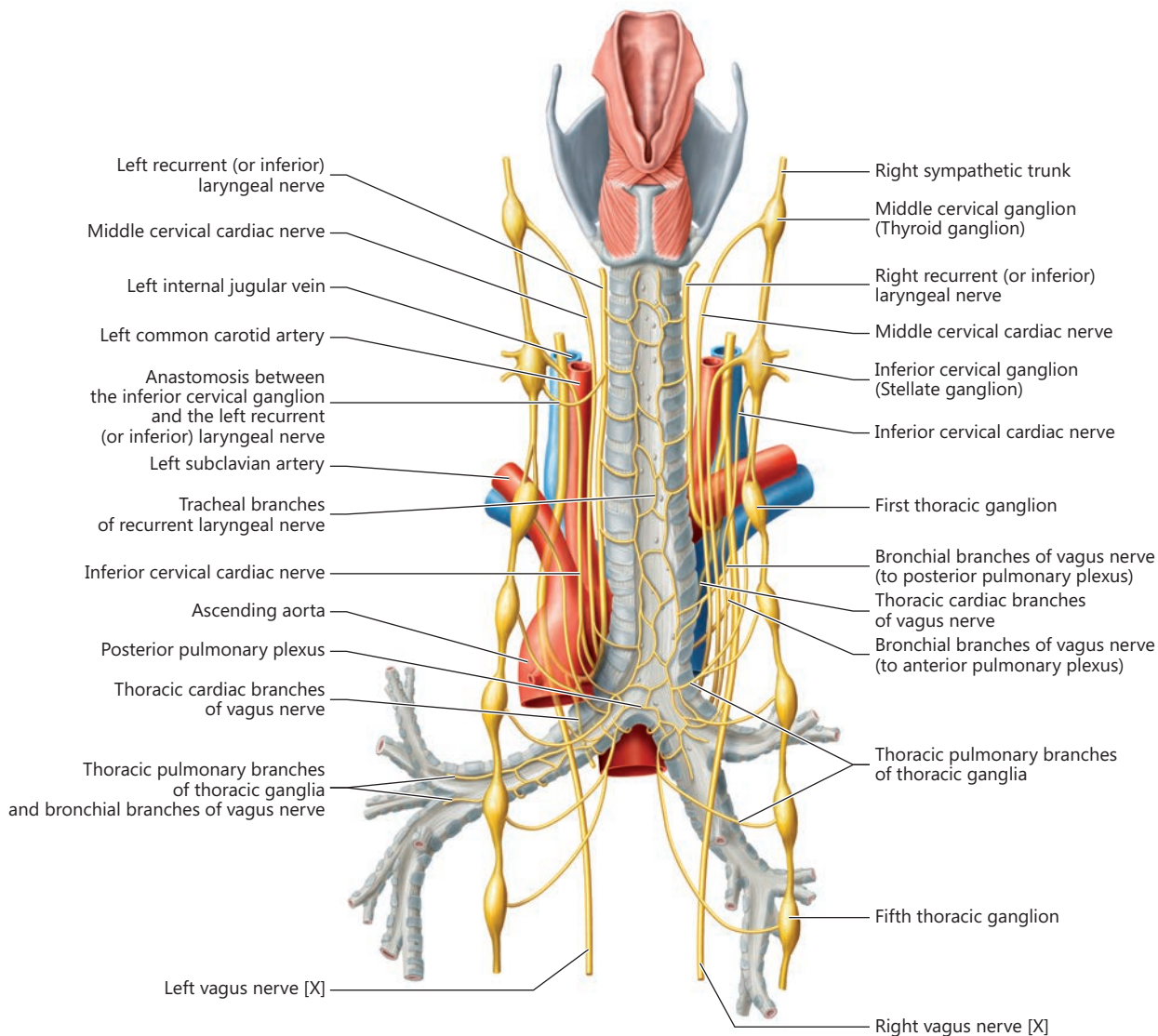
### Subglottic area

The *subglottic area* includes all the part of the laryngeal cavity situated below the glottis (**infraglottic cavity**; see Figs. 8.54 and 8.55). This area of the larynx can be divided into two *parts*, one *superior* and one *inferior*. The **superior part** presents the shape of an upside-down funnel, because of its lateral walls, tilted inward; on the contrary, the **inferior part** presents a cylindrical shape on top of the trachea (see Fig. 8.54). An anteroposterior fissure called *rima glottidis* is situated at its apex.

The subglottic area is formed on its anterior part by the inferior part of the thyroid cartilage and the anterior part of the cricoid cartilage, on its posterior part by the lamina of the cricoid cartilage and laterally by the later parts of the cricoid



**Figure 8.58 - Rima glottidis** viewed from above.



**Figure 8.63 - Representation of the innervation of the trachea and the heart, posterior view.**

**Nerves** - They derive from the vagus nerve and the sympathetic trunk and distribute with the sensory, motor and secretory branches to the mucosa, the tracheal muscle and the tracheal glands (see **Fig. 8.63**).

### MICROSCOPIC ANATOMY

The trachea presents two tunicae, one external, *fibromusculocartilaginous*, formed by the *membranous wall*, the *tracheal cartilages* and the *tracheal muscle*, which altogether form the structure of the duct, and one internal, the *mucosa* (**Figs. 8.65-8.67**).

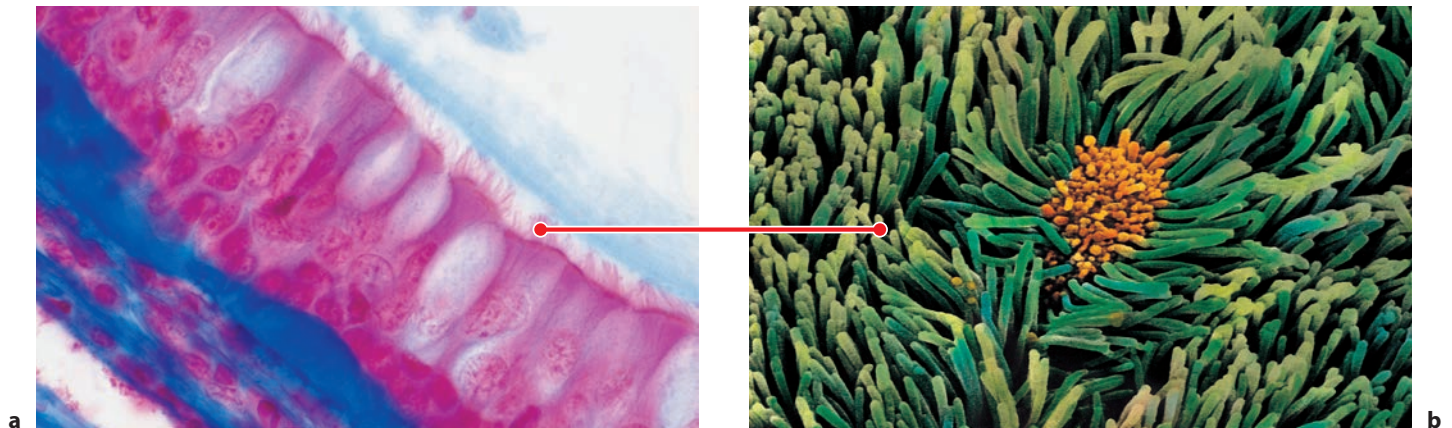
The membranous wall is a fibroelastic membrane, whereas the tracheal cartilages are represented by cartilaginous rings or segments. The membranous wall is formed by connective tissue, rich in elastic fibers. It surrounds cartilagi-

nous rings, merging with their perichondrium and forms *annular ligaments* between the cartilaginous rings.

**Membranous wall** - It occupies without interruptions the whole height of the trachea. It continues at the top with the perichondrium coating the cricoid cartilage, whereas it bifurcates at the bottom, continuing with the bronchial tunica externa. It is formed by collagen fibers and a large number of elastic fibers. It contains muscular fibers forming the tracheal muscle.

**Tracheal cartilages** - They are situated in the thickness of the membranous wall, which splits to cover them. There are between 15 to 20 cartilaginous rings horizontally organized one over the other. Each of them presents an average height of 2-4 mm and an incomplete ring or horseshoe shape, lack-





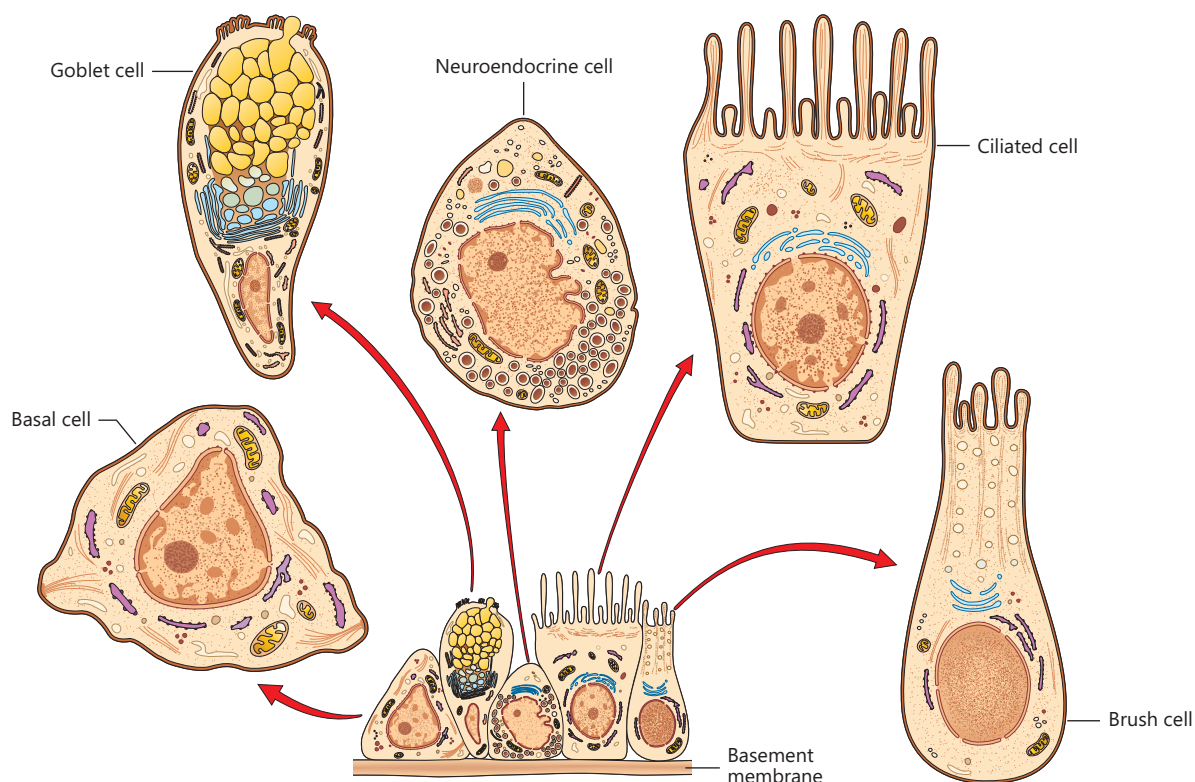
**Figure 8.67 - Epithelium of the trachea.** The cells are cylindrical and present free vibratile cilia on their surface. Among these cells, there are also muciparous (goblet) intercalated cells and brush border cells. **a**, Optical microscopy image; **b**, scan microscopy image; microvilli of brush cells are yellow, whereas the cilia are green.

**Tracheal muscle** - The posterior wall of trachea lacks cartilaginous rings and presents instead smooth muscle cells which form a continuous plane, the *tracheal muscle*, whose thickness presents individual variations (see **Figs. 8.50, 8.62 and 8.65**). The fibrocells of the tracheal muscle insert on the extremities of the membranous wall connecting the cartilaginous rings, thanks to very small elastic tendons and, contracting, get the two extremities of the cartilaginous rings close to each other, diminishing the transversal diameter of

the trachea and resisting to the exhaled air column, which under particular conditions such as coughing or strain tend to remarkably dilate the air duct.

**Respiratory mucosa** - It lines the entire internal surface of the duct with its two layers, formed by the *epithelium* and the *lamina propria* (see **Fig. 8.66**).

The **respiratory epithelium** of the trachea is a composite columnar epithelium including five cell types: *basal cells*



**Figure 8.68 - Cell types in the tracheal epithelium.** Five cell types found in the epithelium of the trachea and extrapulmonary bronchi are represented.

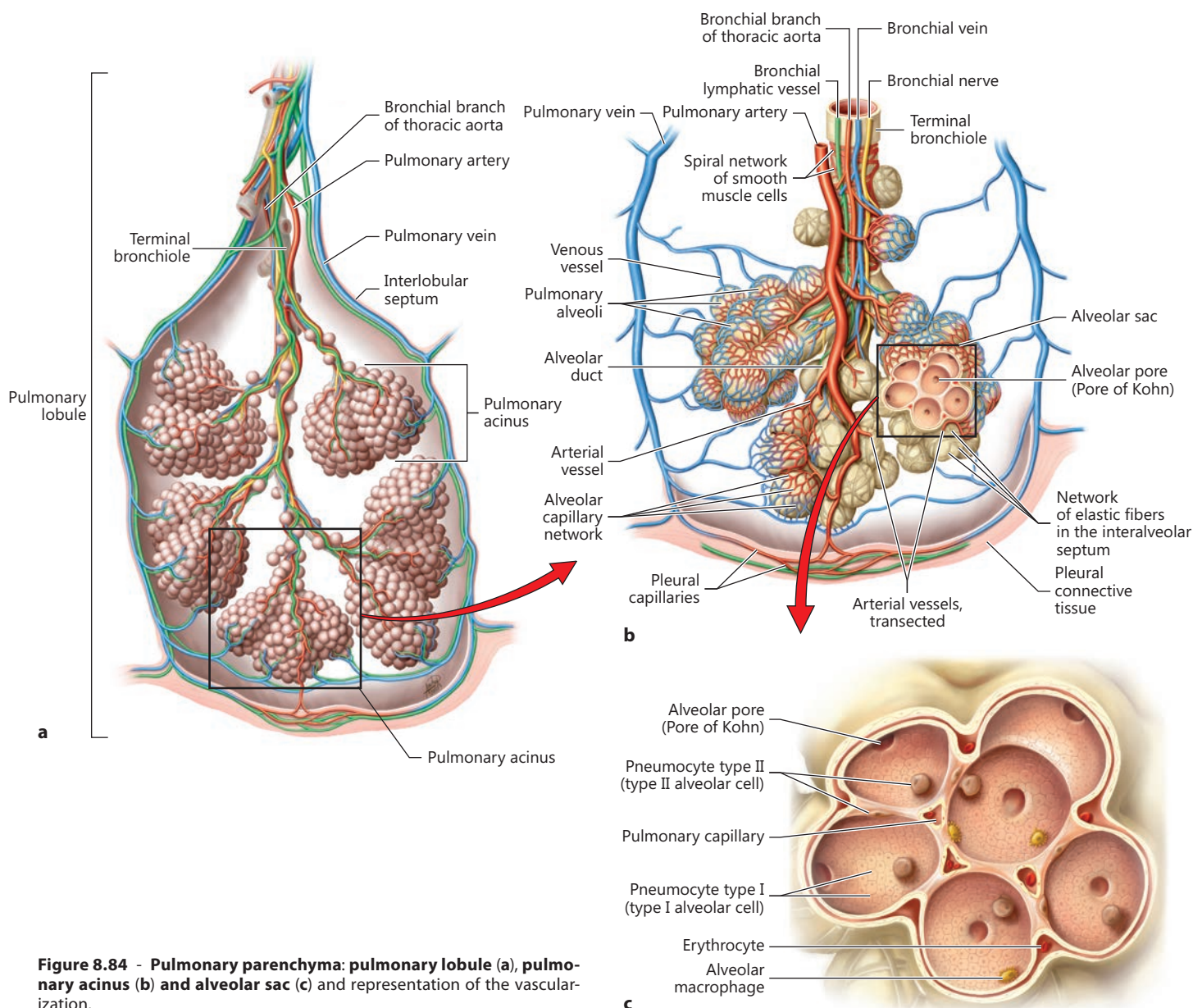
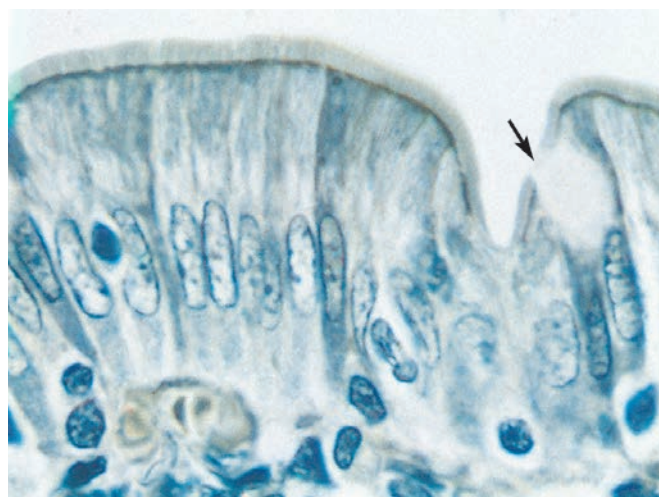
**Figure 8.83** - The **bronchial epithelium** is simple columnar until the intralobular bronchioles and is mainly formed by ciliated cells, among which there are muciparous (goblet) intercalated cells (arrow).

## Pulmonary parenchyma

The *pulmonary parenchyma* is formed by a set of independent territories delimited by connective septa called pulmonary lobules (**Fig. 8.84**).

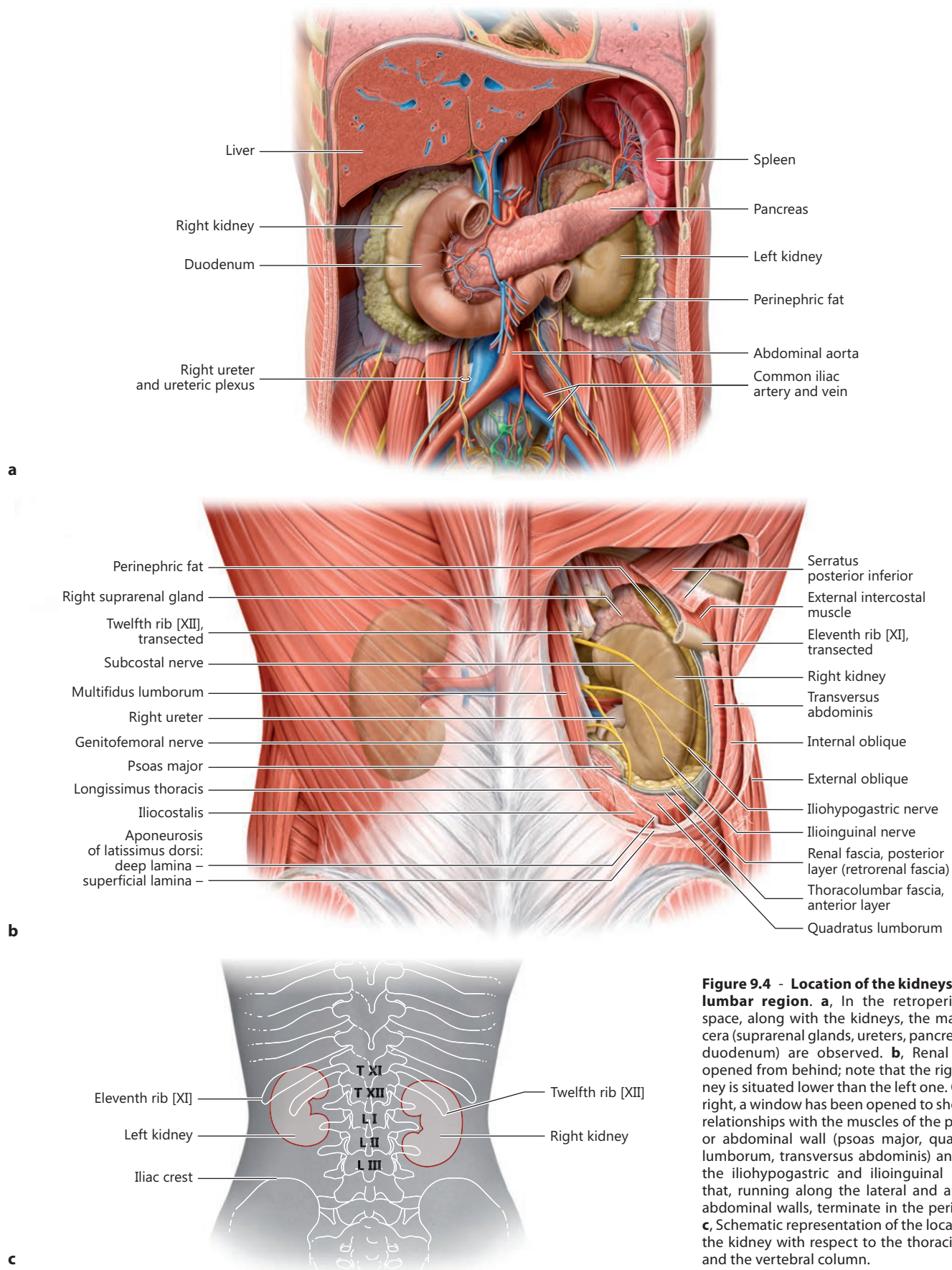
## Pulmonary lobules

The *pulmonary lobules* present an average volume of 0.5 cm<sup>3</sup> and different shape, depending on their superficial or deep position. The **superficial lobules** present the shape of a



**Figure 8.84** - Pulmonary parenchyma: pulmonary lobule (a), pulmonary acinus (b) and alveolar sac (c) and representation of the vascularization.





**Figure 9.4 - Location of the kidneys in the lumbar region.** **a**, In the retroperitoneal space, along with the kidneys, the main viscera (suprarenal glands, ureters, pancreas and duodenum) are observed. **b**, Renal space opened from behind; note that the right kidney is situated lower than the left one. On the right, a window has been opened to show the relationships with the muscles of the posterior abdominal wall (psoas major, quadratus lumborum, transversus abdominis) and with the iliohypogastric and ilioinguinal nerves that, running along the lateral and anterior abdominal walls, terminate in the perineum. **c**, Schematic representation of the location of the kidney with respect to the thoracic cage and the vertebral column.



tion with the inferior vena cava (on the right) and with the abdominal aorta (on the left) (see **Fig. 9.5**). In the tract below the hilum of the kidney, the medial border of the two kidneys is in relation with the initial tract of the ureters.

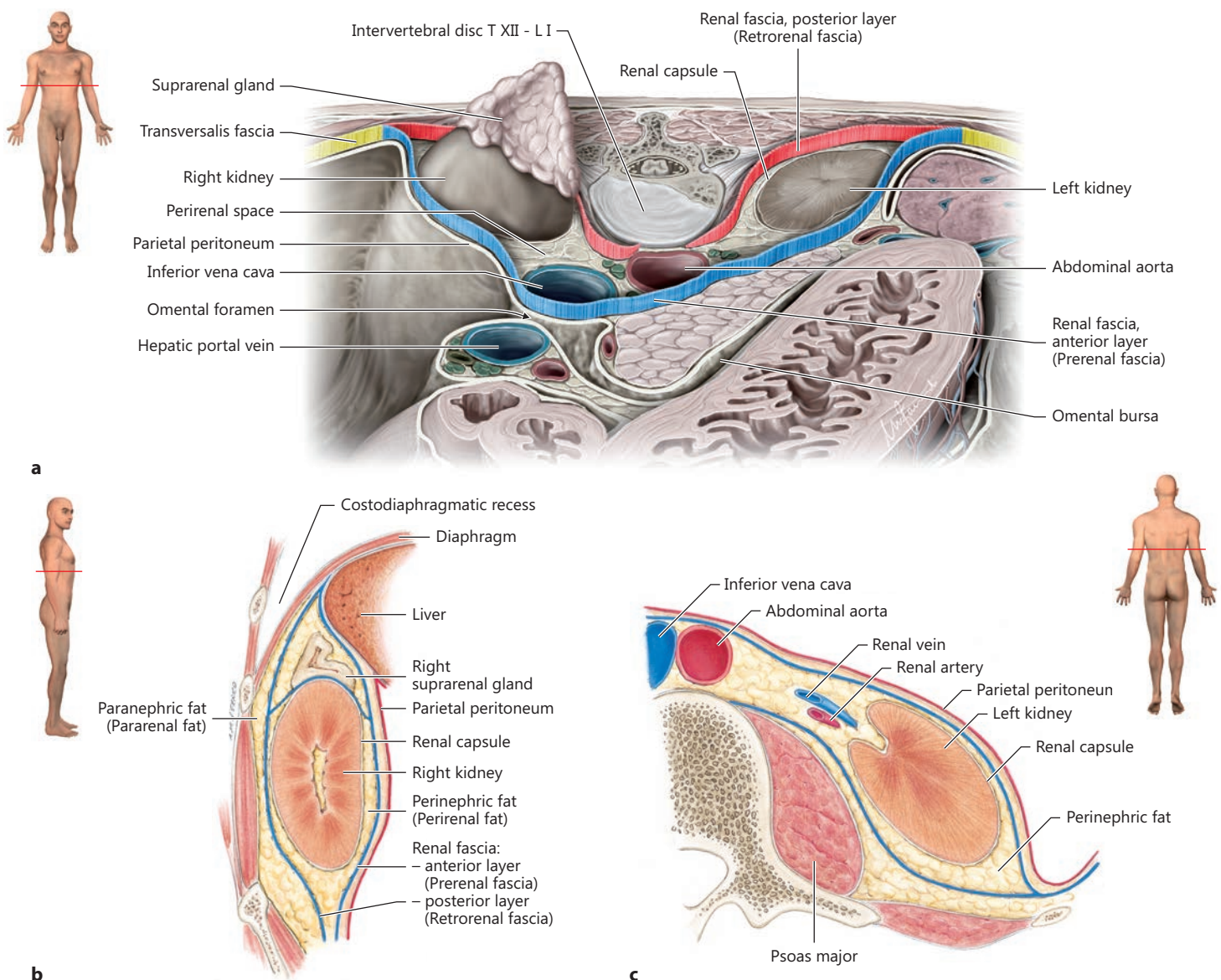
**Hilum of the kidney** - It corresponds approximatively to the transpyloric plane and is located at about 5 cm from the median sagittal plane; the hilum of the left kidney is situated slightly higher than the hilum of the right kidney. Projected onto the posterior abdominal wall, the hilum is situated at a transverse plane passing through the spinous process of the

first lumbar vertebra, with slight differences between the two kidneys (see **Fig. 9.4 c**).

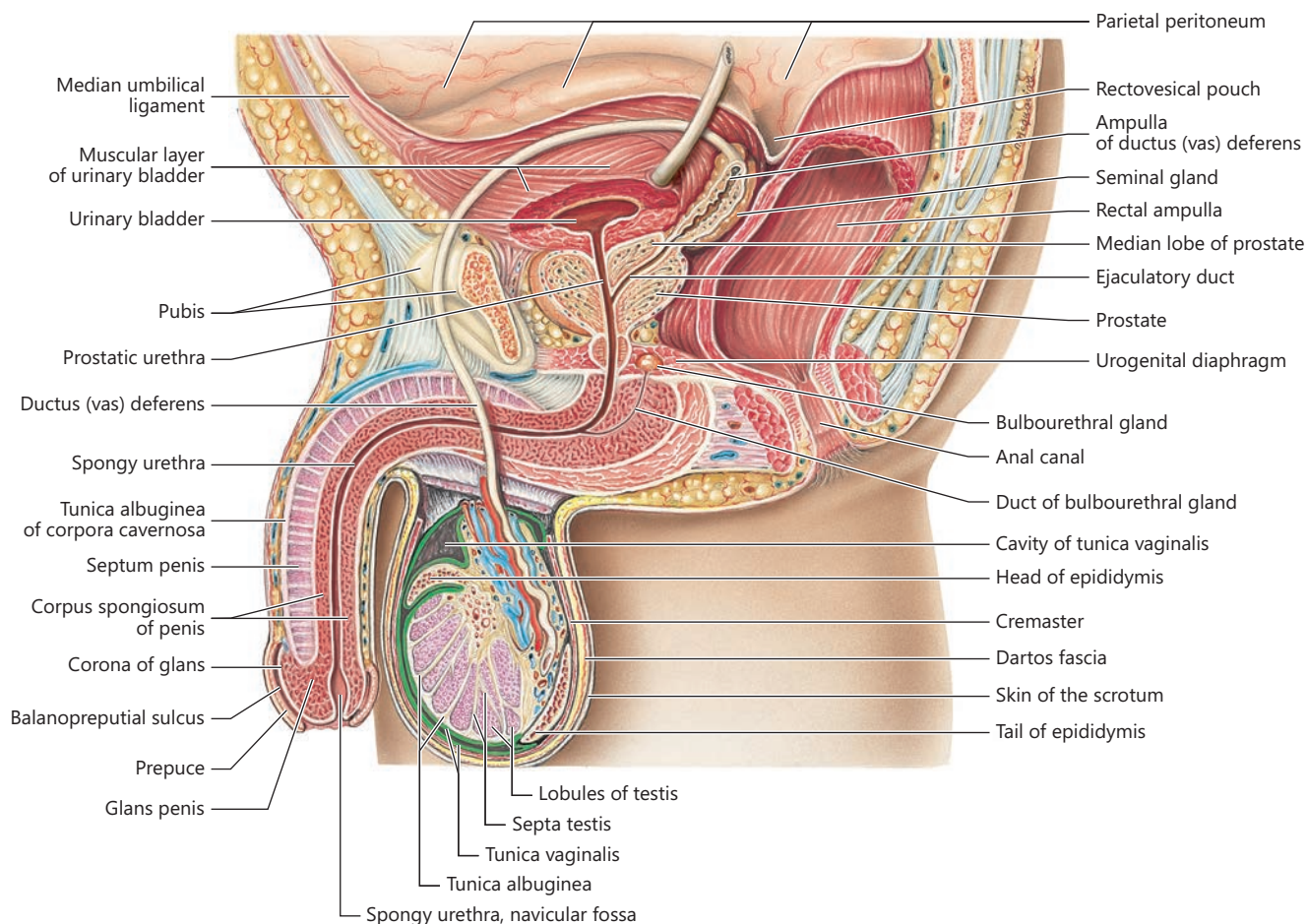
### MEANS OF ATTACHMENT

The kidney has a certain mobility, lowering 2-3 cm during inspiration and returning to its position during exhalation. Also in the supine position, the kidney can move 2-3 cm upwards.

The fixation of the kidney in its anatomical location is allowed by the renal space, the renal vessels, the behavior of



**Figure 9.8 - Renal space.** **a**, Transverse section passing through the left kidney as seen anteriorly. Arrangement of the organs located behind the posterior parietal peritoneum. The figure illustrates the course of the renal fascia. The anterior (prerenal, in blue) and posterior (retrorenal, in red) layers of the fascia bound the renal space, which contains the kidney, the renal pelvis, the renal vessels, the perinephric fat and the right suprarenal gland, with the suprarenal vessels. Laterally, the two layers of the fascia join together at the lateral border of the kidney which then fuse with the transversalis fascia (in yellow). **b**, Sagittal paramedian section passing through the right kidney. Arrangement of the organs located behind the posterior parietal peritoneum (in red). The figure illustrates schematically the course of the renal fascia (in blue). **c**, Transverse section passing through the left kidney as seen from below. Arrangement of the organs located behind the posterior parietal peritoneum (in red). The figure illustrates schematically the course of the renal fascia (in blue).



**Figure 10.2 - Pelvis and perineum of the adult male.** Sagittal section of the lower part of the trunk showing the position and relations of the bladder, rectum and various organs of the male genital system.

and by the *scrotum* or *scrotal sac*, which contains the testes and the first part of the spermatic pathways.

Embryonic remnants in the form of small formations or

*rudimentary organs* may be annexed to the testis and the first part of the spermatic pathways: the *appendix of the testis* and the *epididymis*, the *paradidymis* and the *aberrant ductules*.

## TESTIS

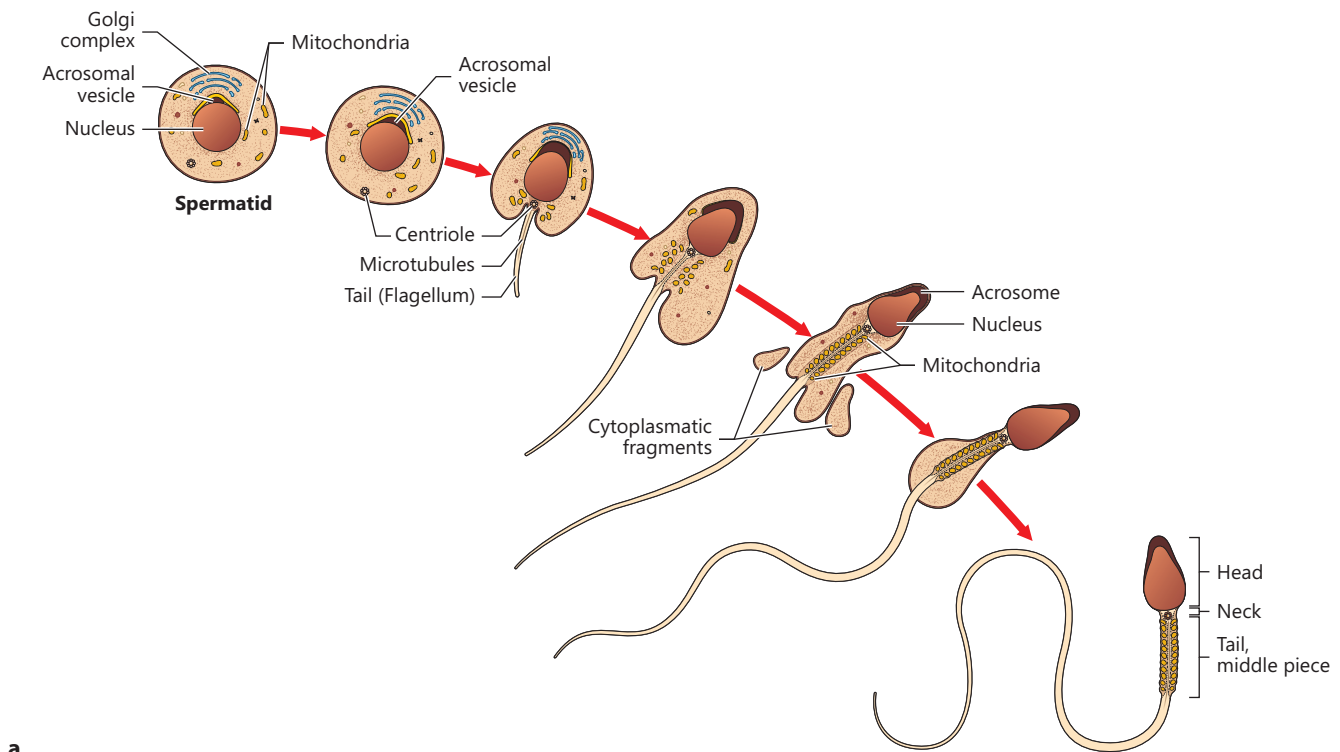
The *testes* (or *male gonads*) develop within the abdomen, at the level of the lumbar region, and then migrate to their final location (scrotum) during intrauterine development and perform both gametogenic (production and maturation of spermatozoa) and endocrine (hormones production) functions.

### SHAPE, LOCATION AND RELATIONS

At the end of the development, the right and left *testes* are contained in a skin pouch, the *scrotum*, situated in the urogenital region (or triangle) below the penis, between the root of the thighs; they are separated from each other by a sagittal

septum, the **septum of the scrotum**. Each testis hangs from the inferior end of the respective **spermatic cord** and is therefore endowed with remarkable mobility, mainly depending on the contraction or relaxation state of the scrotal wall. It has an ellipsoidal shape, slightly flattened transversally, with a soft, elastic consistency and a white bluish bright color. Generally, the left testis has a slightly lower position than the right one (**Figs. 10.3** and **10.4**) due to the different behavior of the veins that drain the blood: in the left testis, the gonadal vein flows into the renal vein, while in the right testis it flows into the inferior vena cava. Due to the different length and elasticity of the venous ducts, the left testis is located lower than the right one.

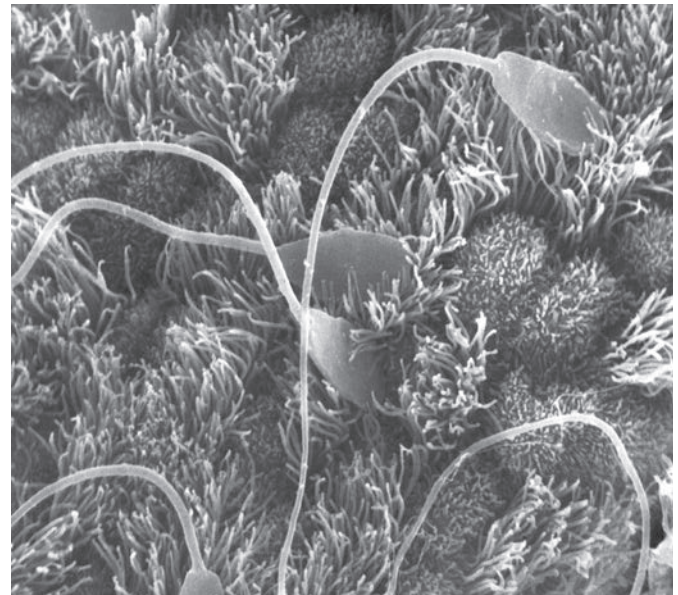




a



b



c

**Figure 10.19 - Stages of spermiogenesis.** **a**, Schematic representation of **spermatids** at different maturation stages, from the round spermatid, through the elongated spermatid to the mature spermatozoon. **b**, **Human spermatid** under the electron microscope. The spermiogenesis is almost complete; in particular, the acrosome is formed (indicated by *arrows*) and the nuclear material is condensed. On the left, the initial tract of the tail is visible with a cytoplasmic mass to the side destined to be expelled (residual body). The mitochondria are arranging themselves around the middle piece of the tail to form the characteristic mitochondrial sheath. 15,000 $\times$ . **c**, Scanning electron microscope photograph showing some **spermatozoa** inside the uterine tube (by Motta and Van Blerkom).

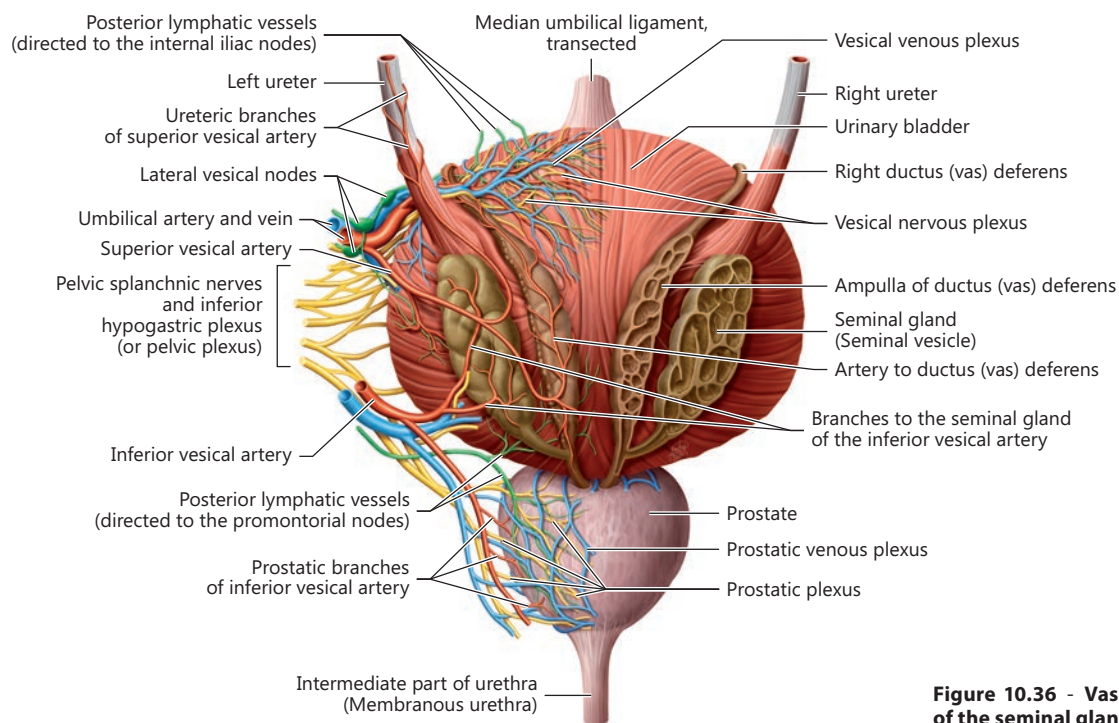
ered by the plasma membrane, forming the tail of the spermatozoa

- *migration of the spermatids towards the apex of the supporting cells*, when the cytoplasmic bridges that joined the germ cell clones break down and a cytoplasmic mass (re-

sidual body) detaches from each spermatid that is phagocytosed by the supporting cells

- *spermiation*, i.e., loss of contact with the supporting cells and fall into the tubular lumen as spermatozoa (Fig. 10.20).



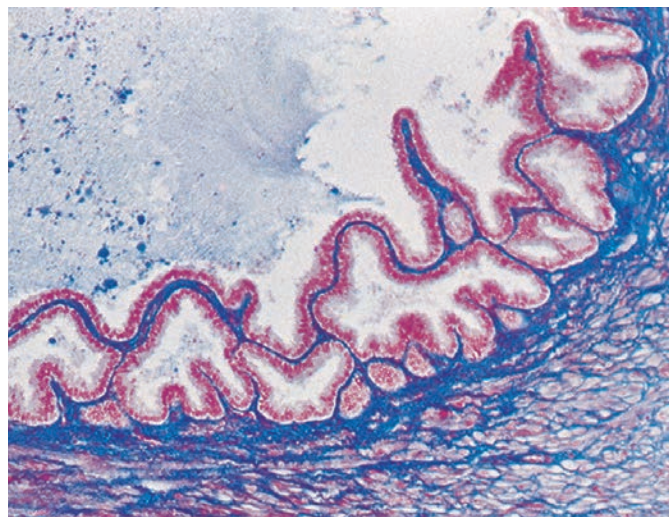


**Figure 10.36 - Vascularization and innervation of the seminal glands (or vesicles) and prostate.**

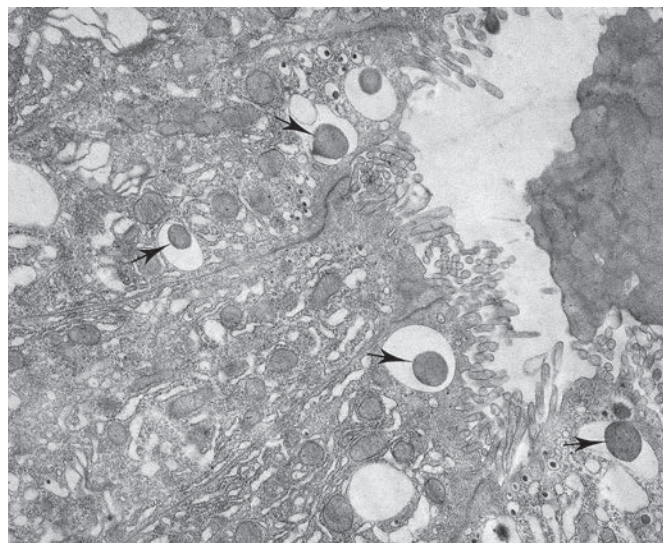
aspect of the external surface corresponds to this conformation. The loops of the duct are held together by an interstitial connective tissue which, at the surface of the organ, forms a thin fibroelastic envelope. The wall of the ducts constituting the seminal glands consists of a *mucosa*, a *muscular layer* and an *adventitia* (Figs. 10.37 and 10.38).

**Mucosa** - It appears extremely irregular due the presence of folds and ridges that give rise to reliefs and concamerations

with a lumen of remarkably variable width. The *lining epithelium* is of high columnar type, sometimes doubled at the level of the ridges, very similar to that of the ampulla of the ductus (vas) deferens and the ejaculatory duct. The rough endoplasmic reticulum is highly represented in the cytoplasm as well as the Golgi complex in the supranuclear position; near the apical surface there are numerous secretion granules and often also granules of lipofuscin pigment, evidence of a remarkable metabolic activity of the cells. The height of the



**Figure 10.37 - Seminal glands (or vesicles).** Note the reticular aspect of the mucosa and the moderate thickness of the muscular layer. A homogeneous material, formed by the secretion product of the epithelial cells, is present in the lumen.



**Figure 10.38 - Seminal gland (or vesicle) observed under electron microscope.** The apical portion of the columnar cells with numerous secretion granules (indicated by arrows) is visible. 15,000x.

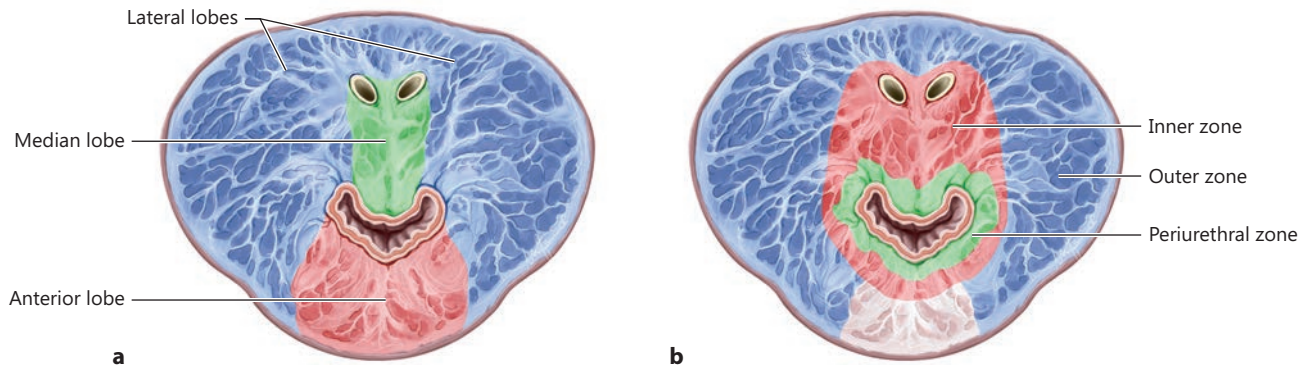


Figure 10.45 - Prostate, subdivisions into lobes (a) and zones (b), shown in a transverse section.

membrane are *polyhedral cells*, shorter, representing replacement elements. Sialomucin-secreting cells (for example, neuraminic acid) or chromaffin cells, like those of the digestive tract, can also be identified in the glandular epithelium. In the lumen of the adenomeres, in addition to secretory material, amylaceous bodies with multilamellar aspect and an average diameter of 0.4 mm are frequently found, especially in elderly subjects. They derive from the precipitation of secretory components around the desquamated glandular cells and undergo calcification (amylaceous bodies or prostatic concretions).

**Secretion of the prostate (or prostatic juice)** - It constitutes approximately 15-30% of the seminal fluid and, in the interval between ejaculations, tends accumulating in the large lumen of the adenomeres. It is a colorless, slightly acidic fluid (pH 6.4). It contains relatively abundant amounts of zinc, citric acid, prostaglandins, immunoglobulins, spermine and spermidine and numerous enzymes such as prostatic acid phosphatase, amylase, fibrinolysin and protease. The prostatic juice also contains the Prostate-Specific Antigen (PSA), whose blood level has a high diagnostic value in prostate pathologies, particularly oncological ones. All these components perform specific functions that are not completely defined in the context of the sperm fertilizing power. In particular, zinc plays a role in the metabolism of testosterone, prostaglandin have a stimulating action on the myometrium, citric acid has a buffering function, spermine stimulates the motility and fertilizing capacity of spermatozoa, lytic enzymes contribute to maintain the fluidity of the sperm. Moreover, spermine, in the dried ejaculate, tends to form typical crystals whose finding has considerable importance in forensic medicine.

The function of the prostate is under control of androgen hormones: the testosterone that reaches the prostate via the blood, is transformed into the active form DiHydroTestosterone (DHT) by the enzyme  $5\alpha$ -reductase, minimally present in the glandular epithelium and, for the most part, at the level of the fibromuscular stroma. This last information further enhances the role played by the stroma in prostate function.

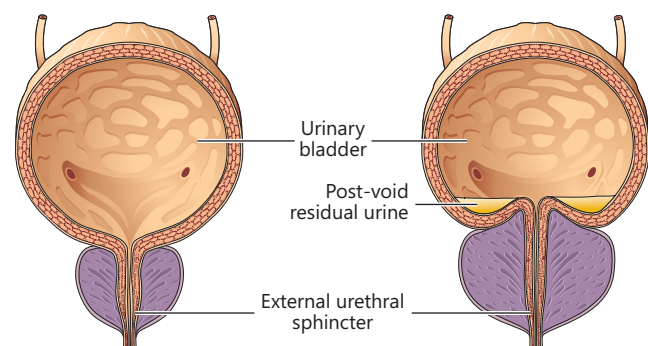


### Transection of the accessory pudendal arteries

In a fair percentage of cases, *accessory* or *aberrant pudendal arteries* are involved in the vascularization of the prostate. These arteries originate from the internal or external iliac arteries or the obturator arteries and provide unilateral or bilateral supply to the corpora cavernosa. Their transection during prostatectomy results in **erectile dysfunctions**.

### Prostatic hyperplasia

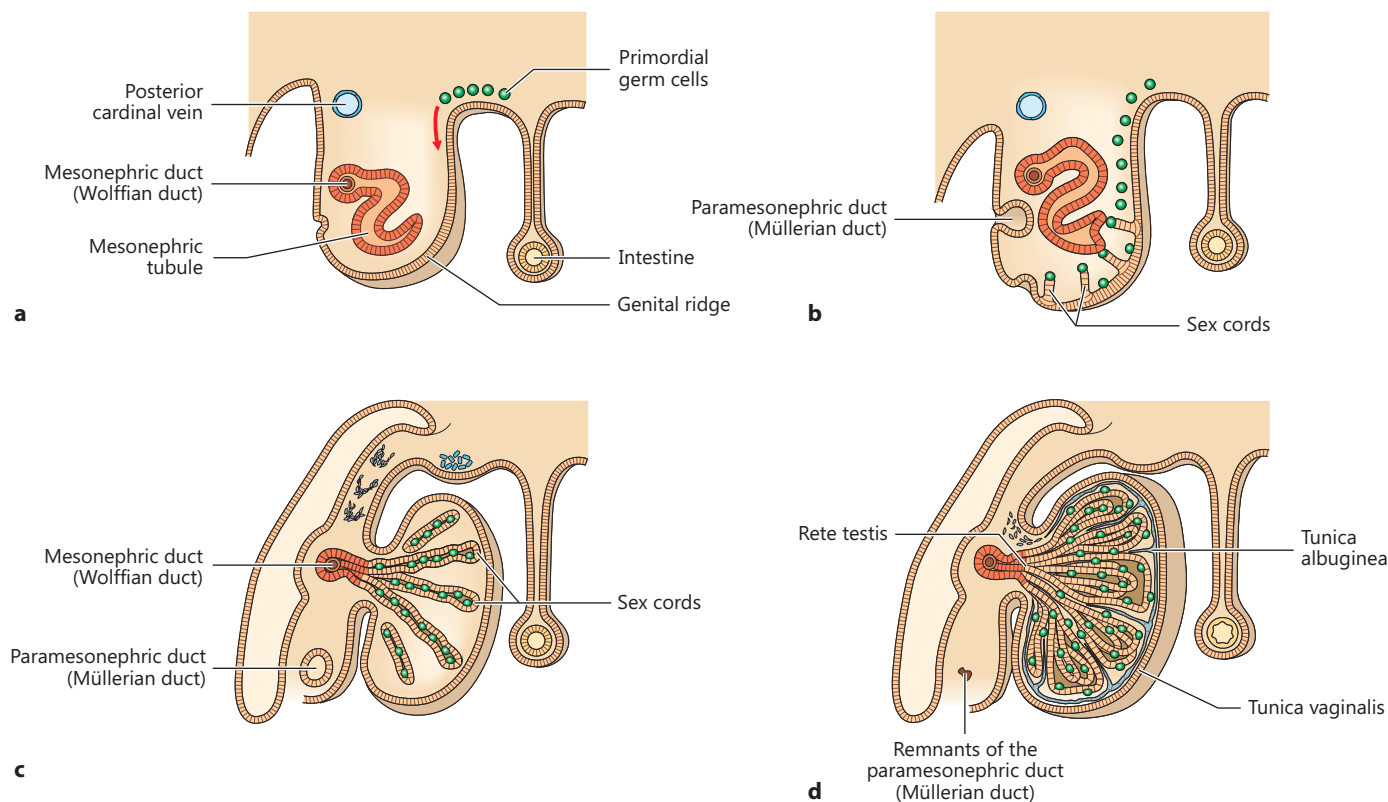
In elderly subjects, the prostate, mainly at the level of the periurethral and inner zones, undergoes *nodular hyperplasia* or *benign prostatic hyperplasia*. This condition causes difficulty to urinate due to the compression of the urethra, urine retention in the bladder due to difficulty in emptying (post-void residual urine) and possibility of infections. Prostatic hyperplasia is caused by DiHydroTestosterone (DHT), which derives from testosterone by the action of the enzyme  $5\alpha$ -reductase. DHT induces the expression of mitogenic growth factors for epithelial and stromal cells and, considering that the enzyme is mostly expressed in the stroma than in the glandular epithelium, prostatic hyperplasia is essentially linked to **stromal hypertrophy**.



### Prostate carcinoma

*Prostate carcinoma* is the most frequent cancer in males over 50 years of age and mainly affects the glands of the external part of the organ, therefore the urinary symptoms are usually modest; it is generally diagnosed by prostatic palpation through rectal examination or by the demonstration of high levels of **Prostate-Specific Antigen (PSA)** in serum. Its development is supported by androgen hormones and for this reason the most drastic therapy involves, in addition to surgical excision and radiotherapy, castra-





**Figure 10.62 - a-d,** Sequence of the morphogenetic stages leading to the **development of the male gonad**. Germ cells, elements of the genital ridge, and part of the mesonephric duct (a) contribute to the development of the convoluted seminiferous tubules and the first part of the spermatic pathways.

The genital ridges start their development in the 4<sup>th</sup> embryonic week and have the same appearance in both sexes (*indifferent gonads*). In them, a coelomic lining epithelium and a series of cellular cords (*sexual cords*) can be distinguished, variously anastomosed, immersed in the underlying mesenchyme and formed by active proliferation of the coelomic epithelium. In the 6<sup>th</sup> week, the genital ridges are invaded by *primordial germ cells*, which, differentiated at the 21<sup>st</sup> day from the endoderm of the yolk sac near the allantoid, migrate along the dorsal mesentery until they reach the genital ridges. The primordial germ cells are voluminous elements (20-30 µm in diameter) with a vesicular nucleus and a cytoplasm rich in glycogen; they are provided with an elevated alkaline phosphatase activity.

After the penetration of the germinal cells, i.e., around the 7<sup>th</sup> week, the undifferentiated gonad starts its evolution and becomes in both sexes the testis or the ovary.

In the male embryo, the sexual cords, which now contain numerous germ cells and are called **testicular cords**, lose contact with the coelomic lining epithelium from which they are separated by a very dense mesenchymal layer that subsequently forms the tunica albuginea, while the epithelium forms the mesothelium of the tunica vaginalis propria of the testis. Then, the testicular cords elongate, transform into tubules and acquire a sinuous course (**seminiferous tubules**); they are separated from each other by mesenchymal septations that originate from the deep surface of the tunica albuginea and divide the testis into compartments. The wall of the seminiferous tubules is constituted by germ cells (prospematogonia) and by epithelial cells derived by the coelomic epithelium; the latter elements (supporting cells of the spermatogenic epithelium or Sertoli cells) assume a

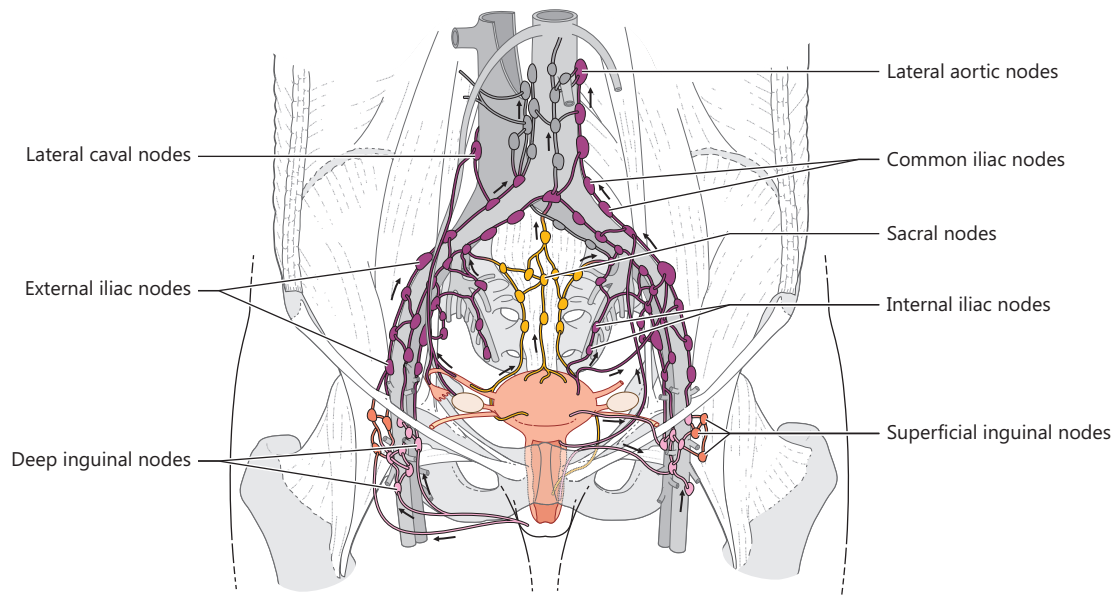
trophic function towards the spermatogonia and acquire an elongated shaper, with the base corresponding to the contour of the tubule. From the intertubular mesenchyme, interstitial endocrine cells (Leydig cells) differentiate at an early stage. These cells are able to secrete androgen hormones already at the end of the 3<sup>rd</sup> month of intrauterine life and therefore regulate, by endocrine mechanism, the differentiation of the various components of the male genital system.

The ends of the seminiferous tubules take a straight course (**straight tubules**) and connect with a canalicular system given by anastomosed tubules (**rete testis**) and contained in a thickening of the tunica albuginea (mediastinum of the testis).

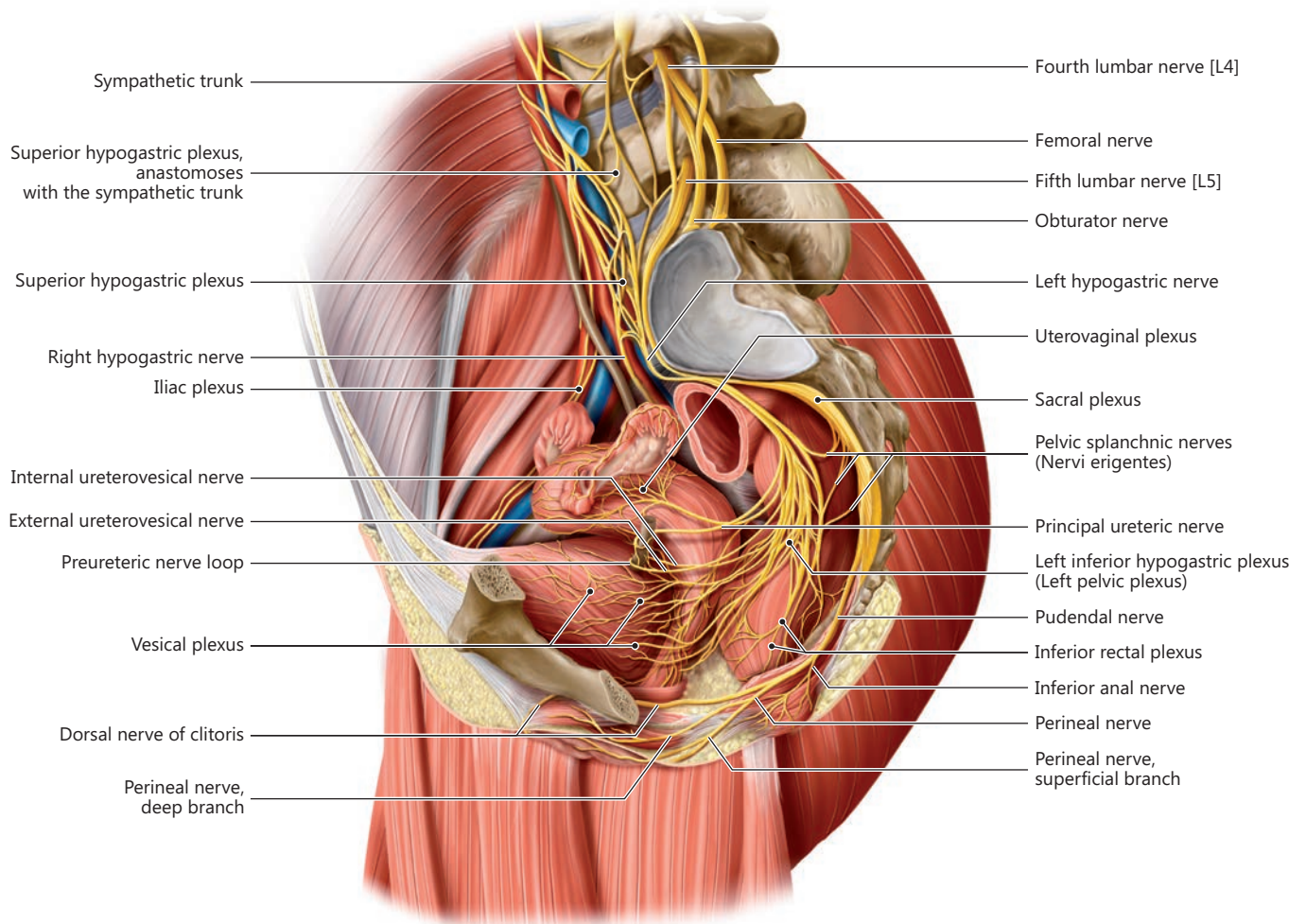
While the testis increases in volume due to the development of its components, the mesonephros undergoes regression. Around the 8<sup>th</sup> week, only a few tubules corresponding to its most caudal portion remain. These tubules become shorter, lose the glomeruli and enter in relation with the canaliculi of the rete testis, forming the efferent ductules that connect the rete testis with the respective **mesonephric duct** (Wolffian duct) which, in the male embryo, remains and transforms into the duct of the epididymis and ductus (vas) deferens. Just before the opening of the urogenital sinus, each mesonephric duct, now become ductus (vas) deferens, gives off a diverticulum which, developing further, will form the seminal gland (or vesicle). The short tract of the duct underlying the respective seminal gland is called ejaculatory duct and opens into the posterior surface of the urogenital sinus. During the 3<sup>rd</sup> month, epithelial discs depart from the posterior wall of the sinus and develop into the mesenchyme surrounding the ejaculatory ducts and represent the primordium of the prostate.

Meanwhile, toward the end of the 2<sup>nd</sup> month, the **paramesone-**

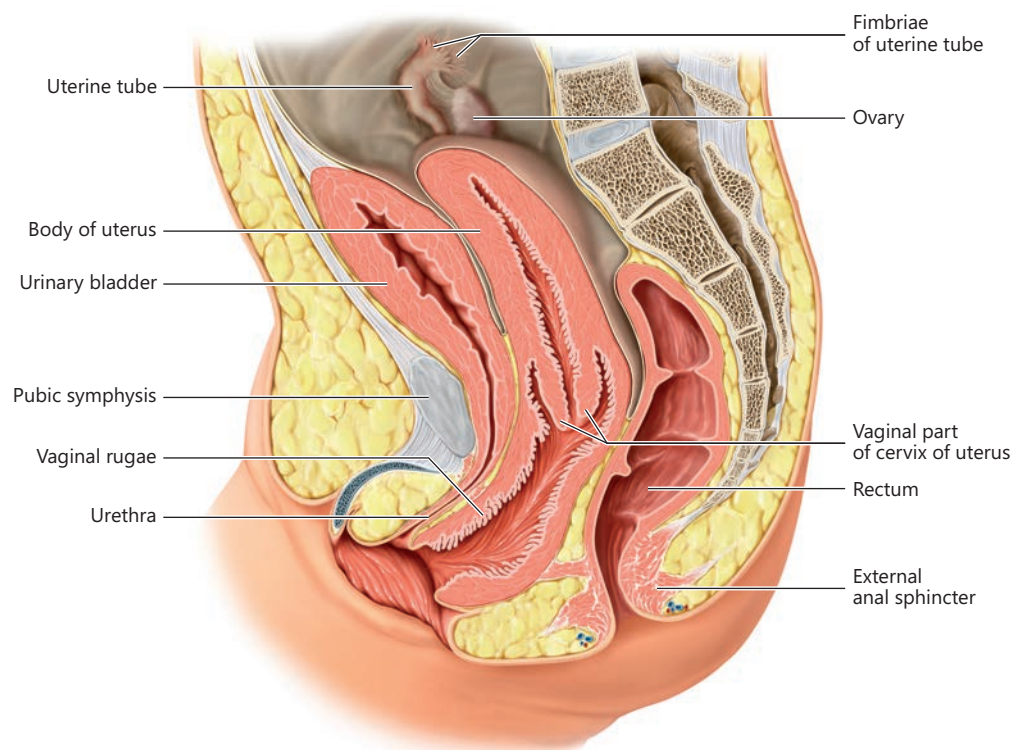




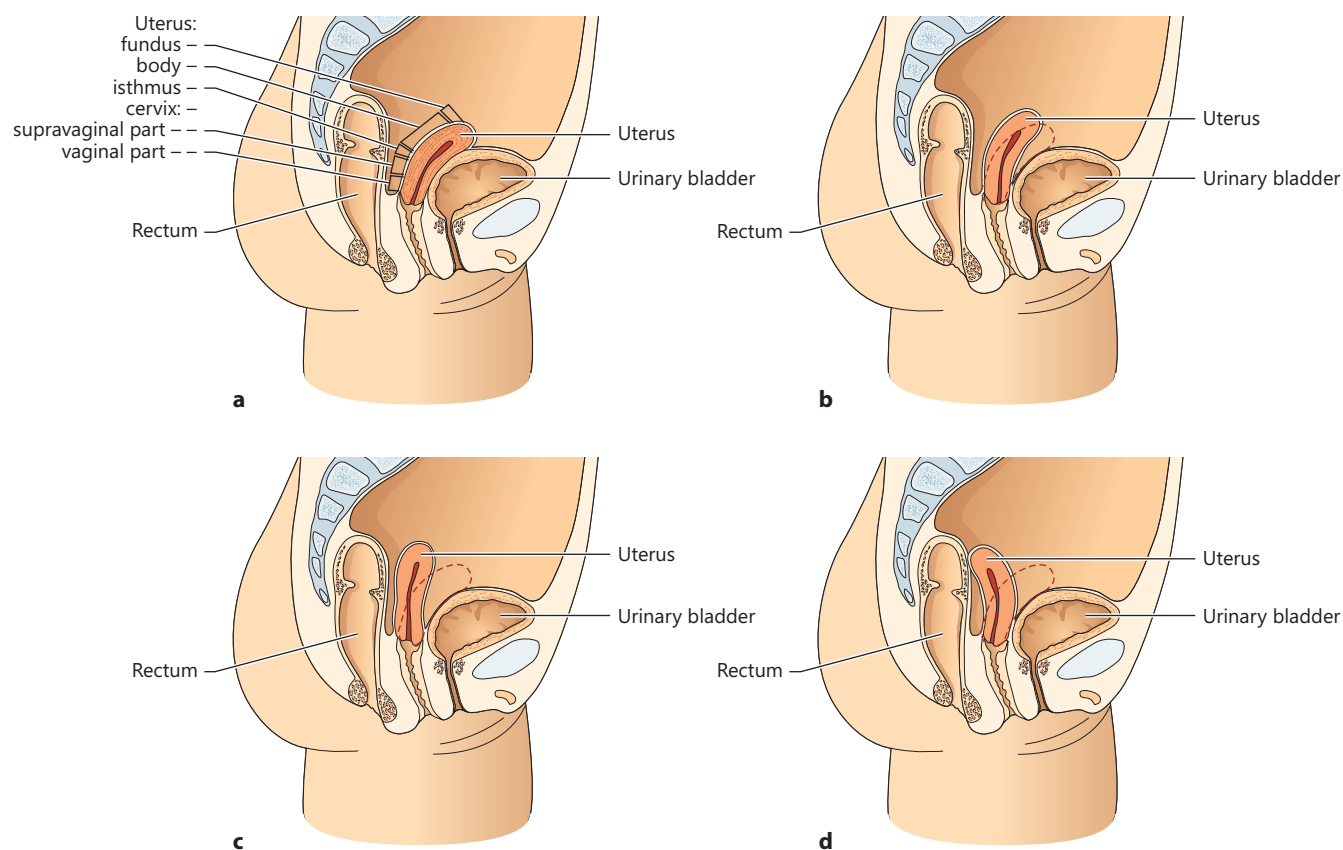
**Figure 11.8 - Lymphatic drainage of the female genitalia, schematic representation.**



**Figure 11.9 - Innervation of the female pelvis.** Left lateral view of the right hemipelvis where the inferior hypogastric plexus, or pelvic plexus, and its branches can be observed.



**Figure 11.32** - Median sagittal section of the **pelvis of a baby girl**. Note that both the uterus and urinary bladder present a high position compared to the adult. This is particularly appreciated in reference to the pubic symphysis.



**Figure 11.33** - Schematic representation of some of the possible **variations of the position of the uterus**. **a**, Normal position (anteversion and ante flexion). Retroversion, a shift of the axis of the uterus backwards with respect to the axis of the vagina, to a modest degree (**b**), and to a more marked degree (**c**). **d**, Retroflexion, a flexion of the body of the uterus backwards with respect to the axis of the cervix.

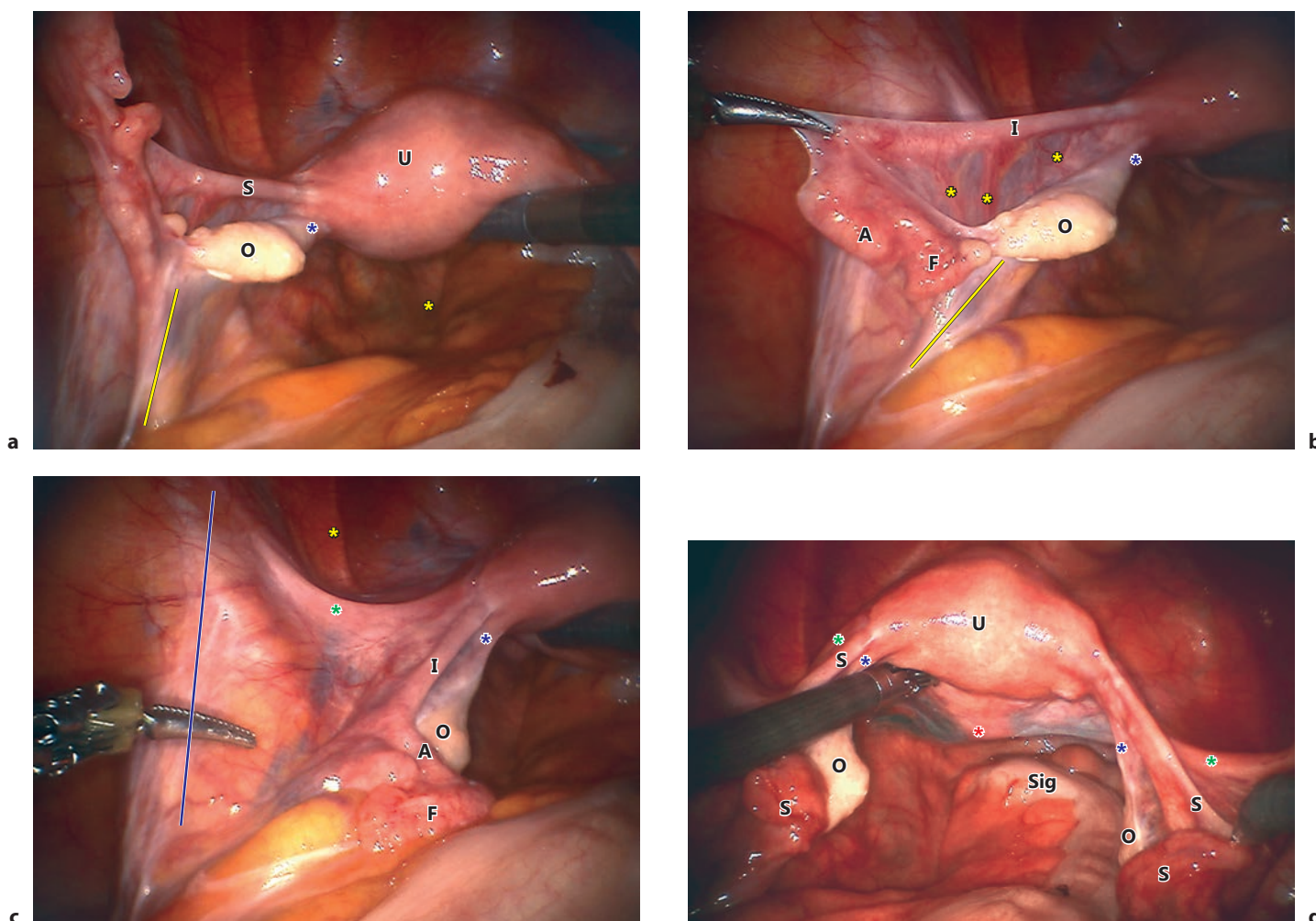


## MEANS OF ATTACHMENT

The uterus is a very movable organ that, physiologically, can have considerable displacements, especially at the level of the body; however, there are several structures that contribute to limiting its mobility, particularly by fixing the cervix in its position in the center of the pelvis. Especially in correspondence to the passage of vessels, the connective tissue tends to thicken and form laminae or cords that are called ligaments, although these structures have the ability to contract, and their development is related to the action of estrogen. In fact, it should be noted that, during pregnancy, there are significant changes in the shape, position and size of the uterus, and that these are made possible by the plasticity of the ligamentous structures as a whole (Fig. 11.36; see Fig. 11.2). From a topographical point of view, the uterus presents

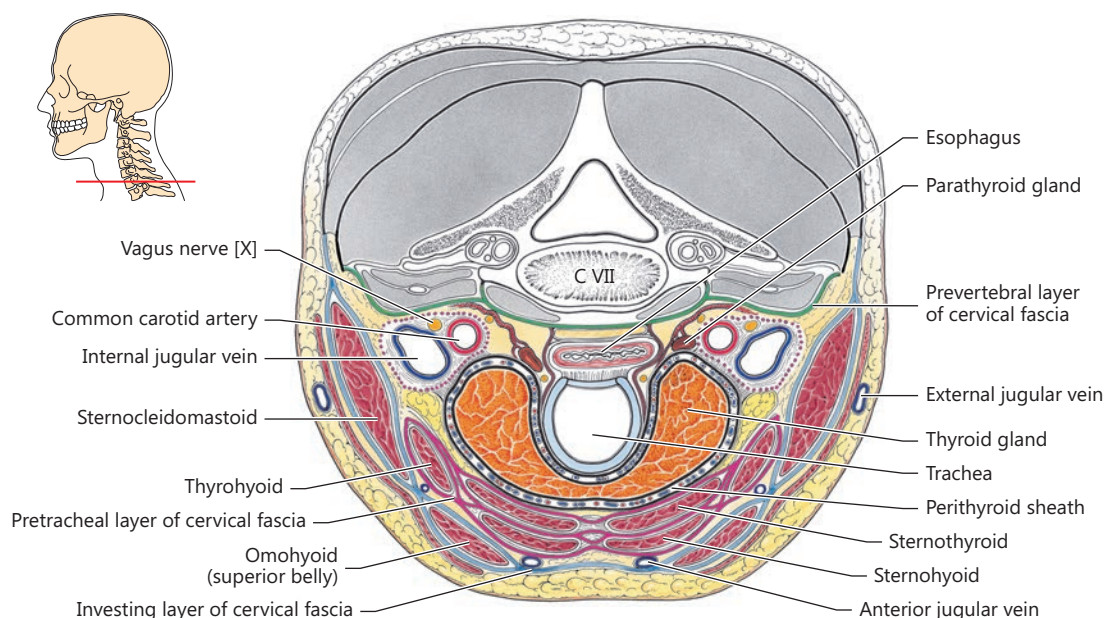
*cranial means of attachment*, represented by the *round ligament of the uterus*, *lateral means of attachment*, constituted by the *broad ligaments of the uterus* – formations belonging to the peritoneum, already described – and *caudal means of attachment*, among which can be identified the *cardinal ligaments*, with transverse direction, and *rectouterine*, *uterosacral* and *vesicouterine ligaments*, with sagittal direction.

The **round ligament of the uterus** is a fibrous cord, 12-15 cm long and with a diameter of 3-5 mm; it originates, on each side, from the superolateral angle of the uterus, anteriorly to the opening of the uterine tube (see Figs. 11.1, 11.3 and 11.31 a). It goes laterally, within the anterior wing of the broad ligament of the uterus (see Fig. 11.35), reaches the anterolateral wall of pelvis and crosses the pelvic inlet with the external iliac vessels; it then moves towards the deep inguinal (or abdominal) ring of the inguinal canal, crossing the



**Figure 11.36 - Normal female pelvis, laparoscopy** of a 45-year-old woman. **a**, Uterus (U), left uterine tube (salpinx) (S), left ovary (O), left ligament of the ovary (blue asterisk), suspensor ligament of the ovary (yellow line), rectouterine pouch (yellow asterisk). **b**, Detail of left annexes. Ovarian fimbria (F), ampulla (A), isthmus (I), tubal and ovarian vessels (yellow asterisks), left ovary (O), left ligament of the ovary (blue asterisk), suspensor ligament of the ovary (yellow line). **c**, Lateral view of the left pelvis and annexes. Ovarian fimbria (F), ampulla (A), isthmus (I), left round ligament of the uterus (green asterisk), left ovary (O), left ligament of the ovary (blue asterisk), left iliopsoas (blue line), occluded part of the left umbilical artery (yellow asterisk). **d**, Panoramic view of the pelvis. Fundus of the uterus (U), cervix of the uterus (red asterisk), uterine tubes (salpinges) (S), ovary (O), ligament of the ovary (blue asterisk), round ligament of the uterus (green asterisk), sigmoid colon (Sig) (courtesy of Prof. E. Vizza).





**Figure 12.29 - Shape, position and relationships of the thyroid gland**, in a transverse section of the neck passing through the seventh cervical vertebra. Note the semiring shape with posterior concavity of the thyroid gland. In front of the isthmus are the infrahyoid muscles with the investing layer (blue) and pretracheal layer (red) of the cervical fascia. The prevertebral layer of the cervical fascia is indicated in green. The gland is surrounded by the perithyroid sheath. In the space between the perithyroid sheath and the thyroid gland capsule there are numerous vessels located in the so-called "danger space".

of each lobe, at the level of its medial third, and relates to the superior parathyroid gland and the recurrent (or inferior) laryngeal nerve.

From the superior border of the isthmus, closer to the left lobe, a conical extension called **pyramidal lobe** (or *Morgagni's pyramid*) may arise that moves upwards, being able to reach even the hyoid bone (see **Fig. 12.27**). This accessory lobe is variable in position, shape and direction, as it represents the ontogenetic remnant of the inferior extremity of the thyroglossal duct which, in the embryo, connects the foramen cecum (located in the terminal sulcus dividing the body from the root of the tongue) with the thyroid primordium. As evidence of the primitive origin of the pyramidal lobe from this duct, there may also be a small fibromuscular cord, called the *suspensor ligament of the thyroid gland*, stretched between the hyoid bone and the superior border of the isthmus or the pyramidal lobe.

## Relations

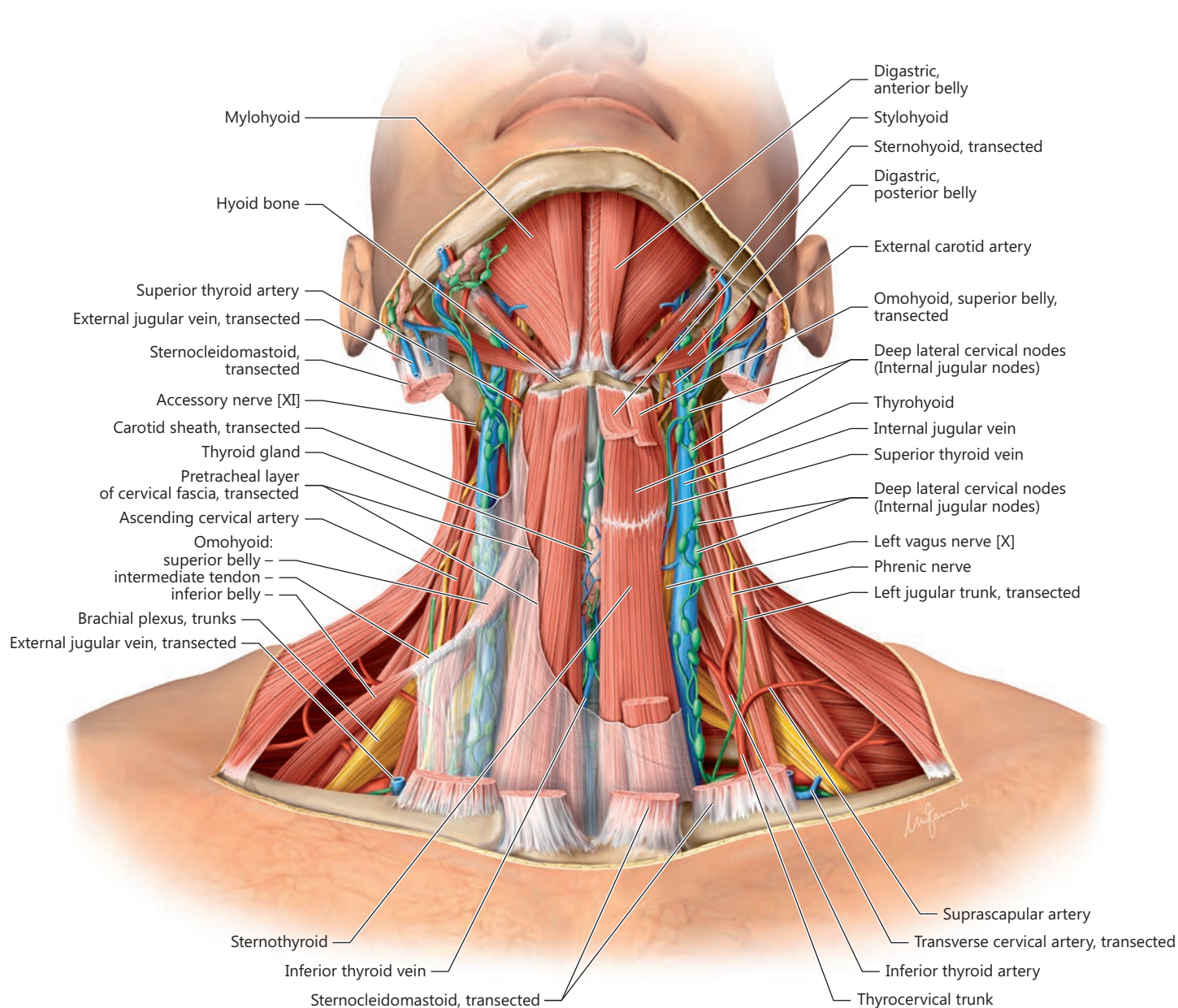
**Anterolateral surface of the lobes** - It continues with the anterior surface of the isthmus and is in relation with the *infrahyoid muscles* (sternothyroid, sternohyoid and thyrohyoid), included in a splitting of the *pretracheal layer of the cervical fascia* (**Fig. 12.30**; see **Fig. 12.29**). More externally, the thyroid gland is related to the *investing layer of the cervical fascia* and, laterally, with the *sternocleidomastoid*. The latter relationship is critical when the gland is to be reached transaxillary; in the case of such surgical intervention, in fact, the gland is reached by passing between the sternal head and the clavicular head of the sternocleidomastoid and, therefore, by progressive detachment the fasciae that cover it laterally. Because of the imperfectly vertical arrangement of the infrahyoid muscles, the sternohyoid being superficial and oblique

upward and medially and the sternothyroid deeper and oblique upward and laterally, on the median plane, the anterior surface of the isthmus is in direct relation to the two cervical fasciae, which separate it from the integument. In the subcutaneous tissue, in this position, the *anterior jugular veins* run on either side of the midline (see **Fig. 12.29**). A connective and avascular adipose cleavage plane (used in surgery to reach the gland and/or remove some parts of it) is between the musculofascial covering planes and the anterolateral surface of the gland and continues laterally into the vascular (or carotid) compartment and inferiorly into the anterior mediastinum.

**Medial surface of the lobes** - It appears concave and continues with the posterior surface of the isthmus; overall, it adapts to the anterolateral surfaces of the laryngotracheal duct, posteriorly to which the anterior and lateral surfaces of the esophagus are located (see **Fig. 12.29**). Since the esophagus and trachea follow a non-median course – with the former back to the left and the latter forward and to the right – the left lobe has a more extensive and frequent relation with the anterior surface of the esophagus. The recurrent (or inferior) laryngeal nerve, a branch of the vagus nerve, and the inferior thyroid artery run almost vertically upwards in the interstitium between trachea and esophagus, posteriorly to the thyroid lobe.

**Posterior surface of the isthmus** - Continuing with the medial surface of the lobes, it represents the part of the gland in close relation with the trachea.

**Posterior surface of the lobes** - It is in posterolateral relation with the neurovascular bundle of the neck and, in particular, with the common carotid artery, which often determines a



**Figure 12.30 - Anterior relationships of the thyroid gland with the infrahyoid muscles.** Transection of the sternocleidomastoid, external jugular vein, investing layer and, in part, also pretracheal layer of the cervical fascia, enables one to observe, in the right half of the neck, the suprahyoid and infrahyoid muscles and the internal jugular vein inside the carotid sheath, which has been in part transected. On the left side, the sternohyoid and omohyoid, located on a superficial plane, have been transected and the carotid sheath removed, rendering visible the sternothyroid and thyrohyoid, located on a deeper plane, and the internal jugular vein with the deep lateral cervical nodes located along the length of its course.

small groove on the gland (see **Fig. 12.28**). Along this surface, received within the sheath that surrounds the thyroid gland, are the parathyroid glands.

### PERITHYROID SHEATH AND MEANS OF FIXATION

The gland, lined by its own fibrous capsule, is enclosed within the **perithyroid sheath** (see **Fig. 12.29**). This sheath, although often considered a dependency of the pretracheal layer of the cervical fascia, is nevertheless distinct from it, as

it represents a vascular sheath of its own whose appendages extend externally surrounding the thyroid vessels. This sheath, separated from the more superficial cervical fasciae, is located at the bottom of a loose connective tissue that represents a cleavage plane useful for the surgical approach to the region. The perithyroid visceral sheath does not adhere to the thyroid capsule, but between these two formations there is a space where the vessels leading to the glandular parenchyma run and for this reason it is called **perithyroid danger space**. The convex external surface of the sheath is smooth



tive gut, near the tract that will give rise to the duodenum. These buds merge at around the 5<sup>th</sup> week of gestation to form the primordium of the definitive pancreas. While the exocrine component of the organ is formed by progressive cavitation of the endodermal formations, the endocrine component is formed by groups of cells that separate from

the nascent exocrine component, arranging to form cords that are immediately reached by vessels and nerves. Within these cords,  $\alpha$  and  $\beta$  cells, which initially are equal in number, differentiate early and begin their secretory activity already during fetal life. At birth,  $\alpha$  cells undergo a progressive reduction until they reach the adult values. ■

## SUPRARENAL GLANDS

The *suprarenal* (or *adrenal*) *glands* are cord-like endocrine glands consisting of two parts: the peripheral *cortex*, which secretes steroid hormones, and the central *medulla*, which secretes catecholamines. The cortex and medulla, although topographically united in the same organ, are ontogenetically, phylogenetically, structurally and functionally different.

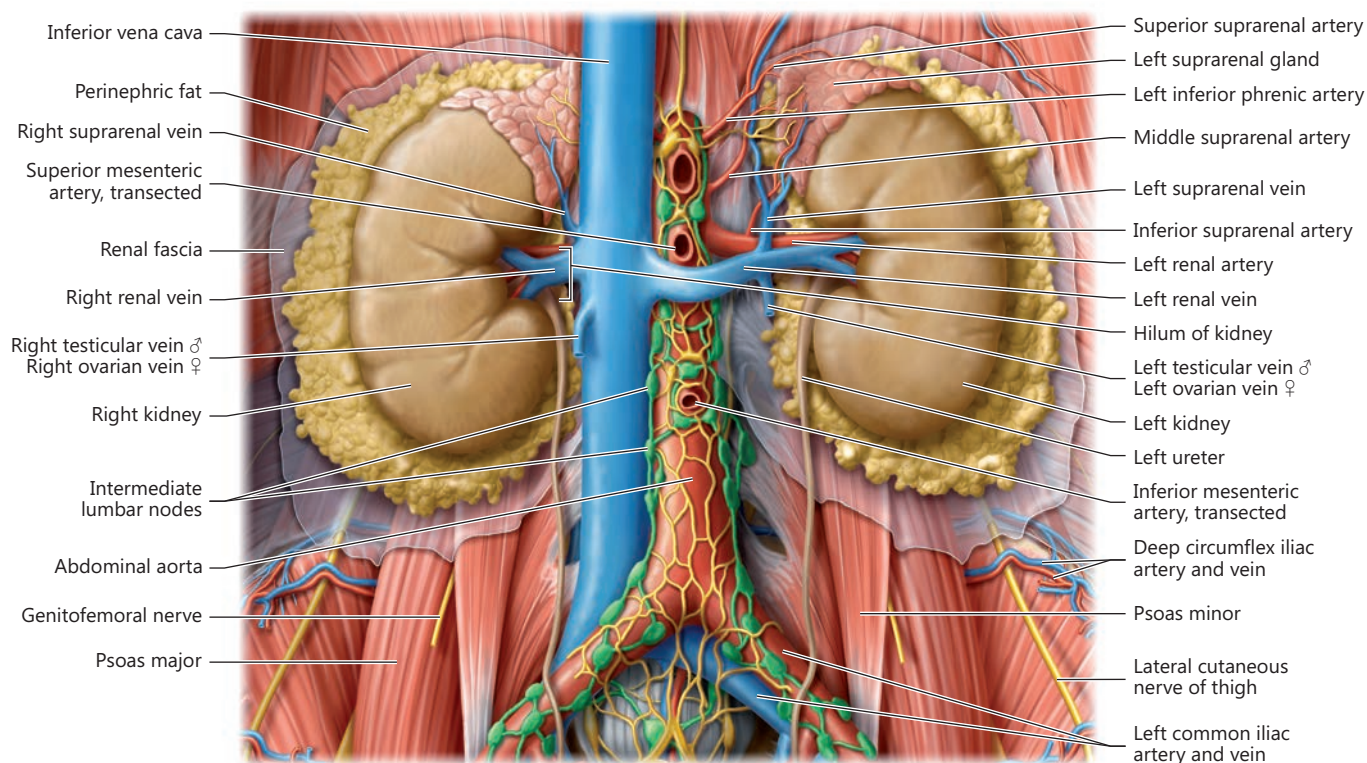
Small **accessory suprarenal glands** can be found near the main suprarenal glands, but also in ectopic area, such as the spermatic cord, epididymis and broad ligament of the uterus.

These accessory glands generally contain steroid-secreting tissue and, therefore, are cortical nature; for this reason, they are also referred to as *cortical bodies*.

### SHAPE, LOCATION AND RELATIONS

#### Shape and location

The suprarenal gland is a paired, primitively retroperitoneal organ, located in the posterosuperior part of the abdominal cavity, at the level of the bodies of the first lumbar vertebrae, above the respective kidney (**Fig. 12.53**). In particular, the suprarenal gland occupies a kind of quadrilateral whose boundaries are constituted: *laterally*, by the medial border of the kidney; *medially*, by the vertebral column and the great vessels; *inferiorly*, by the renal pedicle (i.e., by the vascular structures that cross the hilum of the kidney); *superiorly*, on the right, by the posterior surface of the liver at the level of



**Figure 12.53 - Right and left suprarenal glands, position and relationships.** Partial front of the renal space illustrating the relationships and vascularization of the suprarenal glands.



the bare area, while, on the left, by the lateral crus of the diaphragm.

Kidney and suprarenal gland occupy the *renal space* and are separated by a connective septum, of dependence on the renal fascia. Therefore, there is a sort of very distinct suprarenal space. In addition, thickenings of connective tissue connect the gland to the walls of the space and the diaphragm and anchor it firmly to its site, preventing it, in case of renal ptosis, from following the kidney in its descent.

The suprarenal gland varies in volume, size and weight according to gender, age and pathophysiological conditions. In the average adult, the normal weight of the gland is approximately 5 g and both glands measure 50 mm vertically, 30 mm transversely and about 10 mm anteroposteriorly. During pregnancy, the glands undergo an increase in both weight and volume.

The suprarenal glands do not have a real hilum because the arterial vessels reach the organ from several points. However, it is common to observe, on the anterior surface of the gland, a curvilinear groove, from which the suprarenal (or central) vein emerges and through which some arterioles enter the organ, which therefore could represent a sort of hilum of the suprarenal gland.

The glandular parenchyma is made up of an external part, called *cortex*, and an internal part, called *medulla*. The **cortex** has a yellowish color and is more voluminous (80% of the parenchyma) and of greater consistency than the **medulla**, which represents the remaining 20% of the parenchyma and has a reddish-brown color, a soft consistency and a weight of about one tenth of the total weight (Fig. 12.54).

Although the two suprarenal glands are very similar, they are not identical in shape. In fact, the right suprarenal gland, classically compared to a Phrygian cap (i.e., a cap with a tip that can fall softly to the front or back or remain stiffer in an upright position), has the shape of an irregular tetrahedron with a triangular base and a vertical major axis. Therefore, an anterior surface, a posterior surface, an inferior base, a superior apex, a thin medial border and a lateral border are recognized. On the other hand, the left suprarenal gland has a semilunar shape, flattened on the anteroposterior plane and with an oblique major axis.

The base of the two glands rests on the superior pole of the underlying kidney and is separated from it by a fibrous septum deriving from the renal fascia. However, the left suprarenal gland appears more inclined than the right one and, from the superior pole, descends along the medial border of the kidney until it almost reaches the hilum of the kidney.

## Relations

The suprarenal gland has a deep location within the abdominal cavity and, for this reason, relations with the viscera affect almost exclusively only the anterior surface of the gland (Fig. 12.55).

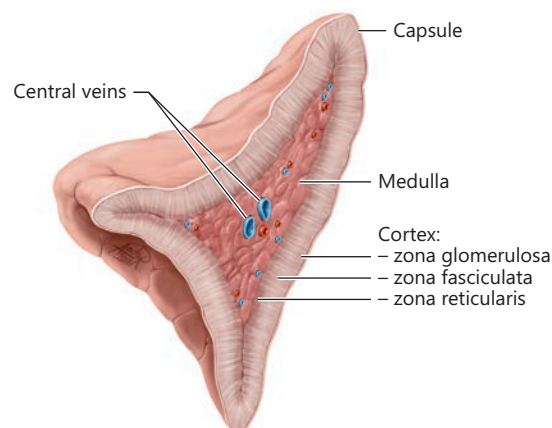


Figure 12.54 - Section of the right suprarenal gland.

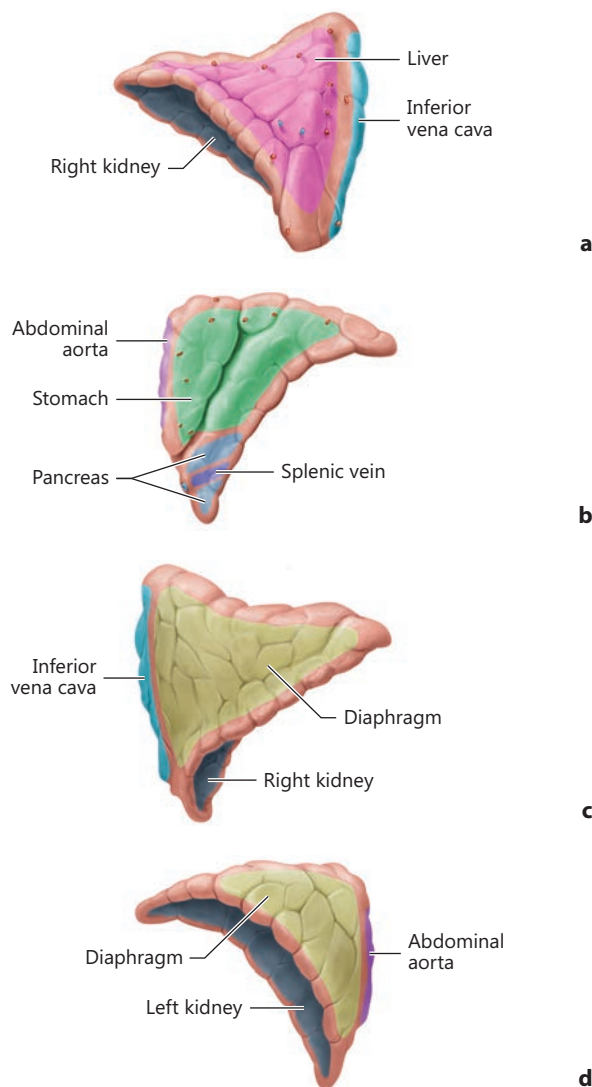
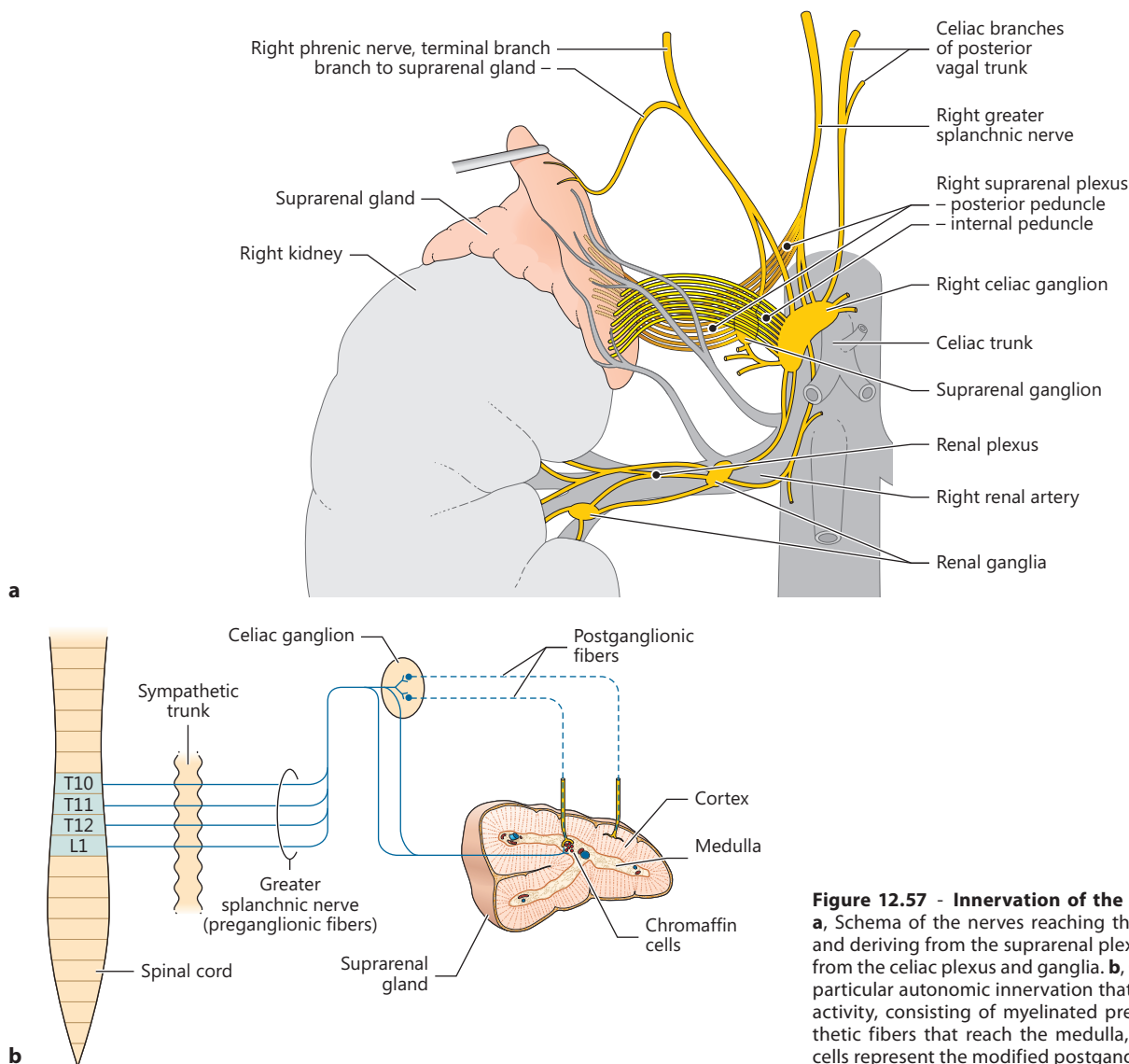


Figure 12.55 - Relationships of the right and left suprarenal glands. Anterior (a and b) and posterior (c and d) surfaces of the right and left suprarenal glands, respectively.



**Figure 12.57 - Innervation of the suprarenal gland.**  
**a**, Schema of the nerves reaching the suprarenal gland and deriving from the suprarenal plexus, in turn efferent from the celiac plexus and ganglia. **b**, Organization of the particular autonomic innervation that controls glandular activity, consisting of myelinated preganglionic sympathetic fibers that reach the medulla, whose chromaffin cells represent the modified postganglionic neurons.

The **cortex** and **medulla**, the two parts of the glandular parenchyma, differ in ontogenesis, phylogenesis, structure and function. Their union into a single organ is relatively recent; in fact, cortex and medulla can be completely separated in lower vertebrates, as in fishes, where they constitute the interrenal tissue and the chromaffin bodies, respectively, or they may be in simple contiguity, as in amphibians, or variously intertwined, as in birds. In mammals, the cortex surrounds the medulla, and this, as will be seen, is of considerable functional importance.

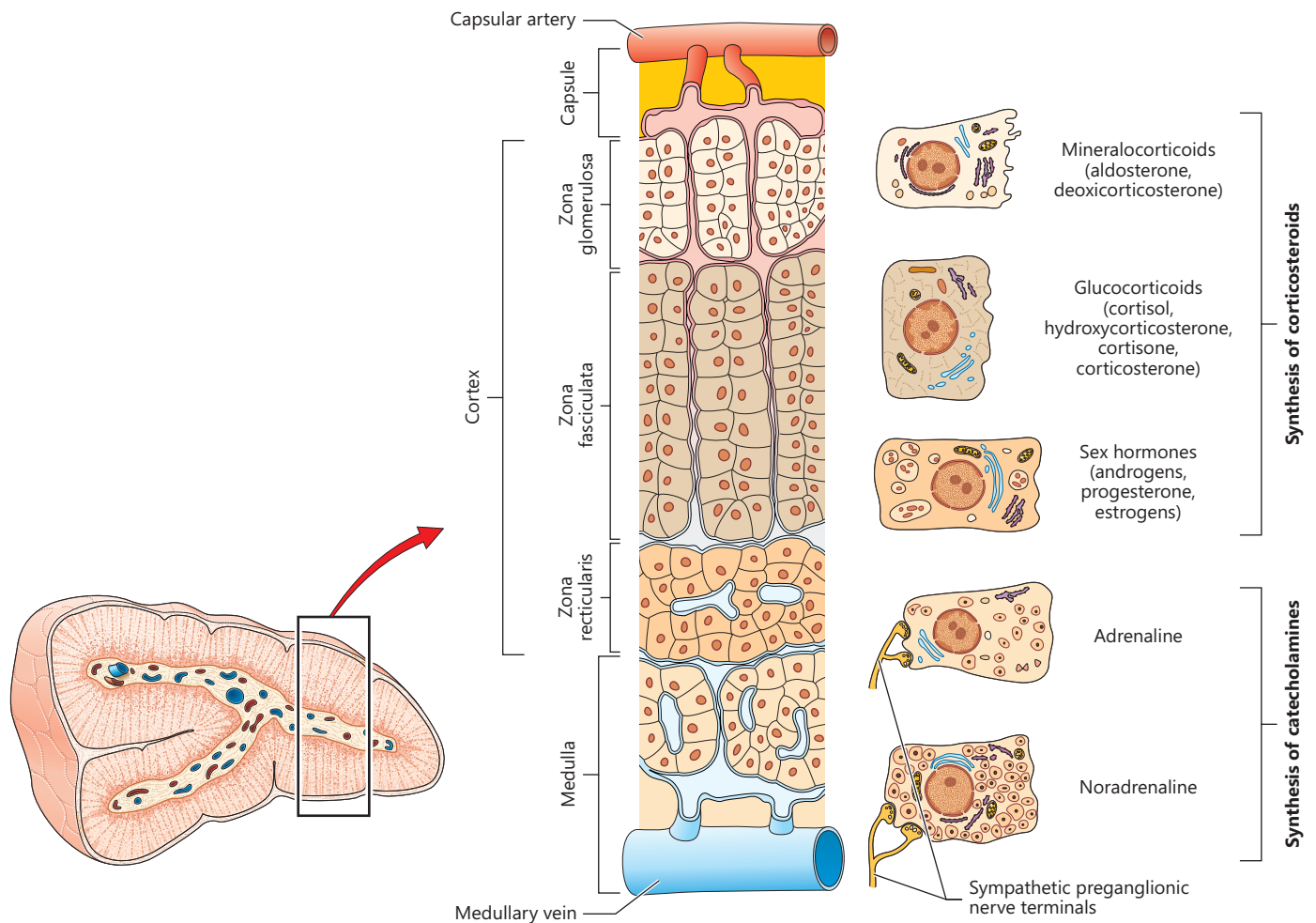
### Cortex

The *cortical parenchyma* consists of cellular cords separated by thin connective branches oriented radially towards the center of the organ. According to the particular organization of these cords, three different zones can be distinguished that, from the outside to the inside, are called: **zona glomer-**

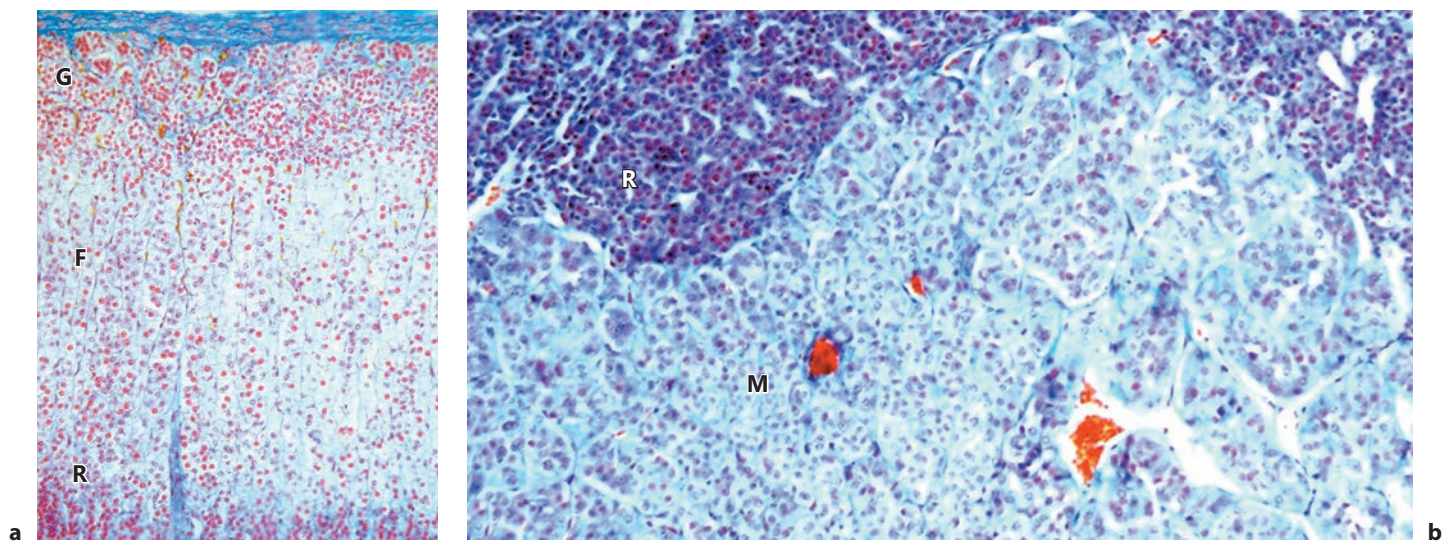
**ulosa**, **zona fasciculata** and **zona reticularis** (Figs. 12.58 and 12.59).

Each of these zones have a different enzymatic set which, starting from the same common precursor, the *cholesterol*, allows the synthesis of three distinct classes of steroid hormones: *mineralocorticoids*, synthesized in the zona glomerulosa, *glucocorticoids*, synthesized in the zona fasciculata, and *sex hormones*, produced in the zona reticularis.

Cholesterol is taken up by the blood via a specific membrane receptor for low-density lipoproteins. Most of the steroid hormone synthesis reactions are catalyzed by enzymes of the *cytochrome p450 family* (hydrolases) located on the mitochondrial membranes and on the smooth endoplasmic reticulum which, for this reason, are the most represented organelles within the cells of the cortex; in particular, the mitochondria are in symbiotic relation with the membranes of the smooth endoplasmic reticulum and have cristae typical of steroidogenic cells, whose morphology varies according to



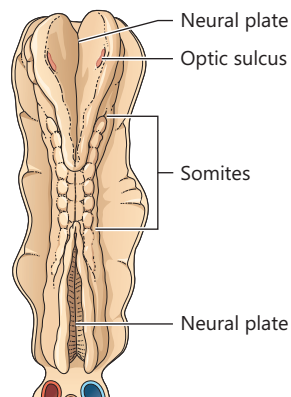
**Figure 12.58 - Suprarenal gland, cortex and medulla:** organization and hormones produced.



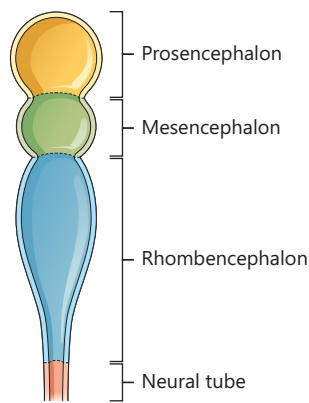
**Figure 12.59 - Structure of suprarenal gland,** optical micrographs. Azan-Mallory staining. **a**, Cortex of the suprarenal gland: the zona glomerulosa (G), zona fasciculata (F) and zona reticularis (R) are recognized under the connective tissue capsule. **b**, Medulla (M) of the suprarenal gland: the cords are short and variable intersected by a dense vascular network.



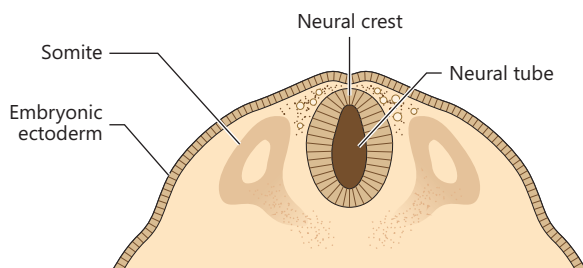
the *pseudounipolar ganglion cells* or T-shaped cells (or first neurons of the sensory pathways) of the posterior (or dorsal) roots of the spinal nerves and of the trigeminal (V pair), facial (VII pair), glossopharyngeal (IX pair) and vagus (X pair) cranial nerves and the bipolar ganglion cells of the vestibulocochlear nerve (VIII pair). Schwann cells, part of the cells of the



**Figure 13.39 - Human embryo at the 7-somite stage**, at approximately 22 days of embryonic life: schematic representation.



**Figure 13.40 - Formation of the primitive brain vesicles** that will give rise to the different segments of the central nervous system: schematic representation. The three vesicles originate from the cranial end of the neural tube.



**Figure 13.41 - Transverse section of the neural tube** immediately after its closure: schematic representation. The dorsal and lateral arrangement of the neural crests in the form of cell cords is also observed.

autonomic nervous system, melanocytes and chromaffin cells of the sympathetic paraganglia and of the medulla of the suprarenal gland also originate from the neural crests (**Fig. 13.42**).

## MORPHOGENESIS AND HISTOGENESIS OF THE NEURAL TUBE AND OF THE BRAIN VESICLES

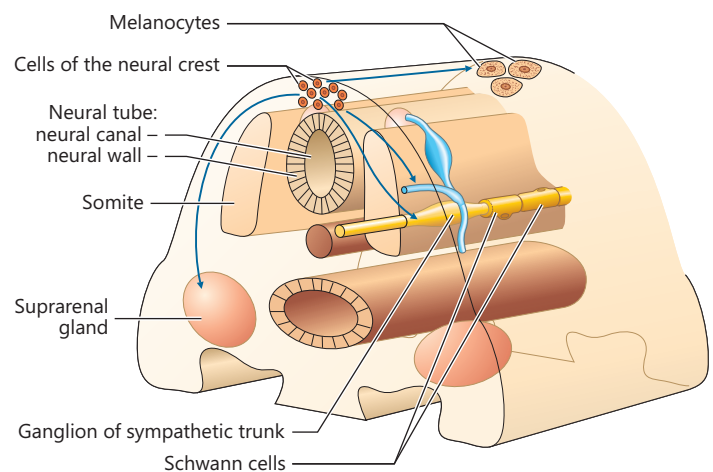
The closure of the neural tube is completed at the *25-somite stage* with the closure of the *posterior neuropore*. On the other hand, the closure of the cephalic part of the neural plate and the consequent formation of the three brain vesicles is completed at the *20-somite stage* with the closure of the *anterior neuropore*, which corresponds, at the end of the morphogenetic processes, to the *lamina terminalis*.

### NEURAL TUBE

The lumen of the neural tube, due to the initial histogenesis processes (→ *Histogenesis*), narrows and has the shape of a fissure with thick lateral walls and thin dorsal and ventral walls (**Fig. 13.43**).

During the post-somite stage, and until the third month, the primitive spinal cord has a cylindrical shape and extends the entire length of the embryo, from the sacrococcygeal part to the cervical flexure that separates it from the rhombencephalon, which is related to the position of the developing head.

Subsequently, the greater growth of the components of the future vertebral column, compared to the primitive spinal cord, results in the apparent retraction of the spinal cord, which stops at the level of the second or third lumbar vertebra



**Figure 13.42 - Differentiation of the central (from the neural tube) and the peripheral (from the neural crests) nervous system.**

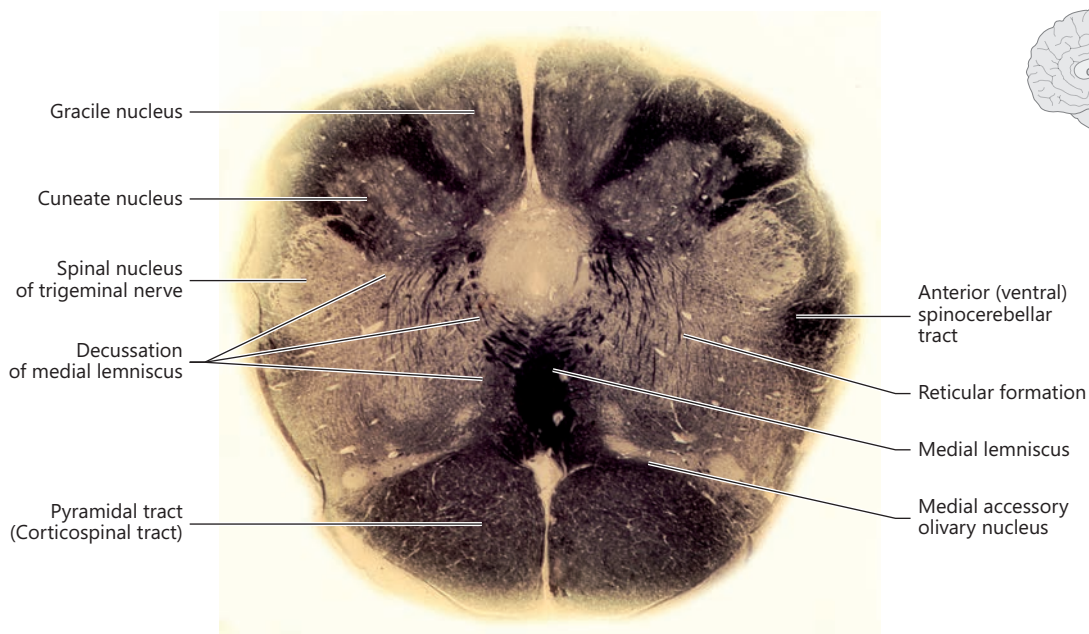
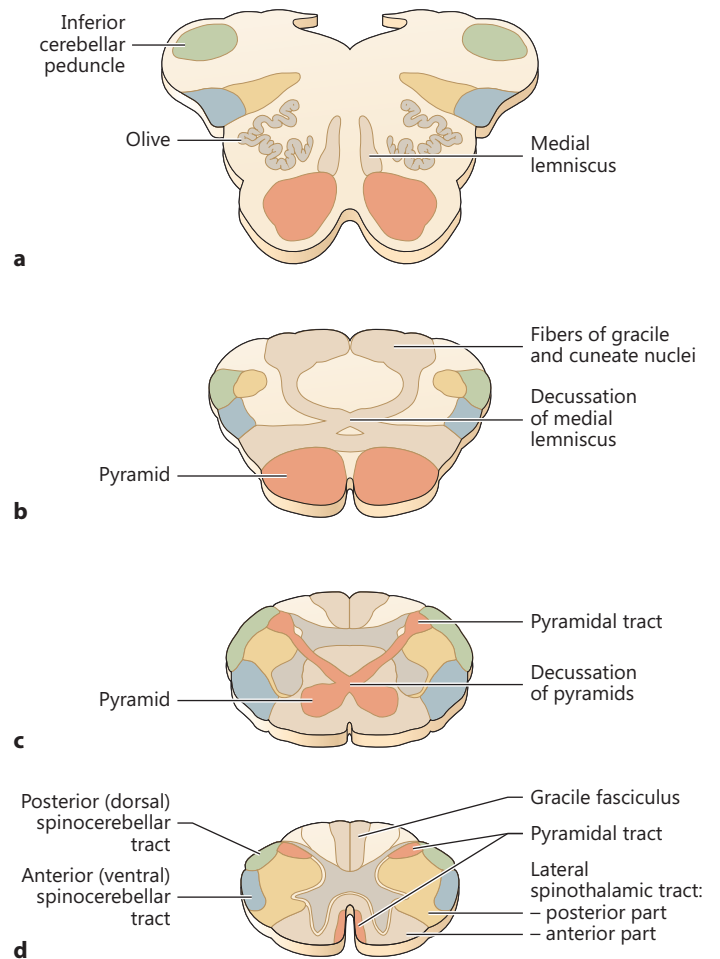
**Figure 13.100 - Medulla oblongata, sections.** **a**, Section of the medulla oblongata at the level of the olive; **b**, section of the medulla oblongata at the level of the decussation of medial lemniscus; **c**, section of the medulla oblongata at the level of the decussation of pyramids; **d**, section of the cervical portion of the spinal cord.

ing the lateral corticospinal tract. In addition, when looking at the anterior (ventral) median fissure, thin nerve fibers can be discerned leading diagonally from side to side (**Fig. 13.100**).

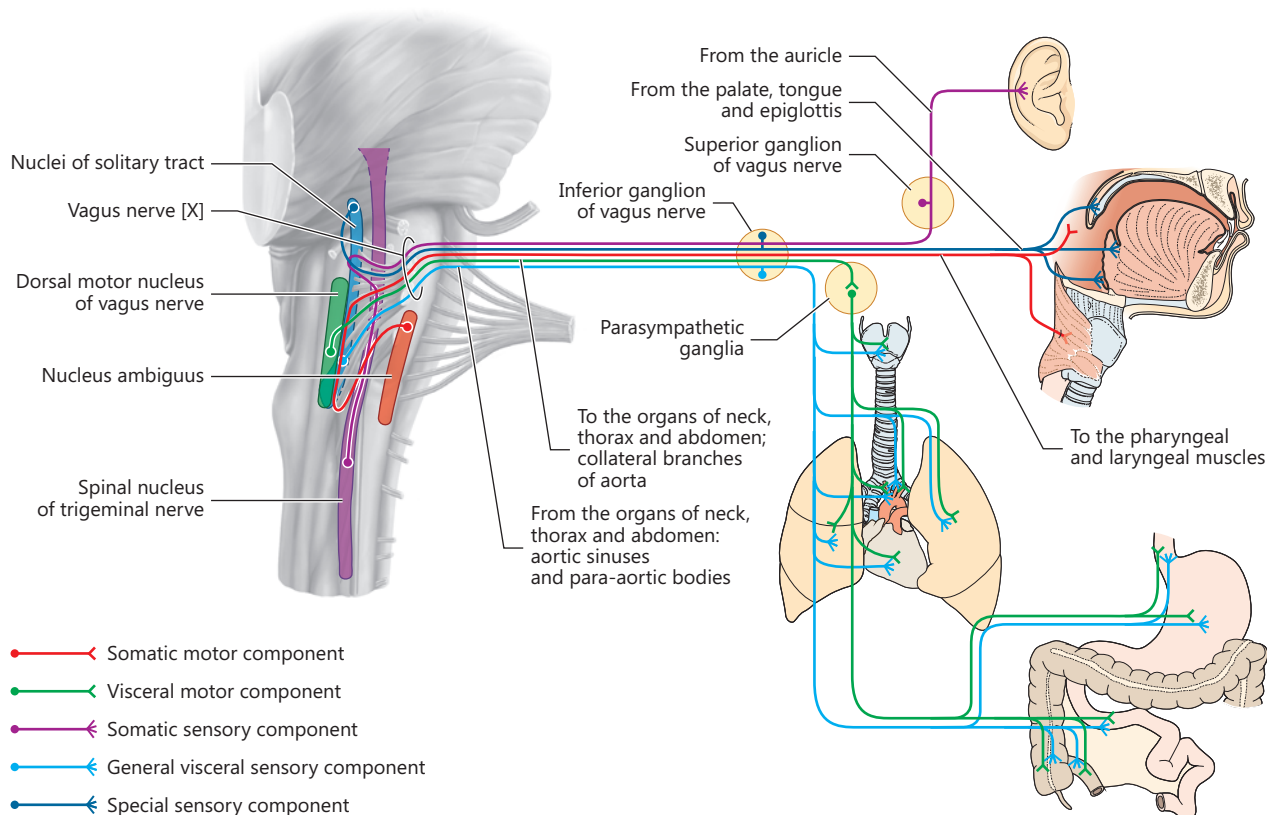
Also in the caudal part of the medulla oblongata, but superiorly to the motor decussation, where the central canal is still present, it is possible to observe, in correspondence to the posterior (dorsal) funiculi of white matter of the spinal cord containing the *gracile* and *cuneate fasciculi*, paired neuronal groups represented by the **gracile** and **cuneate nuclei**, corresponding to the *gracile* and *cuneate tubercles*, visible on the posterior surface of the brainstem (**Fig. 13.101**).

Fibers originating from the neurons of the gracile and cuneate nuclei of both sides cross the midline, anteriorly to the central canal, to form the medial lemniscus. The fibers involved in this crossing, which is the decussation of the medial lemniscus or sensory decussation, are called *internal arcuate fibers*. Crossing the contralateral ones, the internal arcuate fibers form a white stripe that extend along the median plane of the medulla oblongata, called **raphe of the medulla oblongata**.

From the **accessory cuneate nucleus** (also called external cuneate nucleus), situated posterolaterally to the cuneate nucleus, the *posterior (dorsal) external arcuate fibers* depart bilaterally, reaching the cerebellum through the inferior cerebellar peduncle. These *cuneocerebellar fibers*, which together



**Figure 13.101 - Caudal extremity of the medulla oblongata**, transverse section. Dorsally, it is possible to highlight the gracile and cuneate fasciculi with the relative nuclei, from which the internal arcuate fibers branch off and form the medial lemniscus. Dorsolaterally, the spinal tract and the spinal nucleus of trigeminal nerve are clearly visible. Ventrally, the pyramidal (or corticospinal) tract is observed. Weigert's staining for myelinated fibers. 2× (courtesy of Prof. R. De Caro).



**Figure 13.122 - Vagus nerve [X], nuclei and peripheral distribution.**

the otic ganglion for the innervation of the parotid gland, the glands of the cheek and the labial glands. The inferior salivatory nucleus receives afferents from the rostral part of the nucleus of the solitary tract (gustatory nucleus) which reflexively regulate the production of saliva in response to gustatory stimuli, as happens for the superior salivatory nucleus.

Preganglionic parasympathetic cholinergic fibers originate from the **dorsal motor nucleus of the vagus nerve**, also situated in the medulla oblongata, immediately under the floor of the fourth ventricle at the vagal trigone (gray wing), extending up to the most caudal part of the medulla oblongata in the periaqueductal gray substance. The dorsal motor nucleus of the vagus nerve constitutes the main source of preganglionic parasympathetic fibers in the whole brainstem, which come out with the vagus nerve; these fibers reach parasympathetic ganglia attached to numerous innervated organs (trachea, bronchi, heart, esophagus, stomach, small intestine and part of the large intestine near the left colic flexure or, according to some authors, up to the whole descending colon). In this nucleus, neuronal groups are distinguished, each responsible for the innervation of defined organs, so that, for example, the heart and lungs are somatotopically represented in the caudal and lateral parts of the nucleus. The dorsal motor nucleus of the vagus nerve receives afferents from sensory nuclei placed in proximity, mainly from the nucleus of the solitary tract, relevant for reflex ac-

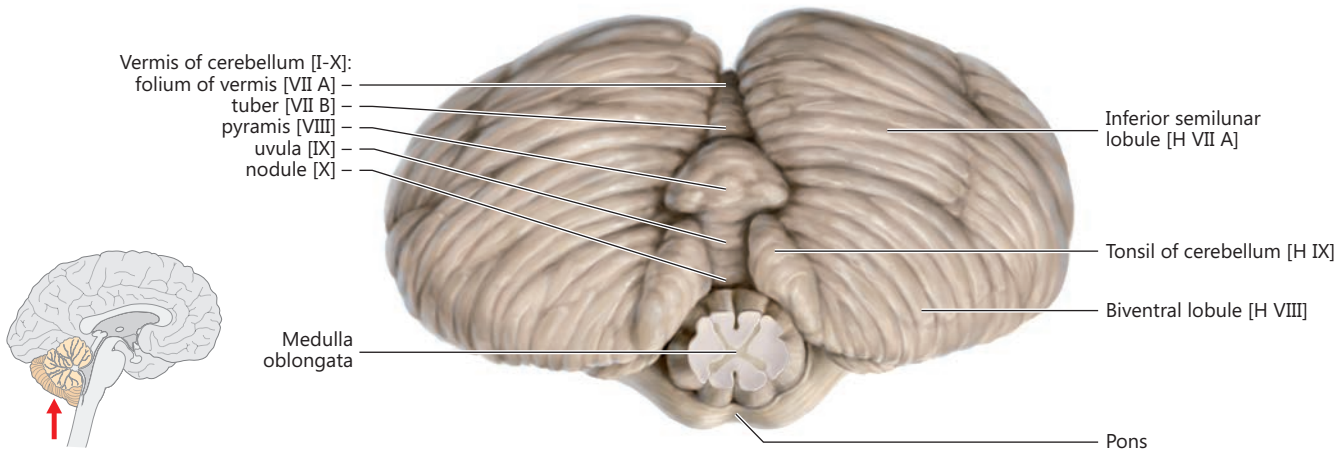
tivities, and from regions of the neuraxis that regulate the activity of the autonomic nervous system, such as hypothalamus and reticular formation.

**Visceral sensory component** - The two contingents of visceral sensory fibers that enter the medulla oblongata with the glossopharyngeal nerve and the vagus nerve are directed inferiorly constituting the solitary tract (already described with the facial nerve), which extends for the whole length of the medulla oblongata running laterally to the dorsal motor nucleus of the vagus until it reaches a neuronal column situated laterally to it (**nucleus of the solitary tract**) (see Figs. 13.115, 13.121 and 13.122). The cranial part of the nucleus of the solitary tract also receives visceral sensory fibers which have entered the brainstem with the facial nerve. Caudally to these neurons are arranged, in order, the neurons to which the fibers of the glossopharyngeal and vagus nerves arrive, respectively originated from the cells in the **inferior** or **petrosal ganglion** of the glossopharyngeal nerve (located along the course of the nerve leaning inferiorly against the petrous part or pyramid of the temporal bone) and in the **inferior** or **nodose ganglion** of the vagus nerve (located along the course of the nerve in the jugular foramen at its exit from the cranium). In the same nucleus terminate the fibers conveying the general visceral sense from the territories innervated by the two nerves (pharynx, larynx, viscera of the thoracic and ab-

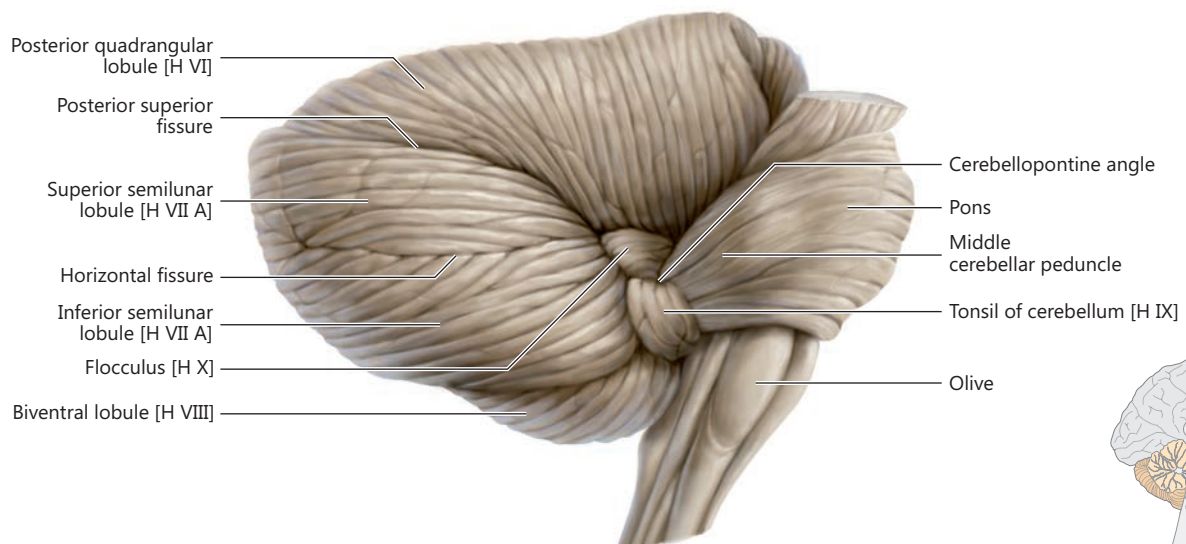




**Figure 13.128 - Superior surface of the cerebellum, external configuration.**



**Figure 13.129 - Inferior surface of the cerebellum, external configuration.**



**Figure 13.130 - Lateral view of the cerebellum, external configuration.**

The flocculi, being constituted by a small group of lamellae independent from the cerebellar hemispheres, can be considered as a separate lobe, to which, for phylogenetic reasons, the nodule is associated and to which is therefore given the name of **flocculonodular lobe**.

The cerebellar hemispheres relate inferiorly and posteriorly with the cerebellar fossae of the squamous part of the occipital bone, while, especially on the posterior side of the vallecule of the cerebellum, the **falx cerebelli** (or *cerebellar falx*) is housed (see **Fig. 13.131**), an incomplete sagittal fold of the cranial dura mater, which inferiorly contributes to delimit the **posterior cerebellomedullary cistern** or *cisterna magna*.

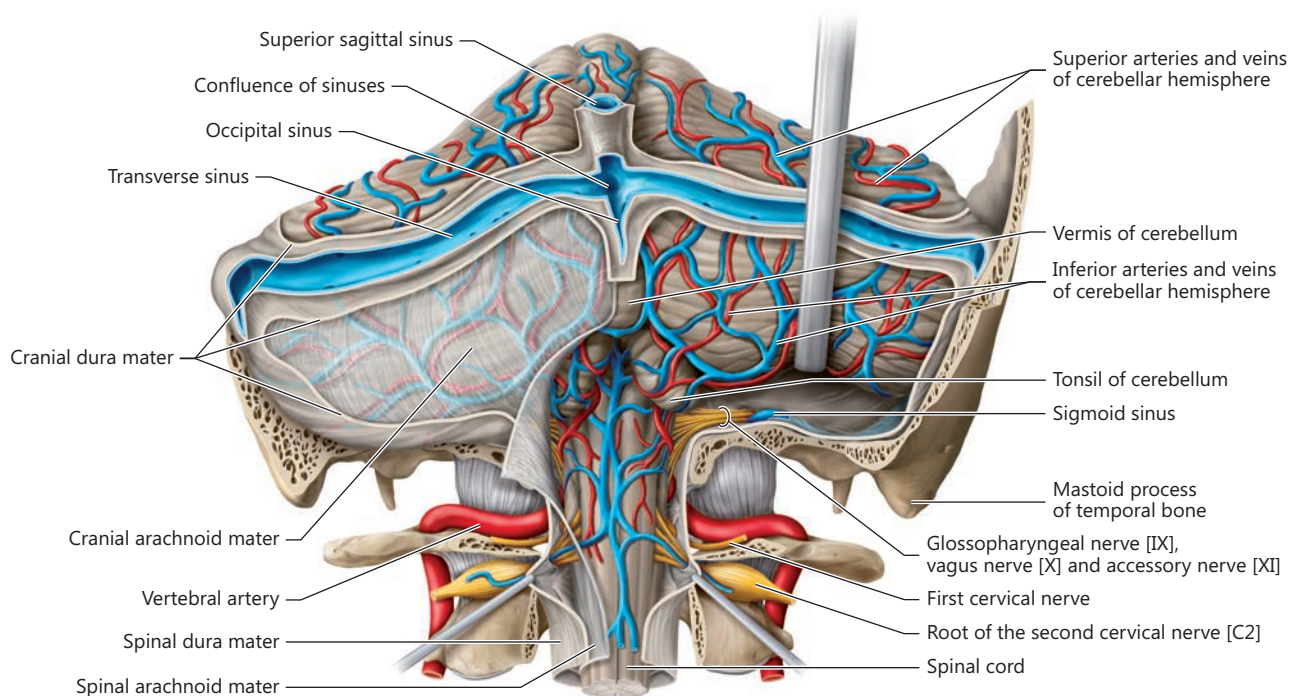
In detail, while the pia mater covers the inferior surface of the cerebellar hemispheres and from here reflects onto the posterior surface of the medulla oblongata, the arachnoid mater and, on the outside, the dura mater directly lead from the circumference of the cerebellum to the posterior surface of the medulla oblongata, delimiting the posterior cerebellomedullary cistern, subarachnoid reservoir of cerebrospinal fluid, where the lateral apertures of the fourth ventricle (or foramina of Luschka) and the median aperture of the fourth ventricle (or foramen of Magendie) open (see **Figs. 13.266** and **13.267**). The posterior cerebellomedullary cistern plays a fundamental crossroads role in the circulation of the cerebrospinal fluid, but it should be remembered that, together with the other cisterns, constitutes a true hydraulic damper that guarantees cerebral statics, given the great mobility of the head made possible by the atlanto-occipital joint.

### Circumference

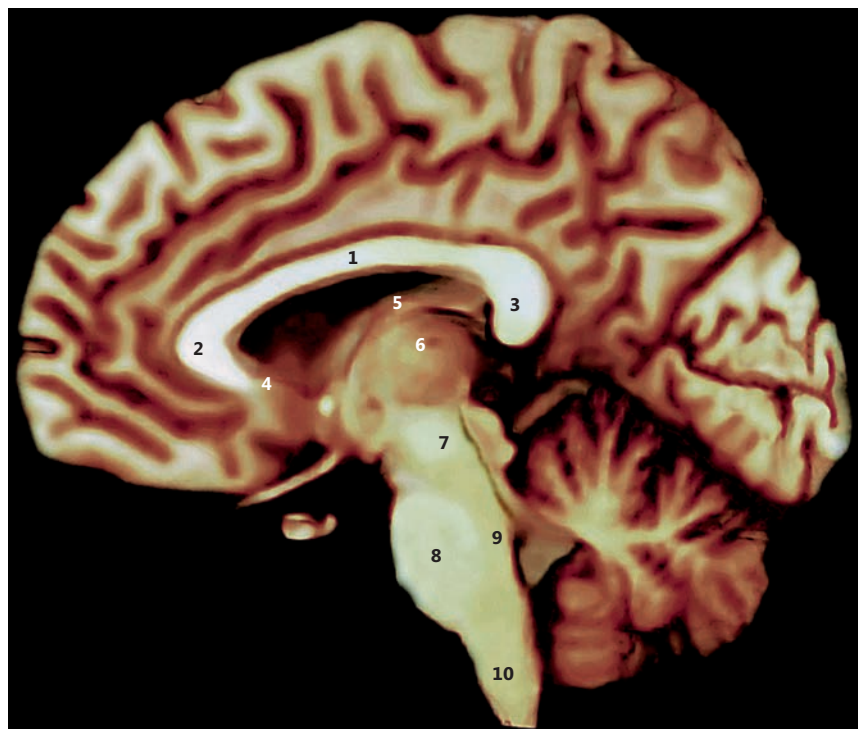
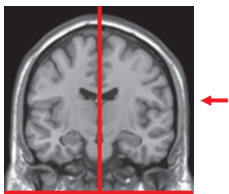
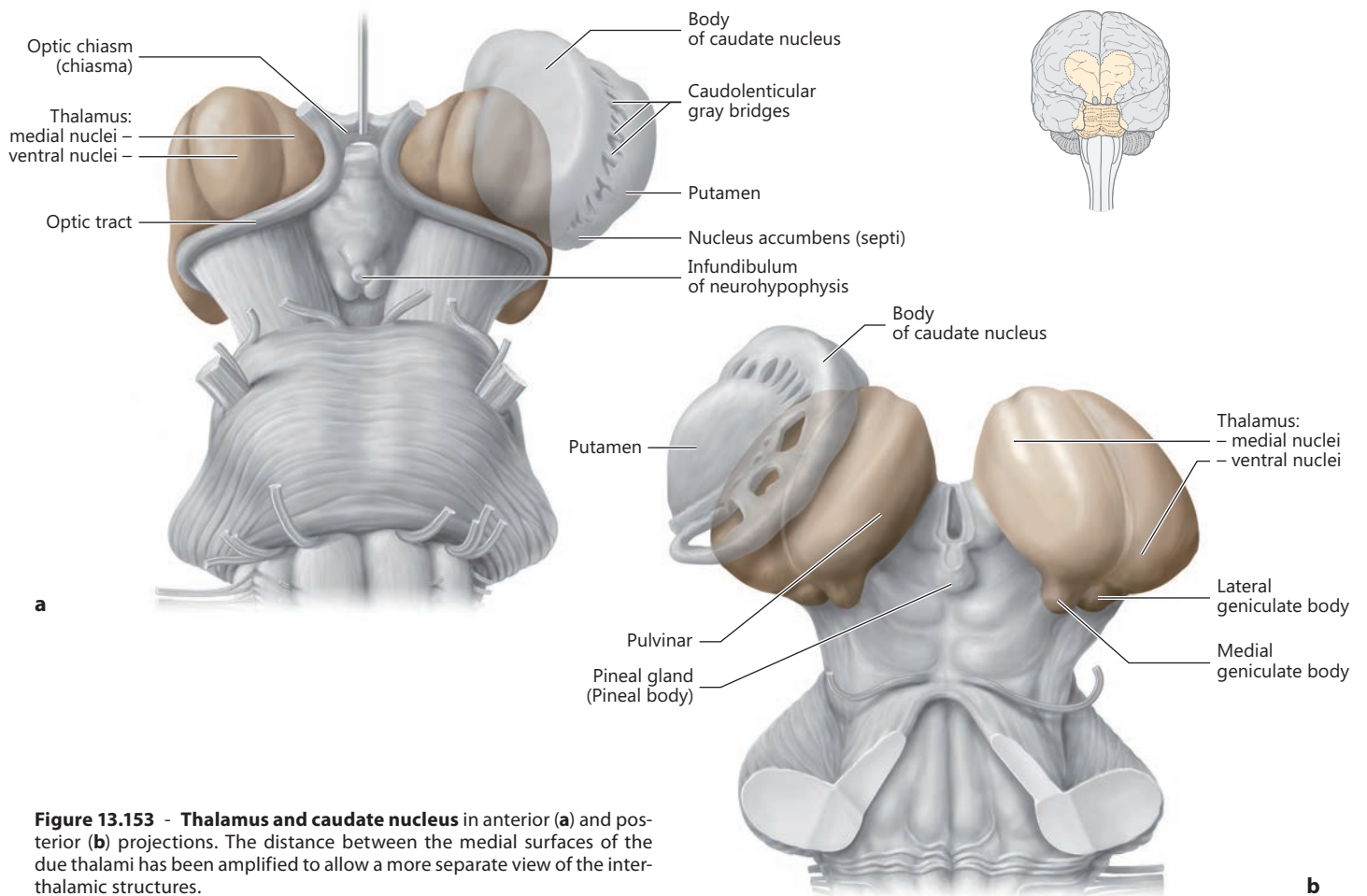
Smooth and rounded, it corresponds to a virtual line that delimits the superior surface of the cerebellum from the inferior one and has two notches, one posterior and one anterior. The **posterior notch** is less extended and deep than the anterior notch; it hosts the falx cerebelli in correspondence to its origin, superiorly, from the tentorium cerebelli and corresponds, on the intracranial surface of the occipital bone, to the internal occipital protuberance, from which it is separated through the interposition of the confluence of the sinuses, housed in the thickness of the dura mater.

The **confluence of the sinuses** (➔ **Figs. 4.165, 4.166** and **15.55**) receives the **straight sinus**, located medially in the thickness of the tentorium cerebelli, and the **superior sagittal sinus**, which runs along the intracranial border of the falx cerebelli (or cerebellar falx), and continues, on each side, with the **transverse sinus**, received in the groove for the transverse sinus of the intracranial surface of the squamous part of the occipital bone (see **Fig. 13.131**). The right and left transverse sinuses, although sometimes asymmetrical in terms of location and volume, are related to the posterior side of the circumference of the cerebellum (**Fig. 13.133**).

Each transverse sinus continues with the **sigmoid sinus**, which is interposed between the posterior surface of the petrous part of the temporal bone and the anterolateral side of the circumference of the cerebellum, moves forward and medially and opens through the jugular foramen into the superior bulb of the internal jugular vein (see **Figs. 13.132** and **13.133**).



**Figure 13.133 - Cerebellum**, posterior view. On the right, the cerebellum has been elevated and the cranium demolished to show the sigmoid sinus reaching the jugular foramen.



**Figure 13.154 - Location and relations of the thalamus,** a three-dimensional image of a living human body, obtained by NMR using a 3D volume rendering technique, showing the configuration of the telencephalon in median sagittal section.

- 1, Trunk of corpus callosum
- 2, Genu of corpus callosum
- 3, Splenium of corpus callosum
- 4, Rostrum of corpus callosum
- 5, Fornix
- 6, Thalamus
- 7, Tegmentum of midbrain
- 8, Pons
- 9, Tegmentum of pons
- 10, Medulla oblongata.



It has been shown that homolateral stereotactic electrocoagulation of the lateral hypothalamic area in obese subjects causes a transient suppression of appetite and a slight body weight. On the other hand, if lesion of this area is induced bilaterally, there is a drastic reduction in body weight that is accompanied by anorexia.

Based on these data, it seems clear that in the *lateral hypothalamic area* is located the so-called “hunger center”, while in the *medial hypothalamic area*, which corresponds to the medial part of the tuberal area, and in the *paraventricular nucleus* of the anterior hypothalamic area is located the “satiety center”.

The **arcuate nucleus** of the tuberal area, involved in modulating the secretory activity of the adenohypophysis, also plays an important role in integrating the hunger center and the satiety center, thus regulating the appetite-satiety balance. In other words, the arcuate nucleus integrates the signals of satiety coming from the gastroenteric canal, through the fibers of the vagus nerve that form synapses with the nucleus of the solitary tract, with the hunger and satiety signals coming through the bloodstream and stimulates, by secreting specific neuropeptides, alternately first one and then the other center. The *medial hypothalamic area* and the *lateral hypothalamic area* are also involved, always carrying out different or almost

opposite activities, in the emotional behavior. In fact, there are valid scientific data showing that both in experimental animals and in humans the medial hypothalamic area, in particular the ventromedial nucleus of the hypothalamus, is responsible for defensive behaviors, while the lateral hypothalamic area is responsible for the aggressive or predatory behaviors.

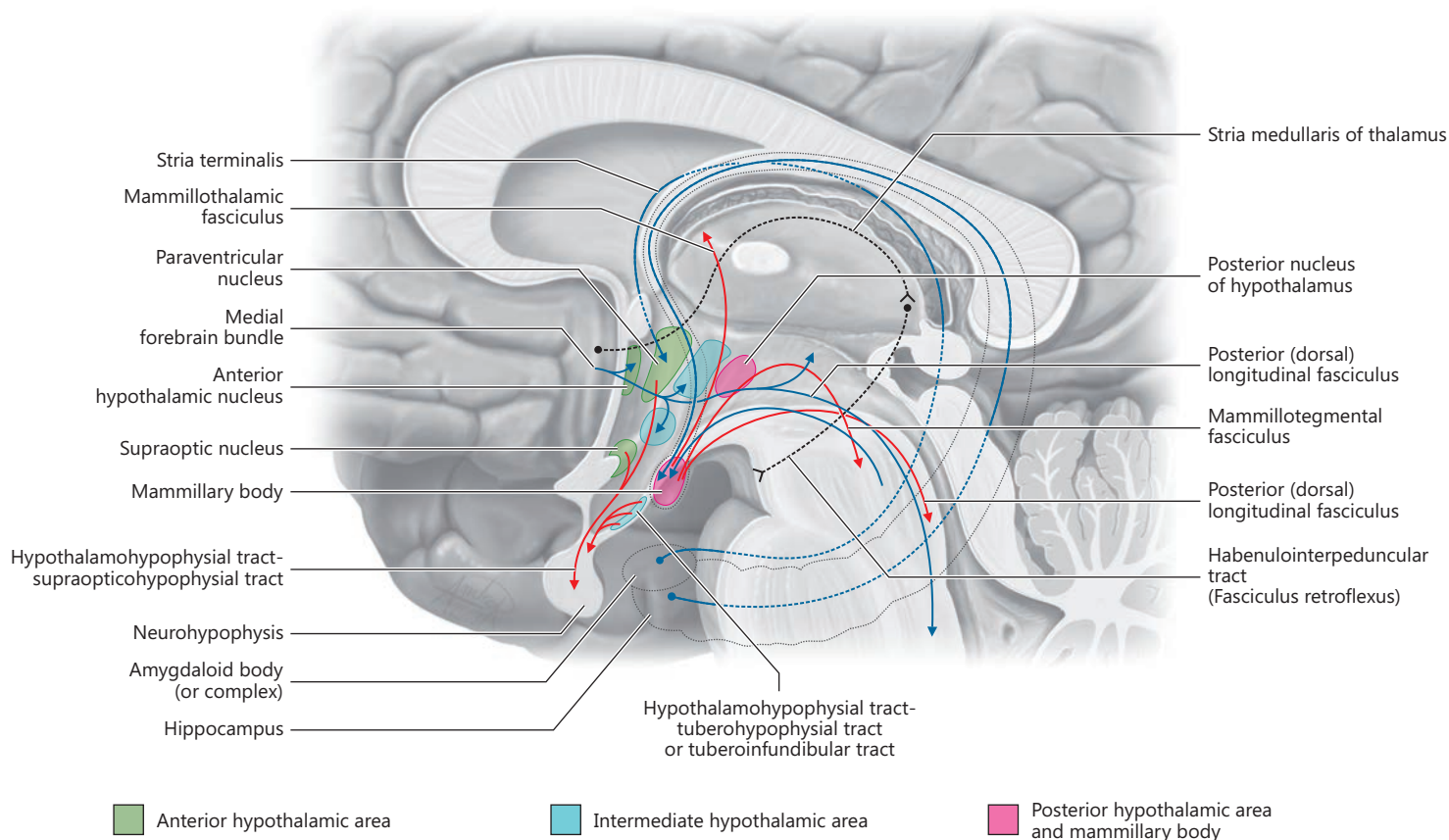
### Connections of the hypothalamus

The white matter of the hypothalamus is formed by its connections, which can be distinguished into three groups:

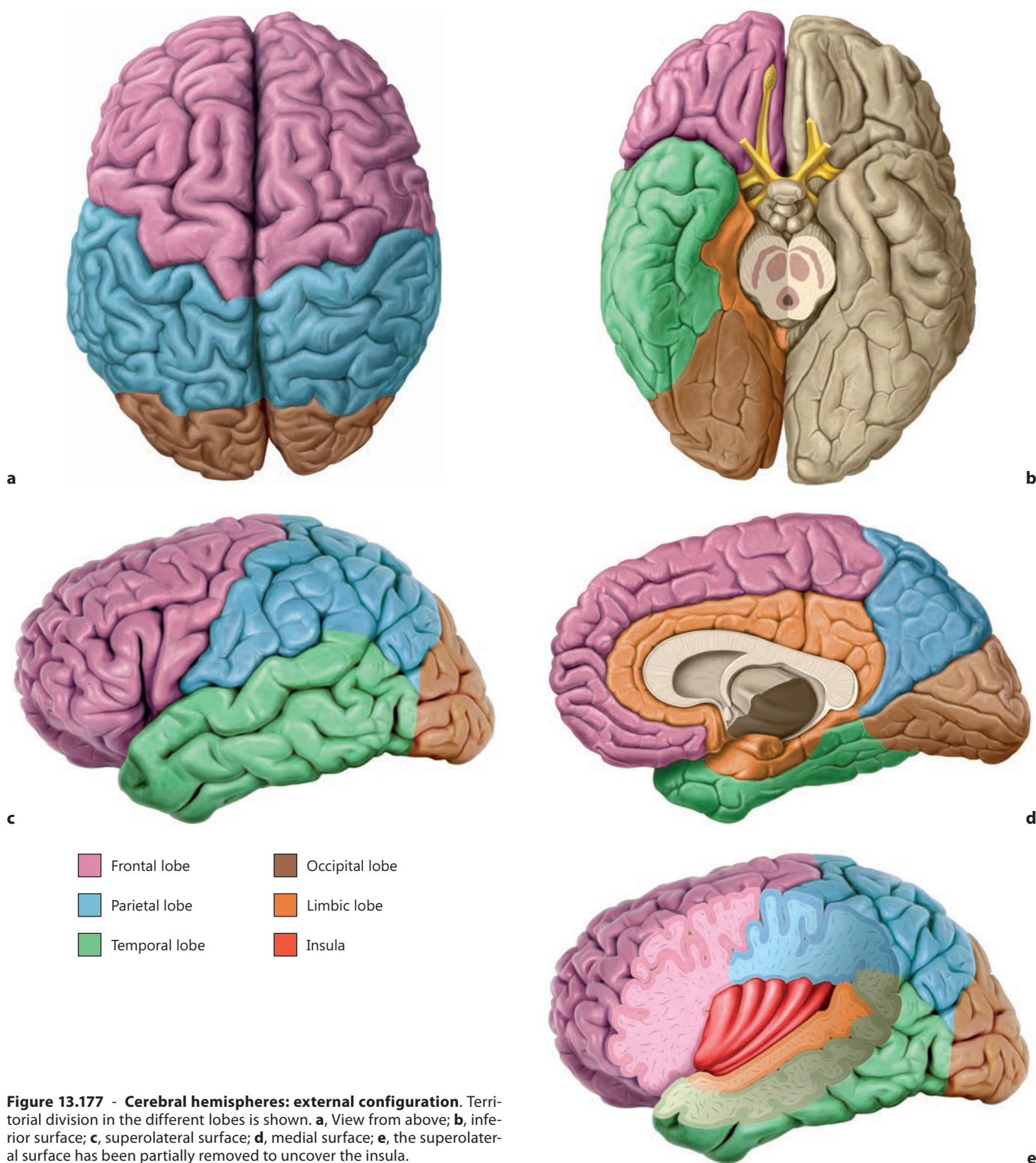
- caudal connections with the brainstem and the spinal cord
- intradiencephalic connections
- rostral connections with the basal nuclei and the cerebral cortex.

**Caudal connections** - The connections with the brainstem and the spinal cord consist of the *posterior* or dorsal *longitudinal fasciculus* and the *mammillotegmental fasciculus* (Fig. 13.165).

The **posterior** (or dorsal) **longitudinal fasciculus** (or bundle of Schütz) is initially part of the periventricular system, mainly originating from the posterior hypothalamic nucleus. It then moves into the mesencephalon (midbrain), placing it-



**Figure 13.165 - Main afferences and efferences of the hypothalamus:** schematic representation showing part of the brain in sagittal section. Afferences (blue lines), efferences (red lines).

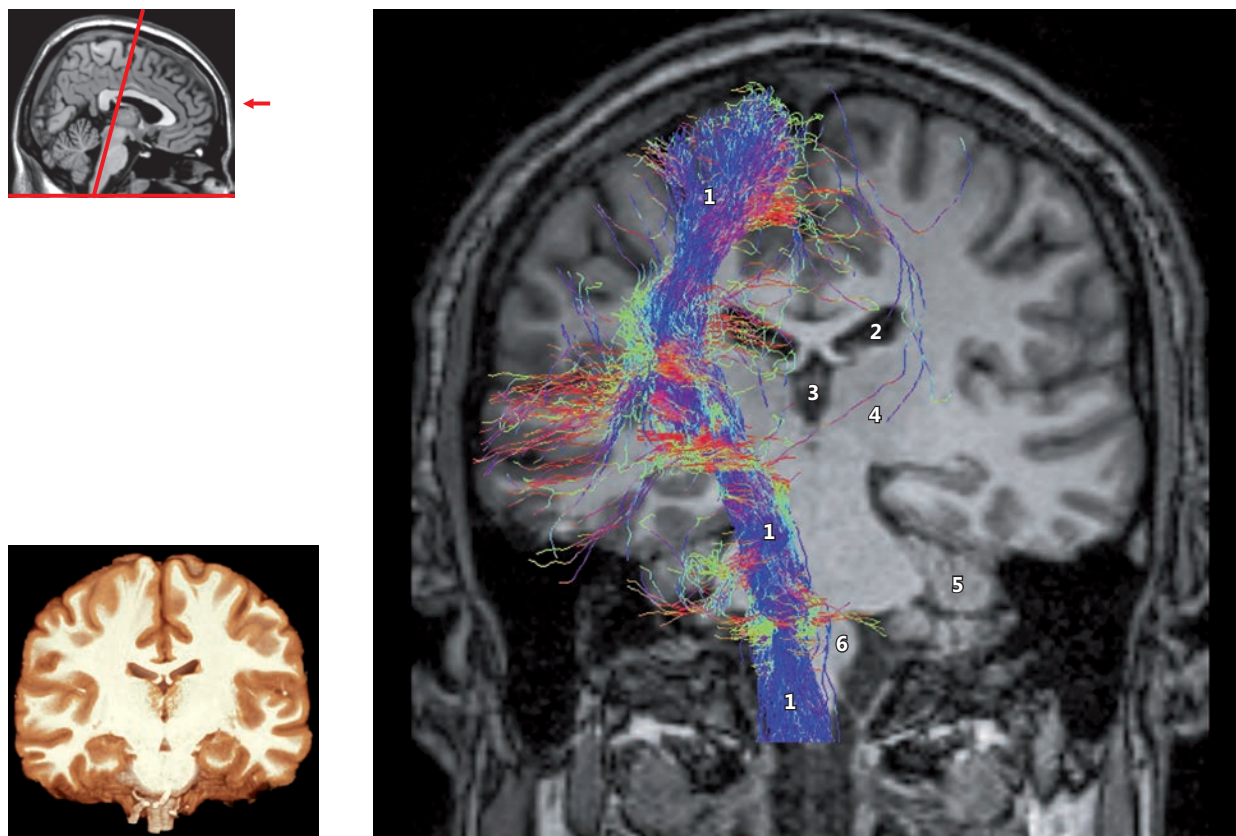


**Figure 13.177 - Cerebral hemispheres: external configuration.** Territorial division in the different lobes is shown. **a**, View from above; **b**, inferior surface; **c**, superolateral surface; **d**, medial surface; **e**, the superolateral surface has been partially removed to uncover the insula.

cus; the *triangular* or middle part (*pars triangularis*) is between the horizontal ramus and the ascending ramus of the lateral sulcus; the *opercular* or posterior part (*pars opercularis*) is located between the ascending ramus and the central sulcus (see Fig. 13.180).

On the medial surface of the cerebral hemisphere, the frontal lobe is separated from the limbic lobe by the cingulate sulcus and from the parietal lobe by the central sulcus; anteriorly to the latter, a small sulcus delimits the **paracentral lobule** (see Fig. 13.181).





**Figure 13.216** - Projections of white matter to the corticospinal tract are highlighted with colors tracking the spatial orientation of the fibers. In *green* fibers following the anteroposterior direction, in *blue* the superoinferior direction and in *red* the laterolateral direction. Three-dimensional image of a living human body obtained by DTNMR using a tractography technique. **1**, pyramidal tract; **2**, lateral ventricle; **3**, third ventricle; **4**, internal capsule; **5**, cerebellum; **6**, medulla oblongata.

The **central (or superior) thalamic radiation** is directed to the parietal lobe and between its fibers there are those that come from the ventral posterolateral and ventral posteromedial nuclei of the thalamus and project to the primary somatosensory area.

The **posterior thalamic radiation** passes through the retrolentiform (or retrolenticular) limb of the posterior limb of the internal capsule, which also includes the fibers of the geniculocalcarine tract, or optic radiation, reaching the cortex of the occipital pole.

The **inferior thalamic radiation** passes through the sublenticular (or sublenticular) part of the posterior limb of the internal capsule, which also includes the fibers of the geniculotemporal tract, or acoustic radiation, reaching the cortex of the temporal lobe.

**Corticofugal fibers** (or efferent fibers) - They mainly come from the effector areas of the cerebral cortex and involve the underlying capsules. The main system of corticofugal pathways is the one originating from the motor areas, known as pyramidal pathways (**Fig. 13.216**).

The **pyramidal pathways** must be distinguished into a contingent destined to the somatomotor nuclei of the cranial

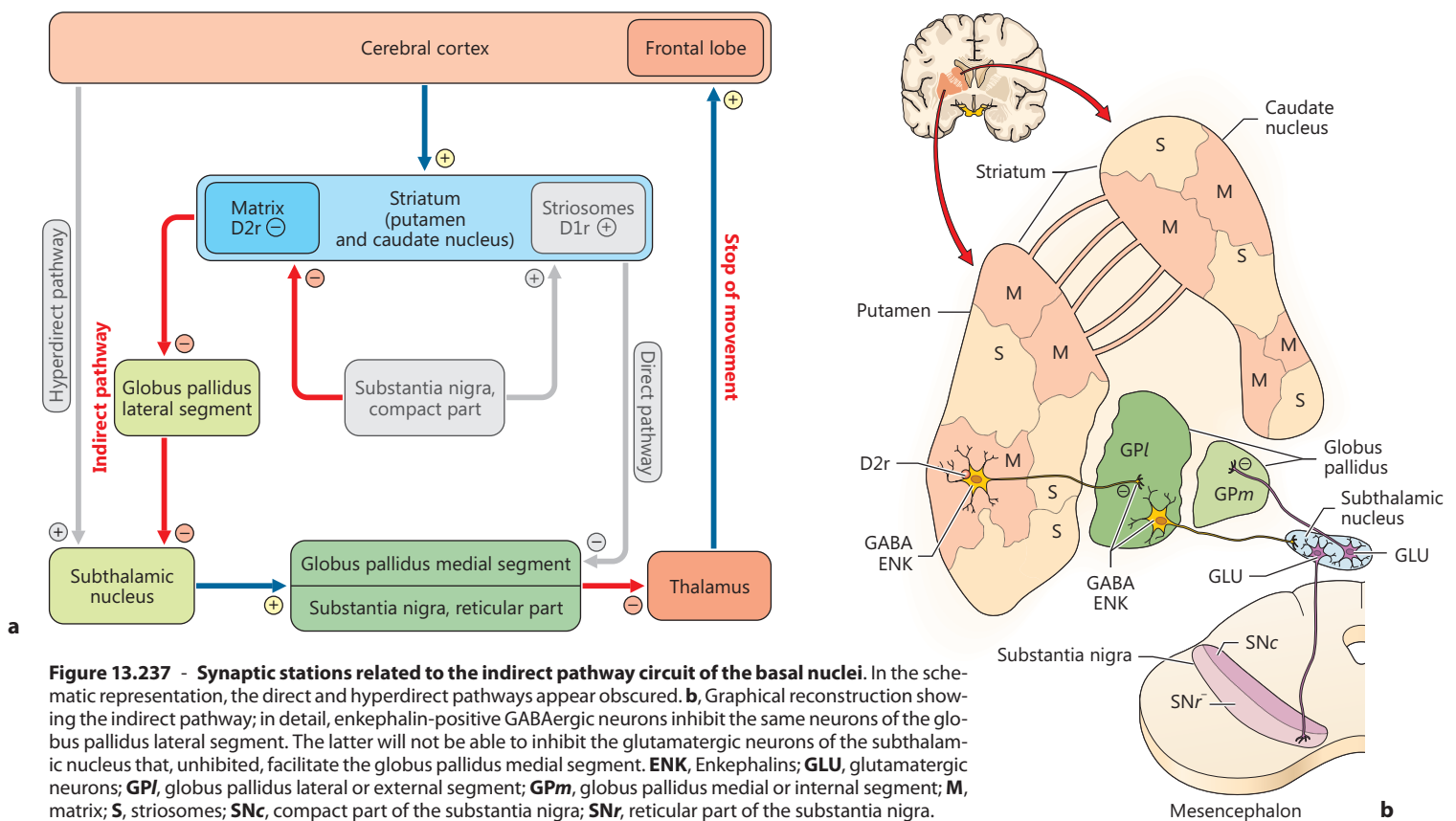
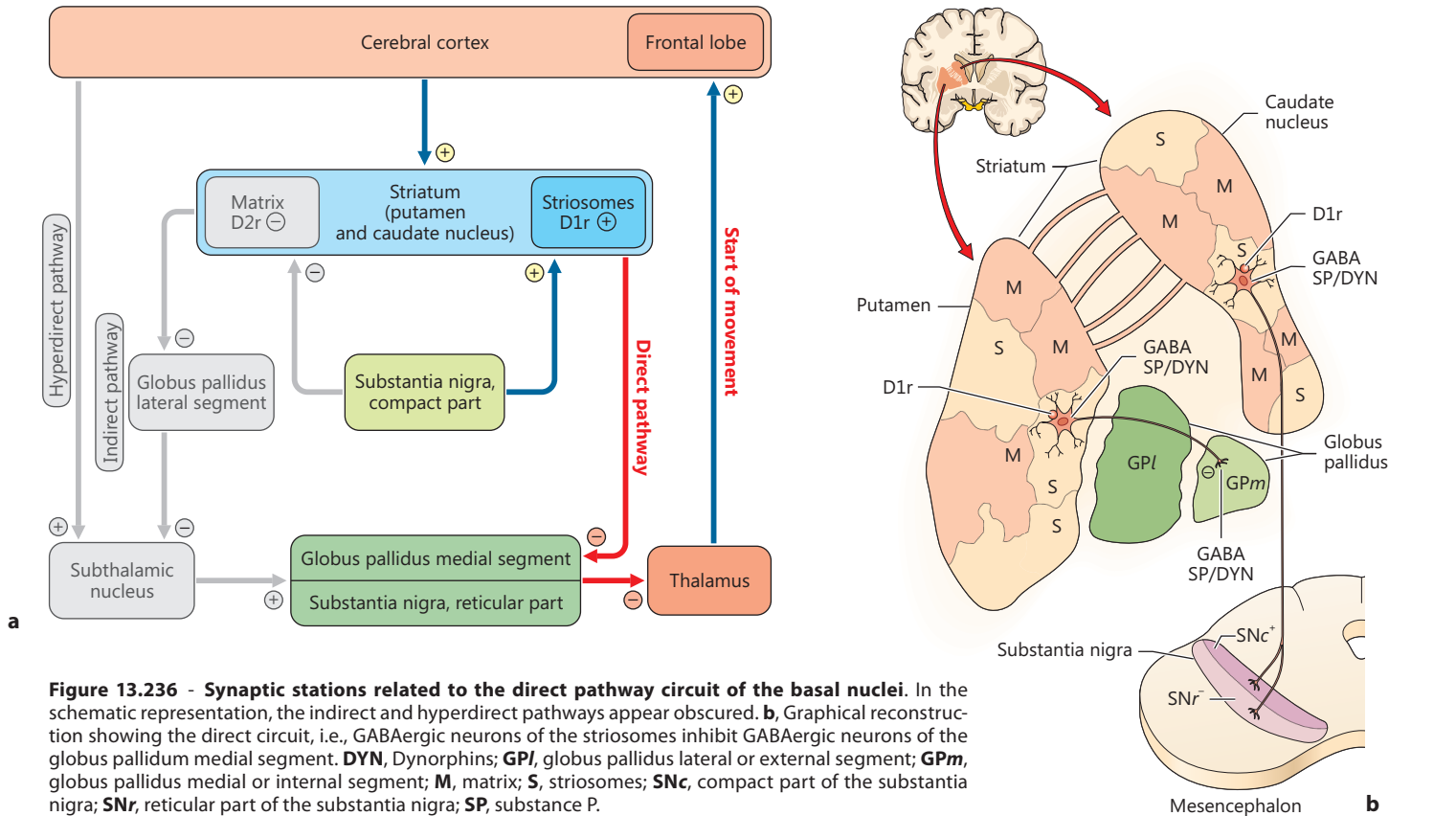
nerves, known as **corticonuclear fibers** or *tract*, which passes through the genu of the internal capsule, and a contingent of fibers destined to the motor neurons of the anterior (ventral) horns of the spinal cord, called **corticospinal fibers** or *tract*.

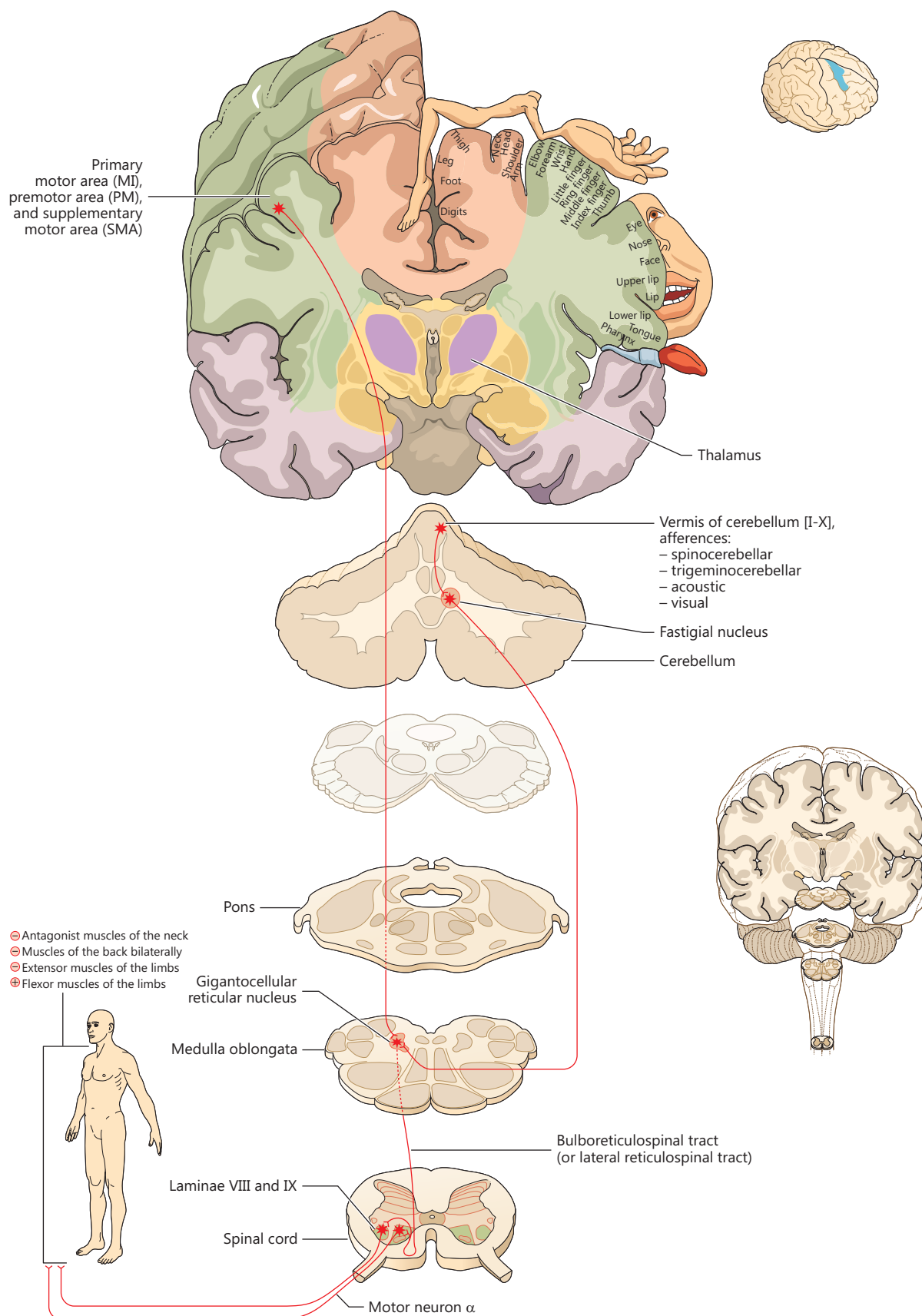
The part of corticospinal fibers destined to the muscles of the upper limb runs in the most anterior part of the posterior limb of the internal capsule, thus resulting adjacent to the corticonuclear tract. The part of corticospinal fibers destined to the muscles of the trunk runs in the posterior limb of the internal capsule, posteriorly to the contingent of corticospinal fibers destined to the muscles of the upper limb, while the part of corticospinal fibers destined to the muscles of the lower limb runs in the most posterior part of the posterior limb of the internal capsule, thus resulting adjacent to the fibers running in the retrolentiform (or retrolenticular) part of the posterior limb of the internal capsule.

This somatotopic organization of the fibers of the pyramidal tract is of semiological importance in cases of vascular lesions of the internal capsule.

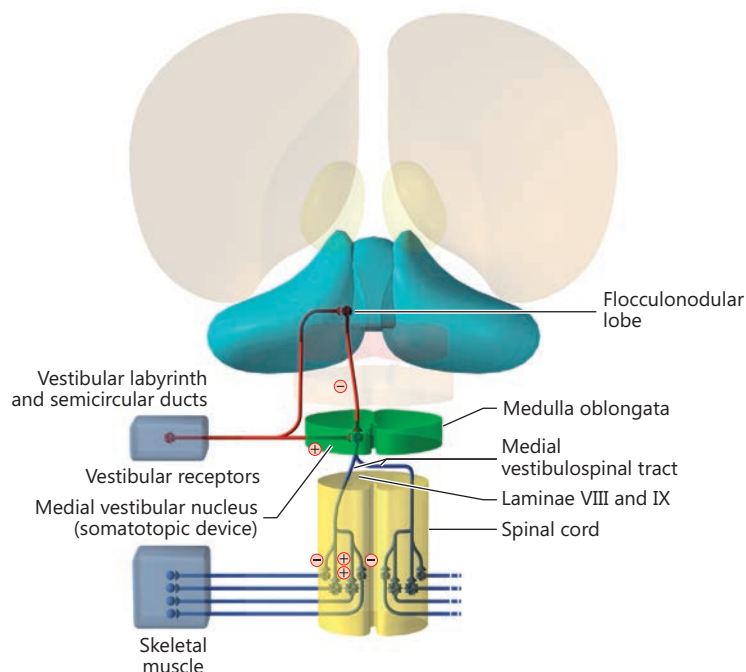
This **corticopontine fibers**, destined to the neocerebellum, also pass through the internal capsule. In detail, the **frontopontine tract** passes through the anterior limb of the







**Figure 13.334 - Course of the lateral bulboreticulospinal tract (or lateral reticulospinal tract): schematic representation.**



The **vestibulospinal tracts (lateral and medial)**, are the only tracts among the extrapyramidal pathways not receiving afferences from the cerebral cortex, and coordinate the spinal mechanisms directed at maintaining the head in a vertical position with respect to the force of gravity

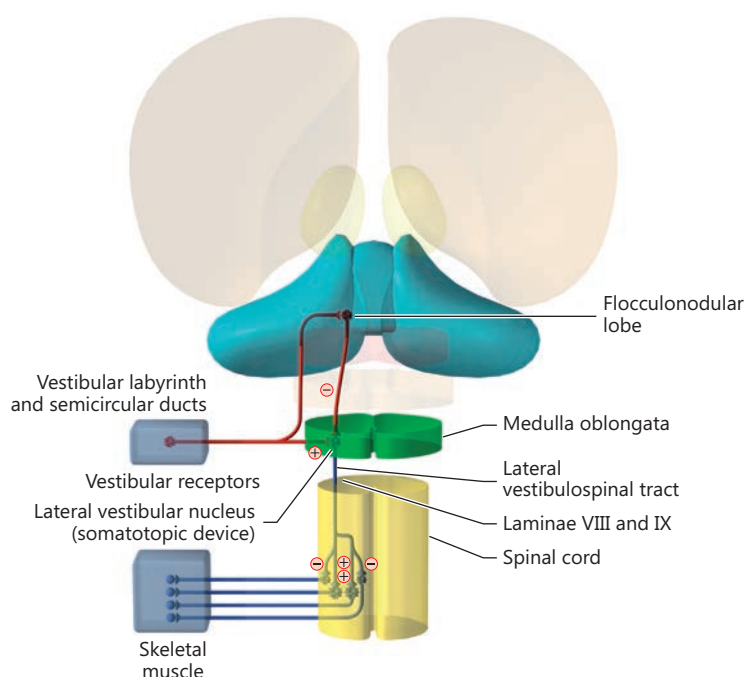
Upper motor neuron	Non existent	
Medial vestibular nucleus	From the medial vestibular nucleus to the laminae VIII and IX of the spinal cord, up to the medi thoracic neuromeres	<i>Afferences</i> – vestibular receptors – cerebellar cortex of the flocculonodular lobe directly without synapses to the fastigial nucleus or nucleus medialis cerebelli
Lower motor neuron	The motor neurons $\alpha$ and $\gamma$ innervating the extensor muscles of the neck and upper limb are facilitated. The motor neurons $\alpha$ and $\gamma$ innervating the flexor muscles of the neck and the upper limb are inhibited	

Figure 13.335 - Medial vestibulospinal tract: schematic representation.

conclusion, it can be said that the reticulospinal system coordinates posture with movement by integrating vestibular signals with information from muscle proprioceptors and spinal afferents and comparing them with the motor commands from the cerebral cortex.

### Medial and lateral vestibulospinal tracts

The system of the *medial vestibulospinal* (Fig. 13.335) and *lateral vestibulospinal tracts* (Fig. 13.336) originates from the **vestibular nuclei** located under the floor of the



Upper motor neuron	Non existent	
Lateral vestibular nucleus	From the lateral vestibular nucleus to the laminae VIII and IX of the spinal cord, up to the lumbosacral neuromeres	<i>Afferences</i> – vestibular receptors – cerebellar cortex of the flocculonodular lobe directly without synapses to the fastigial nucleus or nucleus medialis cerebelli
Lower motor neuron	The motor neurons $\alpha$ and $\gamma$ innervating the extensor muscles of the neck and upper limb, and the flexor muscles of the lower limb are facilitated. The motor neurons $\alpha$ and $\gamma$ innervating the flexor muscles of the neck and upper limb, and the extensor muscles of the lower limb are inhibited	

Figure 13.336 - Lateral vestibulospinal tract: schematic representation.



## VOMERONASAL ORGAN

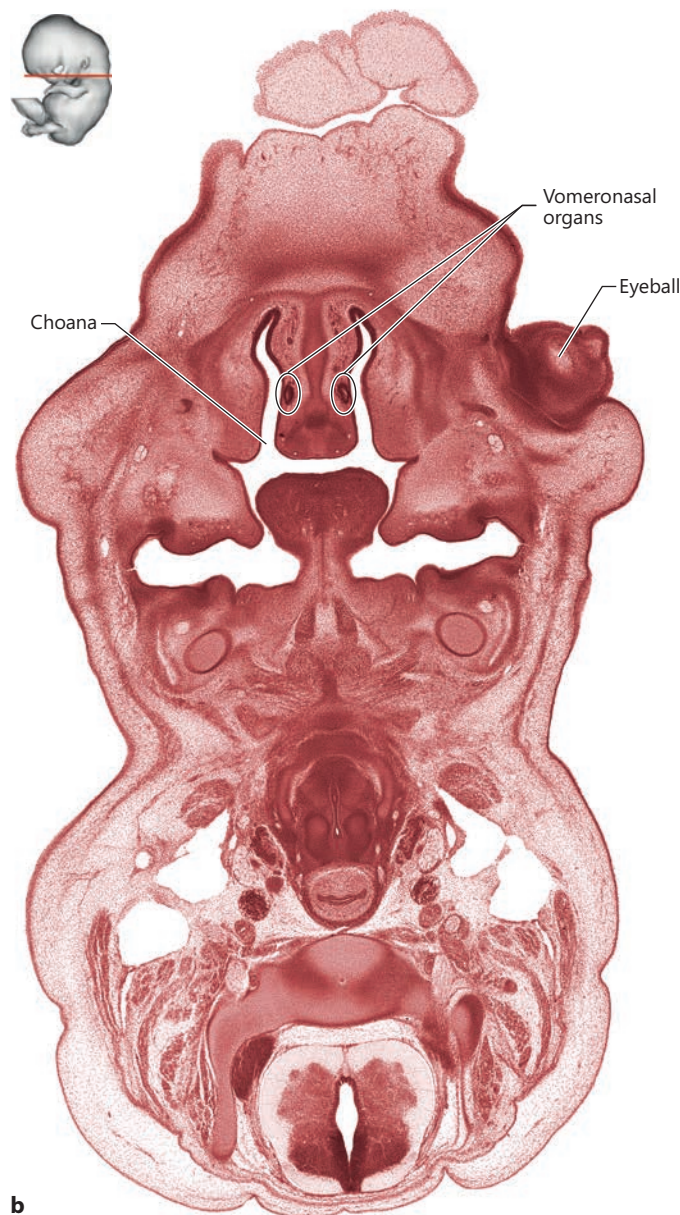
The *vomeronasal organ* is a tubular structure situated in the context of the nasal septum, equipped with a duct that opens into the nasal cavity.

First observed in a child by Frederick Ruysch (1638-1731), its formal description dates back to 1811 when Ludwig Jacobson (1783-1843) studied the vomeronasal organ in a variety of mammals, denying, however, its existence in humans.

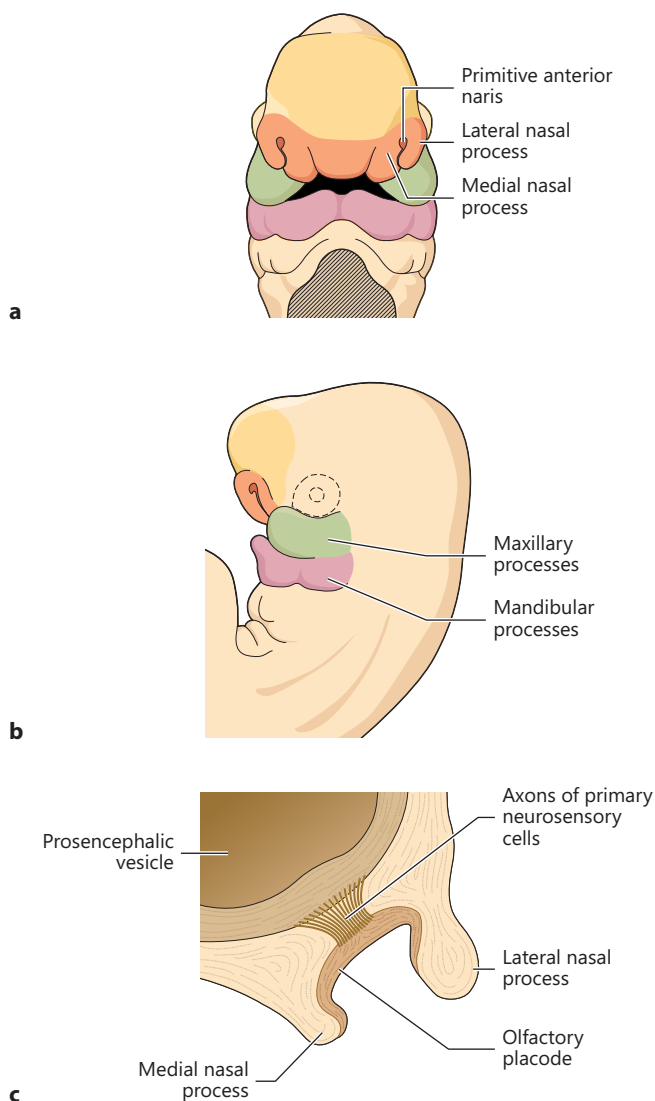
It is part of the *accessory olfactory system* and is connected to the accessory olfactory bulb, which is a separated region of the olfactory bulb, through the **vomeronasal nerves**, where the so-called *vomeronasal glomeruli* are present. In turn, the accessory olfactory bulb projects to the vomeronasal amygdala through the olfactory tract. The *vomeronasal amygdala* projects to the hypothalamus involved in the modulation of numerous physiological and behavioral functions. It is believed that the vomeronasal organ is a specific structure to detect the presence of *pheromones*, substances that influence the behavior and physiological state of other members of the same species, modulating the levels of reproductive hormones and stimulating sexual behavior, as well as aggressive behavior.

The first to discuss the vomeronasal organ as a histologically defined structure in humans was Rudolf Albert von Kölliker (1817-1905) in 1877, who identified it in both fetuses and adults. In humans, the vomeronasal organ is situated bilaterally in the antero-inferior part of the nasal septum, superiorly to the palate, dorsally to the paraseptal cartilages. Nowadays, it is possible to state that the vomeronasal organ is inconstantly present in humans: it is present in human fetuses (**Figure**) but undergoes a regression process that can sometimes be incomplete. In fact, endoscopic

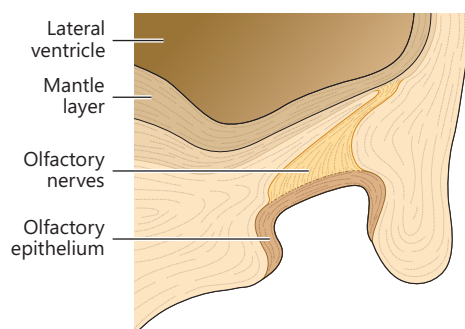
observations have shown, in some individuals, the presence of a blind-ended cavity and provided with a duct, of very variable size and shape, identifiable as vestige of the vomeronasal organ. The vomeronasal organ in humans is devoid of neurons and nerve fibers, being also absent the accessory olfactory bulb, receiving all the afferences from the vomeronasal organ. In humans, the genes encoding the receptor proteins and the specific ion channels essential for transduction processes present in mammals, where it is functional, are silenced. Although recent literature denies the sensory function of the vomeronasal organ in humans, particular connections between the cells of its wall and the underlying capillaries, together with the expression of some calcium-binding proteins, have been recently observed, suggesting its possible endocrine function.



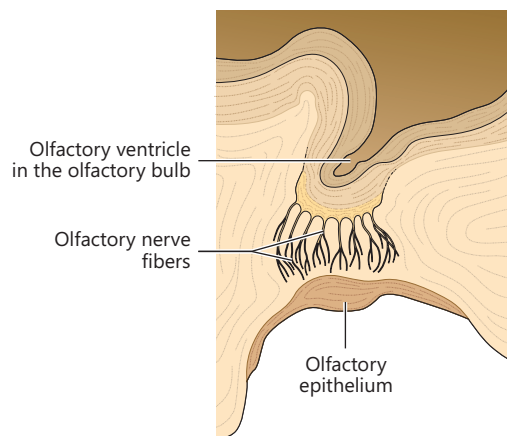
Embryo at the eight week of development, oblique (**a**) and horizontal (**b**) transverse sections passing through the nose (**a**, © Dr Mark Hill 2019, UNSW Embryology <https://embryology.med.unsw.edu.au>; **b**, courtesy of Virtual Human Embryo project, <http://virtualhumanembryo.lsuhs.edu>).



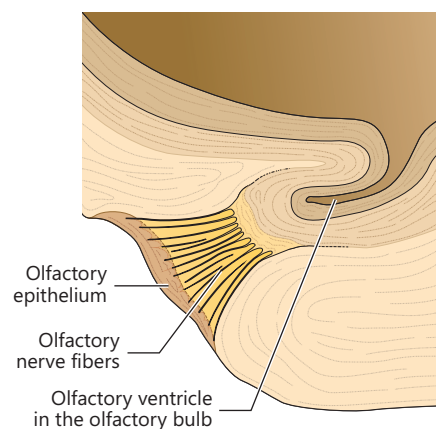
**Figure 14.13 - Cephalic end of human embryo at 5<sup>th</sup> week of development (6.5 mm)** seen from the front (**a**) and from the left side (**b**) and in coronal section (**c**): schematic representation. In **c** the migration towards the telencephalic vesicle of axons of primitive nerve cells is observed.



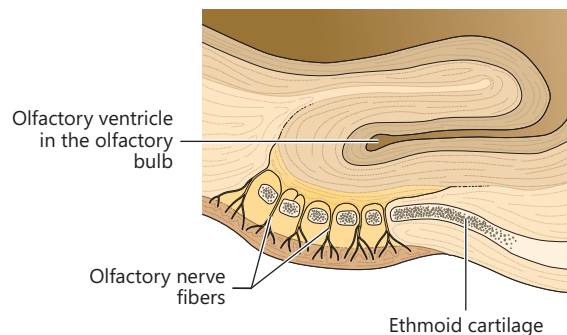
**Figure 14.14 - Development of the olfactory system in a 17 mm human embryo:** schematic representation of the migration towards the telencephalic vesicle of axons of primitive olfactory cells.



**Figure 14.15 - Development of the olfactory system in a 25 mm human embryo:** schematic representation of the relationships between the axons of primitive olfactory cells and the primordium of the olfactory ventricle protruding from the telencephalic cavity.



**Figure 14.16 - Development of the olfactory system in a 45 mm human embryo:** schematic representation showing the progression of the olfactory ventricle towards the vault of the nasal cavity.



**Figure 14.17 - Development of the olfactory system in a 78 mm human embryo:** schematic representation showing the obliteration of the olfactory diverticulum and the migration of the ethmoid cartilage (cribriform plate) that divides the olfactory nerve into small bundles.

## ORGAN OF HEARING AND BALANCE

The **ear** is the **organ of hearing and balance** (*vestibulo-cochlear organ*). It is formed by structures largely contained in the thickness of the temporal bone (➡ **Figs. 3.33-3.36**). The function of these structures is to ensure the perception of two types of **stimuli**, **sound** (or *acoustic*) and **gravitational** and **acceleration** (or *statokinetic*). Consequently, two different types of receptors are housed in the ear: **acoustic receptors** for the auditory sensitivity and **statokinetic receptors** for gravitational and acceleration sensitivity.

The ear is topographically divided into three parts that follow one another in a lateromedial direction: *external ear*, *middle ear* and *internal ear* (**Fig. 14.18**).

The **external ear** and the **middle ear** are exclusively relevant for the auditory sensitivity; instead, in the **internal ear**, a distinction is made between a part (*cochlear duct*) in which the acoustic receptors are located and another part (including the *vestibule* and the *semicircular ducts*) in which the statokinetic receptors are located. The auditory and the statokinetic sensitivities, collected by the *cochlear nerve* and by the *vestibular nerve*, respectively, pass with the respective nerves the fundus of the internal acoustic meatus, which represents the boundary wall between internal ear and cranial cavity, to reach the axial centers of the medulla oblongata and the pons.

### EXTERNAL EAR

The *external ear* acts as a receiver of sound waves and consists of the **auricle** and the **external acoustic meatus**, which is enclosed by the **tympanic membrane**.

The terminal portion of the external acoustic meatus corresponds to the initial part of the internal acoustic meatus, which is visible on the lateral surface of the temporal bone. The fundus of the external acoustic meatus continues in the space of the middle ear (tympanic cavity) from which it is separated by the interposition of the tympanic membrane.

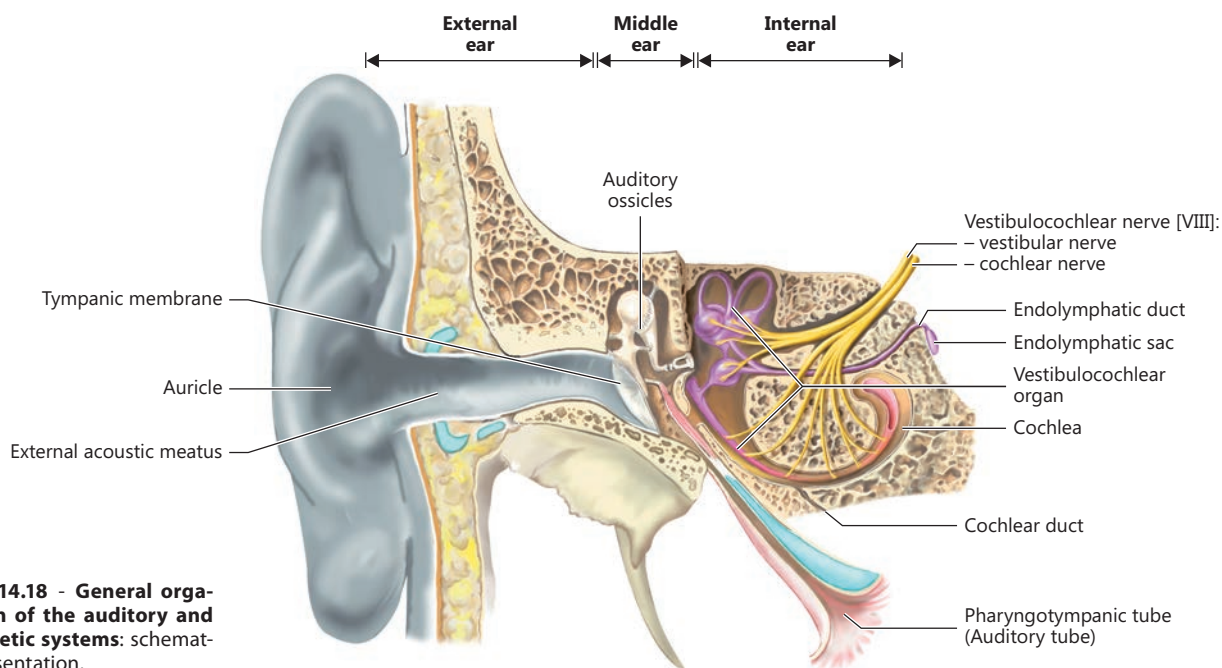
The auricle collects the sound waves and directs them along the external acoustic meatus, so that they can cause the vibration of the tympanic membrane and the following mechanical amplification exerted by the auditory ossicles in the middle ear. In turn, the ossicles transmit the movement to the inner ear.

### AURICLE

#### Shape, location and relations

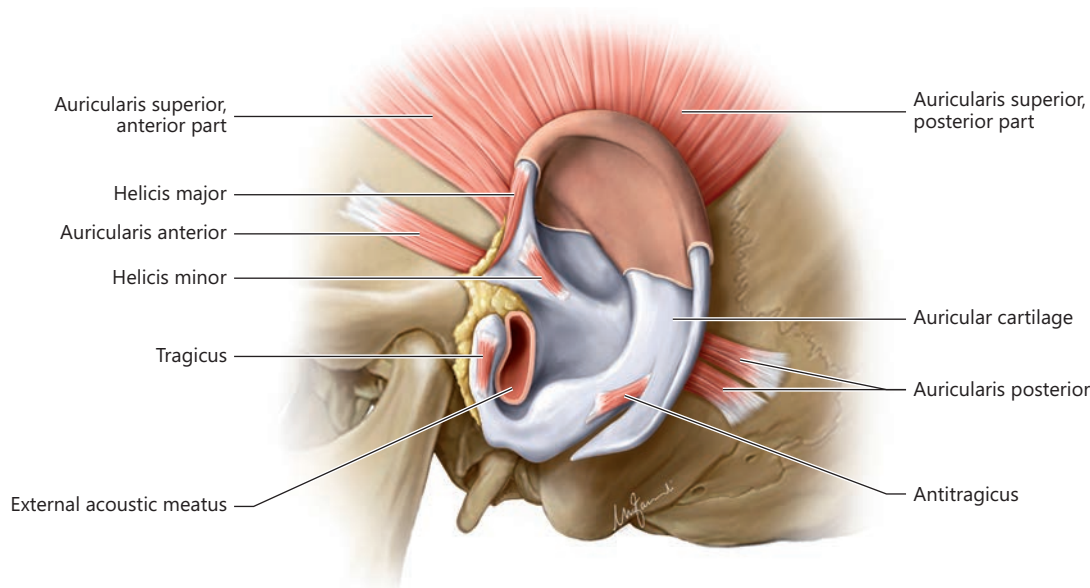
The *auricle* (or pinna) is a fibrocartilaginous process covered by skin, located laterally in the head, in front of the auricular and mastoid region. It presents remarkable individual variations in shape, size and modalities of attachment to the head. A *medial surface* and a *lateral surface* are described.

**Lateral surface** - It is a concavity delimited by a curved border, called **helix**, which presents posterosuperiorly a small **auricular tubercle** (Darwin's tubercle) (**Fig. 14.19**). In the inner part of the concavity there are a series of eminences and depressions. The **antihelix** is a curved prominence placed anteriorly to the posterior border of the helix, from



**Figure 14.18 - General organization of the auditory and kinesthetic systems:** schematic representation.





**Figure 14.22 - Structure of the auricle**, lateral surface of the left external ear.

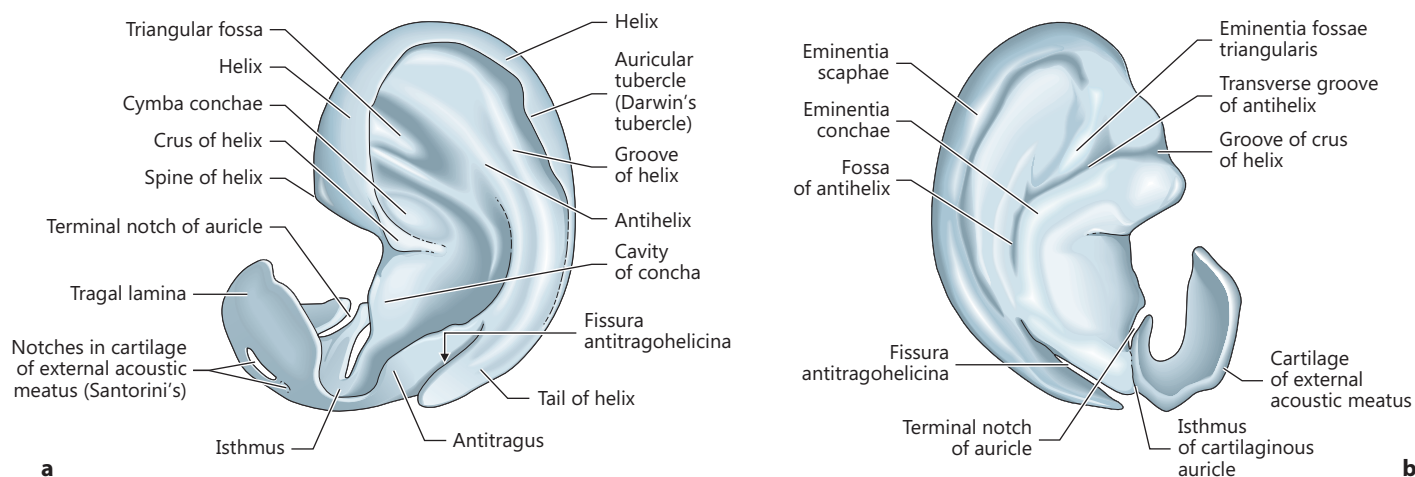
conchae and eminentia scaphae are separated by the **transverse groove of the antihelix**.

The auricular cartilage is in continuity with that of the external acoustic meatus by means of a narrow portion (**isthmus of the cartilaginous auricle**) that corresponds to the lower part of the concha. The cartilage of the tragus is an extension of the cartilaginous skeleton of the external acoustic meatus.

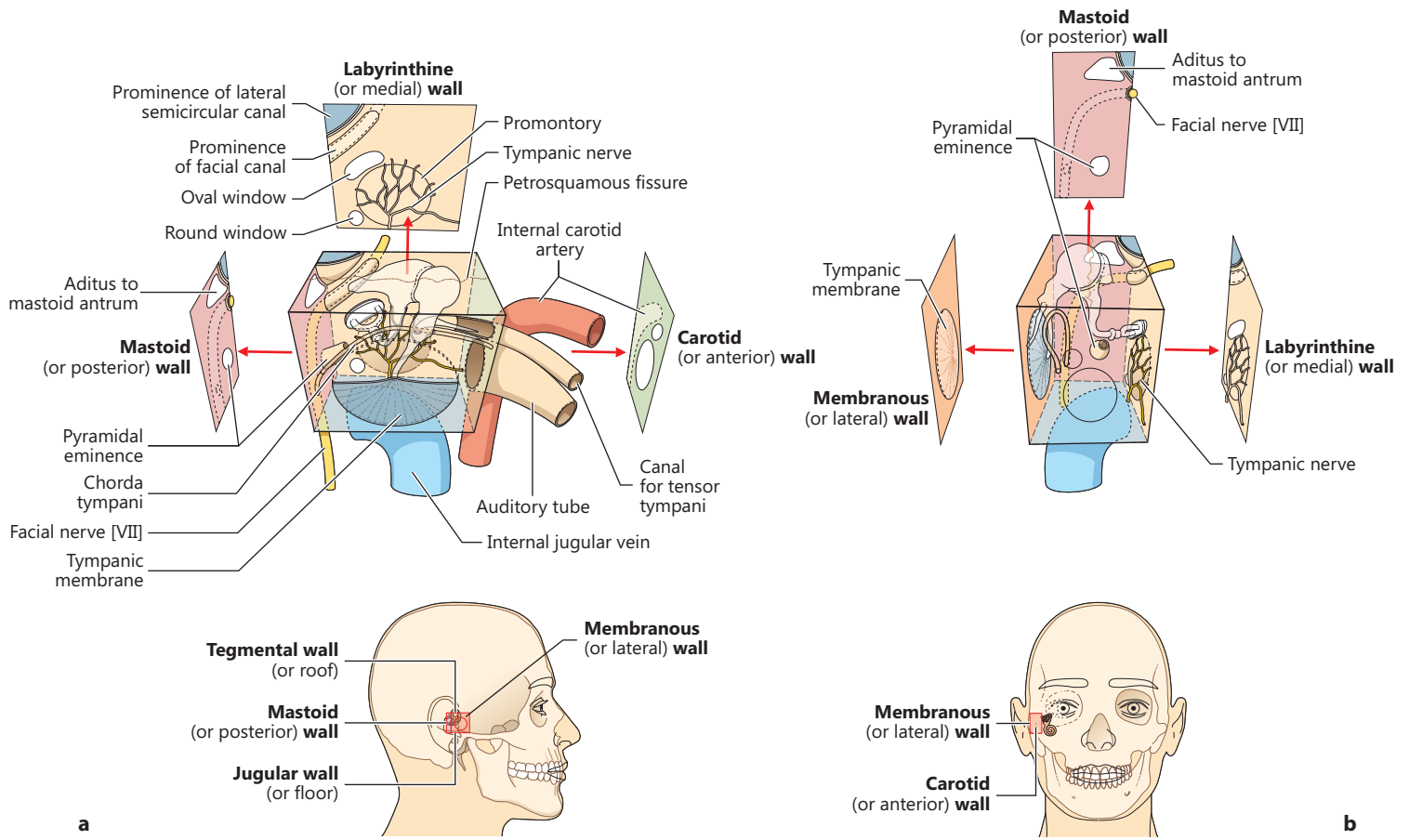
**Ligaments** - The means of union of the auricle to the temporal bone are the *anterior, superior and posterior extrinsic ligaments of the auricle*. The **anterior ligament of the auricle** attaches the tragus to the root of the zygomatic process, the **superior ligament of the auricle** passes between the

spine of the helix and the superior border of the external acoustic meatus, while the **posterior ligament of the auricle** interposes between the posterior portion of the concha of the auricle and the external surface of the mastoid process.

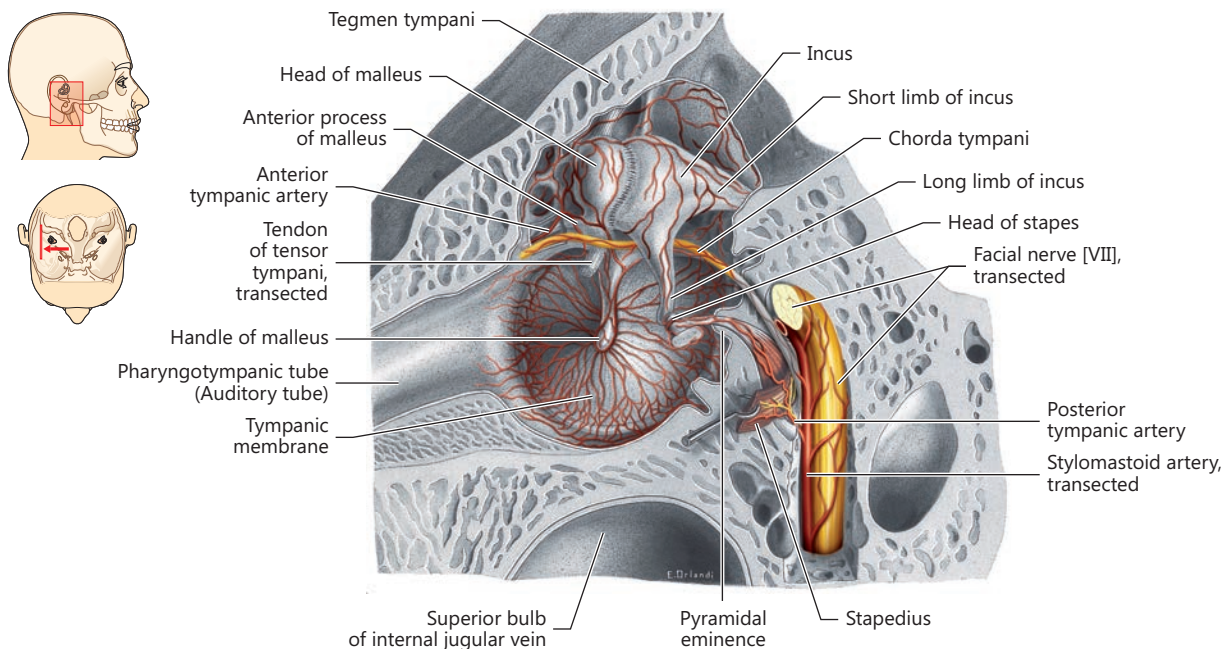
**Muscles** - In addition to the ligaments, a series of **extrinsic auricular striated muscles** (**auricularis anterior, auricularis superior and auricularis posterior**; ➡ Chapter 3, § *Auricular muscles*; Figs. 3.243 and 3.244) connect the auricle to the cranium and scalp, theoretically allowing the movement of the auricle, but in humans, with a few exceptions, the action of these muscles is very limited. There are also **intrinsic auricular muscles** (*helicis major, helicis minor, tragicus* and



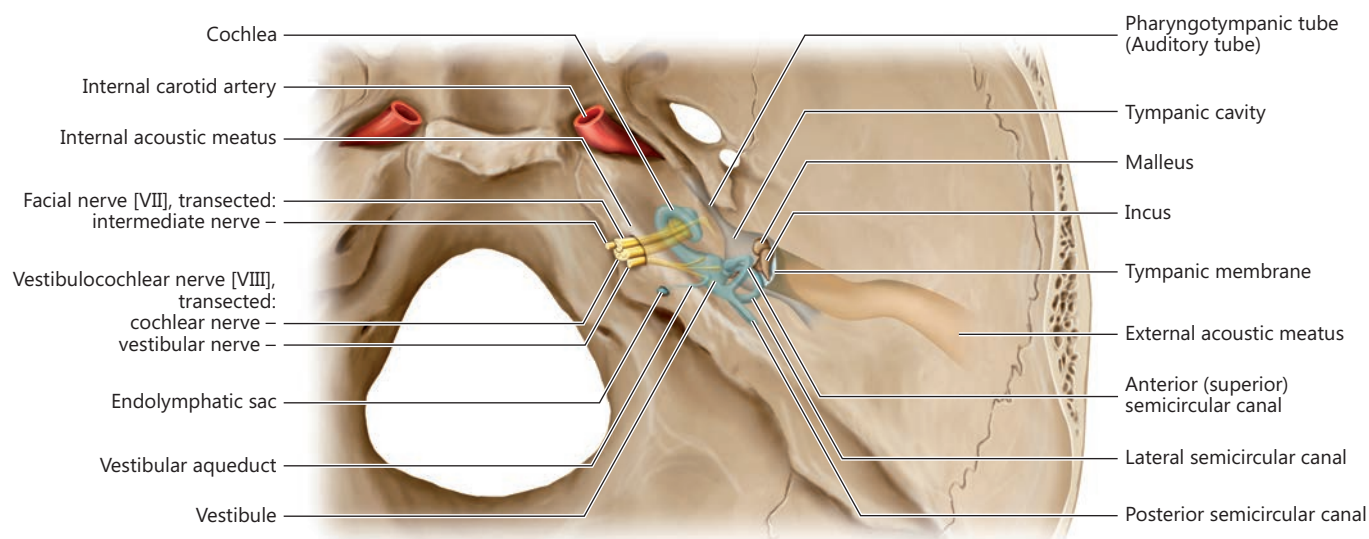
**Figure 14.23 - Auricular cartilage**, lateral (a) and medial (b) views of the left external ear.



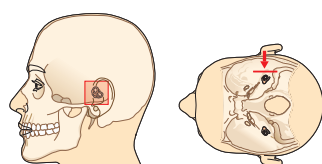
**Figure 14.33 - Boundaries of the tympanic cavity:** schematic representation. **a**, Lateral view; **b**, frontal view.



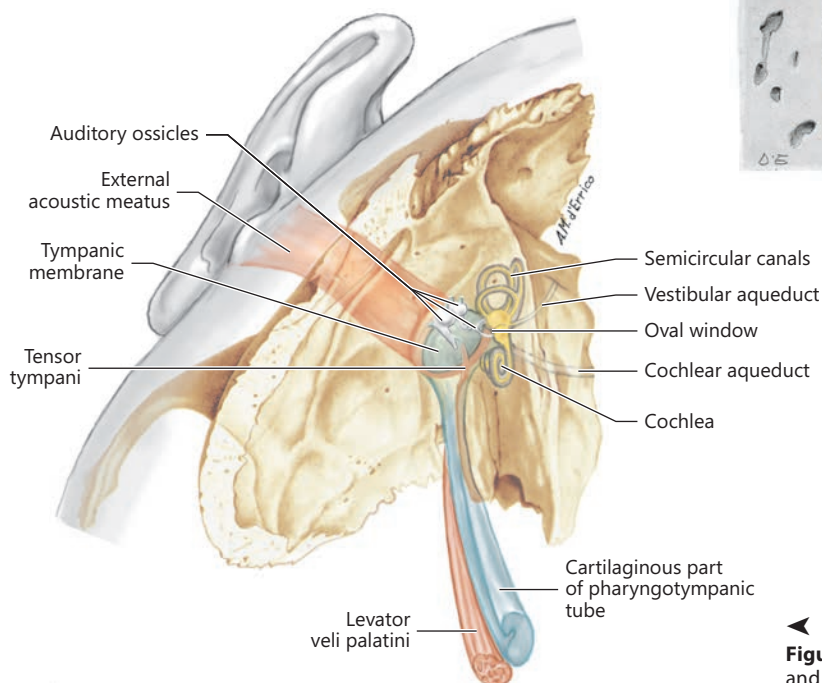
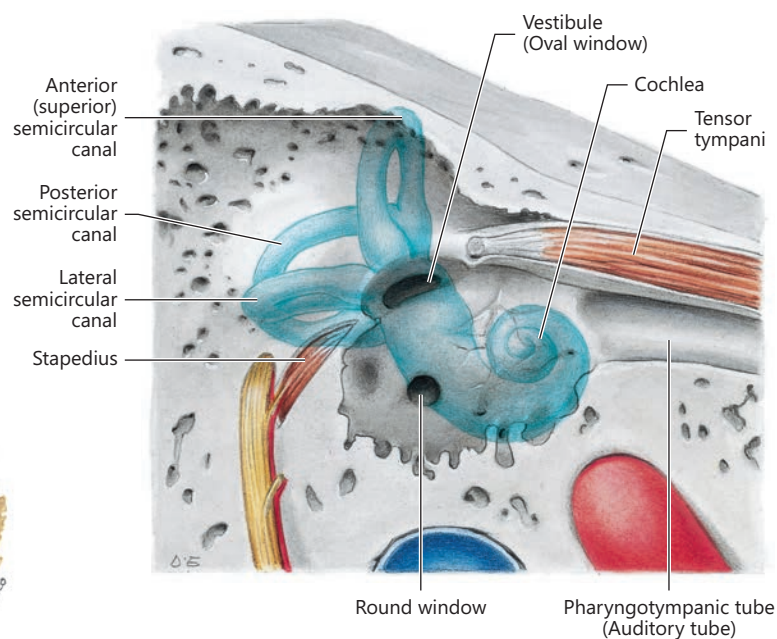
**Figure 14.34 - Membranous (or lateral) wall of the right tympanic cavity.** The tegmental wall, formed by the tegmen tympani, and the jugular wall are also observed.



**Figure 14.45 - Internal ear**, topography of the anterior and posterior formations and their relationships with the other parts of the auditory system. Medially to the bony labyrinth is the internal acoustic meatus that gives passage to the vestibulocochlear [VIII] and facial [VII] nerves.

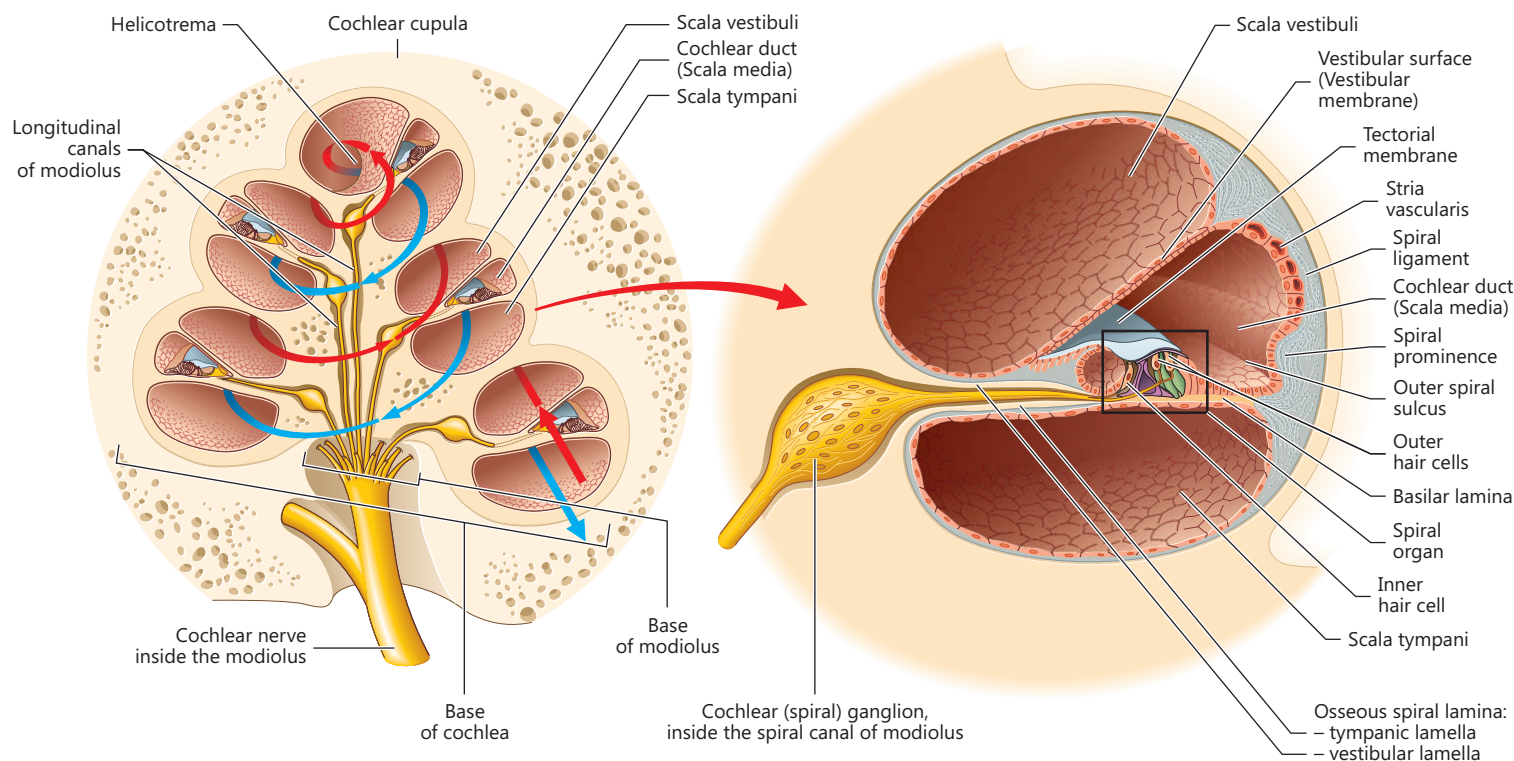


**Figure 14.46 - Bony labyrinth cavity**, represented by transparency, in relation to the medial wall of the tympanic cavity. The lateral wall of the vestibule corresponds to the oval window.

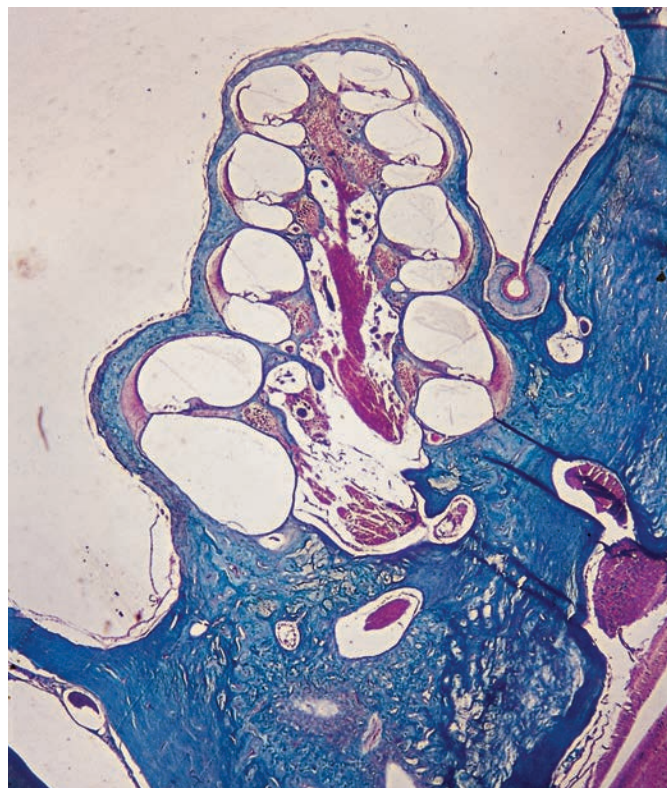


**Figure 14.47 - Bony labyrinth** of the right ear, components and its relationships with the middle ear in superomedial view.





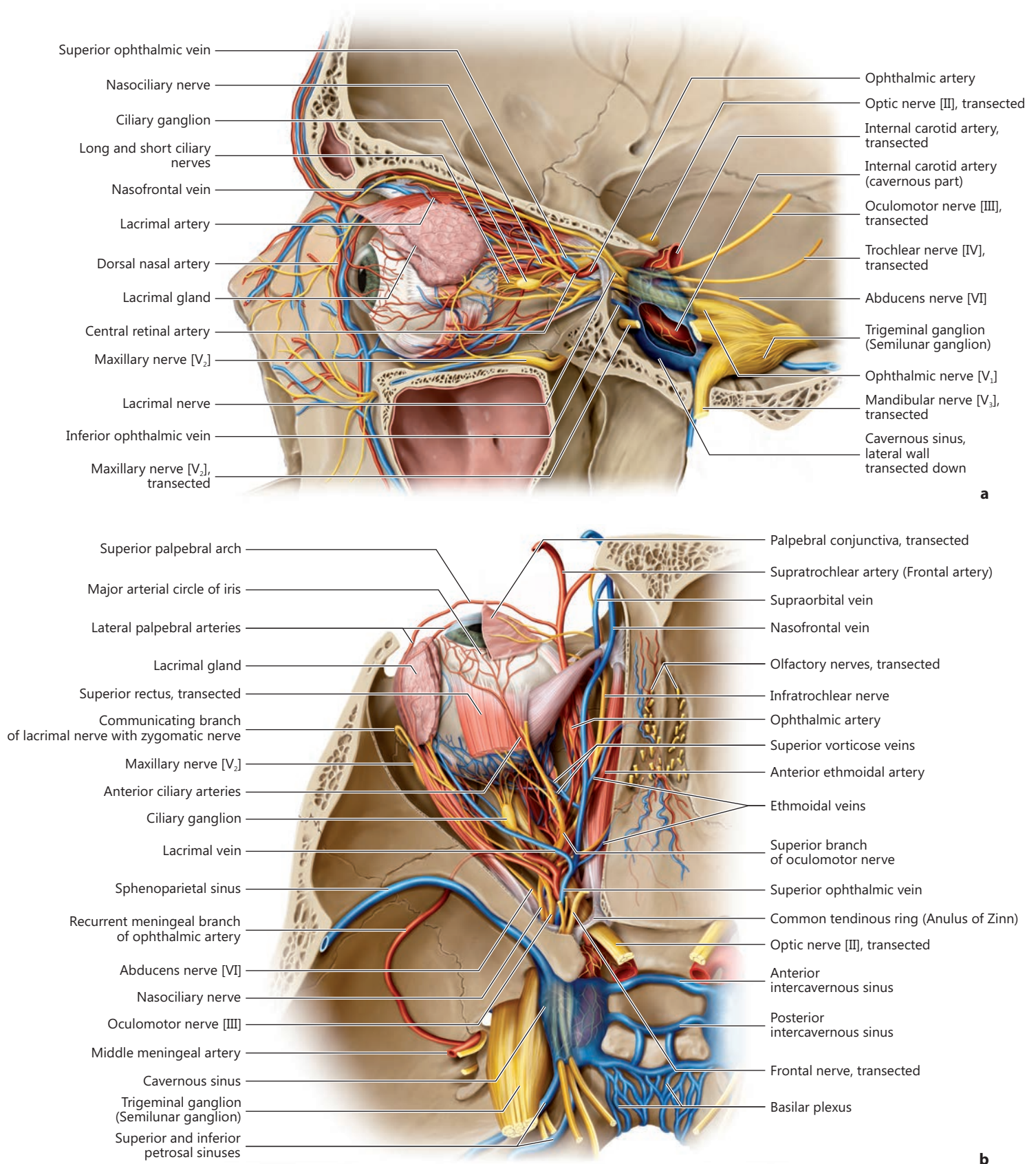
**Figure 14.54 - Structure of the internal ear.** In the enlargement, the relative disposition of the three scalae is illustrated: the scala vestibuli, scala tympani and scala media.



**Figure 14.55 - Structure of the internal ear,** prepared from macerated bone.

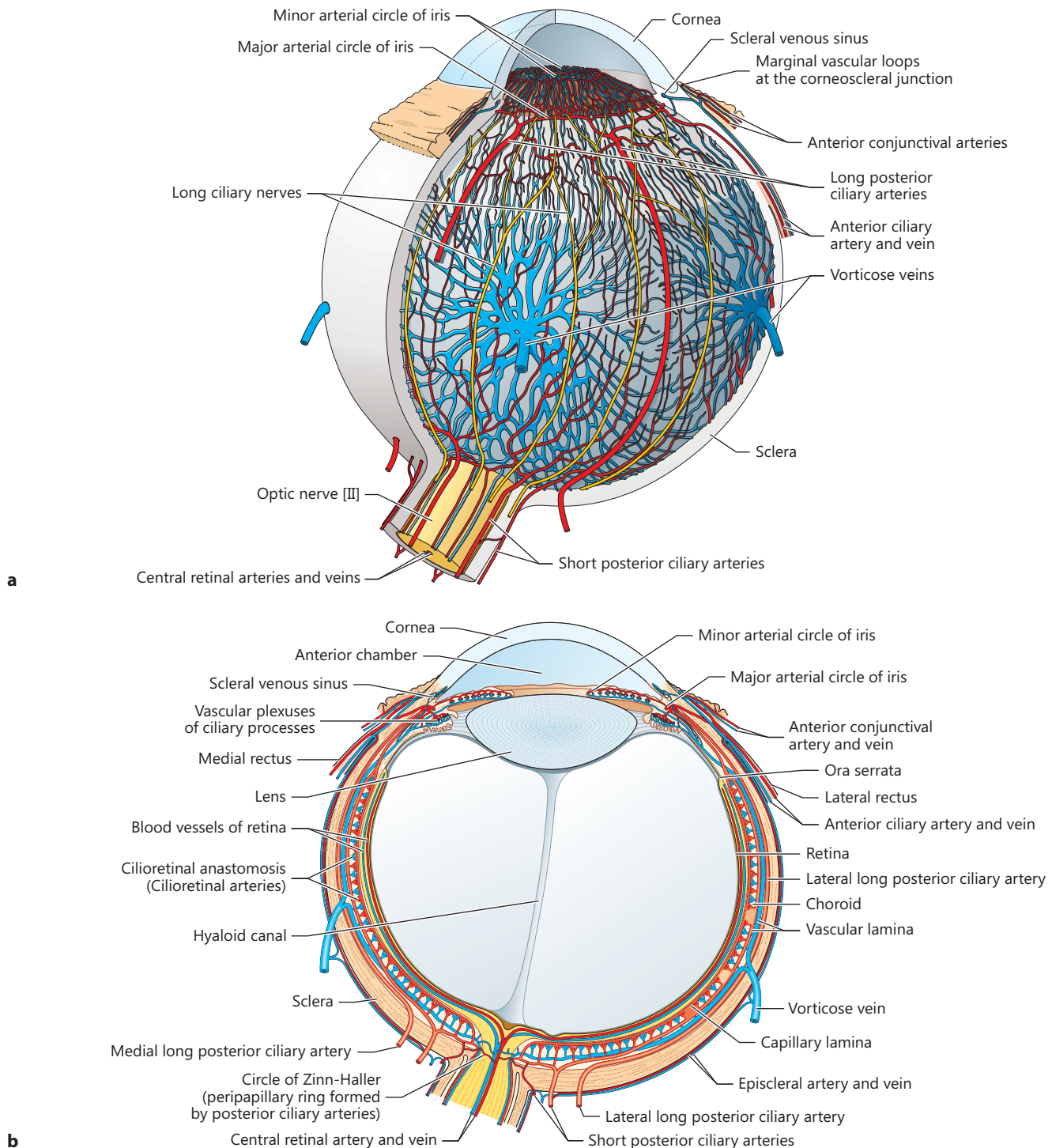
spiral lamina, as already mentioned, separates the cochlear duct from the scala tympani. The spiral organ (organ of Corti) is located on the internal surface of the basilar lamina (§ *Membranous labyrinth*).

The oval window, located at the beginning of the basal turn of the scala vestibuli of the cochlea, would connect the tympanic cavity with the vestibular cavity if it were not completely closed by the insertion of the base of the stapes on its contours. The vibrations of the stapes in response to sound waves generate the oscillatory movements of the perilymph in the scala vestibuli, which also propagate by the helicotrema to the scala tympani, which in turn is separated from the tympanic cavity by the secondary tympanic membrane that closes the round window. The oscillatory movements of the perilymph cause similar movements of the endolymph inside the cochlear duct, resulting in excitation of the spiral organ and generation of the hearing sense. At the base of the modiolus, in correspondence to the most lateral part of the internal acoustic meatus, there is the **tractus spiralis foraminosus**, containing small foramina for the passage of the fibers of the cochlear nerve (Fig. 14.56). Through the tiny **longitudinal canals of the modiolus**, the fibers of the cochlear nerve reach the base of the osseous spiral lamina, where the **spiral canal of the modiolus** (canal of Rosenthal) is located. The latter houses the cell bodies of the sensory neurons of the *cochlear ganglion* (or spiral ganglion or ganglion of Corti), which receive signals perceived by the



**Figure 14.98 - Eye in the orbital cavity. a**, Lateral view of the left orbital cavity and middle cranial fossa after removal of the lateral wall. **b**, Transverse section of the cranium passing just below the roof of the orbital cavity, superior view.





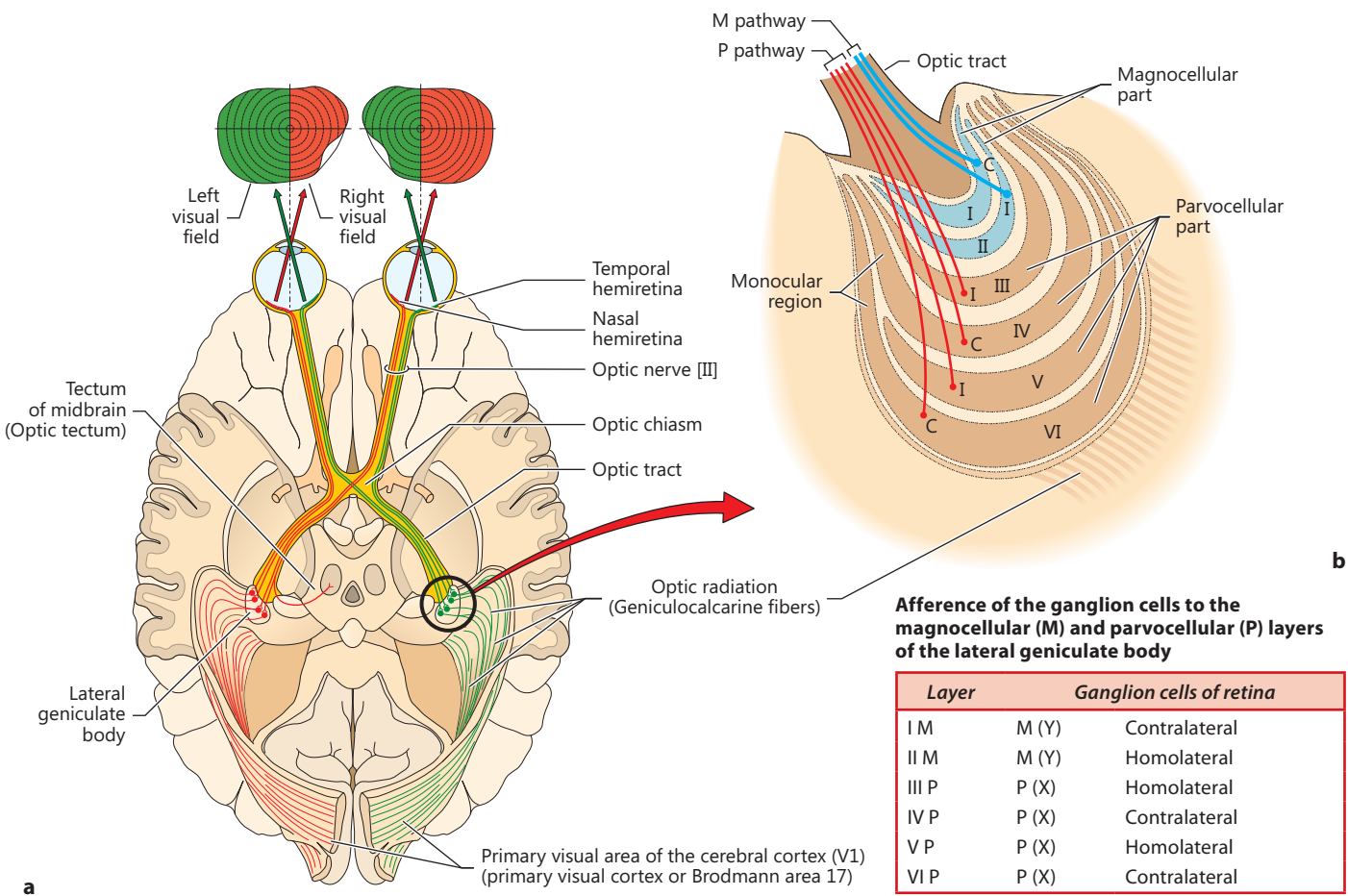
**Figure 14.101 - Blood circulation of the eyeball. a, Blood vessels of the eyeball. b, Schematic representation showing the blood circulation of the eyeball.**

The transition point between the scleral and palpebral conjunctiva is called **conjunctival fornix**. Medially, there is no conjunctival fornix, but there is the lacrimal caruncle, which is a skin fold constituted of stratified squamous epithelium, and the plica semilunaris, which is a fold of the con-

junctiva that also contains accessory lacrimal glands (➔ also § *Conjunctiva*).

The deepest layer of the sclera is rich in melanocytes and is called **lamina fusca** (or *suprachoroid lamina of the sclera*).





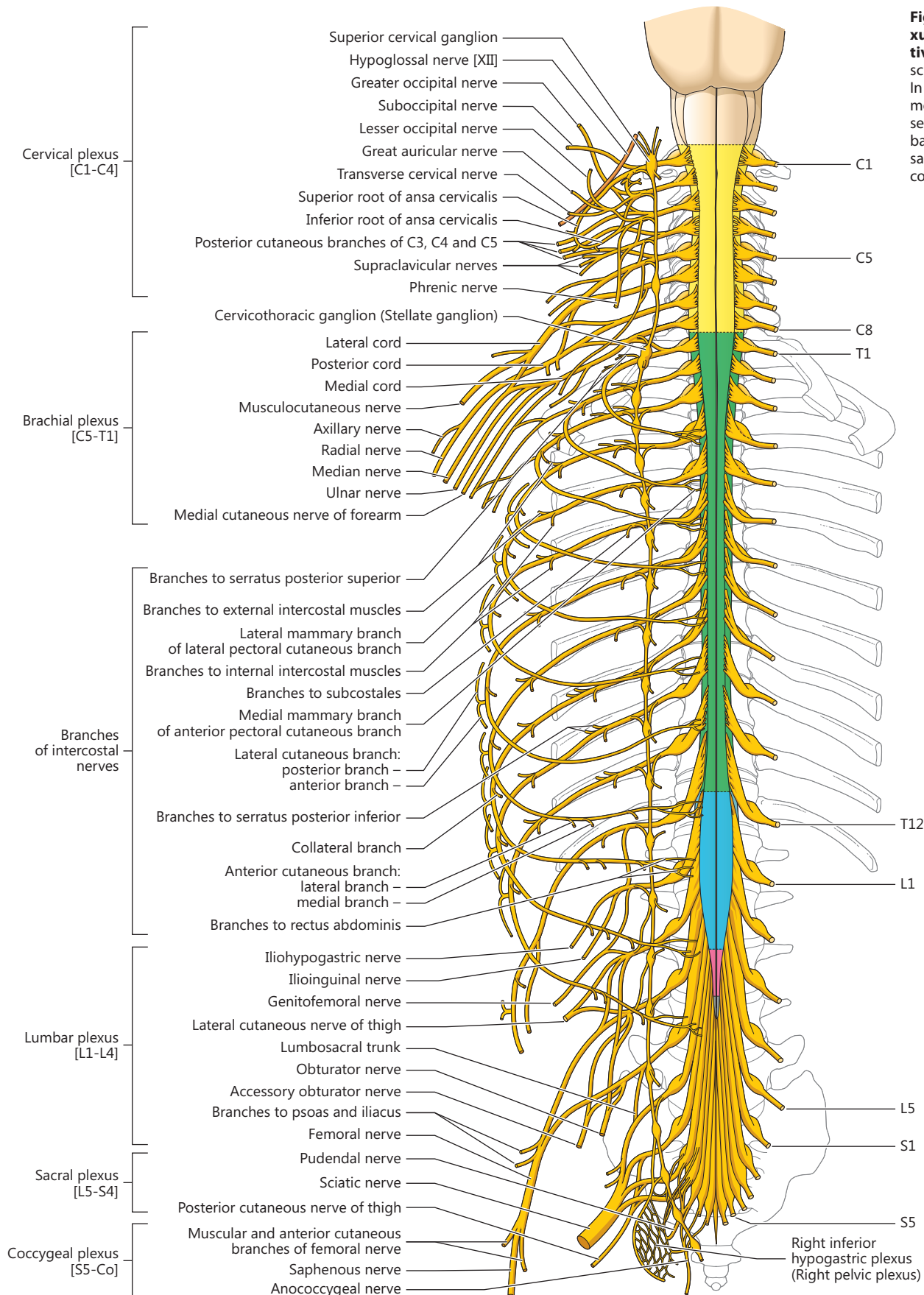
**Figure 14.140 - Circuit of the visual pathways:** schematic representation. **a**, At the level of the optic chiasm the fibers that originate from the nasal hemiretina cross the midline to enter the contralateral optic tract, while the fibers that originate from the temporal hemiretina run in the homolateral optic tract. **b**, Structure and afferences of the lateral geniculate body.

the depth, are called IVA, IVB, IVC $\alpha$  and IVC $\beta$ ; neurons coming from the magnocellular laminae (I and II – M pathway) of the lateral geniculate body project and form synapses

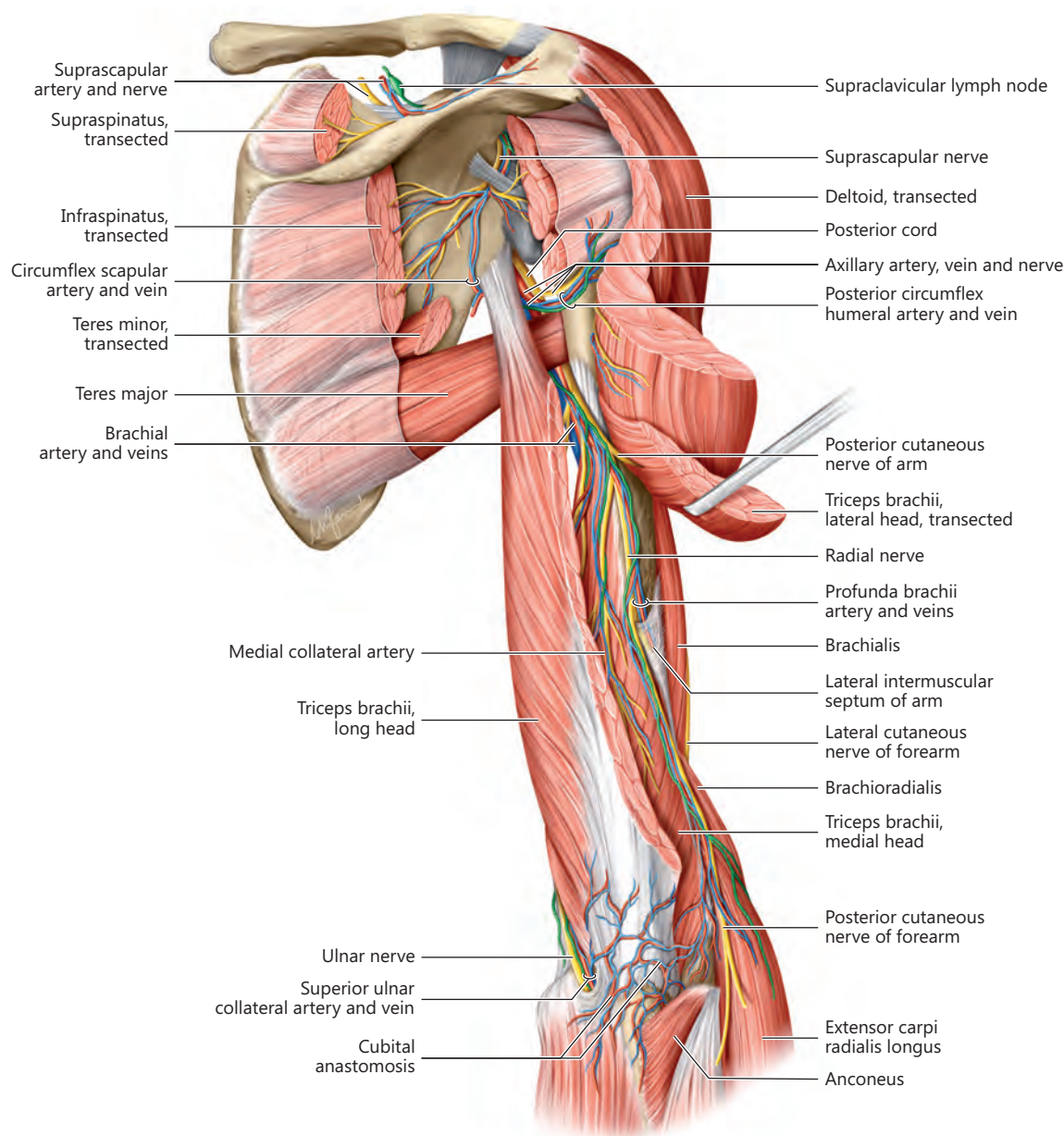
to the sublayer IVC $\alpha$ , while those coming from the parvocellular layers (from III to VI – P pathway) go to the sublayer IVC $\beta$  (Fig. 14.142).



**Figure 14.141 - Primary visual area**, in the context of the brain seen in lateral projection (**a**) and in medial projection after sagittal section of the brain-stem, cerebellum and diencephalon (**b**).



**Figure 15.12 - Nerve plexuses with their respective principal branches:** schematic representation. In *yellow*, the cervical segment; in *green*, the dorsal segment; in *blue*, the lumbar segment; in *red*, the sacral segment; in *gray*, the coccygeal segment.



**Figure 15.26 - Innervation of the shoulder and arm**, in a preparation of the right arm seen posteriorly.

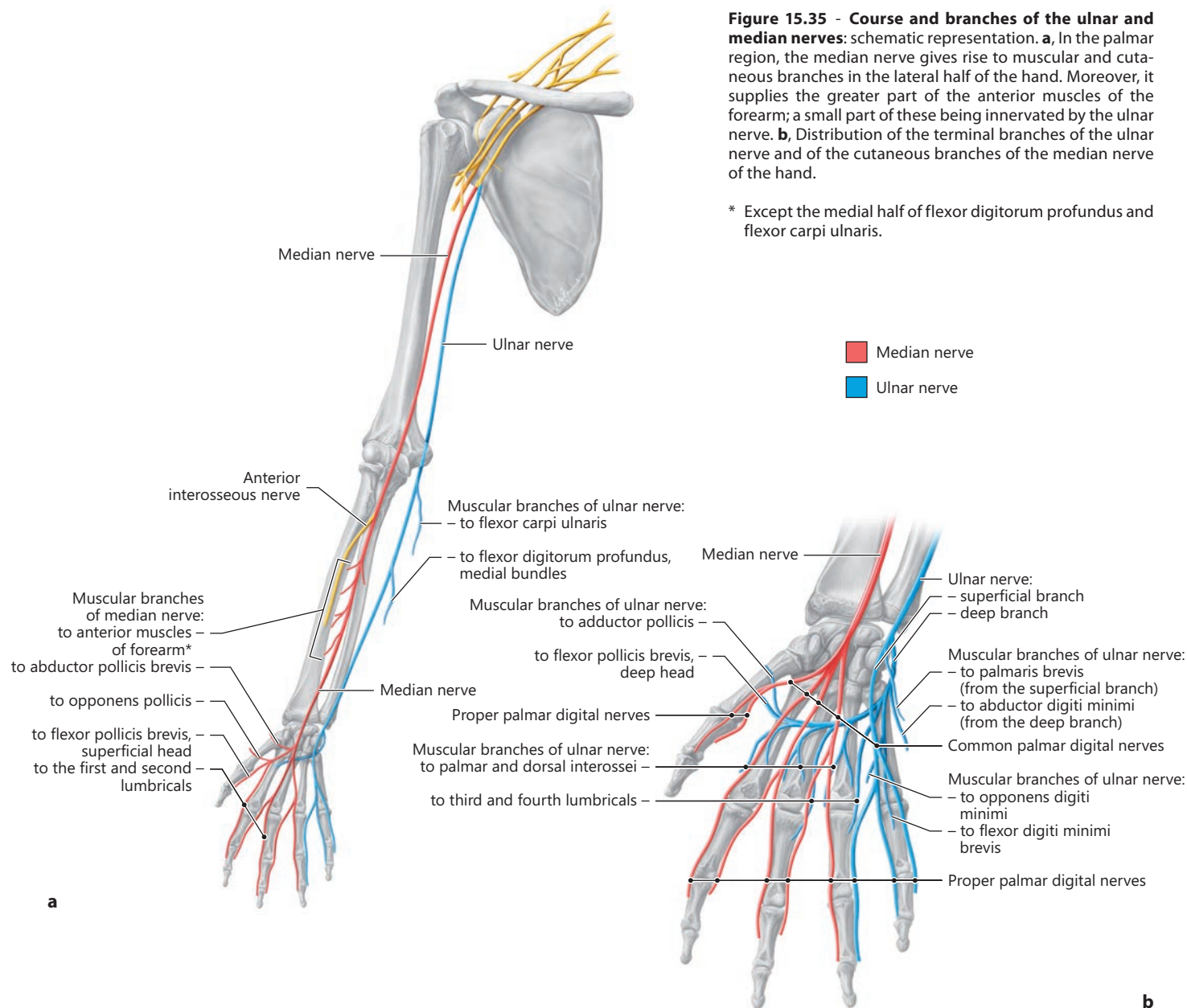
are represented by the **radial nerve**, the **musculocutaneous nerve**, the **median nerve**, the **ulnar nerve**, the **medial cutaneous nerve of the forearm** and the **medial cutaneous nerve of the arm** (see Figs. 15.23-15.25).

#### *Radial nerve [C5-C8, T1]*

The *radial nerve* is the only terminal branch of the brachial plexus originating, behind the axillary artery, as continuation of the posterior cord after that cord has given the axillary nerve. It is a mixed nerve formed by fibers coming from the last four cervical nerves and the first thoracic nerve [C5-C8, T1] and, after originating in the axilla, at the level of the infe-

rior border of the pectoral minor, it runs vertically along the axilla to reach the arm; here, with an oblique course downwards, outwards and backwards, it leads into the posterior compartment of the arm placing itself between the long head and the medial head of the triceps brachii (see Fig. 15.26). Then, it runs together with the profunda brachii artery (or deep artery of the arm) in the *radial groove* (or spiral groove) of the humerus, passing into the interstice between the medial head and the lateral head of the triceps brachii until it reaches the lateral border of the humerus (Fig. 4.93); in this area, after perforating the lateral intermuscular septum of the arm, is brought into the anterior compartment of the arm, laterally to the brachialis and medially to the brachioradialis.





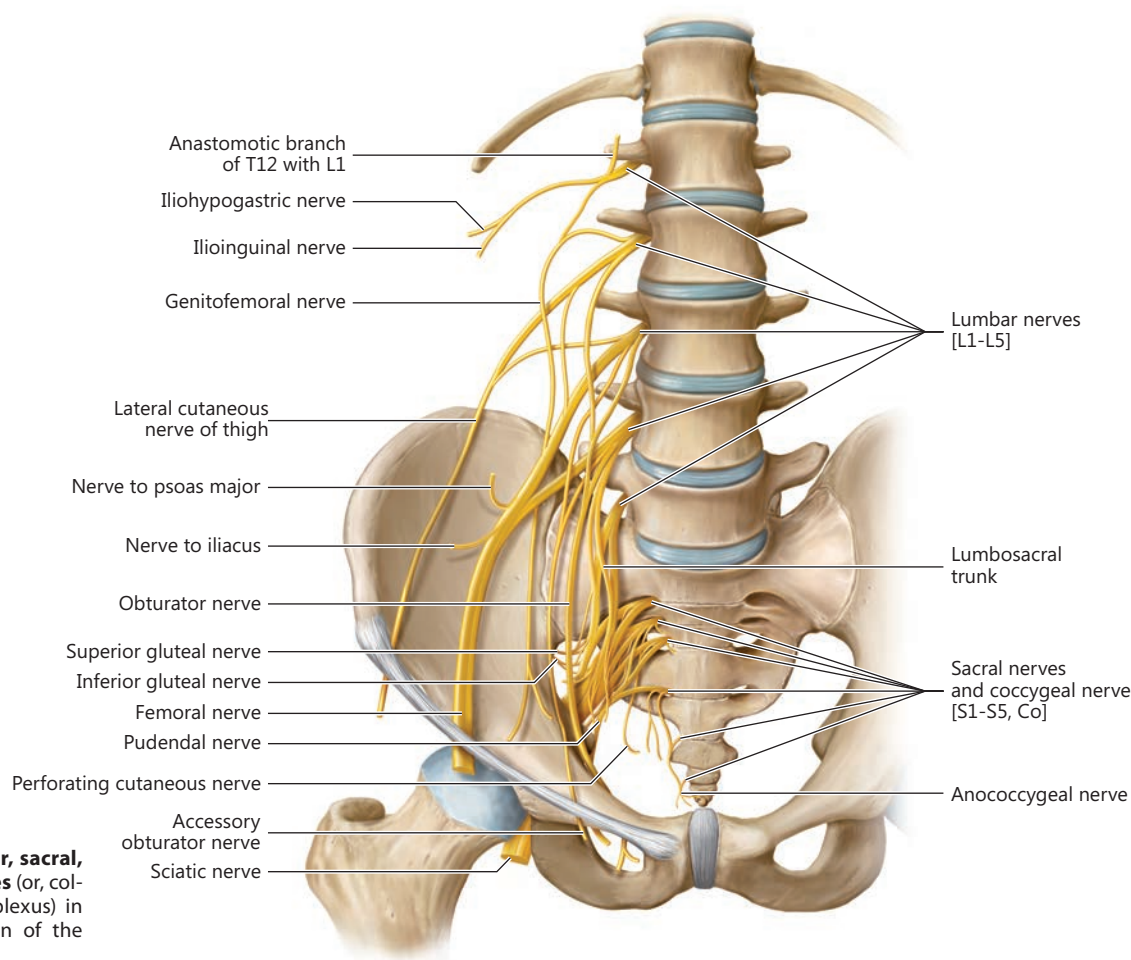
maintain their own individuality as they run in the corresponding intercostal spaces; therefore, in this region we speak of *intercostal nerves* (Figs. 15.37 and 15.38).

The intercostal nerves are formed by the *anterior branches of the twelve pairs of thoracic nerves* and are mixed nerves that innervate the thoracic wall with its musculature and the abdominal wall. The first eleven intercostal nerves run in the corresponding intercostal space, while the twelfth pair is located below the twelfth rib and, therefore, is called *subcostal nerve*.

Each intercostal nerve represents the continuation of the respective anterior root of the thoracic nerve and emerges from the respective intervertebral foramen, placing itself at half height in the intercostal space. From here, it assumes a

lateral course with a slight upward inclination until, having reached the costal angle, it finds itself leaning against the inferior border of the rib above. It continues following the contour of the rib by running in the costal groove adjacent to the intercostal vessels, thus reaching the sternal end of the rib, where it heads, again, to the intermediate part of the intercostal space. In its initial tract, each intercostal nerve is in relation to the deep surface of the external intercostal muscle; beyond the costal angle, the nerve runs between the internal intercostal muscle and the innermost intercostal muscle.

**The first to sixth intercostal nerves** - They reach the lateral margin of the sternum where they cross the internal thoracic artery and, going through the internal intercostal muscle, the

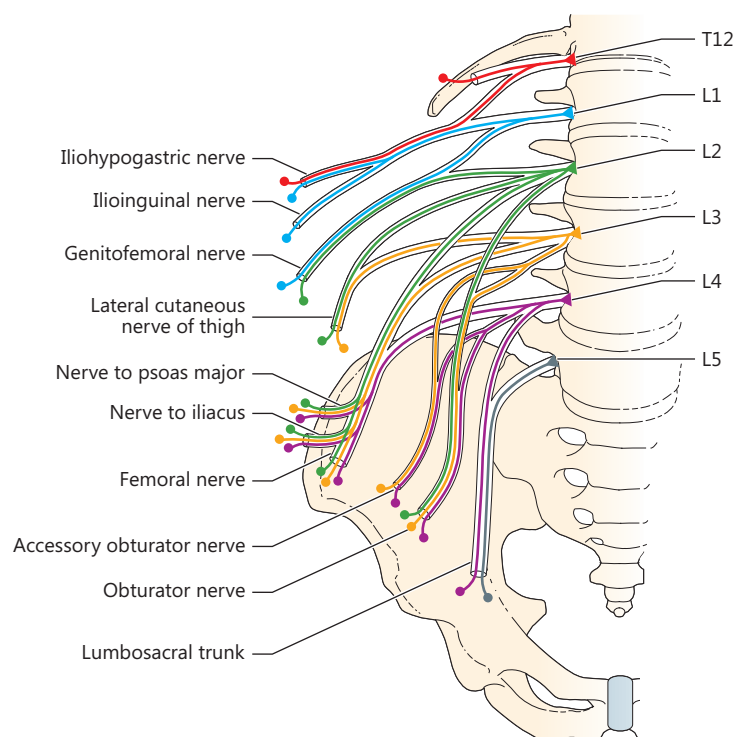


**Figure 15.40 - Lumbar, sacral, and coccygeal plexuses** (or, collectively, lumbosacral plexus) in relation to the skeleton of the vertebral column.

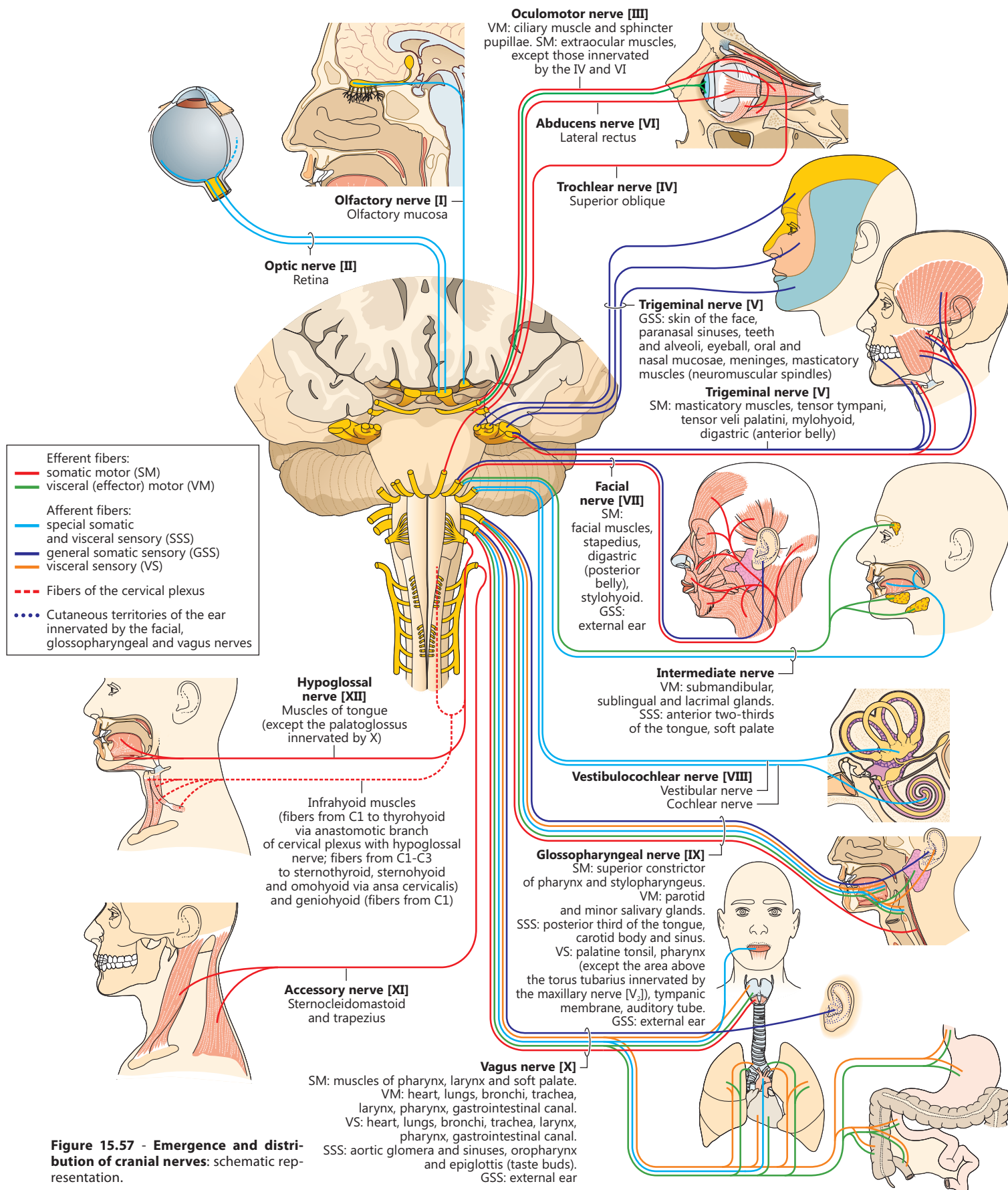
### Long collateral branches

They are represented by the *iliohypogastric nerve*, the *ilioinguinal nerve*, the *genitofemoral nerve* and the *lateral cutaneous nerve of the thigh*.

**Iliohypogastric nerve [T12, L1]** - It is a mixed nerve that originates from the anterior branch of the first lumbar nerve (see **Figs. 15.37, 15.40 and 15.41**); it may arise either isolated or via a common trunk with the ilioinguinal nerve (**Fig. 15.42**). Immediately after its origin, the nerve passes through the bundles of the psoas major and assumes a course heading downward and laterally passing anteriorly to the quadratus lumborum; then, it reaches the aponeurosis of the transversus abdominis and runs between the transversus abdominis and the internal oblique. In this tract, the iliohypogastric nerve passes behind the paranephric fat, located behind the renal space; once it arrives above the inguinal ligament, it gives off collateral branches, i.e., the *lateral cutaneous branch*



**Figure 15.41 - Structure of the lumbar plexus:** schematic representation.



**Figure 15.57 - Emergence and distribution of cranial nerves:** schematic representation.



**Table 15.1 - Classification, origin, course and distribution of the cranial nerves**

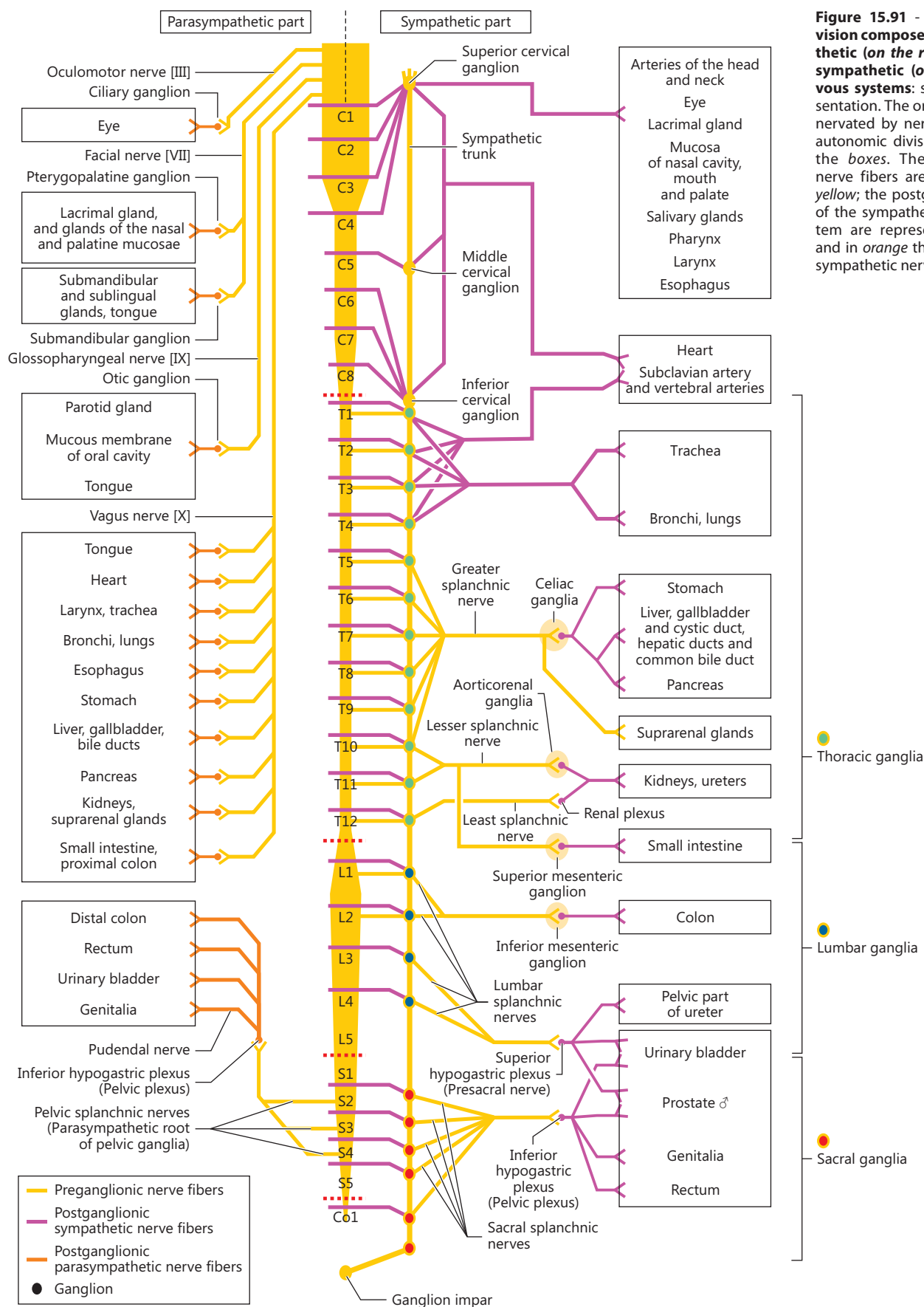
<i>Nerve</i>	<i>Name</i>	<i>Composition</i>	<i>Indications on the nerve course and on its components</i>	<i>Peripheral distribution</i>
I pair	Olfactory	SSS	Filaments of the olfactory nerve → cribriform plate → olfactory bulb	Olfactory part of the mucosa of the nasal cavity
II pair	Optic	SSS	Optic nerve → optic canal → optic chiasm → optic tract	Retina
III pair	Oculomotor	SM	Lateral wall of the cavernous sinus → superior orbital fissure → orbital cavity	Superior rectus, inferior rectus, medial rectus, inferior oblique, levator palpebrae superioris
		VM	Oculomotor nerve → branch to the ciliary ganglion → ciliary ganglion → short ciliary nerves	Sphincter (constrictor) pupillae and ciliary muscle
IV pair	Trochlear	SM	Lateral wall of the cavernous sinus → superior orbital fissure	Superior oblique
V pair	Trigeminal	SM	Motor root of the trigeminal nerve → mandibular nerve → foramen ovale → infratemporal fossa	Masticatory muscles, anterior belly of the digastric, mylohyoid, tensor tympani, tensor veli palatini
		GSS	Ophthalmic, maxillary and mandibular nerves → trigeminal ganglion → sensory root of the trigeminal nerve	Skin of the face, mucosa of the mouth and nose, teeth, conjunctiva, paranasal sinuses, meninges
		GSS	Mandibular and maxillary nerves → sensory root of the trigeminal nerve	Masticatory muscles (neuromuscular spindles) and dental alveoli
VI pair	Abducens	SM	Cavernous sinus → superior orbital fissure → orbital cavity	Lateral rectus
VII pair*	Facial	SM	Internal acoustic meatus → facial canal → stylomastoid foramen → parotid space → face	Muscles of facial expression, stapedius, posterior belly of the digastric and stylohyoid
		GSS	Posterior auricular nerve → facial nerve	Skin of the auricle and the mastoid region
	Intermediate	VM	Greater petrosal nerve → pterygopalatine ganglion → maxillary nerve → zygomatic nerve → lacrimal nerve, greater and lesser palatine nerves and posterior superior medial and lateral nasal branches of the maxillary nerve	Lacrimal gland, glands of the mucosa of the nasal cavity and palate
		VM	Intermediate nerve → chorda tympani → lingual nerve → submandibular and sublingual ganglia	Submandibular and sublingual glands
		SSS	Lingual nerve → chorda tympani → geniculate ganglion → intermediate nerve	Papillae of the tongue (taste) anterior to the terminal sulcus of the tongue (anterior two-third of the tongue)
VIII pair**	Vestibular	SSS	Utricular, utrículoampullary, saccular and ampullary nerves → vestibular ganglion → vestibulocochlear nerve → internal acoustic meatus	Ampullary crest and macula of the utricle and macula of the saccule
	Cochlear	SSS	Peripheral extensions of the neurons of the cochlear ganglion → cochlear ganglion → central extensions of the neurons of the cochlear ganglion in the modiolus of the cochlea → vestibulocochlear nerve → internal acoustic meatus	Spiral organ

GSS, general somatic sensory; SM, somatic motor; SSS, special somatic and visceral sensory; VM, visceral motor; VS, visceral sensory.

\* VII pair, facial nerve (consisting of facial nerve proper and intermediate nerve)

\*\* VIII pair, vestibulocochlear nerve (consisting of vestibular nerve and cochlear nerve)

(continued)



**Figure 15.91 - Autonomic division composed of the sympathetic (on the right) and parasympathetic (on the left) nervous systems:** schematic representation. The organs that are innervated by nerve fibers of the autonomic division are listed in the boxes. The preganglionic nerve fibers are represented in yellow; the postganglionic fibers of the sympathetic nervous system are represented in purple and in orange those of the parasympathetic nervous system.





