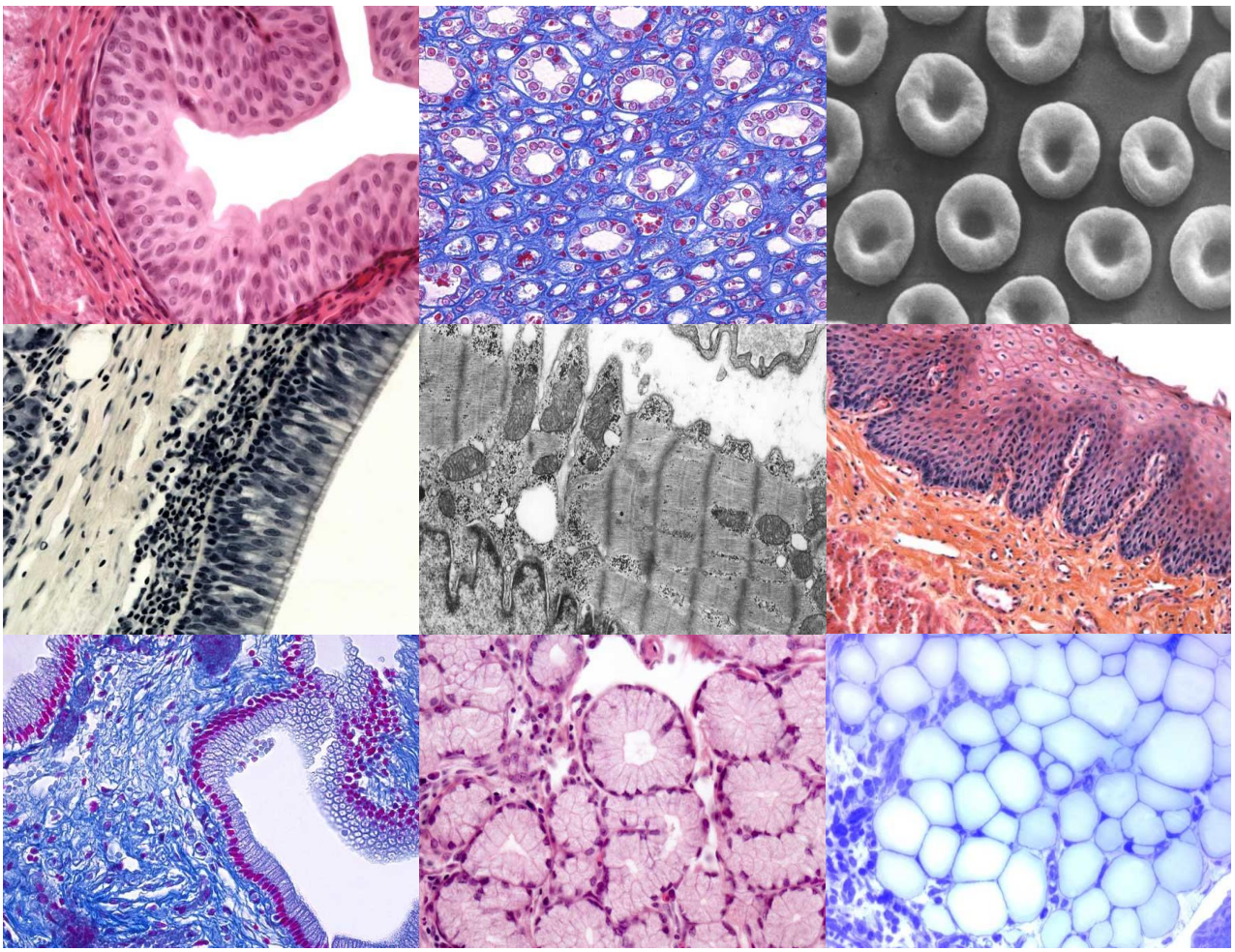
MUNI
FACULTY
OF MEDICINE

Guide to General Histology and Microscopic Anatomy

Petr Vaňhara, Miroslava Sedláčková,
Irena Lauschová, Svatopluk Čech, Aleš Hampl



Masaryk University Press, Brno 2020

MUNI MED
Department of Histology and Embryology

Guide to General Histology and Microscopic Anatomy

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PREFACE

This Guide to General Histology and Microscopic Anatomy seeks to provide effective help to students of Medicine and/or Life sciences enrolled to the courses that are offered by the Department of Histology and Embryology at the Faculty of Medicine, Masaryk University. The Guide includes original, high-quality microphotographs and electronograms, annotated with contemporary terminology on histology and microscopic anatomy of tissues and organs. The Guide, however, does not want to substitute a histology textbook or microscopy anatomy atlas and therefore it avoids detailed textual explanations that can be found elsewhere. The Guide rather contributes to better understanding, follow-up, and self-orientation in practical lessons, lectures, and seminars of the Department. The authors believe that this Guide will help to better appreciate fine patterns of microscopic structures of human body within their amazing complexity and diversity.

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The authors wish to thank the reviewers for their expert and insightful comments.

MUDr. Jana Dumková, PhD., MUDr. Veronika Sedláková, PhD.,
and MVDr. Anna MacGillavry Danylevská, PhD. are acknowledged for critical reading of the Guide.

Technicians and laboratory assistants of the Department are greatly acknowledged for expert preparation and digitalization of tissue samples and microscopic slides.

Image courtesy: Department of Histology and Embryology, Faculty of Medicine, Masaryk University

The tissue sections shown in this Guide were stained by hematoxylin-eosin, hematoxylin-eosin-saffron, and AZAN stains, respectively, unless stated otherwise. Tissue images were acquired using either Leica DM5000B microscope equipped with DFC480 camera or Aperio ScanScope GL System (Leica Biosystems), and then digitally processed. TEM electronograms were acquired using FEI Morgagni 268D (FEI, Thermo Fisher Scientific).

ISBN 978-80-210-9671-4

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LIST OF ABBREVIATIONS

Abbreviation	Latin	English
a., aa.	*arteria*, *arteriae*	artery, arteries
c.	*corpusculum*	corpuscle
c.t.	*textus connectivus*	connective tissue
cart., cartt.	*cartilago*, *cartilagines*	cartilage, cartilages
d.	*ductus*	duct
e.	*epithelium*	epithelium
ECM		extracellular matrix
ext.	*externa*	external
f.	*fascia*	fascia, c.t. sheet
GAG		glycosaminoglycan
gl., gll.	*glandula*, *glandulae*	gland, glands
inf.	*inferior*	lower
int.	*interna*	internal
l.	*lamina*	plate, layer
l. epithelialis m.	*lamina epithelialis mucosae*	epithelial layer of mucosa
l. propria m.	*lamina propria mucosae*	connective tissue layer of mucosa
l. muscularis m.	*lamina muscularis mucosae*	muscular layer of mucosa
lig.	*ligamentum*	ligament
m.	*musculus*	muscle
n.	*nervus*	nerve
ncl.	*nucleus*	nucleus
p.	*pars*	part
rER	*reticulum endoplasmicum granulosum*	rough (granular) endoplasmic reticulum
sER	*reticulum endoplasmicum non granulosum*	smooth (agranular) endoplasmic reticulum
str.	*stratum*	layer
sup.	*superior*	higher
t.	*tonsilla, tunica, tela**	tonsil, tunica, tela*
v., vv.	*vena*, *venae*	vein, veins
TEM		transmission electron microscopy
z.	*zona**	zone*
z.	*zonula*, *zonulae**	small zone(s) or band(s) *

* context dependent

SAMPLE PROCESSING FOR LIGHT MICROSCOPY

- **SAMPLING**
- obtaining of material – cells, tissues, etc.
- solid specimen size 0.5 – 1 cm^3 (~1 mm^3 for electron microscopy)
- **biopsy**
- excision, puncture, curettage, ascites aspiration
- **necropsy**

- **FIXATION**
- denaturation and stabilization of cell structures with minimum artifacts
- **chemical fixation** (duration 12-24 hrs)
- *aldehydes*: 4-8% formaldehyde, glutaraldehyde
- *alcohols*: ethanol
- *organic acids*: acetic acid, picric acid, trichloracetic acid
- *inorganic acids*: chromic acid, osmium tetroxide (OsO_4)
- *salts of heavy metals:* $HgCl_2$
- *compound fixatives*: Flemming (chromic acid, acetic acid, OsO_4), Zenker (acetic acid, $HgCl_2$, $K_2Cr_2O_7$, Na_2SO_4), Helly (formaldehyde, $HgCl_2$, $K_2Cr_2O_7$, Na_2SO_4), Susa (formaldehyde, acetic acid, trichloracetic acid, NaCl, $HgCl_2$), Bouin (formaldehyde, picric acid, acetic acid), Carnoy (ethanol, chloroform, acetic acid)

- **RINSING** (washing) and **DEHYDRATION**
- removal of excess of fixative (with water)
- dehydration in ascending series of ethanol

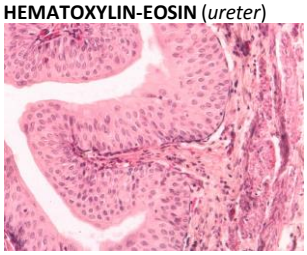
- **EMBEDDING**
- clearing with organic solvent (xylen), infiltration, casting
- **embedding media**
- water soluble (gelatine, celodal, water soluble waxes)
- anhydrous (paraffin, celoidin)

- **CUTTING**
- microtomes: sliding, rotary, cryotomes, ultramicrotomes
- thickness of section:
  5-10 μm (light microscopy), 70-100 nm (electron microscopy)

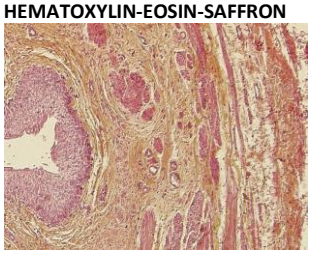
- **AFFIXING**
- attachment of sections with albumin/gelatin to microscopic glass

- **STAINING**
- **ortochromasia**
- structures are stained in same colors as dyes
- **metachromasia**
- structures are stained in different colors than dyes
- **classification of structures according to affinity to dyes**
- chromophobic – no affinity to dyes
- neutrophilic – low affinity to both basic and acid dyes
- chromophilic – high affinity to dyes
- basophilic – affinity to basic dyes (e.g. DNA, RNA, ribosomes)
- acidophilic – affinity to acid dyes (e.g. cytoplasm, hemoglobin)
- **classification of stainings according to intended use**
- routine (e.g. hematoxylin-eosin, AZAN)
- visualization of all tissue components
- special (e.g. oil red, Schmorl, Pappenheim)
- visualization of particular structures only
- silver impregnation (Gomori)
- reduction of $AgNO_3$ to Ag^0 on nerve or reticular fibers

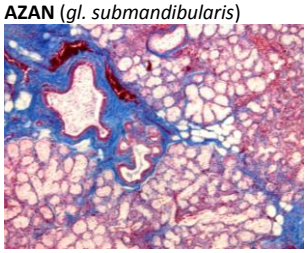
HEMATOXYLIN-EOSIN (*ureter*)



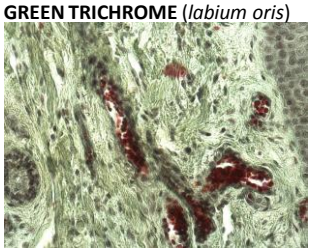
HEMATOXYLIN-EOSIN-SAFFRON



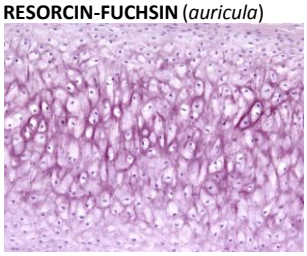
AZAN (*gl. submandibularis*)



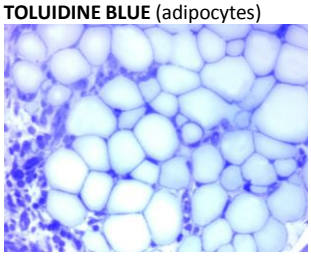
GREEN TRICHROME (*labium oris*)



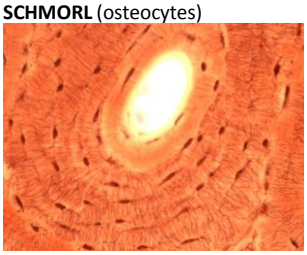
RESORCIN-FUCHSIN (*auricula*)



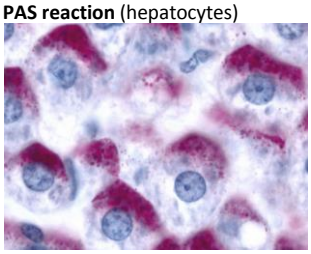
TOLUIDINE BLUE (adipocytes)



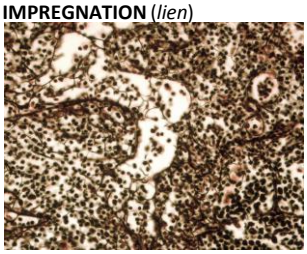
SCHMORL (osteocytes)



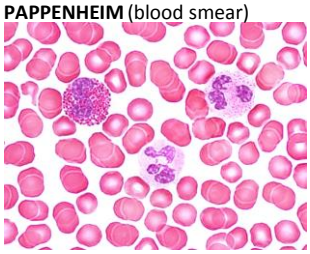
PAS reaction (hepatocytes)



IMPREGNATION (*lien*)



PAPPENHEIM (blood smear)



- **MOUNTING**
- preparation of permanent slides
- mounting media
- xylene soluble (Canada balsam, resin-based media e.g. Eukitt)
- water soluble (glycerol jelly)

Routine stains		Dye	Nucleus	Cytoplasm	Collagen	Other structures
H&E stain		hematoxylin, eosin	**blue**	**pink-red**	**pink**	muscles, erythrocytes - **red**
Trichromes	Yellow (HES)	hematoxylin, eosin, saffron	**blue**	**pink-red**	**yellow**	muscles, erythrocytes - **red**
	Green (Masson)	iron hematoxylin, acid fuchsin, ponceau, orange G, light green	**brown-black**	**yellow**	**green**	
	Blue (Mallory)	iron hematoxylin, ponceau, acid fuchsin, anilin blue	**brown-black**	**pink-red**	**blue**	
	Blue (AZAN)	azocarmin, anilin blue, orange G	**red**	**red**	**blue**	basal membranes, mucin - **blue**, erythrocytes - orange, muscles - **red**

Special stains	Stained structures
Periodic acid Schiff (PAS) reaction	glycogen, glycosaminoglycans, glycoproteins, polysaccharides - **red**
Oil red	adipose tissue, lipids - **red**
Sudan black	adipose tissue, lipids - **blue-black**
Toluidin blue, alcian blue	cartilage, bone, extracellular matrix - **blue**
Impregnation by Gomori	reticular and nerve fibers - **black**
Elastic stain (orcein, resorcin fuchsin)	elastic fibers - **brown** or **red-brown**
Schmorl stain	fine bone structures (canaliculi, lamellae, osteocytes)
Pappenheim (panoptic) stain	blood cells including specific granules

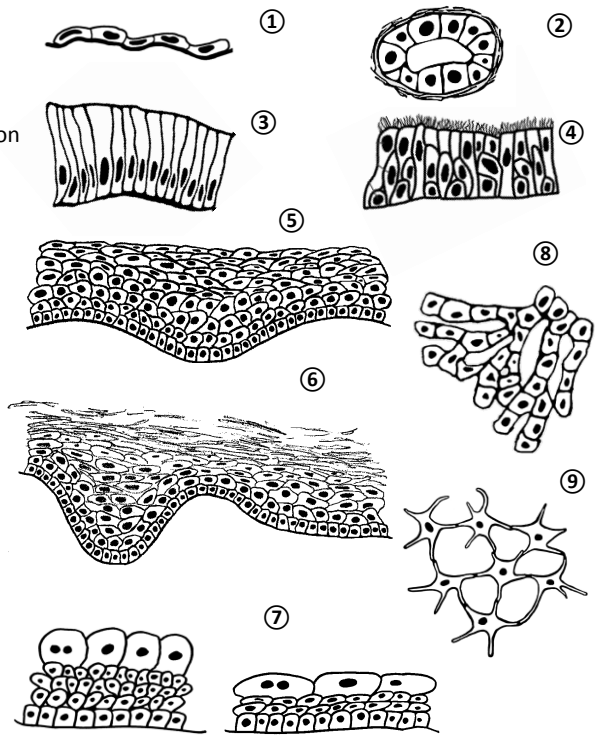
GENERAL PROPERTIES OF EPITHELIAL TISSUE

- apical-basal polarity: intercellular junctions and functional modifications of apical, basal and lateral cell surfaces
- basement membrane
- various functions, e.g. protection, resorption, secretion or perception
- direct vascularization is absent

MORPHOLOGY

- classification based on epithelial cell shape and tissue arrangement
- **sheet epithelium**
- simple squamous e.①
- squamous, polygonal cells, flattened nucleus
- tympanic cavity, parietal sheet of Bowman's capsule, mesothelium, endothelium
- simple cuboidal e.②
- low polyhedral cells, round nucleus
- small ducts of glands, respiratory bronchioles, kidney tubules
- simple columnar e.③
- tall, polyhedral cells, regularly arranged, oval nuclei with long axis parallel to long axis of cells
- digestive tube (cardia → anus), gallbladder, oviduct, uterus, large ducts of ducts
- pseudostratified columnar e. with cilia④
- low basal cells, spindle-shaped cells, tall ciliated columnar cells
- irregularly arranged, oval nuclei
- all cells attached to basement membrane
- respiratory passages – nasopharynx, larynx, trachea, large intrapulmonary bronchi, Eustachian tube
- non-keratinized stratified squamous e.⑤
- ~5-20 layers of cells
- only basal layer in contact with basement membrane
- squamous character prominent towards surface
- c.t. papillae, undulating basement membrane
- lining mucosa of oral cavity, oropharynx, esophagus, vagina, anterior corneal e.
- keratinized stratified squamous e.⑥
- keratin filaments
- epidermis, masticatory mucosa of oral cavity (hard palate, gingiva)
- stratified columnar e.
- basal layer of columnar cells, polyhedral cells and surface columnar cells
- *fornix conjunctivae*, *pars spongiosa* of male urethra, transitional zones to pseudostratified columnar e. with cilia (epiglottis, *regio respiratoria nasi*, soft palate)
- transitional e. (urothelium)⑦
- polyhedral basal cells, pear-shaped cells, large surface (umbrella) cells
- urinary passages (*calyx renalis*, ureter, urinary bladder)
- **trabecular e.**⑧
- epithelial cords assembled in 3D network
- liver parenchyma, endocrine glands (e.g. adenohypophysis, suprarenal cortex, islets of Langerhans)
- **reticular e.**⑨ (cytoreticulum)
- loose meshwork of anastomosing e. cells and processes
- thymus, myoepithelial cells

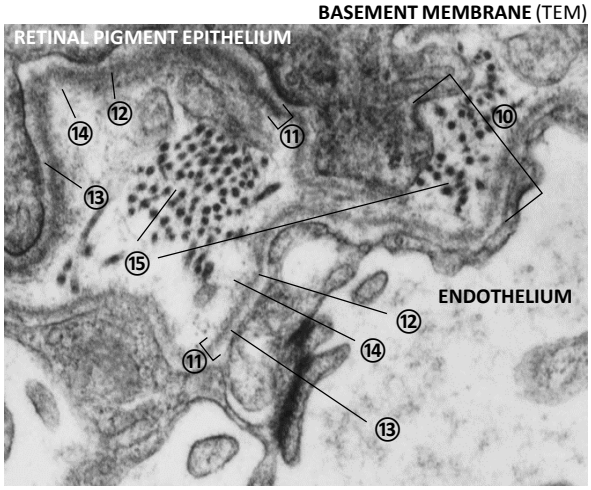
- **basement membrane** (*membrana basalis*, ~0.5-1.0 μm)
- typically located between e. and adjacent c.t. or capillaries
- acellular homogeneous ECM produced by epithelial cells
- often modifications (lung alveoli, glomerular filtration barrier, lens capsule) or fusions in endothelial-epithelial structures⑩
- *lamina basalis* (varying thickness, usually 100-200 nm)⑪
- ECM produced by e. cells
- *lamina rara* at base of e. cells, rich in heparansulfate and GAGs
- in e. to e. fusions⑩, apparent *l. rara externa*⑬ *et interna*⑭ develop
- *lamina densa*⑫, rich in collagen III/IV fibrils and fibrillin
- *lamina fibroreticularis*⑮ (50-500 nm)
- produced by fibroblasts of adjacent c.t.
- present only in genuine e. tissues



Cell surface	Modifications of plasma membrane
Apical	microvilli, brush border, striated border, stereocilia, kinocilia, flagellum
Lateral	desmosomes (*maculae adherentes*), tight junctions (*zonulae occludentes*), adherens junctions (*z. adherentes*), gap junctions (*maculae communicantes*, nexus), interdigitations
Basal	basal labyrinth, hemidesmosomes

	Structure		Major constituents	TEM
Basement membrane (endothelial-epithelial interaction)	*Lamina basalis*	*l. rara ext.*	laminin, perlecan, fibronectin, syndecans, integrins	electron lucent
		l. densa	collagen IV, heparansulfate	electron dense
		l. rara int.	collagen VII, thrombospondin, fibronectin, hyaluronic acid	electron lucent
	Lamina fibroreticularis		collagen I, collagen III, collagen VII, fibronectin, versican	electron lucent, apparent collagen fibrils

BASEMENT MEMBRANE (TEM)



GLANDULAR EPITHELIAL TISSUE

GENERAL PROPERTIES

- synthesis, and secretion or excretion, of various products and compounds
- secretion – further utilization of secretory products (most of gll.)
- excretion – removal of catabolites or toxic compounds (kidney, sweat gll.)
- **endocrine glands** (→ capillaries)
- **exocrine glands** (→ ducts)
- **ultrastructure of glandular cells**
- extensive proteosynthesis → well developed rER and Golgi apparatus, microvesicular system of cisterns and tubules, secretory pathway
- secretory vesicles (secretory granules)
- **secretion cycle**
- ingestion
- simple diffusion, selective resorption, endocytic pathway, pinocytosis
- synthesis
- endoplasmic reticulum and Golgi apparatus → secretory granules
- secretion
- merocrine (eccrine) – exocytosis without altering cell morphology
- apocrine – apical part of cell with secretory products is released
- holocrine – cell disintegrates during secretion

MORPHOLOGY

- **unicellular glands**
- modified secretory cells in e. with other function (e.g. resorptive columnar e., pseudostratified ciliated columnar e.)
- goblet cells①
- narrow basal part with nucleus, apical part extended
- mucous secretory granules (mucin) in apical cytoplasm
- e.g. within e. of respiratory passages, intestine, conjunctiva
- cells of diffuse neuroendocrine system (DNES)
- enterochromaffin cells, argentaffine cells, etc.
- specific secretory granules
- Paneth cells
- large, eosinophilic granules (lysozyme, α-defensins) in apical cytoplasm
- crypts of Lieberkühn (*gll. intestinales*) of *intestinum tenue*
- **multicellular glands**
- secretory cells clustered to anatomical/histological unit

- **classification of multicellular glands according to structure**

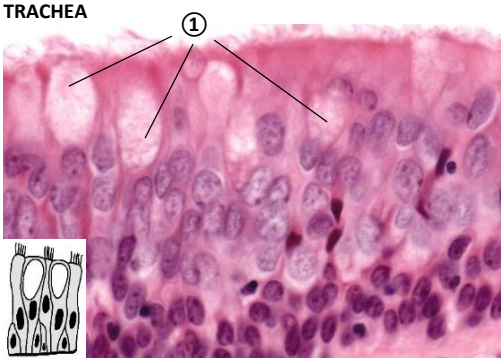
Endoepithelial	within epithelium		male urethra, conjunctiva
Exoepithelial	intramural	within wall of hollow organs	*gll. pyloricae*
	extramural	separate glands	pancreas

Simple	tubular	elongated tubular secretory portion	*gll. intestinales*
	acinar (alveolar)	sac-like secretory portion	rudimentary
Branched	tubular	several tubular secretory parts join to a single common duct	*gll. uterinae* *gll. pyloricae*
	acinar (alveolar)	several acinar secretory parts join to a single common duct	*gll. sebaceae* *gll. tarseae*
Compound	tubular	several elongated tubular secretory parts and their ducts join to a single large common duct	*gll. bulbourethrales* *gll. duodenales*
	acinar (alveolar)	several elongated acinar secretory parts and their ducts join to a single large common duct	pancreas *gl. parotis* *gl. lacrimalis*
	tubuloacinar (tubuloalveolar)	tubular and acinar secretory parts or tubuloacinar units join to a single large common duct	*gl. submandibularis* *gl. sublingualis*

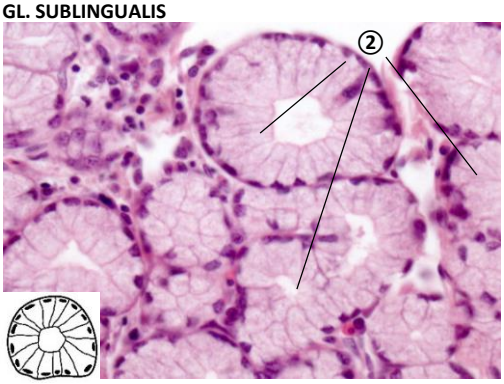
- **classification of multicellular glands according to type of secretion**

Mucous	tubules②	· pale, polyhedral cells · poorly-stained, mucous secretory granules · flat nuclei located basally	*gll. pyloricae* *gll. duodenales*
Serous	acini③	· pyramidal, basophilic cells · round nuclei located in lower 1/3 third of cell · apical secretory (zymogen) granules	pancreas *gl. parotis* *gl. lacrimalis*
Seromucous (mixed)	mucous tubules② serous acini③ serous demilunes (crescents of Gianuzzi)④		*gl. submandibularis* *gl. sublingualis*

TRACHEA



GL. SUBLINGUALIS



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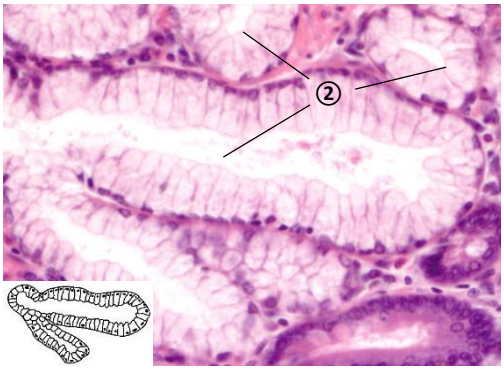
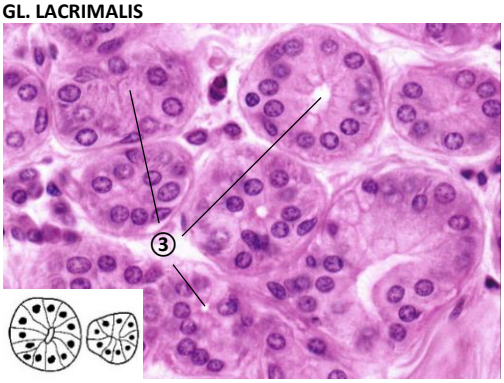
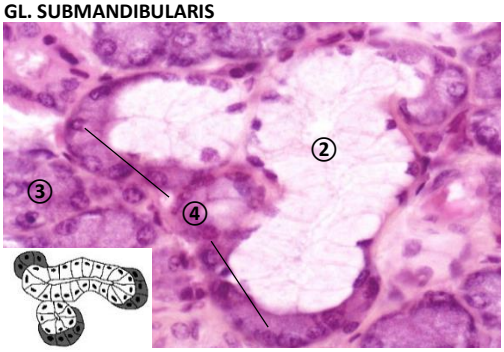


GL. LACRIMALIS



GL. SUBMANDIBULARIS



STRIATED SKELETAL MUSCLE TISSUE

GENERAL PROPERTIES OF SKELETAL MUSCLE TISSUE
- contractility due to unique architecture of cytoskeleton
- complex calcium storage, shuttling and metabolism

SKELETAL MUSCLE FIBER (rhabdomyocyte)①
- long, elongated cell (∅ 10-100 µm, ↔ ~5-6 mm (*m. stapedius*) to ~500 mm (*m. sartorius*)
- 25-40 nuclei/mm② located peripherally under sarcolemma
- deep invaginations of sarcolemma (T-tubules)
- sarcoplasm rich in mitochondria③
- abundant sER (sarcoplasmic reticulum)
- T-tubules and terminal cisternae of sER form triads at junctions of A- and I-bands

• **myofibrils** (∅ 100-200 nm, ↔ full length of rhabdomyocyte)
- linear arrangements of myofilaments in sarcomeres
- stabilized by associated proteins (desmin, plectin, nebulin, dystrophin) and attached to sarcolemma by costamers

• **myofilaments**
• thin myofilaments (6-8 nm, ↔ 1 µm)
- F-actin filaments
- associated with e.g. tropomodulin, nebulin, dystrophin, titin, tropomyosin and troponin complex
- attached to Z-line by α-actinin

• thick myofilaments (∅ ~15 nm, ↔ 1.5 µm)
- myosin II (complex of myosin heavy and light chains)
- associated with e.g. titin and MyBP-C protein
- attached to M-line by myomesin

• **sarcomere**④ (↔ 2-3 µm, contracted ~1 µm)
- structural and functional serial unit of myofibrils
- complex of thin and thick myofilaments defined between two adjacent Z-lines

• A-band⑤ (anisotropic)
- dense band of overlapping thin and thick myofilaments

• I-band⑥ (isotropic)
- pale band of thin myofilaments only

• Z-line⑦
- dense attachment of +ends of actin myofilaments of two adjacent sarcomeres

• H-zone⑧
- pale zone within A-band composed of thick myofilaments only

• M-line
- dense attachment of thick myofilaments

• **neuromuscular junction** (motor-end plate, MEP)
- axon terminus contains numerous mitochondria and synaptic vesicles (acetylcholine, ACh)
- synaptic cleft (↔ 30 nm) with ACh-receptors and acetylcholinesterase on postsynaptic membrane
- non-myelinated terminal axonal branches interact with sarcolemma in shallow depressions (junctional folds)
- action potential is delivered to sER via T-tubules

• **motor unit**
- pre-terminally ramified axon of a motor neuron innervating several muscle fibers
- coordination of muscle contraction

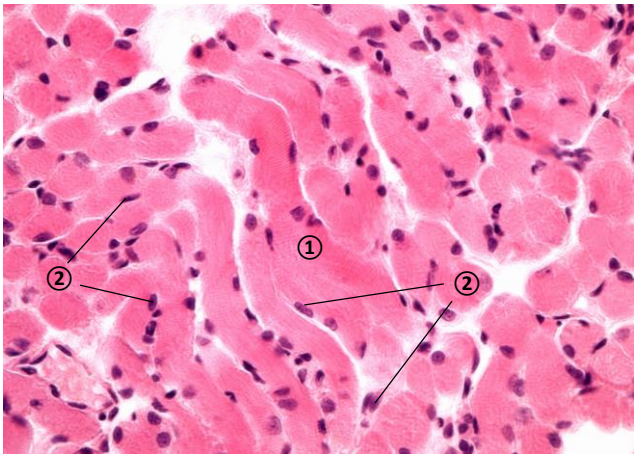
• **connective tissue**
- c.t. around muscle bundles and fibres
- myotendinous junctions

• epimysium
- dense irregular collagen c.t. with elastic fibers; whole muscle

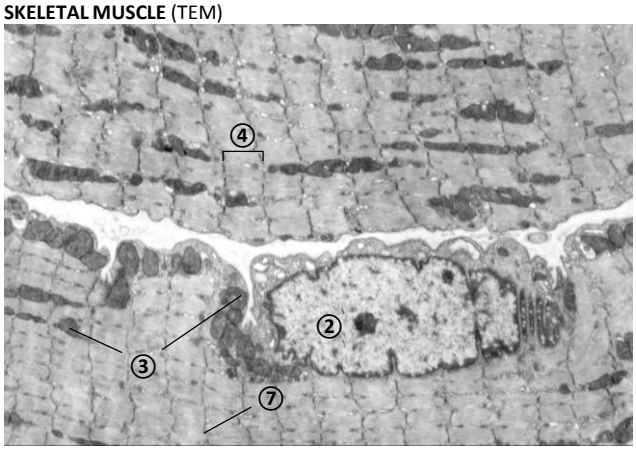
• perimysium⑨
- loose collagen c.t.; primary and secondary muscle bundles
- vascularization, innervation

• endomysium⑩
- reticular fibers and scattered fibroblasts; muscle fibers
- microvascularization

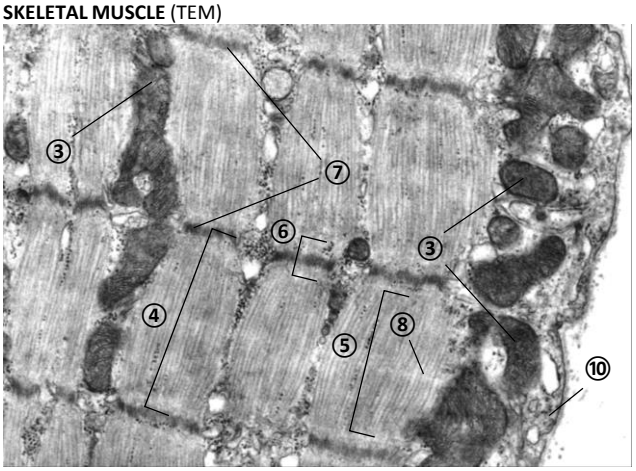
SKELETAL MUSCLE



SKELETAL MUSCLE (TEM)



SKELETAL MUSCLE (TEM)



SKELETAL MUSCLE

CARDIAC MUSCLE

- **cardiac muscle cell** (cardiomyocyte)
  - cylindrical, branched cells (∅ 15 μm, ↔ 100 μm)①
  - 1-2 nuclei② located centrally
  - wide and deep T-tubules, located at Z-line
  - single cistern of sER and T-tubule form short diads
  - cytoplasm rich in myoglobin and glycogen③
  - abundant mitochondria④
  - myofibrils contain sarcomeres⑤ (I-band⑥, A-band⑦, Z-line⑧, H-zone⑨, M-line⑩)
- **intercalated discs** (*discus intercalaris*)
  - end-to-end intercellular junctions of cardiomyocytes
- *fascia adhaerens*
  - actin-associated adherent junction
- desmosomes
  - desmin (intermediate) filaments
- gap junctions (nexus)
- **functional types of cardiomyocytes**
  - working cardiomyocytes
  - conductive cardiomyocytes (Purkinje fibers)
  - specialized cardiomyocytes (myoendocrine cells)

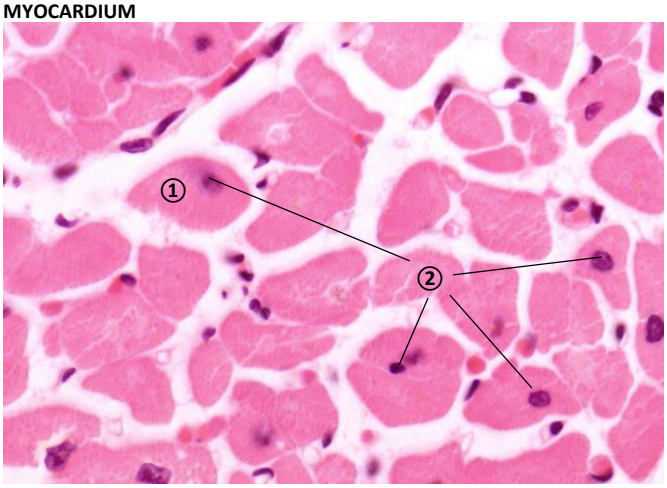
SMOOTH MUSCLE

- **smooth muscle cell** (leiomyocyte)
  - small, fusiform cell⑪ (↔ 20 μm); apparent hypertrophy in pregnant uterus (↔ 500 μm)
  - centrally located nucleus⑫, numerous mitochondria
  - rER and Golgi apparatus (→ ECM secretion)
  - large number of pinocytic vesicles associated with sER and sarcolemma
  - gap junctions (nexus) → propagation of contraction in smooth muscle layers (e.g. walls of tubular organs)
  - close contacts with ECM (mechanotransduction)
- **contractile apparatus**
  - typical organization (striation) of myofibrils is absent
  - thin filaments (actin) associated with tropomyosin, caldesmon and calponin
  - thick filaments (smooth muscle myosin)
  - plasma membrane attachment plaques (focal adhesions)
  - cytoplasmic dense bodies containing α-actinin (equivalent to Z-lines) → anchoring thin filaments
  - caveols (*caveolae*) invaginations of sarcolemma (50-70 nm) involved in Ca^{2+} influx; T-tubules absent
  - cytoskeleton rich in intermediate filaments (desmin, vimentin) anchored to cytoplasmic dense bodies and attachment plaques of sarcolemma
  - myosin light chain kinase (MLCK)- and calmodulin-dependent molecular mechanism of contraction
- **induction of contraction**
- stimulation by autonomic nerve system
  - typical neuromuscular junction is absent
  - large distance between nerve terminus and smooth muscle cell (10-20 μm, occasionally more)
  - various neurotransmitters are released from axonal varicosities
- hormonal stimulation, e.g. epinephrine, oxytocin, ADH
- mechanical stimulation
- spontaneous contraction in absence of external stimuli

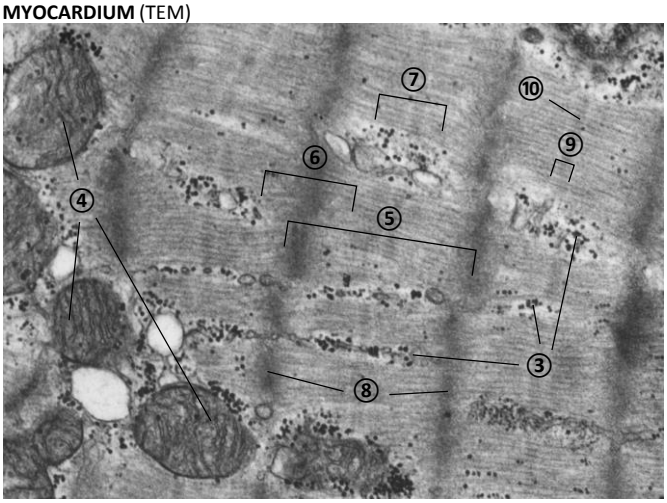
OTHER TYPES OF CONTRACTILE CELLS

- contain contractile myofilaments in cytoplasm
  - diverse tissues and functions
- **myoepithelial cells**
  - secretory portions of glands, iris
- **myofibroblasts**
  - connective tissue
- **myoid cells of testes**
  - peritubular interstitial tissue
- **epithelioid myofibroblasts**
  - perineurium

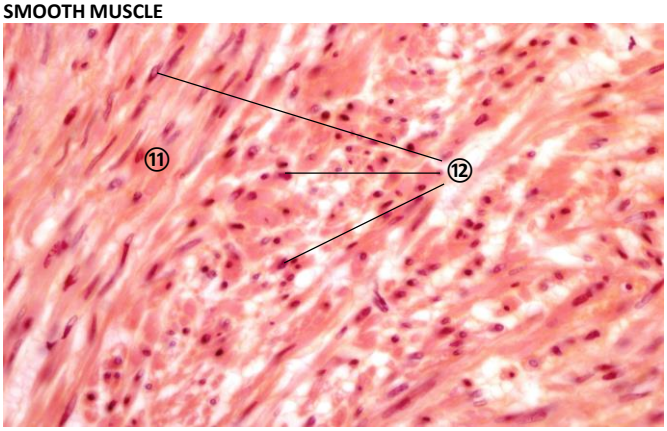
MYOCARDIUM



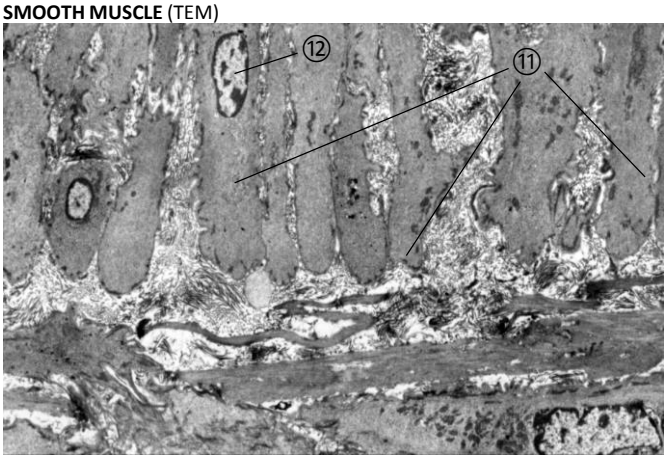
MYOCARDIUM (TEM)



SMOOTH MUSCLE



SMOOTH MUSCLE (TEM)



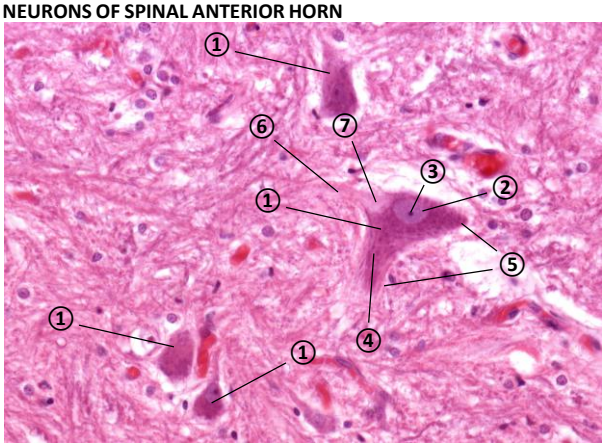
NEURONS

- **soma** (perikaryon)①
  - large, euchromatin-rich nucleus②, often apparent nucleolus③
  - Nissl substance (rER)④
  - polyribosomes, Golgi apparatus, mitochondria
  - lipofuscin, neuromelanin
- **neuronal processes**
- dendrites⑤
  - branched (dendritic tree)
- neurite (axon)⑥
  - single (one of each neuron)
  - varying length (up to 1 m) and thickness (up to 15 μm)
  - axon hillock⑦ without Nissl substance
  - axolemma, axoplasm
- **cytoskeleton**
  - microtubules (neurotubules), actin filaments, neurofilaments
  - anterograde axonal transport
- **synapse**
  - specialized cell junctions transmitting chemical or electrical signal between neurons or neurons and effector cells
  - axodendritic, axosomatic or axoaxonic
- electrical synapses
  - gap junctions (~3.5 nm)
- chemical synapses
  - presynaptic axon terminal
  - synaptic vesicles⑧ (neurotransmitters, 30-60 nm)
  - synaptic cleft (20-30 nm)
  - postsynaptic membrane (receptors for neurotransmitters)
- **neurotransmitters**
  - e.g. acetylcholin, aminoacids (glutamate, GABA, glycin), biogenic amines (epinephrine, norepinephrine, dopamine, serotonin, histamin), peptides (opioids)
- **classification of neurons**
  - number of processes (uni-, pseudouni-, bi-, multipolar)
  - type of neurotransmitter
  - function in neural network (e.g. sensory, motor, interneurons)
  - position in neural network (afferent, efferent, associative)
  - length of axon (Golgi type I and II)

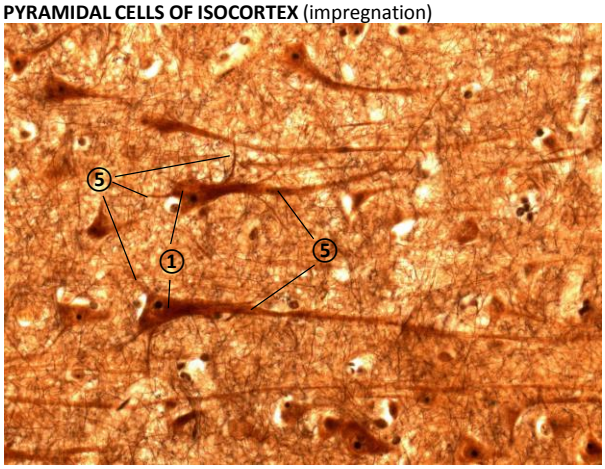
GLIAL CELLS

- more abundant than neurons
- nutritive and structural support of neurons
- control of neuronal microenvironment
- **central nervous system**
  - derived from neuroectoderm (except for microglia)
  - small, dark, round nuclei
- astrocytes
  - fibrous, protoplasmic and radial
  - abundant gap junctions
  - hematoencephalic (blood-brain) barrier
- oligodendrocytes
  - myelin sheaths in CNS
- microglia
  - phagocytosis
  - mesenchymal origin (monocyte-macrophage lineage)
- ependyma cells
  - epithelium-like cells with microvilli and cilia
  - lining of ventricles and central canal of CNS
- **peripheral nervous system**
  - derived from neural crest
- Schwann cells with apparent nuclei⑨
  - basal lamina
  - cellular sheath around neurits (neurilemma)
  - myeline sheaths⑩ of large axons; mesaxon⑪
- satellite glial cells
  - cellular sheath around neuronal perikarya in ganglia

NEURONS OF SPINAL ANTERIOR HORN

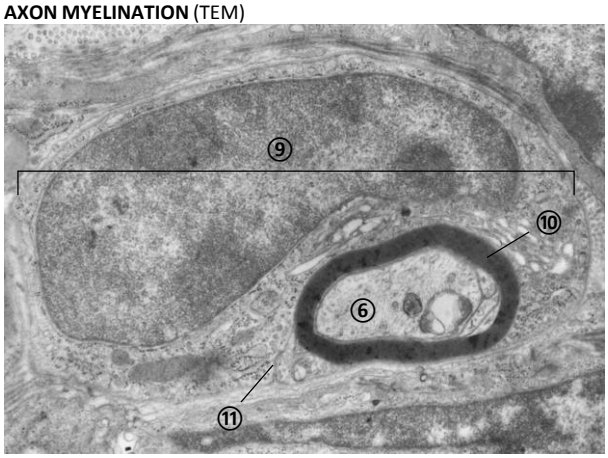


PYRAMIDAL CELLS OF ISOCORTEX (impregnation)



AXON TERMINUS (TEM)

AXON MYELINATION (TEM)



CONNECTIVE TISSUE PROPER

GENERAL COMPOSITION OF CONNECTIVE TISSUE

- **cells of c.t.**
- resident cells of c.t.
- fibroblasts
- euchromatin nucleus①
- abundant rER② and Golgi apparatus③
- synthesis and degradation of ground substance (glycosaminoglycans, glycoproteins, proteoglycans) and collagen I/II microfibrils④
- fibrocytes
- quiescent fibroblasts with low synthetic activity
- reticular cells
- fibroblast-like cells producing reticular fibers
- uni- and multivacuolar adipocytes
- undifferentiated stem cells
- transient cells of c.t.
- cells using blood and lymph vessels for relocation into c.t.
- plasma cells
- mast cells (heparinocytes)
- apparent secretory granules (e.g. heparin, histamin)⑤
- macrophages (histiocytes)
- other leukocytes

- **extracellular matrix**
- fibrilar component
- collagen fibers④
- composed of individual fibrils of tropocollagen polymers
- thickness depends on collagen type (collagen I: ∅ 2-20 μm)
- elastic fibers (∅ 2 μm)
- tropoelastin subunits
- fibrillin scaffolds allow assembly of elastin protein network
- elastic c.t.
- reticular fibers (∅ <1 μm)
- dominant collagen type III
- reticular c.t. e.g. in hematopoietic and lymphatic tissues
- amorphous ground substance
- glycosaminoglycans (GAGs, mucopolysaccharides)
- linear disaccharide polymers, often sulfated
- e.g. hyaluronic acid, chondroitinsulfate, keratansulfate
- proteoglycans and proteoglycan aggregates
- protein core + dominant GAG component
- e.g. aggrecan, syndecan
- glycoproteins
- protein core + oligosaccharide residues
- e.g. fibronectin, laminin

LOOSE COLLAGEN CONNECTIVE TISSUE

- amorphous ground substance, abundant cells
- collagen type I/III, elastic fibers, large amount of GAGs (hyaluronans)
- stroma in epithelial organs, *lamina propria* of *tunica mucosa*, *tela submucosa*, *tunica adventitia* and organ interstitium

DENSE COLLAGEN CONNECTIVE TISSUE

- dominant fibrilar component, cells (mostly fibroblasts) rare
- collagen fibers arranged to paralell or interlaced bundles
- regular dense collagen c.t. (tendons)
- irregular dense collagen c.t. (capsules of organs, sclera)

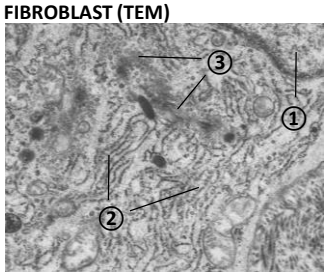
RETICULAR CONNECTIVE TISSUE

- reticular fibers⑥ (collagen type III) produced by modified fibroblasts (fibroblast reticular cells, FRC)
- GAGs, collagen I, fibrillin, elastin, fibronectin, proteoglycans
- bone marrow and secondary lymphatic organs (occasionally in other tissues)

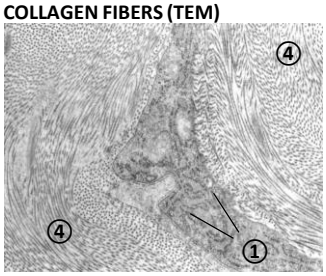
ELASTIC CONNECTIVE TISSUE

- high content of elastic fibers, rare cells
- elastic membranes of aorta, elastic ligaments (vocal ligament)

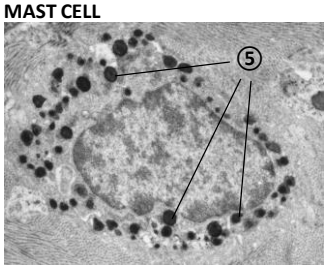
FIBROBLAST (TEM)



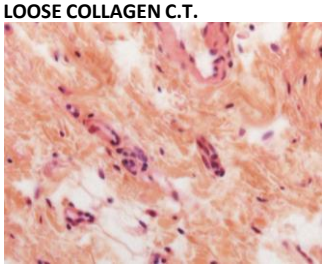
COLLAGEN FIBERS (TEM)



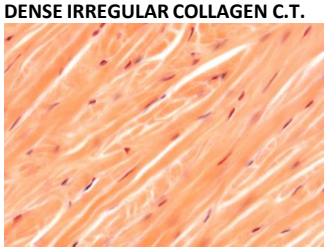
MAST CELL



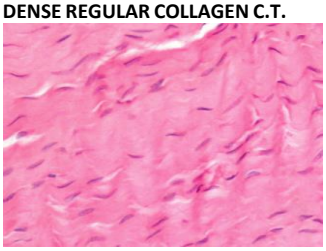
LOOSE COLLAGEN C.T.



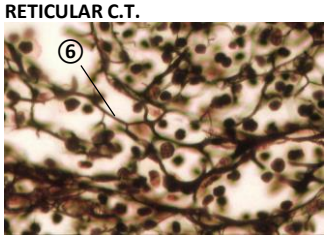
DENSE IRREGULAR COLLAGEN C.T.



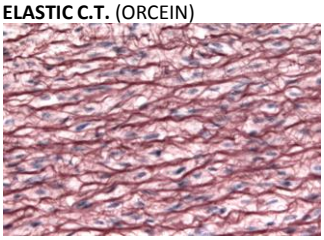
DENSE REGULAR COLLAGEN C.T.



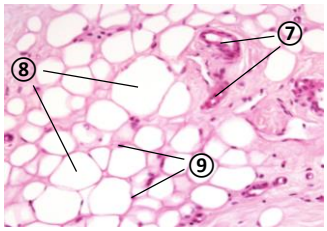
RETICULAR C.T.



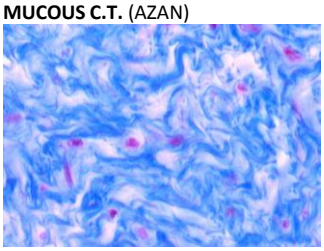
ELASTIC C.T. (ORCEIN)



WHITE ADIPOSE C.T.



MUCOUS C.T. (AZAN)



ADIPOSE CONNECTIVE TISSUE

- **adipocytes**
- high content of lipids (triacylglycerols) stored in vacuoles
- rich vascularization⑦
- **white adipose tissue**
- large, brightly white univacuolar adipocytes⑧
- nucleus⑨ and other organelles localized at cell periphery
- energy storage, hormone production (adipokinins, leptins)
- **brown adipose tissue**
- particularly in full-term fetuses, newborns and small children
- typical localization between shoulder blades, axilla, mediastinum, retroperitoneum
- multivacuolar adipocytes
- thermoregulation

MUCOUS CONNECTIVE TISSUE (Wharton's jelly)

- gelatinous substance in umbilical cord
- derived form extra-embryonic mesoderm
- rich in hyaluronic acid and GAGs (chondroitinsulfate)

GENERAL STRUCTURE OF CARTILAGE (*cartilago*)
- flexible c.t. rich in ECM
- dominant amorphous ground substance with varying proportions of collagen and elastic fibers
- innervation, blood and lymphatic vessels are absent
- nutrition by diffusion from perichondrium or synovial fluid

- **chondroblasts, chondrocytes**
- euchromatin-rich nucleus①, abundant rER② and Golgi apparatus
- synthesis of ground substance (sulfated GAGs, hyaluronic acid, glycoproteins, proteoglycans), collagen I/II microfibrils③, elastin
- cells embedded in ECM can form distinct clusters④ (isogenous groups, chondrons, territories)
- change of cell morphology with increasing distance from perichondrium (spindle → spherical)

- **perichondrium**⑤
- fibrous layer (*stratum fibrosum*)
- dense irregular collagen c.t. with elastic fibers
- rich vascularization and innervation
- perichondral fibroblasts
- chondrogenic layer (*stratum chondrogenicum*)
- proliferation and differentiation of chondroblasts → chondrocytes
- growth and regeneration of cartilage

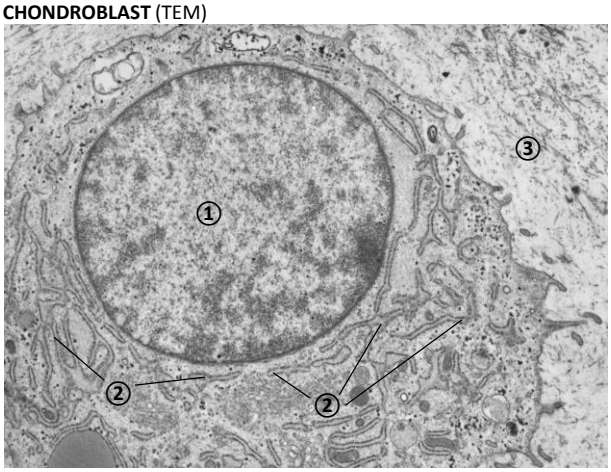
- **synovium** (*stratum synoviale*)
- specialized c.t. lining of inner surface of synovial joint capsules and tendon sheaths (*bursae synoviales*, *vaginae tendineum*)
- numerous blood and lymphatic vessels, nerves
- subintima (*membrana fibrosa*)
- connective tissue (adipose, loose or dense collagen c.t.)
- intima (*membrana synovialis*)
- squamous → cuboidal cells (synovialocytes) with microvilli, mesenchymal origin
- thin intimal folds extending to joint cavity
- synovial fluid
- plasma transudate rich in hyaluronans
- provides nutrition, metabolite and O_2/CO_2 exchange
- leukocyte infiltrations

CLASSIFICATION OF CARTILAGE
- **hyaline cartilage** (*cartilago hyalina*)
- rigid, robust, flexible
- fetal skeleton, ribs, trachea, articular cartilages, laryngeal cartilages (*cart. thyroidea*, *cart. cricoidea*, *cart. arytenoidea*)
- collagen II, chondroitinsulfate A, C
- fibrous component masked by amorphous ground substance
- isogenous groups④ embedded in basophilic territorial matrix⑥
- perichondrium present (except for articular cartt.)

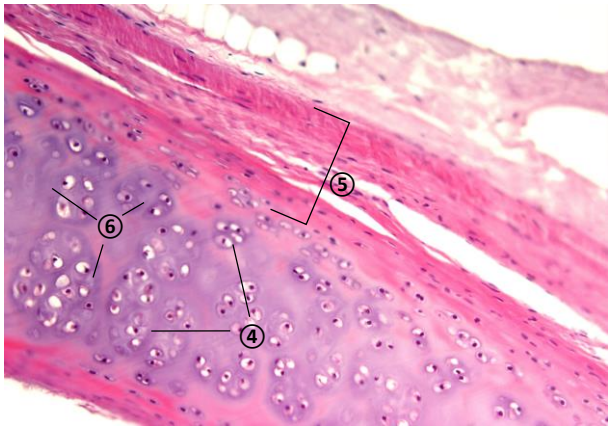
- **elastic cartilage** (*cartilago elastica*)
- highly flexible, elastic
- auricle, Eustachian tube, larynx (*cart. corniculata*, *cart. cuneiformis*), epiglottis
- apparent fibrous component (elastin and collagen II)⑦
- regularly dispersed chondrocytes⑧
- isogenous groups rare or absent
- perichondrium present

- **fibrocartilage** (*cartilago fibrosa*)
- robust, resistant
- intervertebral discs, *symphysis pubis*, *ligamentum teres femoris*, *meniscus*
- dominant fibrous component (collagen I)⑨
- separated individual chondrocytes among collagen fibers⑩
- isogenous groups are absent
- perichondrium is absent

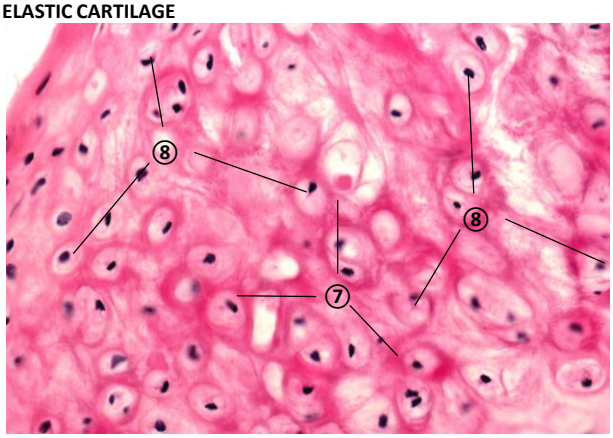
CHONDROBLAST (TEM)



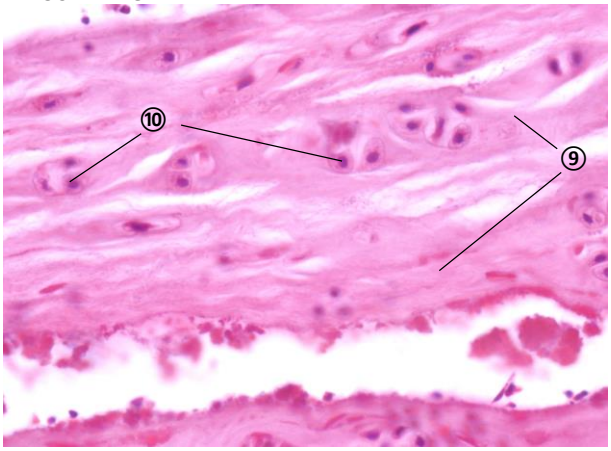
HYALINE CARTILAGE



ELASTIC CARTILAGE



FIBROCARTILAGE



BONE (*os*)
- solid c.t. composed of mineralized ECM
- unique biomechanical properties
• periosteum
- outer bone layer of dense irregular collagen c.t.
- Sharpey's (perforating) fibers
- inner layer of osteoblasts and osteoprogenitor cells
• endosteum
- thin layer of bone lining cells on inner surface
- osteoblasts, osteoprogenitor cells

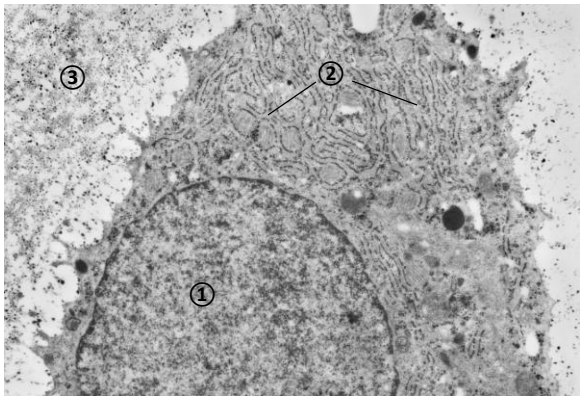
BONE CELLS
• **osteoblasts**
- approx. cuboidal cells, localized on inner and outer bone surface
- euchromatin-rich nucleus①, abundant rER② and Golgi apparatus
- synthesis of organic matrix (osteoid)③ and collagen fibers
- mineralization
• **osteocytes**④
- localized in lacunae⑤ in mineralized bone matrix
- connected by cytoplasmic processes through *canaliculi ossium*⑥
- local bone remodelling
• **osteoclasts**
- localized on bone surface in resorption bays (Howship's lacunae)
- large, multinuclear cells (50-100 μm)
- complex ultrastructure of plasma membrane (ruffled border)
- origin by fusion of monocyte-macrophage progenitors
- resorption of bone tissue

BONE MATRIX
• **bone lamellae**
- parallel layers of mineralized ground substance
- collagen I fibrils (3-5 μm) highly oriented in similar direction
- hydroxyapatite $[3Ca_3(PO_4)_2 . Ca(OH)_2]$
- contains other proteins with structural or metabolic functions (e.g. osteocalcin, osteonectin, osteopontin, bone sialoprotein)

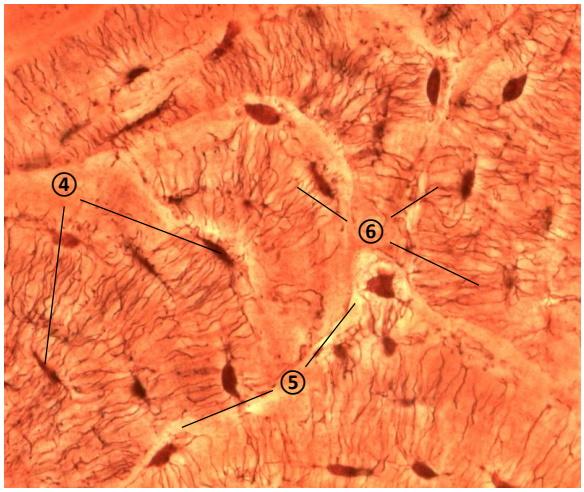
CLASSIFICATION OF BONE TISSUE
• **primary bone** (woven, fibrilar)
- collagen fibers interlaced with no particular structural pattern
- bone cells dispersed rather randomly
- developmentaly primitive
• **secondary** (lamellar)
- mineralized ground substance and collagen fibers form lamellae
• <u>trabecular bone</u> (spongy)
- sheet lamellae parallel to surface form trabecules (~300 μm)
- avascular, nutrition by diffusion from bone marrow
• <u>compact bone</u>
• Haversian systems⑦ (osteons, ∅ 100-400 μm) of 5-20 bone lamellae concetrically arragend around Haversian canal
- Haversian canals⑧ (∅ ~20 μm) with capillaries or postcapillary venules and occasional c.t. and nerve fibers, lined by endosteum
- transverse Volkmann canals
• circumferential lamellae
- external and internal
• interstitial lamellae⑨ – inactive, remodelled osteons

OSSIFICATION OF BONE TISSUE
• differentiation of osteoprogenitor cells and osteoblasts from mesenchymal stem cells
• **intramembraneous ossification**
- formation of osteoid and direct ossification without cartilage model
• **endochondral ossification**
- hyaline cartilage model, e.g. growth plate
• typical zonation
- zone of reserve cartilage
- zone of proliferating cartilage⑩
- zone of hypertrophic (maturing) cartilage⑪
- zone of calcifying cartilage⑫
- line of erosion⑬
- zone of ossification and remodelling⑭

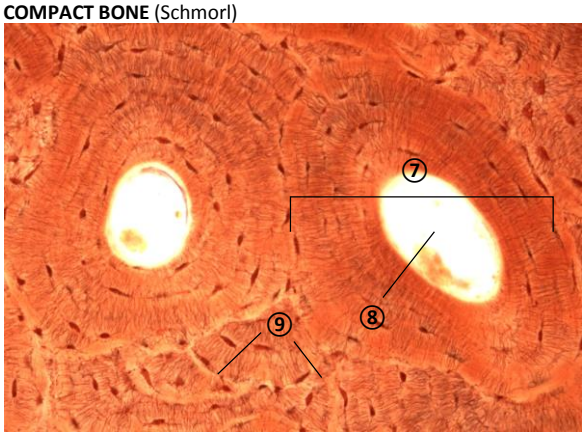
OSTEOBLAST (TEM)



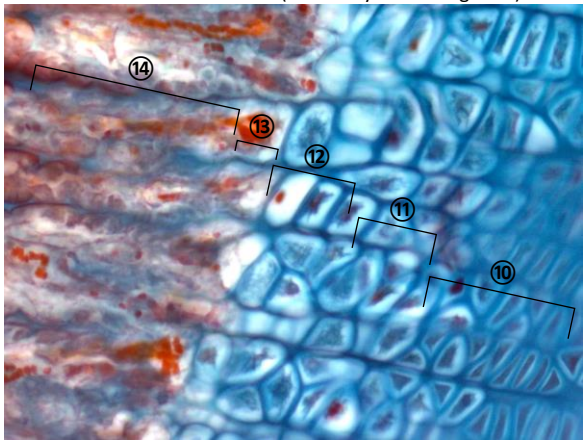
OSTEOCYTES (Schmorl)



COMPACT BONE (Schmorl)



GROWTH PLATE OSSIFICATION (hematoxyline + Congo red)



GENERAL STRUCTURE OF ARTERIES AND VEINS

- ***tunica intima***①
- endothelium②
  - simple squamous e. with *z. occludentes* and gap junctions
  - selectively permeable, non-thrombogenic layer
  - production of vasoactive agents
  - immune responses
- subendothelial layer③
  - loose collagen c.t.
- *membrana elastica interna*
- ***tunica media***④
  - circumferential layer of spindle-shaped smooth muscle cells
  - c.t. (collagen I, proteoglycans) produced by smooth muscle cells
  - undulating, eosinophilic *membrana elastica externa*
- ***tunica externa*** (***t. adventitia***)⑤
  - c.t. containing collagen I and elastic fibers
  - smooth muscle cells
  - occasional macrophages
  - innervation, vascularization

- **nerves of blood vessels**⑥ (*nervi vasorum*)
  - postganglionic, non-myelinated vasomotoric fibers from sympathetic ganglia branching in *t. adventitia*
  - button-like neuroeffector junctions at adventitial-medial border
  - in *t. adventitia* of aorta and large arteries – small ganglia and bundles of myelinated fibers
  - vasoconstriction, vasodilatation

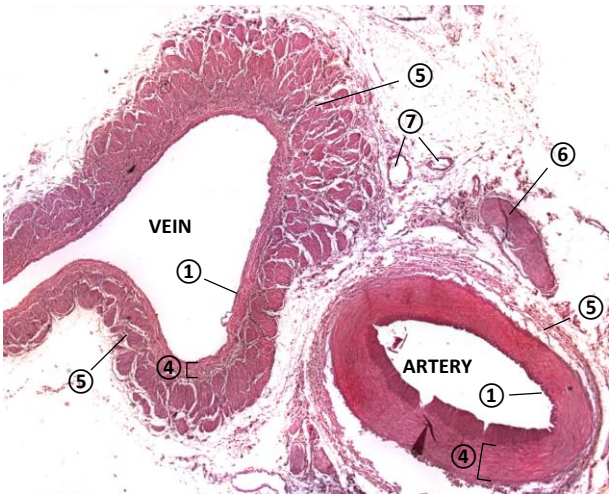
- **blood vessels of blood vessels**⑦ (*vasa vasorum*)
  - vascular plexus (*vasa vasorum*) in peripheral layers of walls of larger vessels (> 1 mm, especially large veins)
  - density of *v. vasorum* depends on type, size and location of nourished vessels
  - nutrition and oxygenation of inner layers by diffusion from lumen of nourished vessel

MUSCULAR ARTERIES (∅ 1-10 mm)

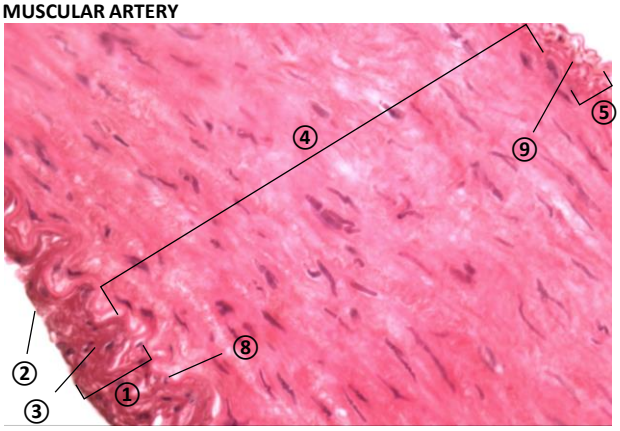
- medium-sized, distributing arteries
- most arteries
- ***t. intima***
  - longitudinally arranged endothelium
  - apparent subendothelial layer with smooth muscle cells
  - *membrana elastica int.*⑧ between *t. intima* and *t. media*
- ***t. media***
  - 5 - 40 circular layers of smooth muscle cells
  - varying content of collagen I and elastic fibers
  - *membrana elastica ext.*⑨ between *t. media* and *t. adventitia*
- ***t. adventitia***
  - relatively thin, contains collagen I
  - occasional *vasa vasorum*

MEDIUM-SIZED VEINS (∅ 1-10 mm)

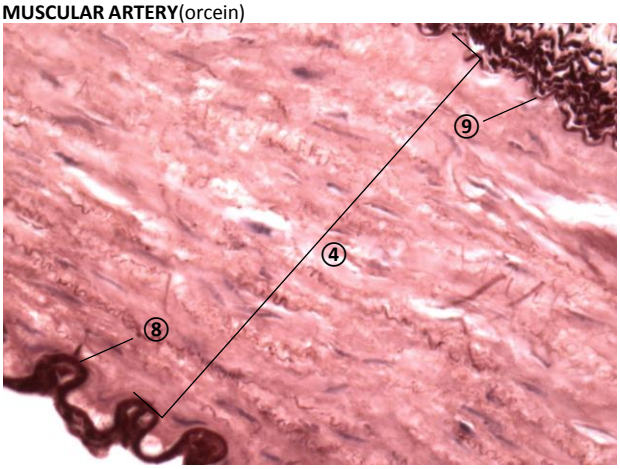
- most veins
- in sections lumen often collapsed, irregular, with occasionally preserved erythrocytes
- ***t. intima***
  - endothelium and thin subendothelial layer
  - occasionaly *membrana elastica int.*
  - semilunar valves (duplicatures of *t. intima*)
- ***t. media***
  - thin, 3-5 circular layers of smooth muscle cells and dispersed collagen and elastic fibers
- ***t. adventitia***
  - thickest layer, collagen and elastic c.t., bundles of longitudinally oriented smooth muscle cells



MUSCULAR ARTERY



MUSCULAR ARTERY(orcein)



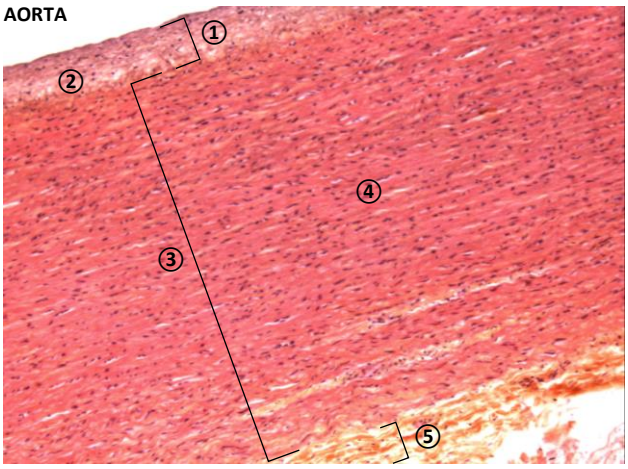
MEDIUM VEIN

ELASTIC ARTERIES (∅ > 10mm)
- large-sized arteries adapted for pulse wave hydrodynamics
- e.g. *aorta*, *arteria pulmonalis*, *a. carotis communis*, *truncus brachiocephalicus*, *a. vertebralis*, etc.
- ***t. intima***①
- elongated endothelium oriented in paralell to blood flow
- Weibel-Palade bodies (von Willebrand factor, P-selectin)
- thick subendothelial layer containing collagen I and elastic fibers
- undulating, fenestrated, eosinophilic *membrana elastica interna*② between *t. intima* and *t. media*
- ***t. media***③
- varying number of fenestrated, concentric elastic membranes (*membranae fenestratae*)④ intercalated between low-pitch, spiral (concentric) layers of smooth muscle cells
- reticular c.t. (collagen III), proteoglycans and chondroitinsulfate produced by smooth muscle cells
- eosinophilic *membrana elastica externa*
- ***t. adventitia***⑤
- relatively thin when compared to veins
- collagen I, elastin
- eosinophilic *membrana elastica externa* between *t. media* and *t. adventitia*
- *vasa*⑥ *et nervi*⑦ *vasorum*

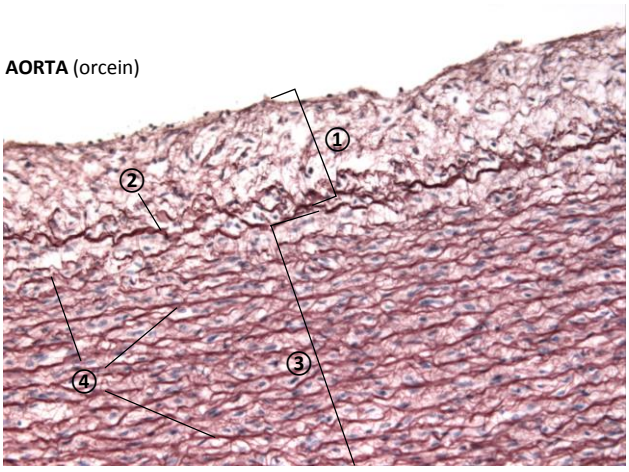
LARGE VEINS (∅ > 10mm)
- e.g. *vena cava inferior et superior*, *v. portae*
- inconspicious boundaries between individual layers (tunics)
- ***t. intima***①
- polygonal endothelium with apparent subendothelial c.t. layer
- valves derived from t. intima (endothelium and elastic c.t.)
- ***t. media***③
- > 5 circumferential → irregular layers of smooth muscle cells
- reticular (collagen III) and collagen I fibers
- ***t. adventita***⑤
- thickest layer, rich in collagen I and elastin
- longitudinally arranged bundles of smooth muscle cells⑧

SOME EXAMPLES OF ATYPICAL BLOOD VESSELS
- atypical structure of vessel wall
- **coronary arteries** (*a. coronaria*)
- ***t. intima*** with subendothelial layer progressively thickening with age
- ***t. media*** thicker than in comparable arteries
- ***t. adventitia*** rich in collagen I fibers, continuous with epicardium
- **dural venous sinuses**
- cavities in *dura mater* lined by endothelium, lacking smooth muscle cells
- drain brain veins and arachnoideal cerebrospinal fluid to internal jugular vein (*v. jugularis interna*)
- **medullary veins of *gl. suprarenalis***
- irregular wall with eccentric clusters of contractible smooth muscle cells bundles (cushions)
- regulation of blood flow to *v. suprarenalis*

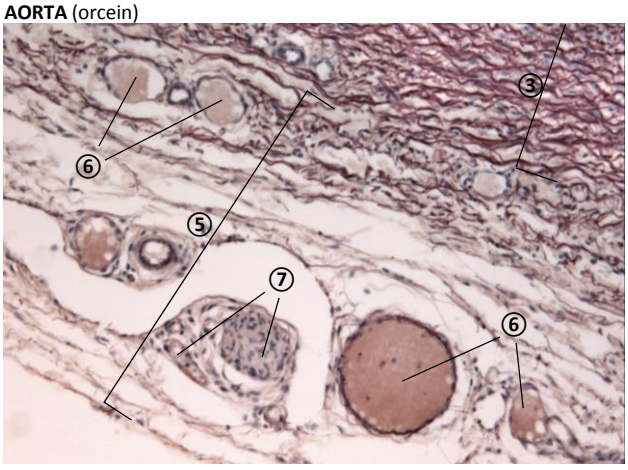
AORTA



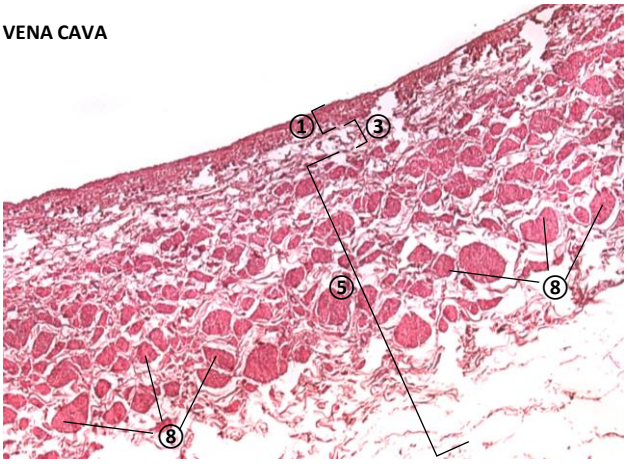
AORTA (orcein)



AORTA (orcein)



VENA CAVA



SMALL ARTERIES (∅ 0.1-1 mm)
- ***t. intima***
- endothelium and thin subendothelial c.t. with smooth muscle cells
- *membrana elastica interna* often absent
- ***t. media***
- 3-10 complete layers of smooth muscle cells in *t. media*
- ***t. adventitia***
- c.t. thinner than *t. media*
- *vasa vasorum* absent

ARTERIOLES (∅ 10-100 µm)
- ***t. intima*** ①
- composed of endothelium, c.t and smooth muscle cells absent
- ***t. media*** ②
- 1-3 complete layers of smooth muscle cells
- ***t. adventitia*** ③
- thin, collagen c.t.

ARTERIOVENOUS (CIRCULATORY) ANASTOMOSES
- arteriovenous (AV) shunts bypassing capillary circulation
- regulated straight or coiled (glomeriform) anastomoses

CAPILLARIES ④ (∅ ~4-10 µm)
- **endothelium** ⑤ with basal lamina
- thin cells (0.2 µm) with protruding nuclei, pinocytic vesicles
- *zonulae adherentes*, *z. occludentes*, desmosomes, gap junctions
- continuous, fenestrated or discontinuous (sinusoids)
- **pericytes** ⑥
- common basal lamina with endothelial cells
- tight interaction of their cytoplasmic processes with endothelium
- contractile, support vasculogenesis and stability of capillaries

POSTCAPILLARY VENULES (∅ ~10-30 µm)
- ***t. intima***
- endothelium with pericytes, intimal valves absent
- in lymph nodes: high endothelial venules → cuboidal endothelium
- ***t. media*** and ***t. adventitia*** absent

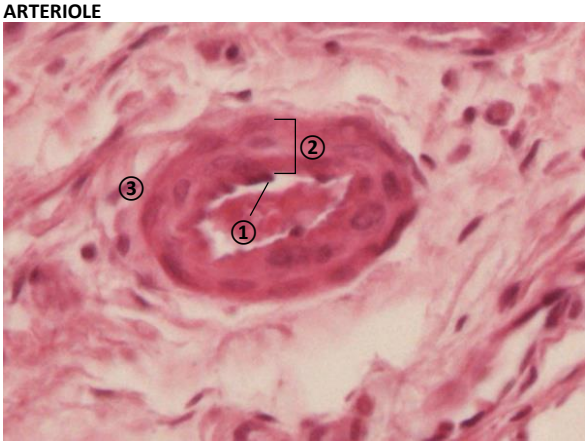
COLLECTING VENULES (∅ ~30-50 µm)
- ***t. intima***
- endothelium, pericytes present
- ***t. media*** absent
- ***t. adventitia*** inapparent, collagen c.t.

MUSCULAR VENULES (∅ ~50-100 µm)
- ***t. intima***
- endothelium, pericytes absent
- ***t. media***
- 1-2 layers of smooth muscle cells
- ***t. adventitia***
- apparent, collagen c.t.

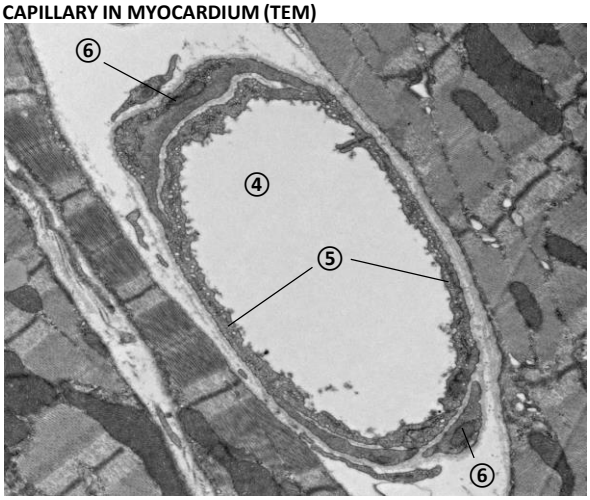
SMALL VEINS (∅ ~0.1-1 mm)
- ***t. intima***
- endothelium with valves
- thin subendothelial c.t. with smooth muscle cells
- ***t. media***
- 2-3 layers of smooth muscle cells
- collagen and rare elastic fibers
- ***t. adventitia***
- apparent, thicker than *t. media*, collagen c.t.

LYMPHATIC VESSELS (∅ ~20-100 µm)
- **lymphatic capillaries** ⑦ (*vasa lymphocapillaria*)
- irregular, blunt-ended lymphatics with permeable endothelium
- continuous basal lamina and pericytes absent
- often association with lymphatic tissue
- **medium-sized lymphatic vessels**
- similar structure to small- and medium-sized veins
- wall thickness gradually increases with size of lymphatic vessel
- impermeable endothelium with valves and continuous basal lamina
- elastic fibers and occasional smooth muscle cells in ***t. media***
- ***t. adventitia*** dominant in larger vessels
- rich in collagen I and elastic fibers, smooth muscle cells
- vascularization and innervation similar to blood vessels
- continuous with interstitial c.t.
- **lymphatic trunks** (*d. thoracicus*, *d. lymphaticus dexter*)
- thick **t. media** with smooth muscle bundles and rich c.t.
- ***t. adventitia*** rich in collagen and elastic fibers, smooth muscle cells

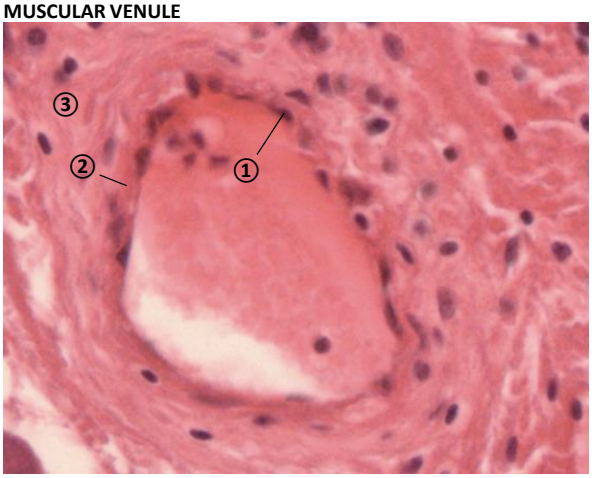
ARTERIOLE



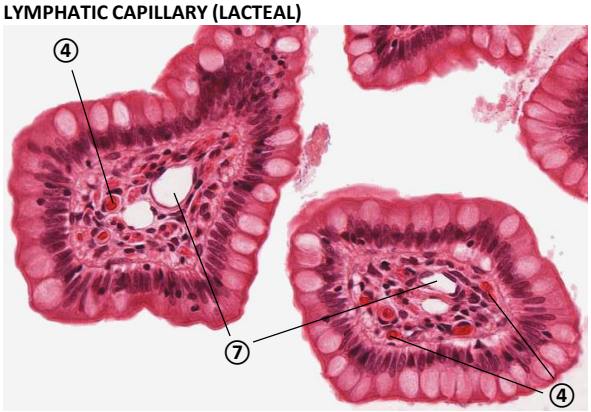
CAPILLARY IN MYOCARDIUM (TEM)



MUSCULAR VENULE



LYMPHATIC CAPILLARY (LACTEAL)



GENERAL STRUCTURE OF HEART WALL

- **endocardium** (corresponds to *t. intima*)
- endothelium and subendothelial c.t.
- middle myoelastic layer of c.t. with smooth muscle cells
- subendocardial layer continuous with c.t. of myocardium
- **myocardium** (corresponds to *t. media*)
- cross-striated cardiac muscle tissue
- bundles of cardiomyocytes① with 1 or 2 nuclei②
- interstitial c.t. with collagen and reticular fibers③
- high density of capillaries and lymph vessels④
- intercalated discs⑤ – *fascia adhaerens*, desmosomes, gap junctions
- sarcomere⑥ with wide T-tubules, diads formed by a single T-tubulus and terminal cistern of sarcoplasmic reticulum⑦
- abundant mitochondria⑧
- apparent secretory granules (200-300nm) in atrial cardiomyocytes secreting atrial natriuretic peptide (ANP) → volume balance of extracellular fluid
- **epicardium** (corresponds to visceral pericardium)
- single layer of simple squamous e.
- collagen and adipose c.t. continuous with interstitial c.t. of myocardium
- coronary vessels

- **fibrous skeleton**
- *anuli fibrosi cordis*
- *trigona fibrosa*
- *septum membranaceum*
- dense irregular collagen c.t.
- accumulation of calcium with age

- **heart valves**
- endocardial duplicatures attached to *anuli fibrosi*
- endothelium-lined plates of dense collagen c.t. with elastic fibers
- avascular, non-innervated
- *chordae tendineae* (tricuspid and mitral valve) – collagen-elastic tendons
- papillary muscles (*musculi papillares*) – myocardial protrusions into ventricles

HEART CONDUCTING SYSTEM

- functional atrial and ventricular syncytium
- **sinoatrial** (SA) and **atrioventricular** (AV) **node**
- modified cardiomyocytes
- smaller cell size, reduced myofibrils
- gap junctions
- branching into AV bundle of His and Purkinje fibers, etc.

- **Purkinje fibers**
- subendocardial layer
- short, modified cardiomyocytes with myofibrils at cell periphery
- large amount of glycogen (→ pale appearance)
- 1-2 large and round nuclei
- variable number and location of desmosomes and gap junctions

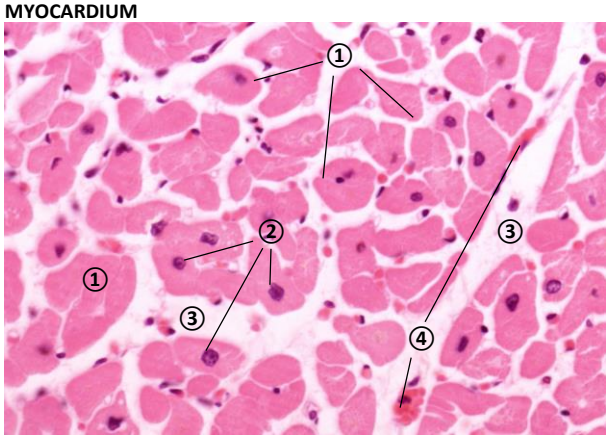
INNERVATION

- myelinated and non-myelinated nerve fibers at heart apex
- direct myoneural junctions absent

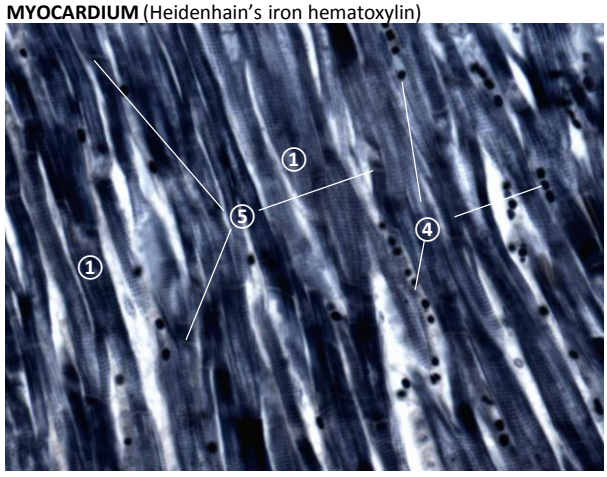
PERICARDIAL CAVITY

- **pericardium**
- outermost fibrous layer of collagen c.t. (**fibrous pericardium**)
- serous **parietal pericardium** composed of elastic c.t. lined by simple squamous to cuboidal e.
- serous **visceral pericardium** (epicardium)
- pericardial fluid between pariteal and visceral pericardium

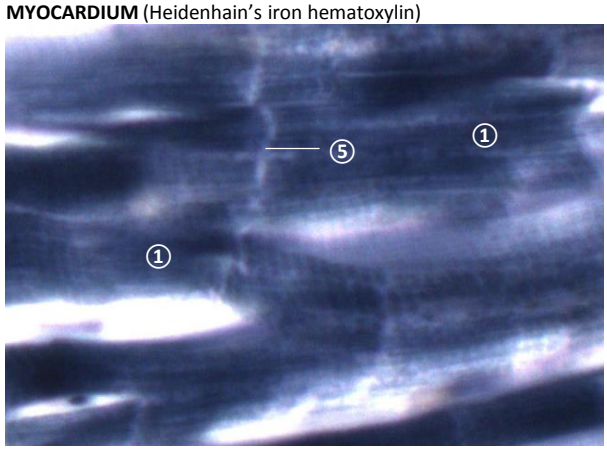
MYOCARDIUM



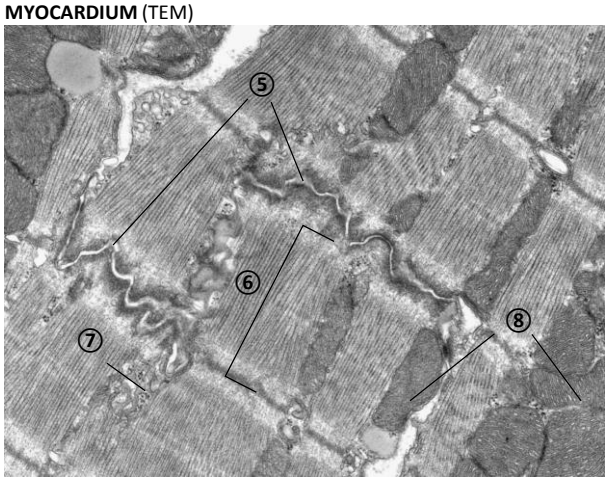
MYOCARDIUM (Heidenhain's iron hematoxylin)



MYOCARDIUM (Heidenhain's iron hematoxylin)



MYOCARDIUM (TEM)



FORMED ELEMENTS OF BLOOD
- **red blood cells** (erythrocytes)
- ♂ 4.1-6.0x10^{12}/L, ♀ 3.9-5.5x10^{12}/L (↑ polyglobulia/polycythemia, ↓ anemia)
- **white blood cells** (granulocytes, agranulocytes)
- 4-9x10^{9}/L (higher in children)
- **thrombocytes**① (0.15-0.30x10^{12}/L)

PLASMA
- water 91-92%
- proteins (albumins, globulins, fibrinogen) 7-8%
- other (electrolytes, glucose, gases, non-protein substances, hormones) 1-2%

HEMATOCRIT
- % of sedimented formed elements to total volume of blood
- erythrocytes ~45%
- leukocytes ~1%
- plasma ~55%

ERYTHROCYTES②
- life span ~120 days
- anucleate, organelles absent including mitochondria → anaerobic glycolysis
- eosinophilic cytoplasm
- hemoglobin (HbA_1, HbA_2, HbF) up to 33% of cytoplasm
- occasionally Howel-Jolly bodies (basophilic residues of DNA)
- cytoskeletal architecture associated with plasma membrane (spectrin)
- reticulocytes up to 0.5-1.5% in peripheral blood

- **normocytosis** (normocyte, biconcave disc)
- 7-8 µm (average 7.4 µm), central thickness: 0.8 µm, edge thickness: 2.6 µm
- size depends on tonicity of solution (hypertonic, hypotonic, isotonic)
- **anisocytosis** (abnormal size)
- macrocytes (>9 µm)
- microcytes (<6 µm)
- **poikilocytosis** (abnormal shape)
- spiked cell membrane (acanthocytes)
- concentric rings of hemoglobin (codocytes)
- thorny membrane projections (echinocytes)
- other than biconcave shape – elliptic, spherical (elliptocytes, spherocytes)
- swelling and bursting appearance (stomatocytes)
- sickle-shape (drepanocytes)
- missing cell fragments of various size (schistocytes, degmacytes)

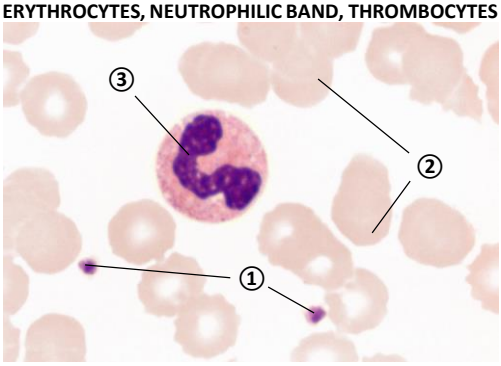
GRANULOCYTES (polymorphonuclear leukocytes)
- terminally differentiated cells with short lifespan
- nucleus segmented to lobes connected by karyoplasm (chromatin bridges)
- condensed chromatin
- non-specific, azurophilic granules (primary lysosomes)
- specific granules containing various biologically active substances

- **neutrophilic granulocyte** (~12 µm in smear)
- nucleus non-segmented (young neutrophils, stabs/bands③) or segmented to 2-5 lobes (mature neutrophils, segments④)
- Barr body⑤ – drumstick projection on one of nuclear lobes in females (inactive X chromosome)
- light pink neutrophil specific granules containing alkaline phosphatase, lactoferrin, bactericide proteins (phagocytins), NADPH oxidase, elastase
- glycogen β granules

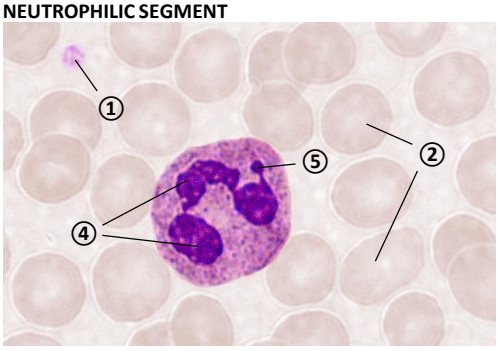
- **eosinophilic granulocyte**⑥ (12-15 µm in smear)
- irregularly-shaped nucleus segmented to 2 lobes
- bright red eosinophil specific granules of variable size derived from lysosomes, containing e.g. peroxidase, acid phosphatase, cathepsins, ribonuclease, major basic protein (MBP)
- in TEM, apparent granules with crystalloid and transparent matrix⑦

- **basophilic granulocyte**⑧ (~10-12 µm in smear)
- irregularly-shaped nucleus partially segmented to 2 lobes ("S"-shaped)
- violet or purple to black granules of variable size containing e.g. heparin, histamine, proteolytic enzymes, cytokines, leukotriens

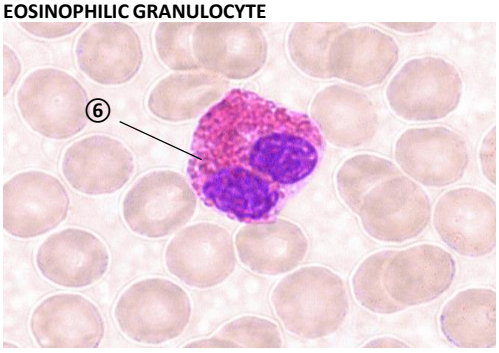
ERYTHROCYTES, NEUTROPHILIC BAND, THROMBOCYTES



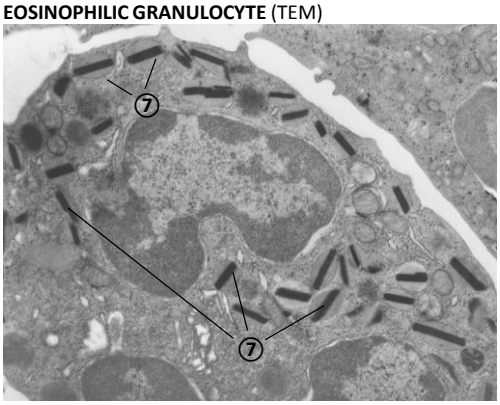
NEUTROPHILIC SEGMENT



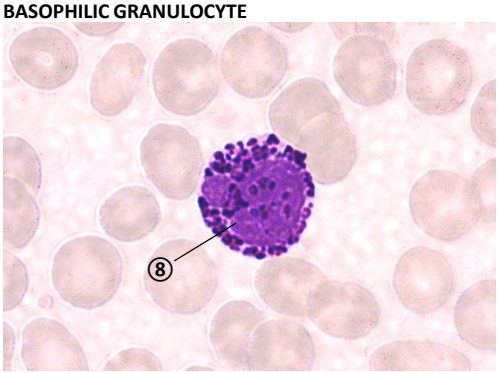
EOSINOPHILIC GRANULOCYTE



EOSINOPHILIC GRANULOCYTE (TEM)



BASOPHILIC GRANULOCYTE



AGRANULOCYTES (mononuclear leukocytes)

- non-segmented nuclei
- azurophilic granules (50-250 nm), specific granules absent

• **lymphocytes**① (small ~6-8 µm, medium and large ~8-18 µm)
- biologically highly variable leukocytes with uniform morphology
- round nucleus, rich in heterochromatin
- high nuclear-cytoplasmic ratio
- basophilic cytoplasm reduced to a sickle-shape edge around nucleus
- rare mitochondria, small Golgi apparatus, rare azurophilic granules
- further differentiation and maturation (e.g. B-lymphocytes to plasma cells)

• **plasma cells**
- abundant rER② , Golgi apparatus and secretory vesicles③ (Ig production)

• **monocytes**④ (~15-18 µm in smear)
- in circulation only, after extravasation differentiate to **macrophages**
- indented, bean shaped, eccentric nucleus
- less condensed (dense) chromatin
- 2-3 nucleoli
- voluminous, basophilic, blue-gray cytoplasm
- numerous mitochondria
- well developed Golgi apparatus close to indentation of nucleus
- abundant azurophilic granules (primary lysosomes)

• **macrophages**
- c.t. macrophages, alveolar macrophages, osteoclasts, Kupffer cells, etc.
- large, round nucleus, abundant vacuolated cytoplasm
- membrane vesicles – phagocytic vacuoles⑤ (phagosomes), lysosomes, etc.

• **dendritic cells**
- antigen presenting cells mediating immune response

DIFFERENTIAL WHITE BLOOD CELL COUNT

	Children up to 8 years	Adults	Word description of alterations
Neutrophil bands	to 6%	2-6%	neutrophilic granulocytosis neutrophilic granulocytopenia shift to the left/ right
segments	25-60%	55-70%	
Eosinophils	5%	1-4%	eosinophilic granulocytosis eosinophilic granulocytopenia
Basophils	1%	0-1%	basophilic granulocytosis basophilic granulocytopenia
Monocytes	6%	2-8%	monocytosis, monocytopenia
Lymphocytes	25-50%	25-40%	lymphocytosis, lymphocytopenia

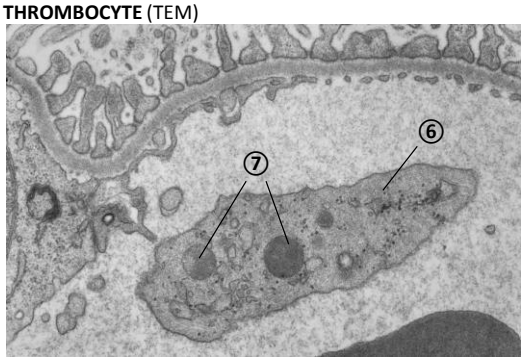
THROMBOCYTES⑥ (~2-5 µm)

• discoid cell fragments originating from megakaryocytes

• **granulomere** (chromomere)
- darker, reddish central region
- lysosomes
- rare, small mitochondria with few cristae, glycogen granules
- dense-core granules⑦ (with clotting cascade and vasoactive substances)

• **hyalomere** (clear zone)
- less-stained periphery
- cytoplasmic matrix
- complex cytoskeleton composed of microfilaments and microtubules

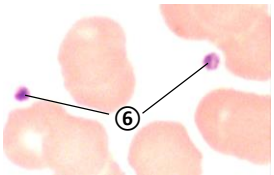
THROMBOCYTE (TEM)



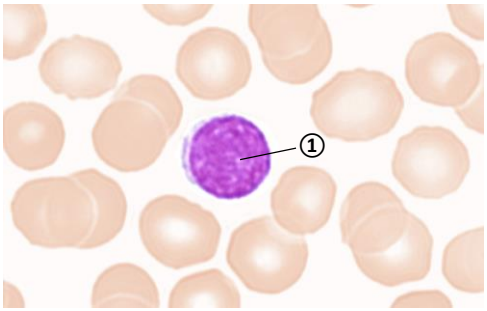
α-granules 300-500 nm — fibrinogen, PDGF

δ-granules 250-300 nm — serotonin, Ca^{II+} pyrophosphate ADP, ATP

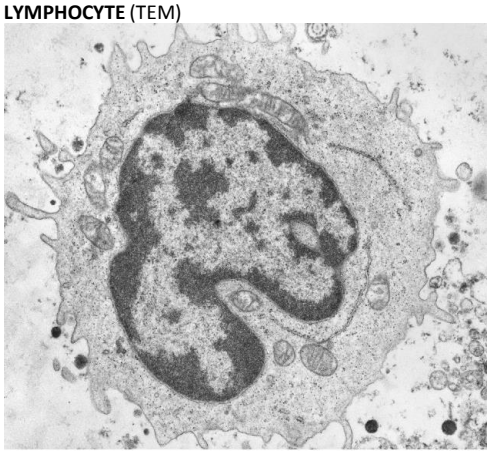
λ-granules 175-200 nm — lysosomal enzymes



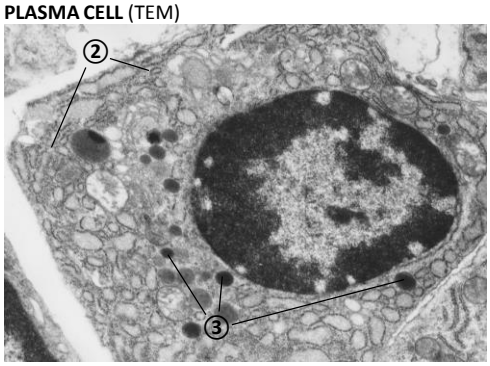
LYMPHOCYTE



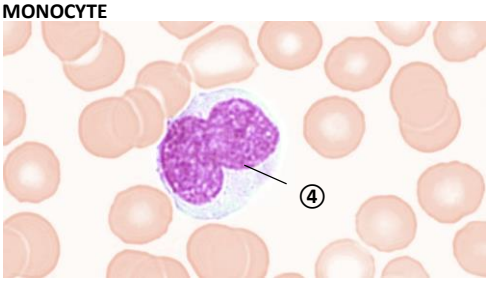
LYMPHOCYTE (TEM)



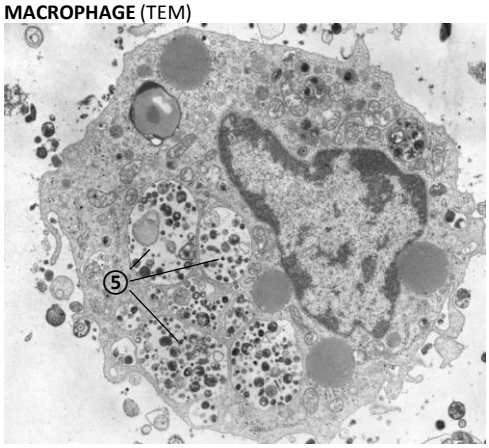
PLASMA CELL (TEM)



MONOCYTE



MACROPHAGE (TEM)



HEMATOPOIESIS: ERYTHROPOIESIS AND THROMBOPOIESIS

<table>
<tr><td colspan="8">Hematopoietic Stem Cell (HSC)</td></tr>
<tr><td colspan="5">Common myeloid progenitor (CMP)</td><td colspan="3">Common lymphoid progenitor (CLP)</td></tr>
<tr><td colspan="3">Granulocyte/monocyte progenitor (GMP)</td><td colspan="2">Megakaryocyte/erythrocyte progenitor (MEP)</td><td colspan="3" rowspan="2">Lymphoblast
↓</td></tr>
<tr><td>CFU-M
↓
Monocyte progenitor</td><td colspan="2">CFU-G
↓</td><td>CFU-Meg
↓
Megakaryoblast</td><td>CFU-E
↓
Erythrocyte progenitor</td></tr>
<tr><td>Monoblast
↓</td><td>Neutrophilic progenitor</td><td>Basophilic progenitor</td><td>Eosinophilic progenitor</td><td>Megakayrocyte
↓</td><td>Proerythroblast
↓</td><td>Pro-NK cell
Pre-NK cell
Immature NK cell</td><td>Pro-T cell
Pre-T cell
Immature T-cell</td><td>Pro-B cell
Pre-B cell
Immature B-cell</td></tr>
<tr><td>Monocyte</td><td>Neutrophilic graulocyte</td><td>Basophilic granulocyte</td><td>Eosinophilic granulocyte</td><td>Thrombocyte</td><td>Erythrocyte</td><td colspan="3">↓
All lymphocytes</td></tr>
<tr><td>MONOCYTO POIESIS</td><td colspan="3">GRANULOPOIESIS</td><td>THROMBO POIESIS</td><td>ERYTHRO POIESIS</td><td colspan="3">LYMPHOPOIESIS</td></tr>
</table>

HEMATOPOIESIS OVERVIEW

- **hematopoietic stem cells (HSC)**
  - multipotent, capable of self-renewal and differentiation
  - indistinguishable in routine preparations by morphology
- **common myeloid (CMP) and lymphoid progenitor (CLP) → colony forming units (CFU)**
  - lineage-restricted progenitors without any morphological hallmarks

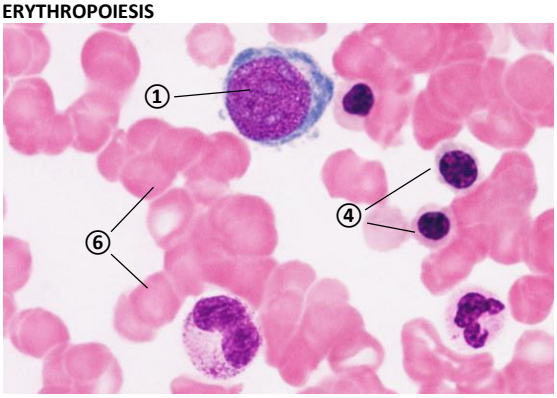
ERYTHROPOIESIS

- **proerythroblast**① (~14-19 µm)
  - mitotically active
  - dominant, round nucleus with 1-2 nucleoli
  - mildly basophilic cytoplasm
- **basophilic erythroblast**② (~13-16 µm)
  - mitotically active
  - heterochromatic nucleus with inconspicuous nucleoli
  - basophilic cytoplasm (sometimes more than in proerythroblast)
- **polychromatophilic erythroblast**③ (~13-16 µm)
  - mitotically active
  - production of hemoglobin
  - blue-gray cytoplasm due to combined basophilic (polyribosomes) and acidophilic aspects (hemoglobin)
  - heterochromatic nucleus (checkerboard appearance)
- **orthochromatophilic erythroblast**④ (~8-10 µm)
  - mitotically inactive
  - small, compact, eccentric, pycnotic nucleus → extrusion
  - mildly acidophilic cytoplasm with basophilic residues
- **reticulocyte**⑤ (polychromatophilic erythrocyte, ~ 7-8 µm)
  - acidophilic cytoplasm
  - *substantia reticulofilamentosa* visible by supravital staining (brilliant cresyl blue)
- **erythrocyte**⑥ (~7-8 µm)
  - anucleate, biconcave disc
  - acidophilic cytoplasm

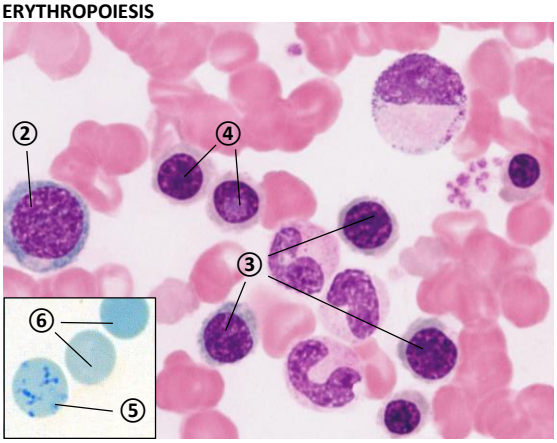
THROMBOPOIESIS

- **megakaryoblast** (up to 30 µm)
  - large oval, nonlobed nucleus with prominent nucleoli
  - basophilic cytoplasm
  - successive endomitoses without karyokinesis and cytokinesis
- **promegakaryocyte** (up to 100 µm)
  - large cell with polyploid nucleus (8n-64n)
- **megakaryocyte**⑦ (80-150 µm)
  - polyploid, multilobed nucleus⑧ (8n-64n)
  - azurophilic and platelet granules
  - multiple centrioles, ER and Golgi apparatus
  - numerous peripheral invaginations of plasma membrane–platelet demarcation channels defining individual thrombocytes
  - release of **thrombocytes** into bone marrow sinusoids

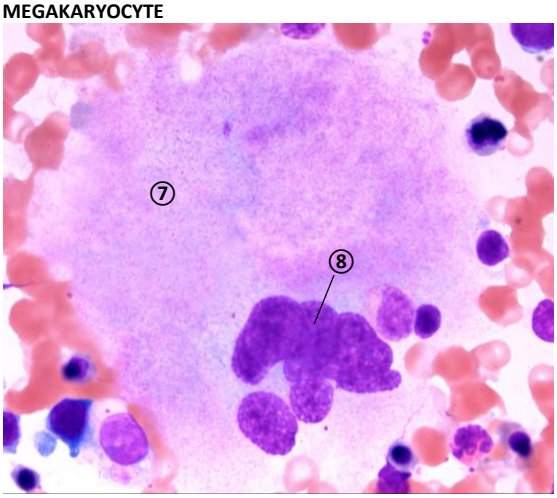
ERYTHROPOIESIS



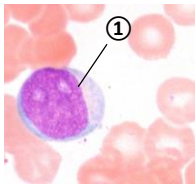
ERYTHROPOIESIS



MEGAKARYOCYTE



GRANULOPOIESIS



- **myeloblast**① (~15 µm)
- mitotically active
- round-oval, euchromatic nucleus
- 2-6 apparent nucleoli
- weakly basophilic cytoplasm without granules
- **promyelocyte**② (~15-24 µm)
- mitotically active
- round-oval nucleus with partly condensed chromatin
- basophilic cytoplasm with azurophilic③ granules
- neutrophilic④, eosinophilic⑤ or basophilic **myelocyte** (~10-16 µm)
- mitotically active
- oval or bean-shaped nucleus with condensed chromatin
- increasing number of specific granules in cytoplasm
- neutrophilic⑥, eosinophilic or basophilic **metamyleocyte** (~10-12 µm)
- mitotically inactive
- horseshoe-like nucleus with condensed chromatin
- neutrophilic⑦, eosinophilic or basophilic **granulocyte** (~10-12 µm)
- segmentation of nucleus
- cytoplasm rich in specific and azurophilic granules

MONOCYTOPOIESIS

- **monoblast** (~16 µm)
- round, bean shaped nucleus with 2-6 nucleoli
- mildly basophilic cytoplasm
- **promonocyte** (~16-20 µm)
- mitotically active (1-2 divisions)
- large nucleus with mild indentation, unapparent nucleoli
- basophilic cytoplasm with azurophilic granules
- **monocyte**
- short-time in circulation, then extravasate and differentiate to tissue macrophages and other phagocyting cells
- denritic cells share common progenitor with monocytes and granulocytes

LYMPHOPOIESIS

- **lymphoblast** (~18-20 µm)
- round-oval nucleus with several nucleoli
- mildly-basophilic cytoplasm without azurophilic granules
- **prolymphocyte** (~12-15 µm)
- morphological transition and maturation to lymphocytes
- **lymphocyte**
- further maturation and differentiation outside bone marrow

BONE MARROW (*medulla ossium*)

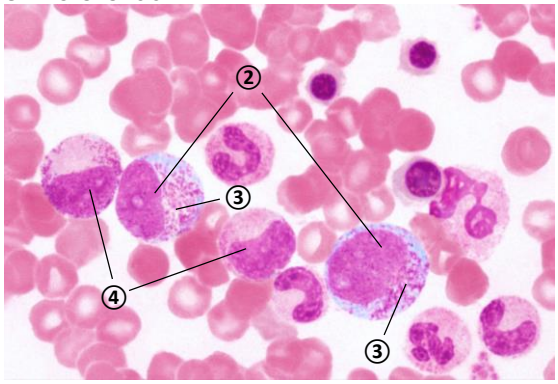
- bone cavities
- complex 3D microenvironment for developing blood cell progenitors
- vascular and endosteal hematopoietic niches

- **red bone marrow**
- endosteal bone surface⑧
- reticular c.t. stroma
- fibroblast reticular cells (FRC) assembled into 3D sponge-like matrix
- adipocytes⑨ increasing with age (→ yellow bone marrow)
- macrophages
- associated with bone marrow sinusoids
- phagocytosis of immature apoptotic cells and cellular residues
- removal of senescent erythrocytes from circulation
- bone marrow sinusoids⑩
- squamous endothelium with discontinuous basal lamina
- interaction with cytoplasmic processes of reticular cells
- passage of mature blood cells to circulation
- hematopoietic cords⑪

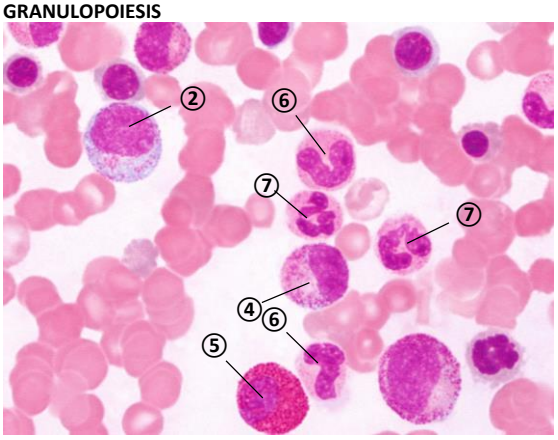
- **yellow bone marrow**
- abundant adipocytes
- reversible conversion to red bone marrow

- **gray bone marrow**
- irreversible conversion from yellow bone marrow in senium
- hematopoietically inactive

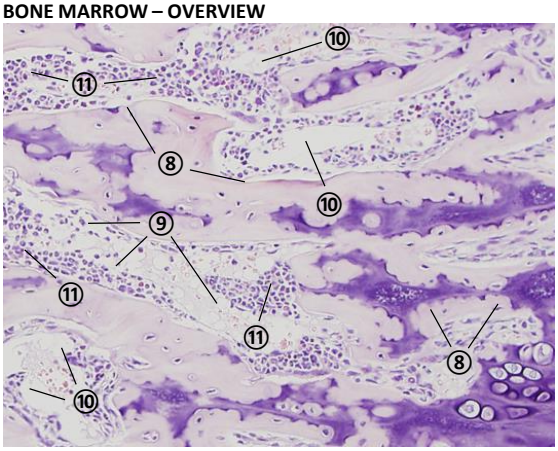
GRANULOPOIESIS



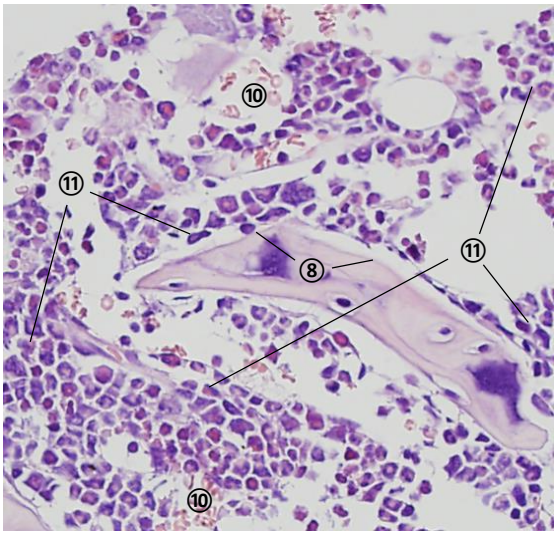
GRANULOPOIESIS



BONE MARROW – OVERVIEW



BONE MARROW – HEMATOPOIETIC CLUSTERS



LYMPHATIC SYSTEM: LYMPHATIC FOLLICLE AND LYMPH NODE

LYMPHATIC FOLLICLE (*nodulus lymphoideus*)
- ovoid aggregation of B-lymphocytes (B-dependent area), antigen presenting cells (APC), fibroblast reticular cells (FRC), macrophages, etc.
- reticular fibers produced by FRC
- c. t. capsule absent
- **primary follicles**
- darker, homogeneous
- naïve, inactive small B-lymphocytes
- **secondary follicles**
- germinal center① with antigen-activated B-lymphocytes
- centroblasts – pale cells with round nucleus; rapid proliferation and differentiation
- centrocytes – dark cells with cleaved nucleus; maturated centroblasts, precursors of memory and plasma B-cells
- follicular dendritic cells (FDCs, T_H-dependent) – pale cells with cleaved nucleus
- macrophages
- mantle zone② (corona)
- asymmetric, continuous with T-dependent zone
- small basophilic lymphocytes, memory and plasma B-cells

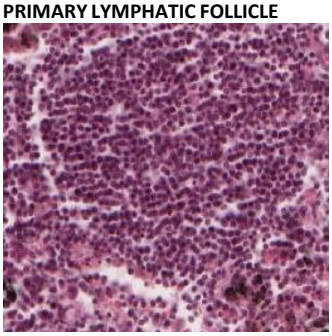
T-DEPENDENT AREAS
- homogeneous aggregations of T-lymphocytes
- APC – interdigitating dendritic cells
- light nucleus, numerous cytoplasmic processes
- high endothelial venules (HEV)
- post-capillary venules with inapparent lumen
- lined by cubic cells with light nucleus and prominent ER, GA, polyribosomes
- expression of ligands to lymphocyte homing-receptors (addressins)
- lymphocytes (basophilic) in HEV walls
- diapedesis, initial stage of recirculation

LYMPH NODE (*lymphonodus*)
- ovoid shape, up to 1-2 cm,
- ~400-450 lymph nodes inserted to course of lymph vessels
- dense collagen c.t. capsule③, trabecules
- convex side – many afferent lymph vessels (*vasa afferentia*) with valves (unidirectional flow of lymph)
- concave side (hilum) – 1-2 efferent lymph vessel (*vasa efferentia*), artery, vein
- reticular c.t. stroma with variable appearance
- immuno-platform involved in chemoatraction and adhesion of immune cells established by FRC, FDC and HEV

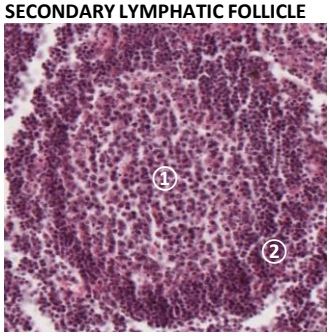
- **cortex**④
- lymphatic follicles (B-dependent areas)⑤
- **paracortex or inner cortex**⑥ (T-dependent areas)
- **medulla**⑦
- medullary cords (plasma cells, macrophages)
- **lymphatic sinuses**
- subcapsular (marginal), internodular (peritrabecular) and medullary sinuses
- channels lined and stretched by squamous, endothelium-like cells and reticular fibers
- lymphocytes, macrophages, APC

- accumulation of carbon pigments within macrophages⑧ in anthracosis

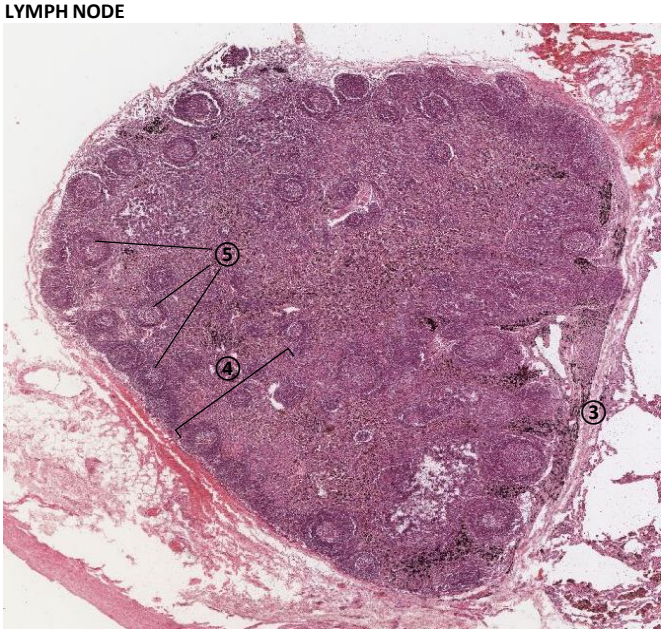
PRIMARY LYMPHATIC FOLLICLE



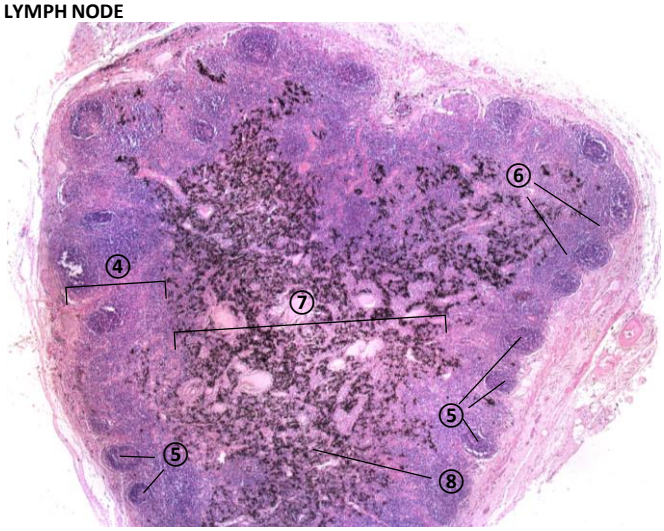
SECONDARY LYMPHATIC FOLLICLE



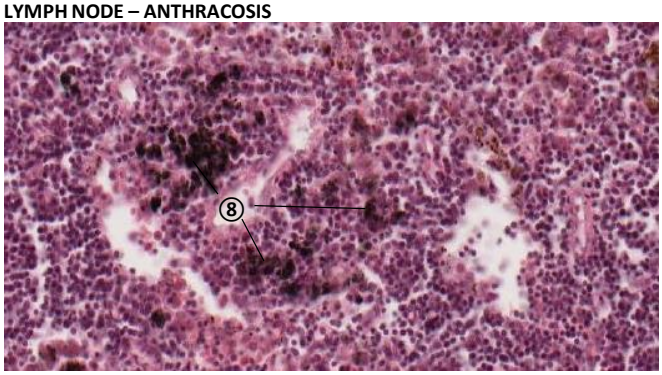
LYMPH NODE



LYMPH NODE



LYMPH NODE – ANTHRACOSIS



SPLEEN

- fibrous, dense collagen c.t. capsule① covered by simple squamous e. (peritoneum, *t. serosa*)②
- reticular c.t.③ produced by fibroblastic reticular cells (FRC)
- c.t. trabecules④ followed by large vessels (*a. trabecularis*, *v. trabecularis*)

• **vascularization**
- HEV absent
- *arteria lienalis* (hilum) → *a. trabecularis* → **white pulp:** *a. centralis* → **red pulp:** *arteriola penicillata* → venous sinuses or extravasal space of splenic cords → *vena trabecularis* → *v. lienalis* (hilum)
- open and closed blood microcirculation: *aa. penicillatae* open directly to venous sinuses (closed microcirculation) or to extravasal space of red pulp (open microcirculation)
- efferent lymph capillaries and vessels in white pulp; afferent lymph vessels absent

• **white pulp** (*pulpa alba*)⑤
- lymphoid

• periarteriolar lymphoid sheath (PALS)
- T-dependent area
- surrounds *a. centralis*
- concentric sheath of reticular c.t., contractile FRC
- T-lymphocytes, interdigitating dendritic cells
- continuous with splenic lymphoid follicles

• lymphoid follicles (splenic Malphigian bodies, peripheral white pulp, PWP)
- major part of white pulp, follicles of ∅ 0.2-0.7 mm
- B-dependent area
- excentrical *a. centralis*⑥
- B-lymhocytes, follicular dendritic cells

• marginal zone
- localized between red and white pulp
- abundant B- and T- lymphocytes, macrophages, antigen presenting cells (dendritic cells)

• **red pulp** (*pulpa rubra*)⑦
- non-lymphoid

• medullary cords (cords of Billroth, *chordae splenicae*)
- composed of reticular c.t.
- anastomosing FRC, plasma B-cells, macrophages, erythrocytes

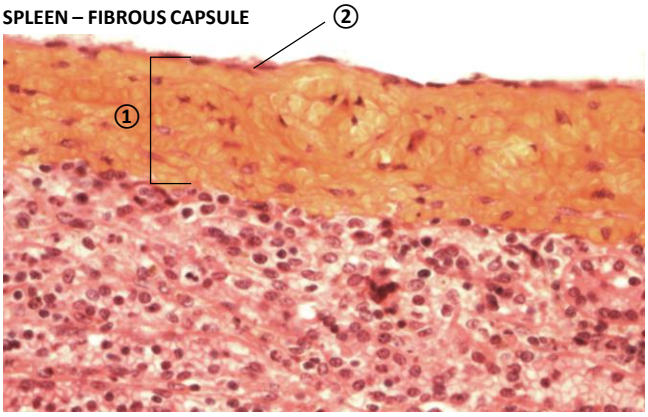
• venous sinuses
- discontinuous, rod-shaped endothelium
- 2-3 μm intercellular slits
- incomplete basal lamina reduced to circumferential strands
- pericytes and smooth muscle cells absent in sinus wall

• perifollicular zone
- continuous with marginal zone of white pulp
- open terminal parts of *a. penicillatae* with phagocytic Schweigger-Seidel sheath (sheathed arterioles)

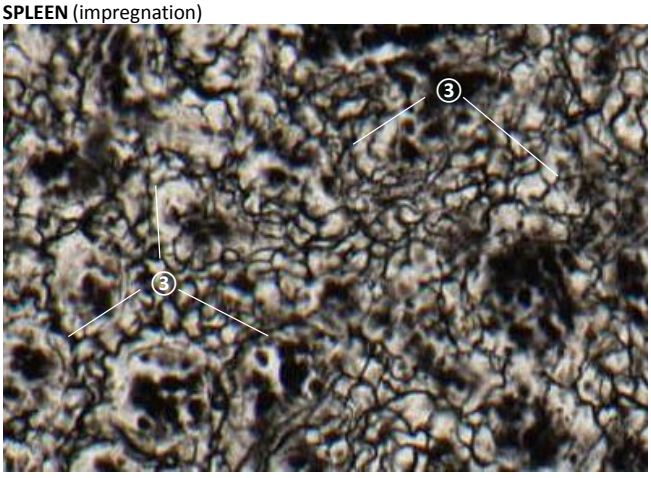
• extravasal space
- migration of T-lymphocytes → PALS; B-lymphocytes → PWP
- erythrocytes, thrombocytes, granulocytes → venous sinuses

• macrophages of extravasal space
- phagocytosis of aberrant or aged erythrocytes
- iron binding, deposition and recycling (ferritin, hemosiderin, transferrin)
- visualization by Perls' Prussian Blue staining (hemosiderin)

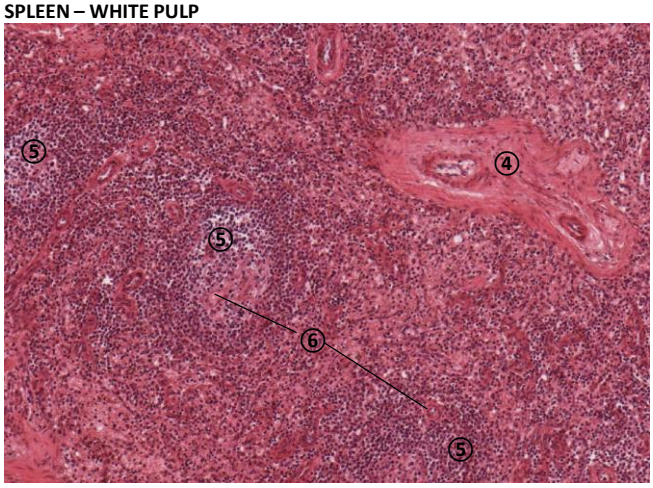
SPLEEN – FIBROUS CAPSULE



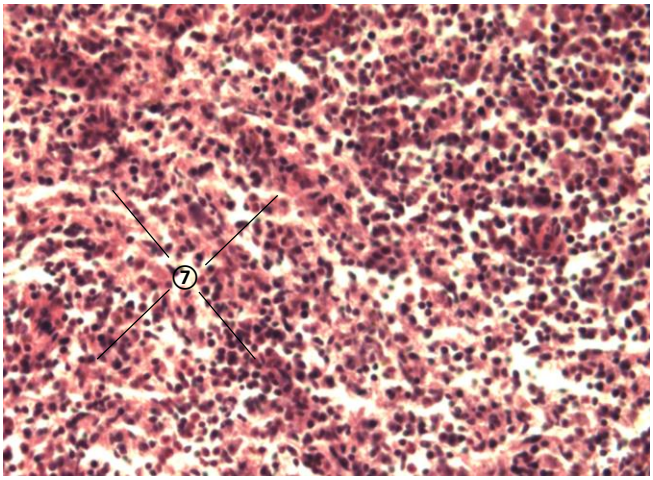
SPLEEN (impregnation)



SPLEEN – WHITE PULP



SPLEEN – RED PULP



THYMUS

- thin, dense collagen c.t. capsule with extending septa①
- parenchyma divided into incomplete lobules (↔ 0.5-2 mm)
- vascularization from *arteria thoracica interna*, *a. thyreoidea superior* and *a. thyreoidea inferior* along c.t. septa
- age-related changes in structure and function

- **thymocytes**
- small basophilic precursors of T-lymphocytes dispersed between cellular processes of TECs (cytoreticulum)
- genome rearrangement, differentiation and selection of T-lymphocytes with functional T-Cell Receptor (TCR) in cortex
- selection of auto-tolerant T-lymphocytes in medulla

- **thymic epithelial cells (TECs)**
- squamous to stellate cells with large, euchromatic nuclei
- form epithelial cytoreticulum providing microenvironment for development, selection, commitment and homing of lymphocytes and scavenging macrophages
- production of cytokeratin intermediary filaments
- production of hormones (thymopoietin, thymosin)
- distinct types of TECs in cortex and medulla
- endodermal origin (3rd pharyngeal pouch)

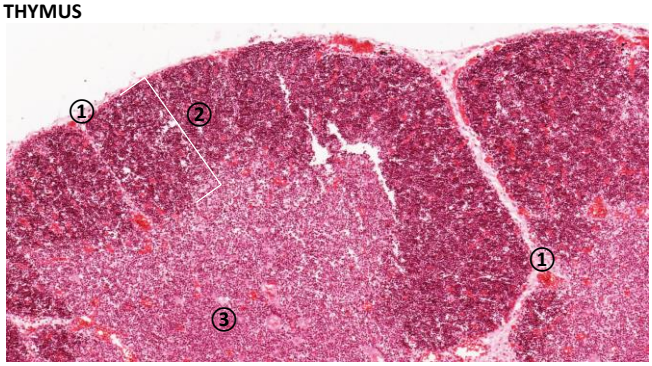
- **cortex**②
- dark, basophilic
- cortical TECs constitute:
- cytoreticulum supporting development of $CD4^-CD8^-$ negative T-lymphocytes → $CD4^+CD8^+$ double-positive T-lymphocytes → $CD4^+$ or $CD8^+$ single-positive T-lymphocytes
- blood-thymus barrier (continuous endothelium of cortical capillaries, basal lamina, reticular sheath)
- corticomedullary barrier

- **medulla**③
- pale, lightly stained
- medullary capillaries and venules permeable for T-lymphocytes
- medullar TECs constitute:
- corticomedullary barrier
- cytoreticulum supporting selection of auto-tolerant $CD4^+$ and $CD8^+$ (negative selection) and homing → colonization of T-dependent zones of secondary lymphatic organs

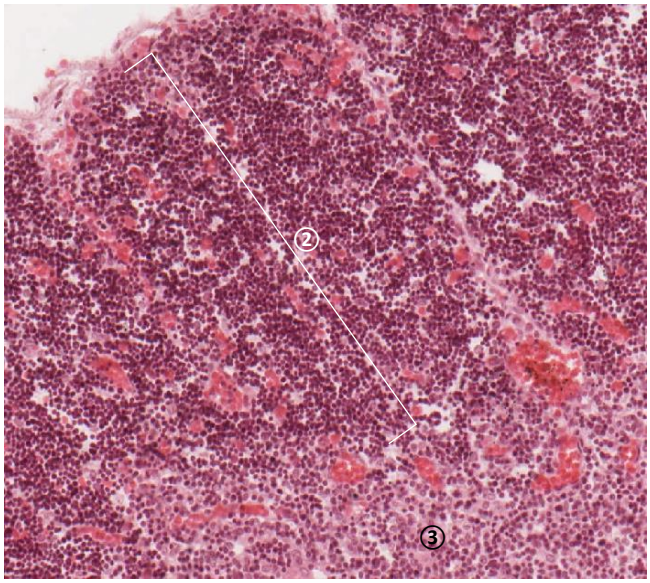
- **Hassall's corpuscles**④ (~30-100 µm)
- acidophilic spherical corpuscles in thymic medulla
- composed of clusters of lamellary-arranged TECs
- involved in maturation of T-lymphocytes

- **thymic involution**
- physiological (age-related) or accidental (acute)
- thymopoiesis partially active even in involuted thymus
- morphological hallmarks:
- reduction of cytoreticulum
- increase of perivascular interstitial space
- increase of adipocyte-rich c.t.⑤
- loss of demarcation of thymic medulla and cortex
- disorganization of cortico-medullary junction
- decreased production of T-lymphocytes
- abundant, often calcifying Hassall's corpuscles

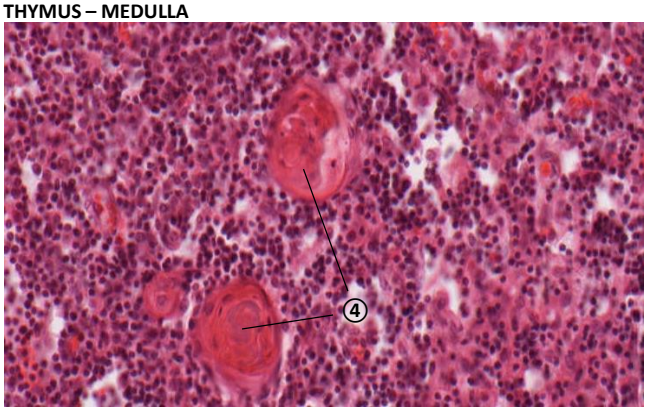
THYMUS



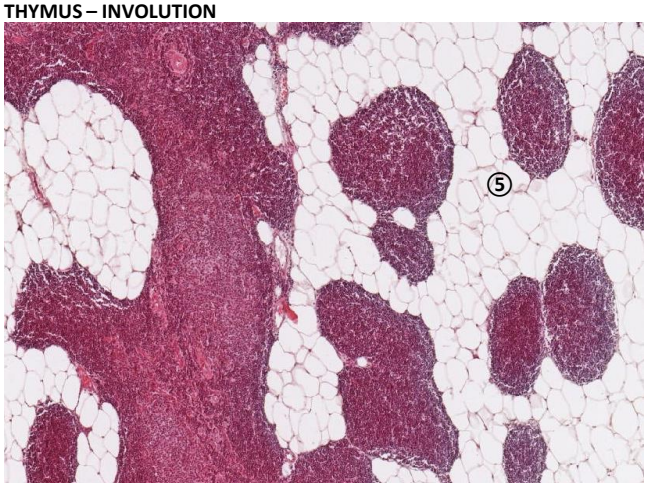
THYMUS – CORTEX



THYMUS – MEDULLA



THYMUS – INVOLUTION



LYMPHATIC SYSTEM: MALT AND TONSILS

MUCOSA-ASSOCIATED LYMPHOID TISSUE (MALT)
- diffuse lymphoid tissue in *l. propria* of mucosa (e.g. gastrointestinal, urinary, respiratory, etc.)
- immunomodulation and immunesurveillance of *t. mucosa*
- reticular c.t. containing B- and T- dependent areas
- c.t. capsule absent
- high endothelial venules (HEV)
- follicle-associated epithelium (FAE)
- reticulated appearance, loose connection between e. cells
- e. infiltrated by lymphocytes, macrophages and granulocytes
- incomplete basal lamina
- antigen transport and delivery to immune cells

- **regional terminology**
- GALT, BALT, LALT, NALT (bronchus-, larynx-, nasal-ALT)
- CALT (conjunctival-ALT)

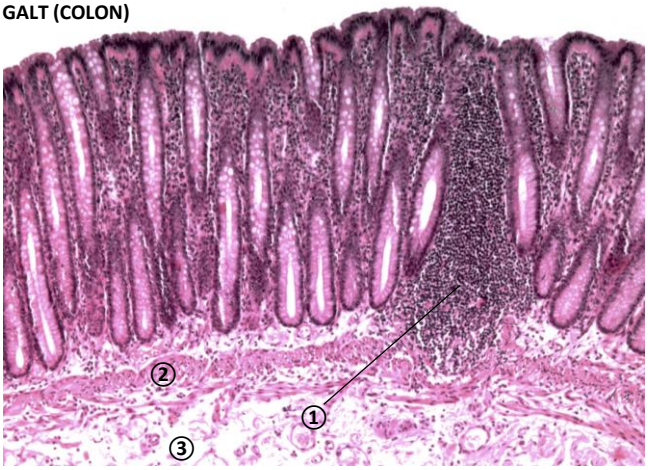
- **GALT** (gut-ALT)
- lymphatic follicles① (*noduli lymphatici solitarii*) covered by FAE – occasionally extending through *l. muscularis m.*② to t. submucosa③
- Peyer's patches (*noduli lymphatici aggregati*) covered by FAE in ileum and appendix
- modified mucosa – villi, crypts of Lieberkühn and goblet cells absent
- M-cells (microfold cells)
- intestinal e. covering Peyer's patches and lymphatic follicles
- membrane microfolds on apical surface; microvilli absent
- deep pocket-like invagination on basolateral surface
- transcytosis and presentation of native antigens
- association with macrophages, lymphocytes and intraepithelial dendritic cells
- plasma B-cells dispersed in *l. propria m.*

- **MALT in respiratory passages**
- subepithelial aggregations of lymphocytes in nose (NALT), larynx (LALT) or upper bronchi (BALT)④

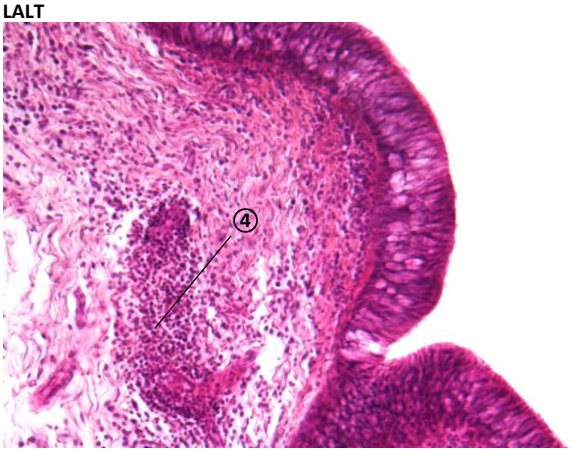
TONSILS
- mucosa-associated aggregations of lymphoid tissue in naso- and oropharynx
- incomplete c.t. capsule
- **Waldeyer's tonsillar ring** (pharyngeal lymphoid ring, Waldeyer's lymphatic ring)
- *tonsilla palatina*, *t. lingualis*, *t. pharyngea*, *t. tubaria*

- ***tonsilla palatina***
- bilaterally in *fossa tonsillaris*
- laterally covered by c.t. capsule with fine septa
- free surface covered by stratified squamous FAE
- deep crypts containing detritus⑤
- apparent secondary lymphatic follicles adjacent to FAE⑥
- interfollicular T-dependent area⑦
- ***t. lingualis***⑧
- subepithelially in *radix linguae*
- structure similar to *t. palatina*
- mucous glands open to crypts (*gll. linguales posteriores*, *gll. radicis linguae, gll. Weberi*)⑨
- ***t. pharyngea***
- subepithelially in nasopharynx
- pseudostratified ciliated columnar e. with FAE regions
- ***t. tubaria***
- around pharyngeal opening of *tuba auditiva*
- abundant secondary follicles

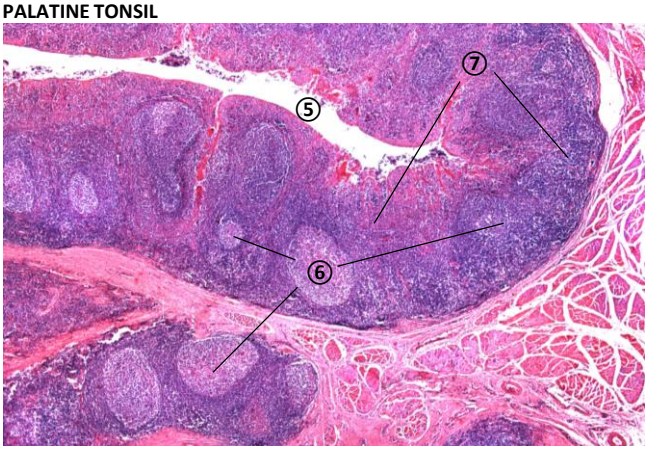
GALT (COLON)



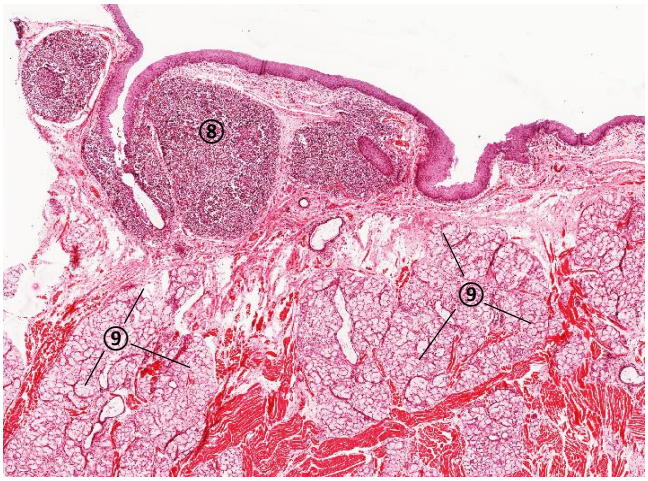
LALT



PALATINE TONSIL



LINGUAL TONSIL



NASAL CAVITY (*cavum nasi*)
- ***regio vestibularis*** (*vestibulum nasi*)
- skin with long hairs (*vibrissae*) and sebaceous glands
- stratified squamous keratinized → non-keratinized e.
- ***regio respiratoria nasi***
- pseudostratified columnar ciliated e.
- typical for all respiratory passages
- several principal cells types (ciliated columnar, goblet, brush, DNES, basal cells)
- *l. propria m.* continuous with periost or perichondrium of nasal skeleton
- seromucous tuboalveolar glands (*gll. nasales*)
- ***regio olfactoria nasi***
- olfactory e.
- bipolar, olfactory neurons → *n. olfactorius*
- supportive (sustentacular) and basal (stem) cells
- *l. propria m.* continuous with periost
- serous tuboalveolar olfactory glands (*gll. olfactoriae*, Bowman's glands)

NASAL CONCHA (*concha nasi*)
- turbinate spongy bone①
- ***tunica mucosa***
- pseudostratified columnar ciliated e. with abundant goblet cells in *l. epithelialis m.*②
- thin, cavernous, venous plexuses③ in *l. propria m.*

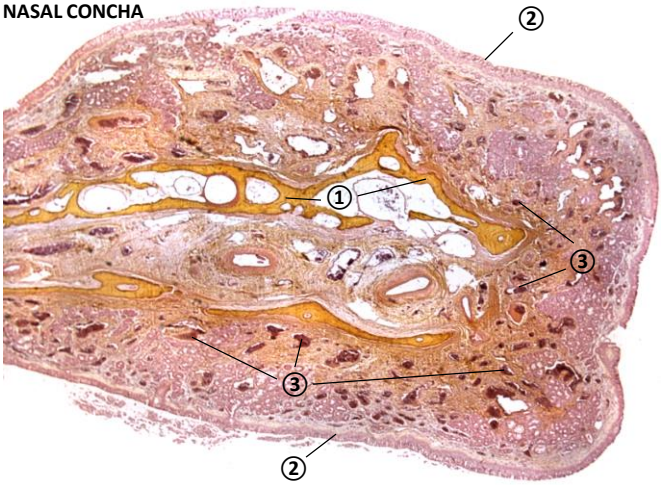
NASOPHARYNX (*pars nasalis pharyngis*)
- pseudostratified columnar ciliated e. continuous with *pars cartilaginea tubae auditivae*
- lymphocyte infiltrations, *tonsilla pharyngea*, *t. tubaria*

EPIGLOTTIS
- elastic cartilage④
- ***tunica mucosa***
- non-keratinized stratified squamous e.⑤ on lingual and partly on laryngeal surface
- pseudostratified columnar ciliated e. with goblet cells⑥ on laryngeal surface
- in *l. propria m.* seromucous *gll. epigloticae*⑦ and often lymphocyte infiltrations⑧
- often metaplasia of pseudostratified columnar ciliated e. → non-keratinized stratified squamous e.

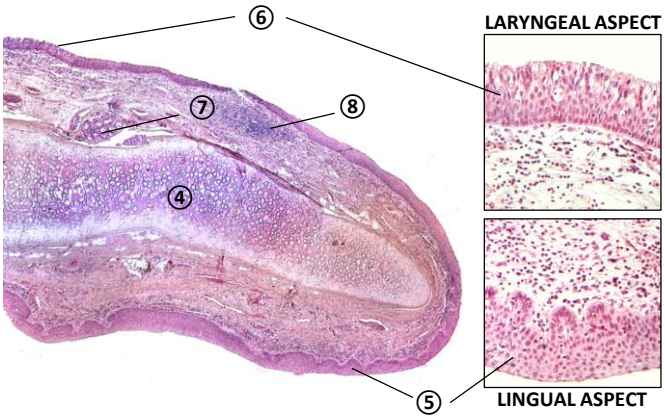
LARYNX
- cartilages
- *cart. thyreoidea*, *cart. cricoidea*, *cartt. arytenoideae* – hyaline cartilage
- *cart. epiglottica*, *cartt. corniculatae*, *cartt. cuneiformes*, *processus vocalis* – elastic cartilage
- often calcification of cartilages
- ligaments
- intrinsic and extrinsic striated skeletal muscles

- **false vocal cord** (*plica ventricularis*)
- *l. epithelialis m.*
- pseudostratified columnar ciliated e.⑨ with goblet cells
- *l. propria m.*
- elastic fibers (elastic membrane)
- tubuloacinar seromucous glands (*gll. laryngeales*)
- lymphocyte infiltrations (LALT)⑪
- adipocytes⑫
- **true vocal cord** (*plica vocalis*)
- phonation
- non-keratinized stratified squamous e.
- *lig. vocale*⑭ – elastic fibers
- *m. vocalis*⑮ – striated skeletal muscle

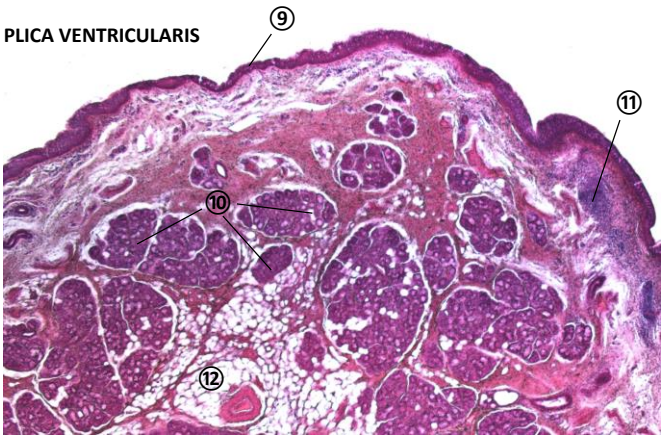
NASAL CONCHA



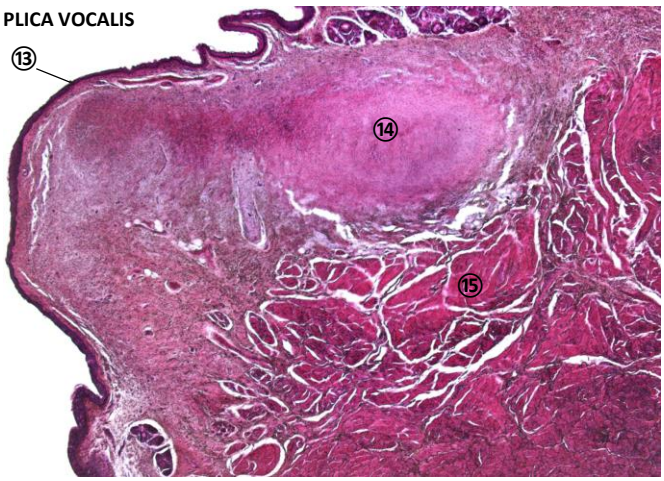
EPIGLOTTIS



PLICA VENTRICULARIS



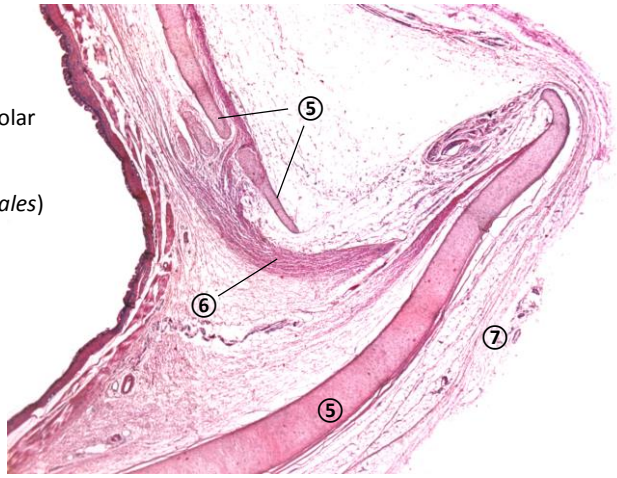
PLICA VOCALIS



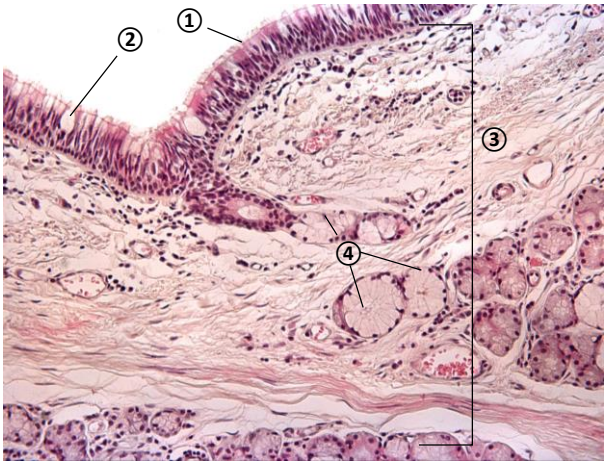
TRACHEA

- ***t. mucosa***
  - *l. epithelialis m.* – e. of respiratory passages (pseudostratified columnar ciliated e.); in bifurcation stratified squamous e.
  - distinct ciliated columnar① and goblet② cells
  - *l. propria m.*③ – collagen c.t., lymphocyte infiltrations, tuboalveolar seromucous glands④ (*gll. tracheales)*, longitudinal elastic fibers
- **fibro-cartilaginous layer** (*tunica fibro-musculo-cartilaginea)*
  - 16-20 "C"-shaped hyaline cartilages⑤ (*cartt. tracheales*/*bronchiales*)
  - *ligg. annularia* continuous with perichondrium
  - *paries membranaceus* – fibrous elastic membrane with smooth muscle cells⑥ (*m. trachealis*)
- ***t. adventitia***⑦
  - loose collagen c.t. continuous with c.t. in mediastinum

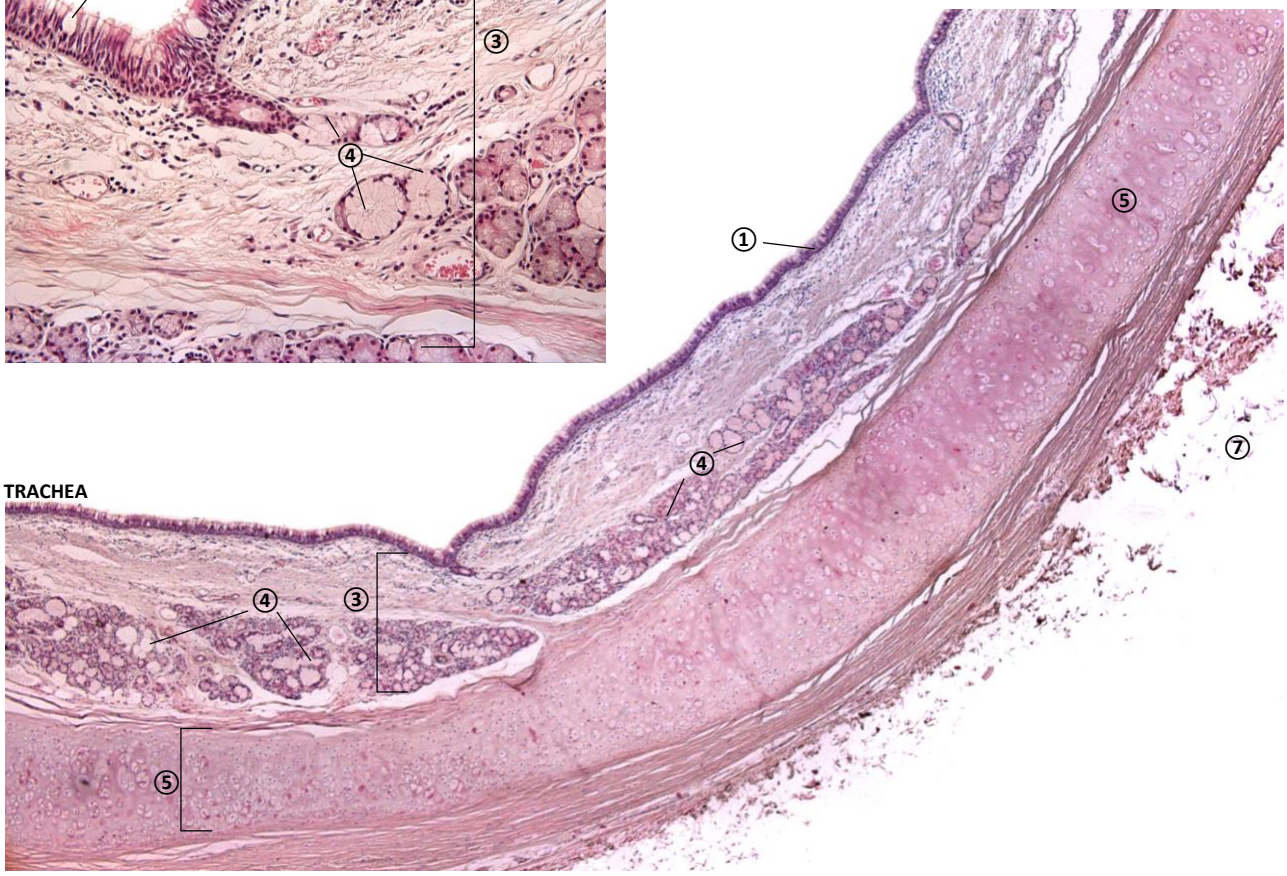
PARIES MEMBRANACEUS



TRACHEAL MUCOSA



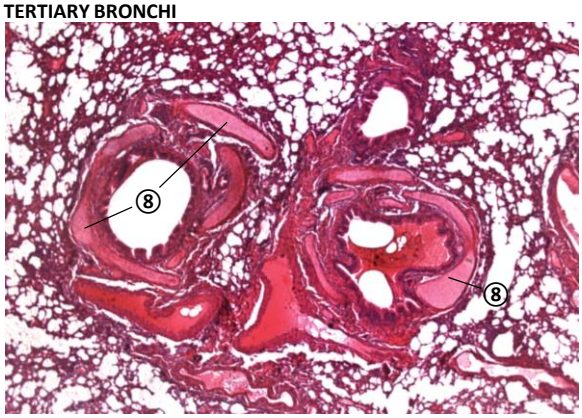
TRACHEA



BRONCHIAL TREE

- **primary (extrapulmonary) bronchi** (*bronchus dexter et sinister*)
  - similar to trachea, cartilage and muscle rings complete
  - tuboalveolar, seromucous glands (*gll. bronchiales*)
  - dichotomous branching
- **secondary (lobar) bronchi** (left 2, right 3)
  - similar to primary bronchi
  - distinct muscular layer of smooth muscle cells between *t. mucosa* and fibro-cartilaginous layer
- **tertiary (segmental) bronchi** (left 9, right 10)
  - ventilate individual bronchopulmonary segments
  - cartilages⑧ form irregular plates rather than complete rings
  - distinct muscular layer of smooth muscle cells
- **large and small subsegmental bronchi**
  - decreasing height of e. in respiratory passages
  - decreasing number of ciliated and goblet cells
  - distinct muscular layer of smooth muscle cells

TERTIARY BRONCHI



BRONCHIOLI①

- cartilage and glands absent
- further dichotomous branching
- height of e. decreases with increasing order of branching: pseudostratified columnar ciliated e. → simple cuboidal e.
- elastic fibers and smooth muscle cells in *l. propria*

• **terminal bronchiole** (*bronchiolus terminalis*)

- simple cuboidal or low columnar ciliated e.
- rare goblet cells
- non-ciliated club cells containing secretory granules

• **respiratory bronchiole** (*b. respiratorius*)

- simple cuboidal ciliated e.
- goblet cells absent
- spherical alveoli evaginating from bronchiolar walls
- elastic fibers and smooth muscle cells in *l. propria*

• **alveolar ducts** (*ductus alveolaris*)

- distal ends of respiratory bronchioli
- non-ciliated squamous e.
- in *l. propria* collagen and elastic fibers in ducts and alveoli; layer of smooth muscle cells around alveolar opening
- abundant spherical alveoli evaginating from ductal walls

• **atria and alveolar sacs** (*sacculi alveolares*)

- distal ends of alveolar ducts

ALVEOLI②

• ~200 µm sacs opening to respiratory bronchioli, alveolar ducts, atria or alveolar sacs

- simple squamous e. specialized for gas exchange (pneumocytes type I)

• **interalveolar septa**

- elastic and reticular fibers
- rich, anastomosing network of continuous capillaries
- fibroblasts, mast cells, macrophages

• **alveolar pores** (of Kohn)

- ~10-15 µm pores connecting adjacent alveoli
- pressure compensation, collateral air flow

ALVEOLAR CELLS

• **type I** ③ (pneumocytes type I, alveolar cells type I, squamous/membranous alveolar cells)

- constitute 97% of alveolar surface
- very thin (down to 25 nm)
- organelles (GA, ER, mitochondria) accumulated around nucleus
- abundant pinocytic vesicles (surfactant recycling)
- desmosomes, *zonulae occludentes*

• **type II** ④ (alveolar cells type II, pneumocytes type II, granular pneumocytes, septal cells)

- cuboidal morphology, spherical nuclei
- abundant mitochondria, GA
- lamellar bodies (1-2 µm)⑤, apical secretory pathway
- desmosomes, *z. occludentes*

• **alveolar macrophages** (dust cells)

- surface of interalveolar septs or interstitium
- phagocytosis

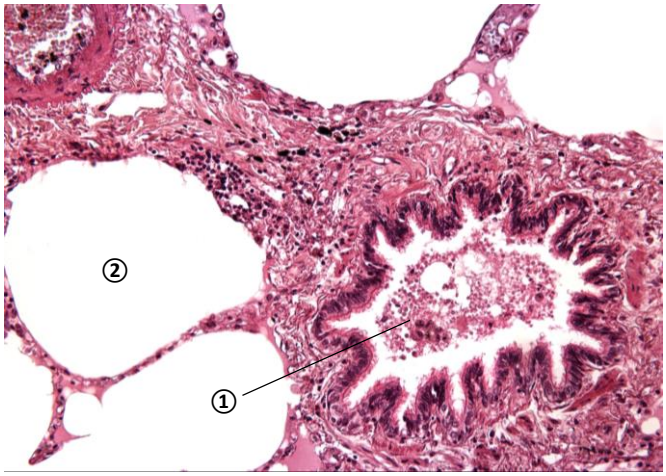
• **blood-air barrier** ⑥ (~0.1-1.5 µm)

- alveolar surfactant, cytoplasm of pneumocyte type I, fused *laminae basales* of pneumocyte type I and endothelium, cytoplasm of capillary endothelium⑦

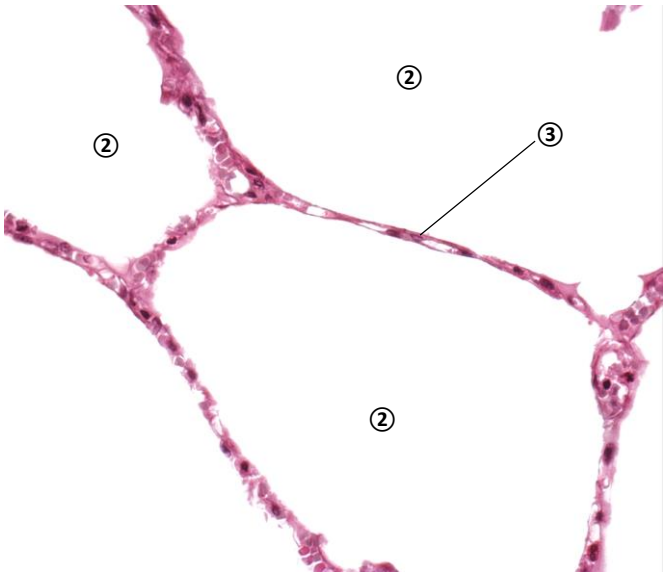
• **surfactant**

- produced by pneumocytes of type II (granular)
- reduce surface tension, bactericide activity
- protein-rich aqueous hypophase overlaid by phospholipid-rich surface film

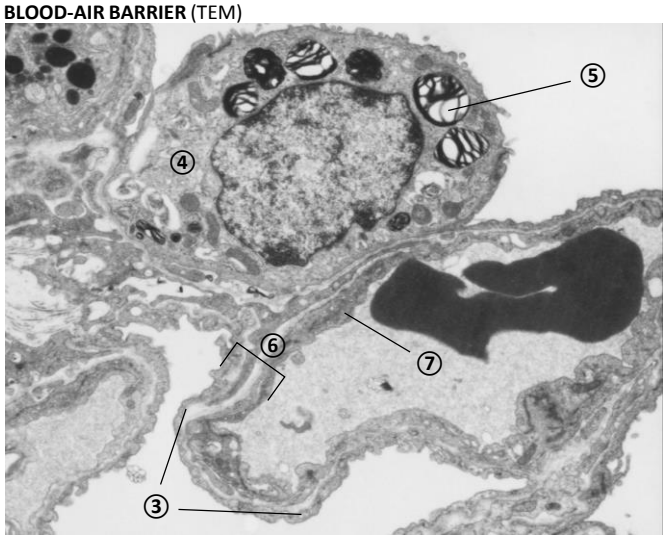
BRONCHIOLUS



ALVEOLI



BLOOD-AIR BARRIER (TEM)



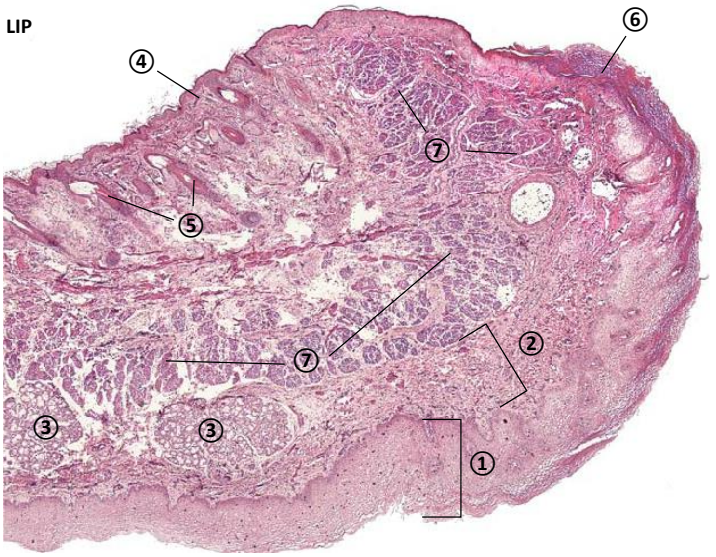
ORAL MUCOSA

- *lamina epithelialis mucosae*
- stratified squamous e.
- *l. propria m.*
- loose collagen c.t.
- three functional types of oral mucosa
- lining mucosa (buccal, labial) – non-keratinized stratified squamous e., well developed submucosal c.t (most of oral cavity)
- masticatory mucosa – keratinized stratified squamous e., submucosal c.t. absent, mucosa directly attached to periost (*gingiva*, *pallatum durum*)
- specialized mucosa – papillae, taste buds (*dorsum linguae*)

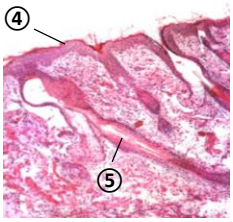
LIP (*labium oris*)

- **dorsal aspect** (oral mucosa of lining type):
- non-keratinized stratified squamous e.①
- *l. propria m.* continuous with submucous c.t.②
- ***tela submucosa***
- loose collagen c.t.
- *gll. labiales*③ (seromucous salivary glands)
- **ventral aspect** (skin, external)
- epidermis④ (keratinized stratified squamous e.)
- dermis with hair follicles⑤ and sebaceous and sweat glands
- **vermillion border**⑥
- transition zone, rich in eleidin
- **skeletal muscle**⑦ (*m. orbicularis oris*)

LIP

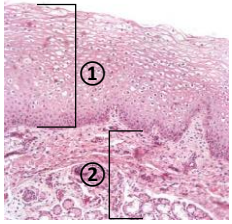


VENTRAL ASPECT

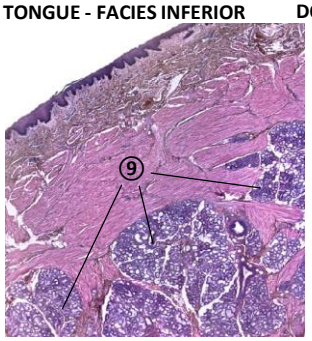


VERMILLION BORDER

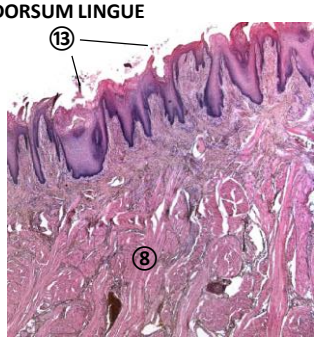
DORSAL ASPECT



TONGUE - FACIES INFERIOR



DORSUM LINGUE



TONGUE (*lingua*)

- *aponeurosis linguae*, *septum linguae*
- skeletal muscle⑧ (*mm. linguae*)
- salivary glands
- *gl. lingualis anterior* (Blandin's gland)⑨, seromucous
- *gll. papillae vallatae*, *gustatoriae* (von Ebner's gland)⑩, serous
- *gll. linguales posteriores* (Weber's gland)⑪, mucous

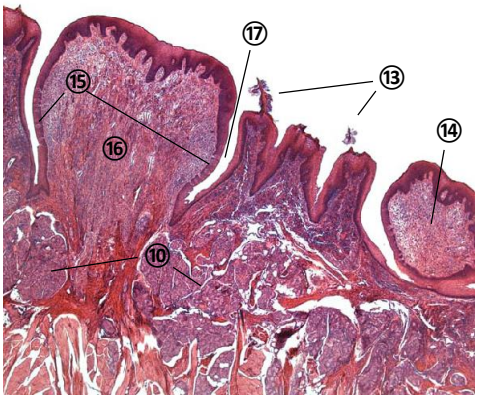
- ***t. mucosa***
- dorsal aspect (*dorsum lingue*)
- anterior 2/3: specialized oral mucosa with lingual papillae
- *l. epithelialis m.* – stratified squamous e.
- *l. propria m.* – loose collagen c.t. continuous with *aponeurosis linguae*
- posterior 1/3: *tonsila lingualis*⑫ (Waldeyer's lymphatic ring)
- ventral aspect (*facies inferior*, *f. mylohyoidea*)
- smooth, non-specialized oral mucosa
- *l. epithelialis m.* – stratified squamous e.
- *l. propria m.* – loose collagen c.t. continuous with perimysium of muscle bundles

LINGUAL PAPILLAE

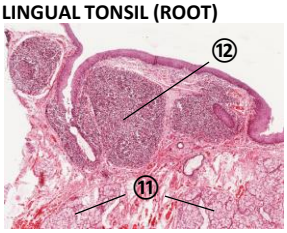
- primary and secondary processes of mucosal c.t., covered by stratified squamous e.

- *pp. filiformes*⑬ (filiform papillae):
- most abundant
- massively keratinized e.
- taste buds absent
- mechanosensitive, rich innervations
- *pp. fungiformes*⑭ (fungiform papillae)
- apex and partly body of tongue
- non-keratinized e.
- occasional taste buds⑮
- mechano- and thermoreceptors in c.t. stroma
- *pp. foliatae* (foliate papillae)
- several (4-5) vertical ridges on lateral margins between root and body of tongue
- non-keratinized e.
- abundant taste buds
- often rudimentary
- *p. vallatae*⑯ (circumvallate papillae)
- 10-12, sulcus terminalis, ↔ ca. 1-2 mm
- typical intraepithelial taste buds⑮
- serous, tubular von Ebner's glands⑩ opening to circular trench (*fossa*)⑰

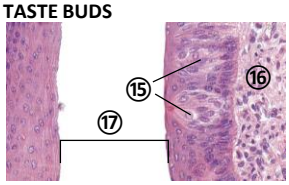
DORSUM LINGUAE (APEX AND BODY)



LINGUAL TONSIL (ROOT)



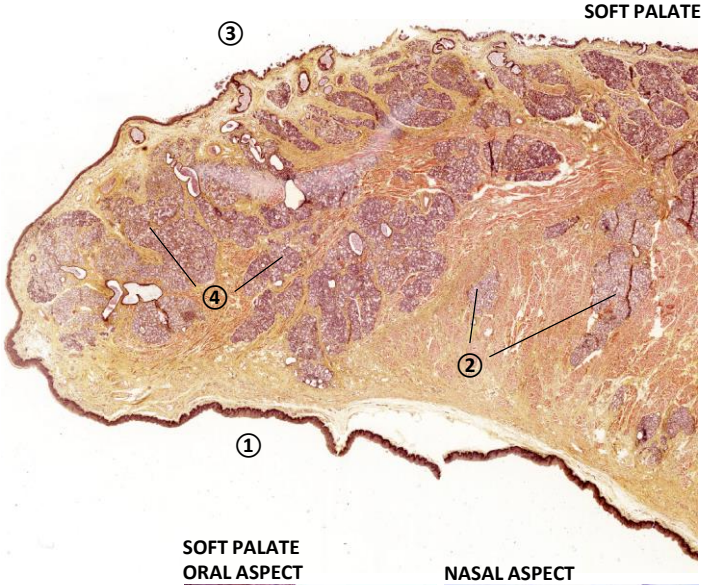
TASTE BUDS



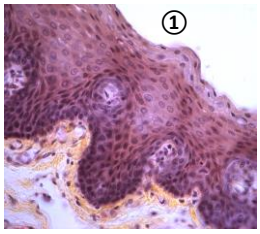
SOFT PALATE (*palatum molle*)
- **oral mucosa**①
- lining type
- *lamina epithelialis mucosae* – stratified squamous e.
- *l. propria m.* – loose collagen c.t.
- ***tela submucosa***
- loose collagen c.t.
- mucous palatine glands (*gll. palatinae*)②
- ***aponeurosis palatina***
- dense collagen c.t.
- skeletal muscle (*m. tensor veli palatini*)
- **nasal mucosa**③
- *l. epithelialis m.*
- pseudostratified columnar e. with cilia
- common metaplasia → stratified squamous e.
- *l. propria m.*
- seromucous nasal glands (*gll. nasales*)④

TOOTH (*dens*)
- **enamel** (*substantia adamantina*)
- thickness ~2.5 mm
- >95% inorganic salts
- **dentin**⑤ (*substantia eburnea*)
- ~70% inorganic salts
- dentinal matrix (collagen fibers + interfibrillar matrix)
- dentinal tubules, odontoblast processes (Tomes' fibers)
- nonmineralized dentin⑥ (predentin)
- **dental pulp**⑦ (*pulpa dentis*)
- mucous c.t. with fibrocytes, immune cells and undifferentiated mesenchymal cells
- odontoblasts⑧ at pulp periphery
- nerve fibers (*plexus subodontoblasticus Raschkowi*)
- rich capillary network
- **cementum**⑨ (*substantia petrosa*)
- avascular
- fibrous (woven) bone
- cementocytes (primary and secondary cementum)
- **periodontium**⑩ and **alveolus**
- alveolar bone
- cementum
- gingiva, gingival sulcus and junctional e.⑪ (epithelial attachment of Gottlieb)
- periodontal ligament

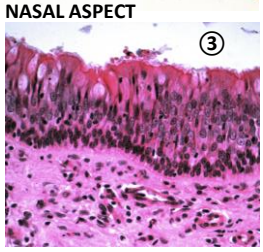
SOFT PALATE



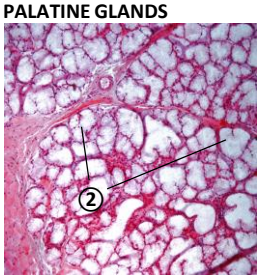
SOFT PALATE
ORAL ASPECT



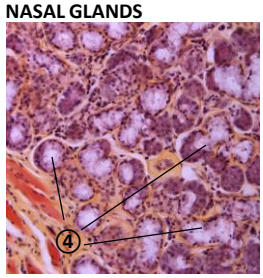
NASAL ASPECT



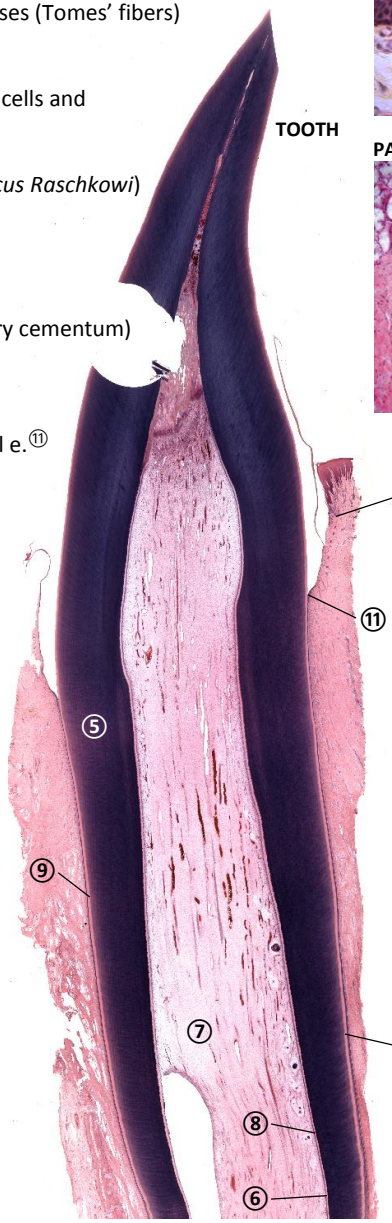
PALATINE GLANDS



NASAL GLANDS

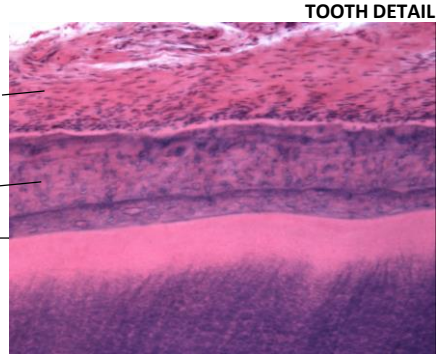


TOOTH

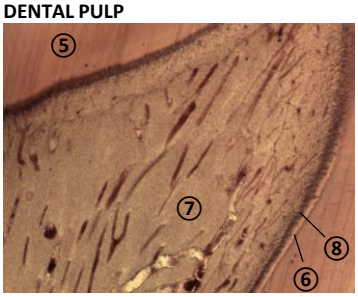


TOOTH OVERVIEW

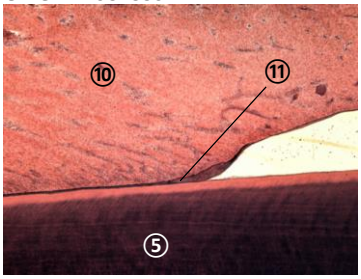
TOOTH DETAIL



DENTAL PULP



GINGIVAL SULCUS



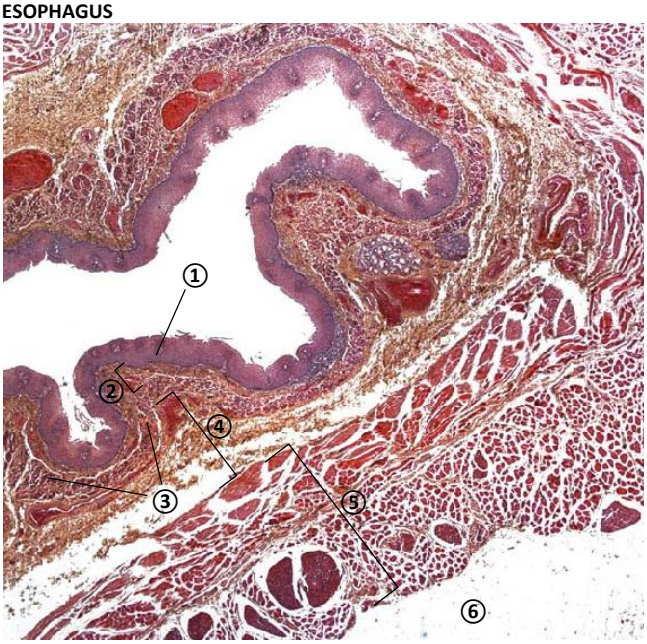
GENERAL STRUCTURE OF DIGESTIVE TUBE

- ***tunica mucosa***
- *lamina epithelialis mucosae*①
- stratified squamous or simple columnar e.
- *l. propria mucosae*②
- loose collagen or reticular c.t.
- *l. muscularis mucosae*③
- several layers of smooth muscle cells with various orientation
- ***tela submucosa***④
- loose collagen c.t.
- vascularization
- innervation (*plexus submucosus Meissneri*)
- inner branch – under *l. muscularis m.* – innervates *t. mucosa*, outer branch – dispersed in *t. submucosa*
- mostly parasympathetic innervation
- ***tunica muscularis externa***⑤
- smooth muscle cells arranged into inner (circular) and outer (longitudinal) layers with regional alterations
- *plexus myentericus* (*Auerbachi*)
- innervates both sublayers of *t. muscularis ext.*
- parasympathetic and sympathetic innervation
- interstitial Cajal cells
- ***tunica serosa***
- *lamina epithelialis serosae* – simple squamous e.
- *lamina propria serosae* – loose collagen c.t.
- or ***tunica adventitia***⑥ – loose collagen c.t.

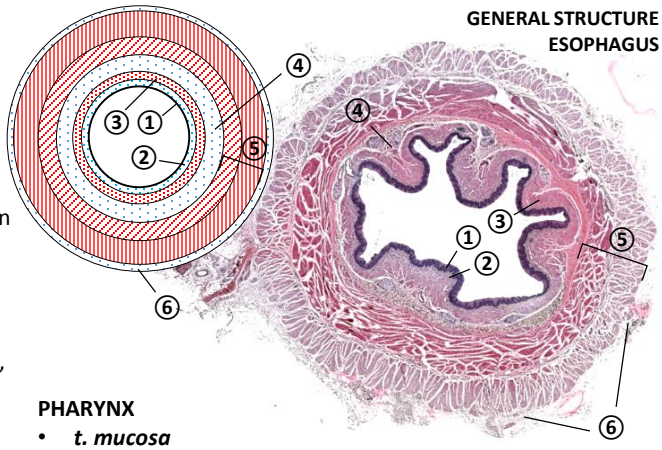
ESOPHAGUS (*oesophagus*)

- ***t. mucosa***
- *l. epithelialis m.*①
- stratified squamous e.
- *l. propria m.*②
- loose collagen c.t.
- *l. muscularis m.*③
- circular and longitudinal layers of smooth muscle cells
- ***t. submucosa***④
- loose collagen c.t.
- *plexus submucosus Meissneri*
- *gll. oesophageales*
- ***t. muscularis externa***⑤
- circular and longitudinal layers of skeletal (upper third) or smooth muscle cells (lower third) or both (middle third)
- *plexus myentericus Auerbachi*
- ***t. adventitia*** *or* ***t. serosa*** (intra-abdominal part)⑥

ESOPHAGUS



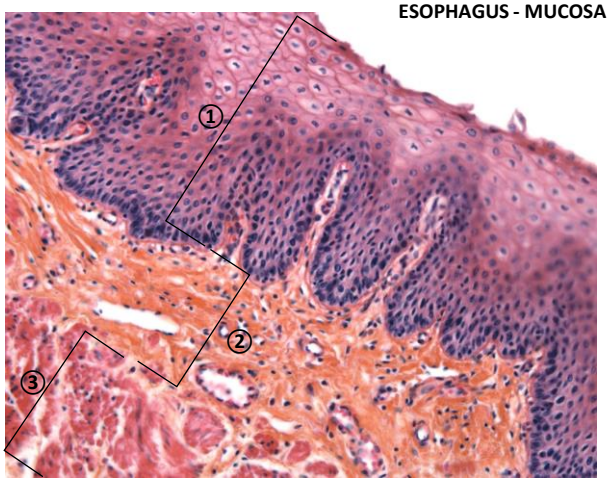
GENERAL STRUCTURE ESOPHAGUS



PHARYNX

- ***t. mucosa***
- *pars nasalis pharyngis*
- pseudostratified columnar ciliated e. with goblet cells
- *l. propria m.* – seromucous glands, *t. pharyngea*
- *pars digestoria pharyngis* (*p. oralis*, *p. laryngea*)
- stratified squamous e.
- mucous glands
- *l. muscularis m.* absent
- ***t. submucosa***
- reduced in *p. digestoria*, continuous with elastic c.t.
- ***t. muscularis externa***
- two layers of striated skeletal muscle fibers
- absent in *fornix pharyngis* → fibroelastic tissue

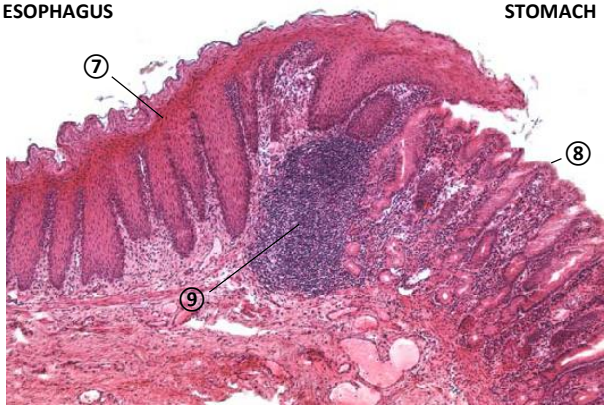
ESOPHAGUS - MUCOSA



ESOPHAGOGASTRIC JUNCTION

- junction of esophagus and cardia of stomach (cardiac notch)
- change of epithelial type from stratified squamous e.⑦ → simple columnar e.⑧
- lymphatic follicle⑨

ESOPHAGUS **STOMACH**

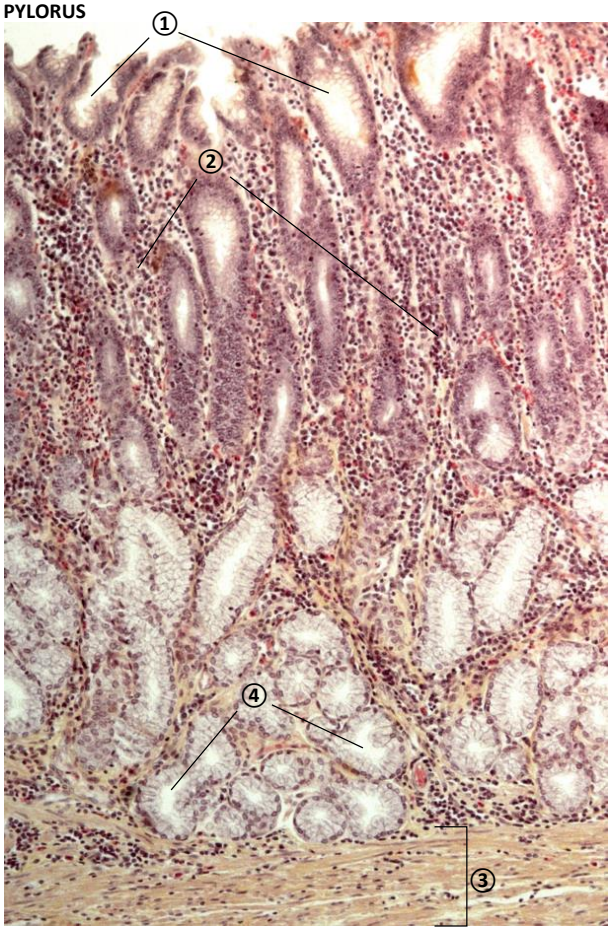


STOMACH (*gaster, ventriculus*)
- ***t. mucosa***
- *areae gastricae* and gastric pits (*foveolae gastricae*)①
- *l. epithelialis m.* – simple columnar e.
- *l. propria m.*② – loose collagen and reticular c.t., stomach glands
- *l. muscularis m.*③ – smooth muscle cells
- ***t. submucosa***
- loose collagen c.t. folded in *rugae gastricae*
- ***t. muscularis externa***
- circular, longitudinal layers of smooth muscle cells
- in fundus third oblique layer (*fibrae oblique*)
- in pylorus thickened circular layer → *m. sphincter pylori*
- ***t. serosa***

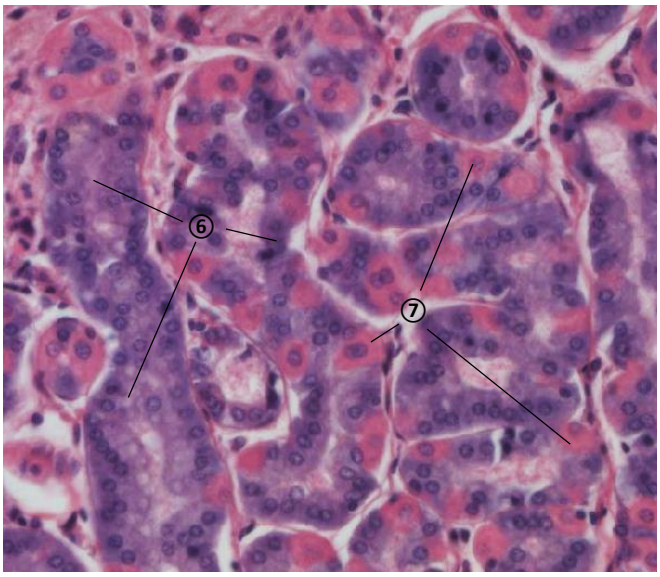
GLANDS OF *PARS CARDIACA* AND *PARS PYLORICA*
- **cardial gastric glands** (*gll. cardiacae*)
- **pyloric glands** (*gll. pyloricae*)
- *l. propria mucosae*
- mucous, branched tubular glands④
- open to gastric pits①
- mucous and enteroendocrine cells (G-cells)

GLANDS OF *FUNDUS* AND *CORPUS VENTRICULI*
- **proper gastric glands** *(gll. gastricae propriae)*
- *l. propria mucosae*
- mostly branched tubular glands⑤
- 2-4 open to gastric pits①
- **chief cells**⑥ (pepsinogenic, adelomorphic)
- columnar, basophilic
- well developed rER, Golgi apparatus, secretory pathway
- proteosynthesis
- zymogen granules (digestive enzymes)
- abundant at bases of glands
- **parietal cells**⑦ (oxyntic, delomorphous)
- large, oval, eosinophilic, 2-3 nuclei, numerous mitochondria, complex invaginations of plasma membrane → system of intracellular secretory canaliculi
- production of HCl and intrinsic factor
- bodies of glands
- **neck cells**
- mucous secretion
- renewal of gastric mucosa
- **enteroendocrine cells**
- EC cells, G-cells, L-cells, D-cells

PYLORUS



FUNDUS VENTRICULI

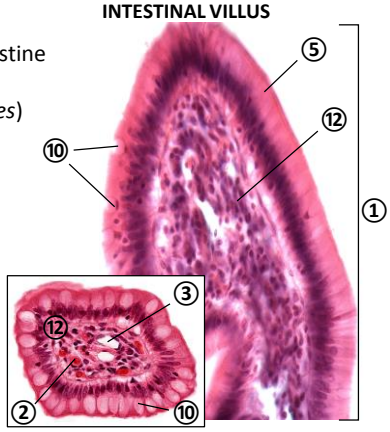


FUNDUS VENTRICULI

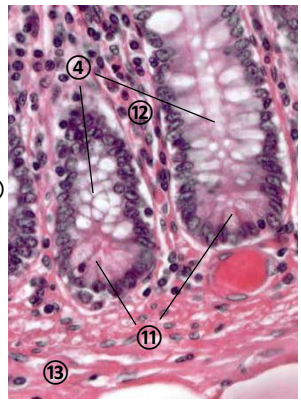
SMALL INTESTINE (*intestinum tenue*)

- ***t. mucosa***
- instestinal villi① (*villi intestinales*)
- mucosal projections (0.5-1.5 mm) into lumen of small intestine
- blood② and lymphatic③ capillaries (lacteal)
- crypts of Lieberkühn④ (*cryptae intestinales*, *gll. intestinales*)
- simple tubular glands in *t. mucosa*
- ***l. epithelialis m.***
- simple columnar e.
- enterocytes⑤
- striated border (*microvilli*)⑥, apical junctional complex (*zonula occludens*⑦, *z. adherens*⑧, desmosome⑨)
- goblet cells⑩
- Paneth cells⑪
- Microfold cells (M cells)
- enteroendocrine cells, tuft cells and intestinal stem cells
- ***l. propria m.***⑫
- reticular c.t.
- lymphocyte infiltrations or Peyer's patches (GALT) in ileum
- ***l. muscularis m.***⑬
- apparent thin layer of smooth muscle cells
- ***t. submucosa***⑭loose collagen c.t. often with adipocytes
- *plicae circulares*⑮ (*Kerckringi*)
- *plexus submucosus* (*Meisnerri*)
- Brunner's glands⑯ (*gll. duodenales, gll. Brunneri*)
- mucous, compound tubular glands in proximal duodenum
- open to crypts of Lieberkühn
- ***t. muscularis externa***
- circular⑰ and longitudinal⑱ layers of smooth muscle cells
- *plexus myentericus Auerbachi*
- ***t. serosa*** or ***t. adventitia***⑲

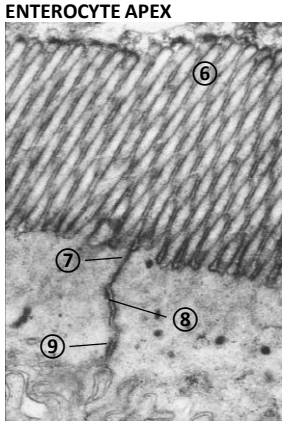
INTESTINAL VILLUS



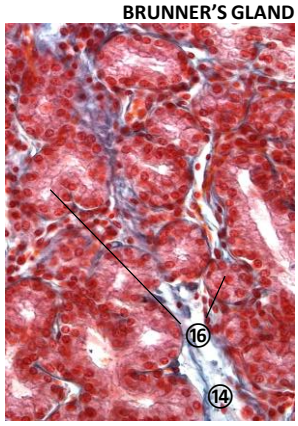
CRYPT OF LIEBERKŰHN



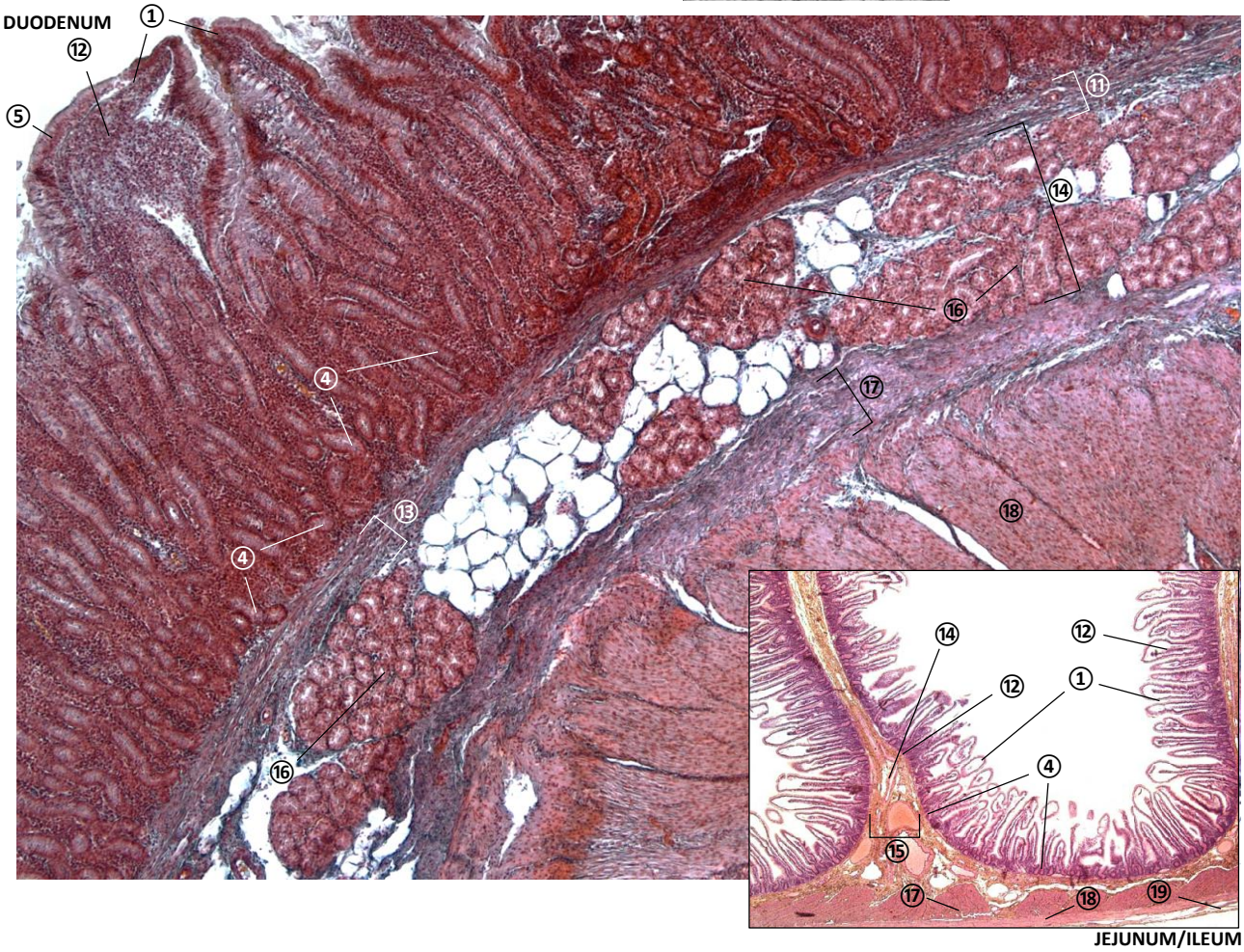
ENTEROCYTE APEX



BRUNNER'S GLAND



DUODENUM

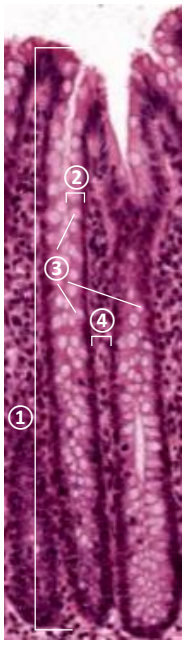


JEJUNUM/ILEUM

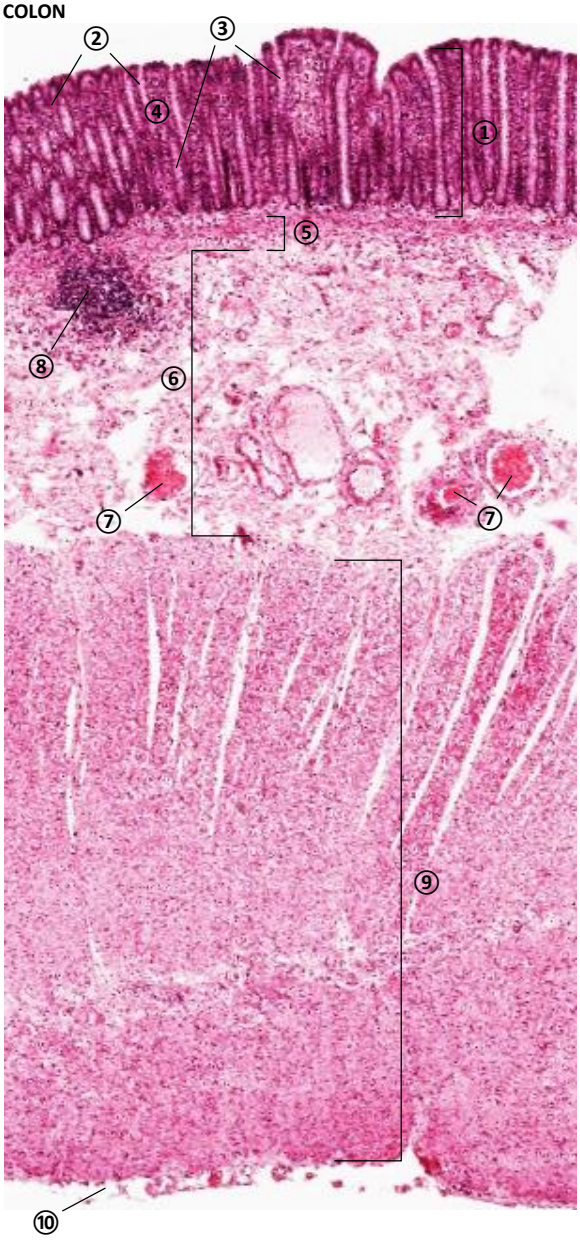
LARGE INTESTINE (*intestinum crassum*)

- ***t. mucosa***
- crypts of Lieberkühn① (*cryptae intestinales*)
- intestinal villi absent
- *l. epithelialis m.*
- simple columnar e.②
- enterocytes (colonocytes) with striated border, goblet cells③, enteroendocrine cells, intestinal stem cells
- *l. propria m.*④
- reticular c.t.
- solitary lymphatic follicles
- pericryptal fibroblasts
- *l. muscularis m.*⑤
- ***t. submucosa***⑥
- vascularized⑦ loose collagen c.t.
- *plicae semilunares*
- *plexus submucosus Meissneri*
- solitary lymphatic follicles⑧ and vessels
- ***t. muscularis externa***⑨
- longitudinal layer reduced to *taeniae coli* (*taenia libera*, *t. mesocolica*, *t. omentalis*)
- *plexus myentericus Auerbachi*
- ***t. serosa***⑩ or ***t. adventitia*** (retroperitoneum)
- adipocytes in *t. serosa* form appendages (*appendices epiploicae*)
- **anorectal junction**
- intestinal mucosa (*zona columnaris*) → non-keratinized stratified squamous e. (*z. hemorrhagica*) → epidermis (*z. cutanea*)
- *t. muscularis ext.* → *m. sphincter ani internus*

COLON MUCOSA



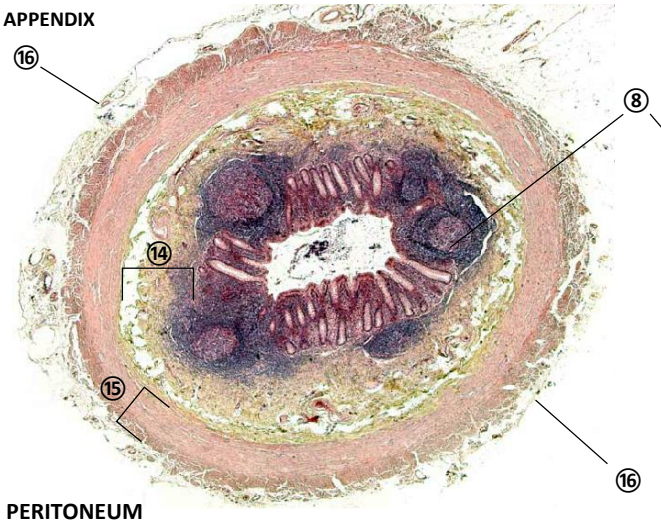
COLON



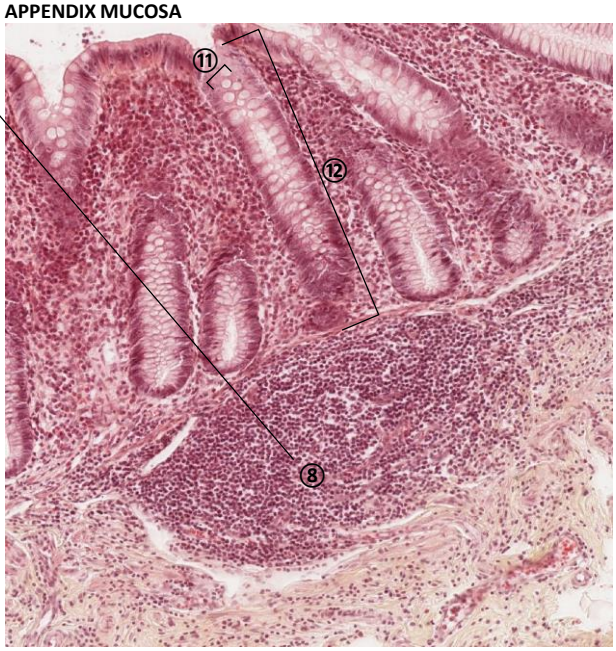
APPENDIX (*appendix vermiformis*)

- ***t. mucosa***
- *l. epithelialis m.*⑪ – simple columnar e.
- crypts of Lieberkühn⑫ (*cryptae intestinales*)
- abundant lymphatic tissue in *l. propria m.*
- mucosa above lymphatic follicles lacks crypts and contains M-cells
- *l. muscularis m.* often absent
- ***t. submucosa***⑭
- loose collagen c.t.
- numerous lymphatic follicles⑧
- ***t. muscularis externa***⑮
- complete circular and longitudinal layers
- *taeniae coli* absent
- ***t. serosa***⑯

APPENDIX



APPENDIX MUCOSA



PERITONEUM

- serous membrane lining peritoneal and pelvic cavities and visceral organs (*peritoneum parietale et viscerale*) with various duplicatures (mesenteries)
- simple squamous e. (*mesothelium*)
- tightly assembled polyedric cells with small microvilli.
- subepithelial dense collagen c.t. → loose collagen c.t.

LIVER (*hepar*)

- *tunica fibrosa hepatis* (Glisson's capsule) of dense collagen c.t. with simple squamous e. (mesothelium)
- **vascularization**
- ***v. portae*** (nutrient-rich, ~70%) → *vv. interlobulares* → *vv. circumlobulares* → *hepatic sinusoids* → ***v. centralis***
- ***a. hepatica*** (oxygen-rich, ~30%) → *aa. interlobulares* → *aa. circumlobulares* → *hepatic sinusoids* → ***v. centralis***
- *vv. centrales* → *vv. sublobulares* → *vv. hepaticae* → *v. cava inferior*

HEPATIC LOBULE

- ***vena centralis***①
- thin *t. media* with rare smooth muscle cells
- **hepatic sinusoids**②
- abundant fenestrations (↔ ~100 nm)
- diaphragm and basal lamina absent
- **hepatocytes**
- radially arranged in anastomosing sheets③
- large (~25 μm) basophilic cells, often two nuclei
- abundant mitochondria, sER and rER, lysosomes, peroxisomes
- glycogen inclusions (α-granules – rosettes)
- blood pole: basolateral surface, microvilli oriented to perisinusoidal space (space of Disse)
- biliary pole: apical surface, microvilli oriented to bile canaliculi, junctional complexes
- **Kupffer cells**④
- monocyte-macrophage system → phagocytosis
- inside sinusoids
- **hepatic stellate cells** (cells of Ito, perisinusoidal cells)
- pericytes of sinusoids
- lipid droplets in cytoplasm – storage of retinoids
- production of fine ECM

PORTAL AREA⑤ (portal space)

- fibrous c.t.
- *a. interlobularis*⑥
- *v. interlobularis*⑦
- *d. biliferus interlobularis*⑧

Glisson's portal triad

- lymph vessels
- autonomous nerve fibers (*n. vagus*)

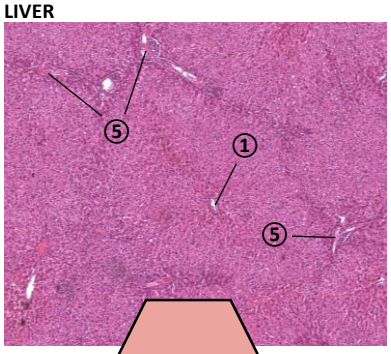
EXAMPLES OF ORGANIZATION OF HEPATIC PARENCHYMA

- **hepatic lobule** (*lobulus venae centralis*)
- approx. hexagonal prism (∅ 1 mm, ↔ 2 mm) around *v. centralis*, separated by interstitial c.t and portal areas
- histological (morphological) model
- **hepatic acinus** (Rappaport's acinus)
- area of hepatocytes supported by *aa.* and *vv. circumlobulares* of adjacent portal areas, defining three distinct physiological zones (1 – periportal, 2 – intermediate, 3 – perivenous)
- model of metabolic zonation
- **portal lobule**
- triangular, centered around portal area
- functional model based on bile drainage

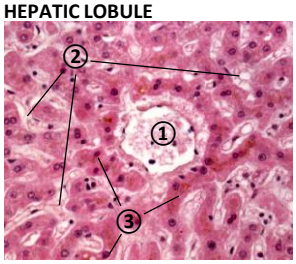
BILIARY DUCTS

- **intrahepatic bile ducts**: bile canaliculi (∅ ~1 μm): no lining → canals of Herring: simple squamous e. → interlobular bile ducts: simple cuboidal to columnar e. → *d. hepaticus dexter et sinister:* simple columnar e.
- **extrahepatic bile ducts**: *ductus hepaticus* → *d. cysticus* → *d. choledochus*
- *t. mucosa*: mucosal folds, simple columnar e. with microvilli, *l. propria m.* – loose collagen c.t. with mucous glands
- fibromuscular layer: collagen and elastic fibers with smooth muscle cells (*m. sphincter hepatoduodenalis*)

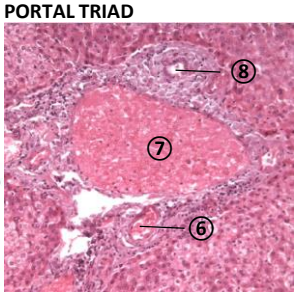
LIVER

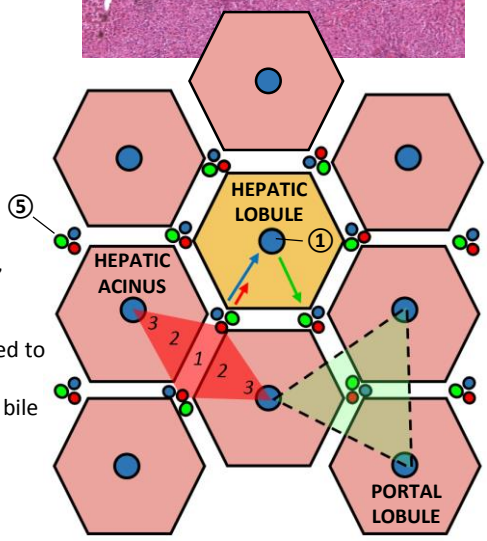


HEPATIC LOBULE

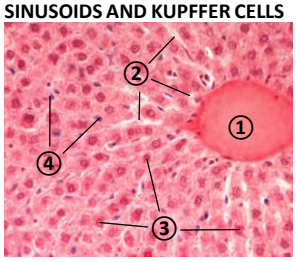


PORTAL TRIAD





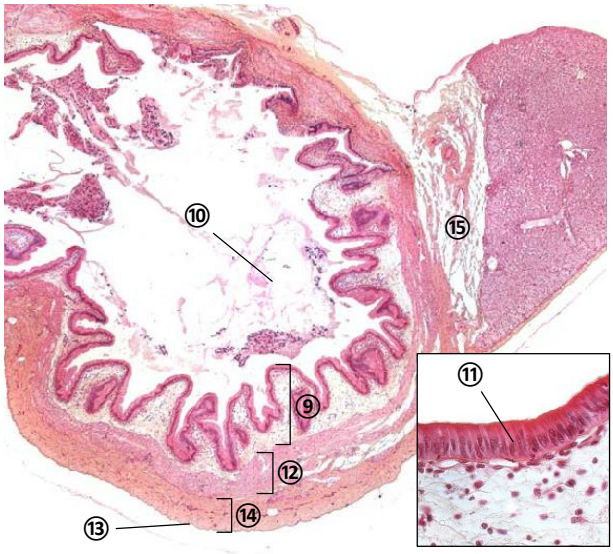
SINUSOIDS AND KUPFFER CELLS



GALL BLADDER (*vesica fellea*)

- ***t. mucosa***⑨
- mucosal folds (*plicae mucosae*)
- mucus⑩ secretion, water absorption, concentration of bile
- *l. epithelialis m.* – simple columnar e.⑪ with microvilli and junctional complexes (cholecystocytes), basal nuclei, pale appearance of cells
- *l. propria m.* – tubuloacinar mucous glands in neck region with enteroendocrine cells
- **fibromuscular layer**⑫
- smooth muscle cells, elastic fibers
- typical *tela submucosa* or *t. muscularis ext.* absent
- ***t. serosa***
- mesothelium⑬
- dominant subserous c.t.⑭
- *t. adventitia*⑮ on upper gall bladder surface

GALL BLADDER LIVER



MAJOR SALIVARY GLANDS (*gll. salivariae*)
- *capsula fibrosa* → septa with ducts and vessels → lobules
- glandular parenchyma
- secretory units and ducts
- myoepithelial cells between basal lamina and epithelial glandular cells

- **secretory units**
- serous acinus①
- spherical structure with small, often inapparent lumen
- pyramidal cells with round nuclei, well developed rER and apical secretory granules
- intercellular junctions (*z. adherentes*, z. *occludentes*)
- isotonic secretion rich in proteins
- mucous tubule②
- tubular structure with apparent lumen
- pale, columnar mucous cells, with apical secretory granules and basally located, flattened nuclei
- production of hydrophilic mucus
- tubuloacinar unit
- combined mucous and serous secretion
- serous cells③ at distal ends of mucous tubules forming serous demilunes (crescents of Gianuzzi)
- crescent shape of demilunes partly artifactual
- **ducts**

<u>intralobular ducts</u>
- intercalated ducts
- low cuboidal e. with myoepithelial cells
- striated ducts④
- simple cuboidal – low columnar e. equipped with basal labyrinth → transmembrane transport of water and ions

<u>interlobular ducts</u>
- interlobular ducts⑤
- simple tall columnar e.
- main ducts
- pseudostratified – strafied columnar e.

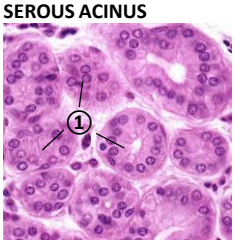
PAROTID (*gl. parotis*)
- purely serous, branched acinar gland
- intercalated ducts present, abundant striated ducts④
- abundant adipocytes⑥
- parotid duct (Stenson's)
- opens opposite to maxillary M_2 on buccal mucosa

SUBMANDIBULAR GLAND (*gl. submandibularis*)
- seromucous, branched tubuloacinar gland
- dominant serous component
- mucous tubules with abundant serous demilunes
- intercalated ducts and striated ducts present
- submandibular duct (Wharton's)
- opens at sublingual caruncle

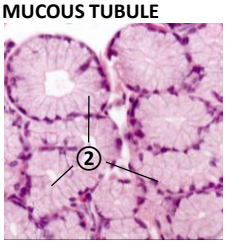
SUBLINGUAL GLAND (*gl. sublingualis*)
- seromucous, branched tubuloacinar gland
- dominant mucous component
- mucous tubules with occasional serous demilunes
- intercalated ducts virtually absent, striated ducts short
- sublingual duct (Bartholin's) opens at sublingual caruncle
- additional small ducts open along sublingual fold

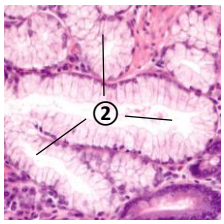
MINOR SALIVARY GLANDS
- nonencapsulated
- *gll. labiales* – seromucous
- *gll. buccales* – seromucous
- *gll. palatinae* – mucous
- *gl. lingualis anterior* (*gl. Blandini*) – seromucous
- *gll. papillae vallatae*, *gustatoriae* (*gll. Ebneri*) – serous
- *gll. linguales posteriores* (*gll. Weberi*) – mucous

SEROUS ACINUS

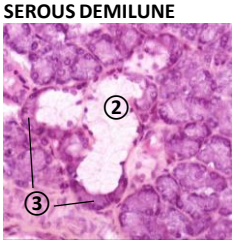


MUCOUS TUBULE

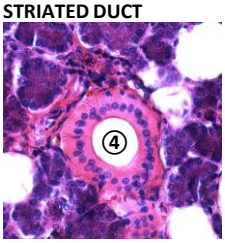




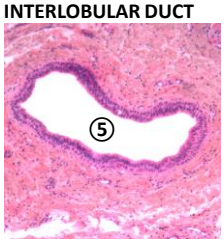
SEROUS DEMILUNE



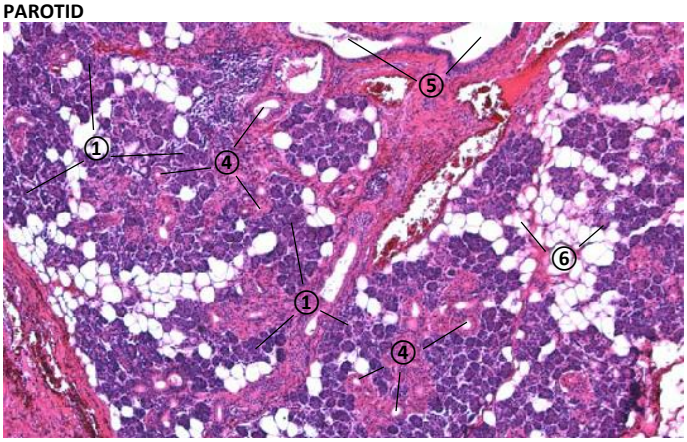
STRIATED DUCT



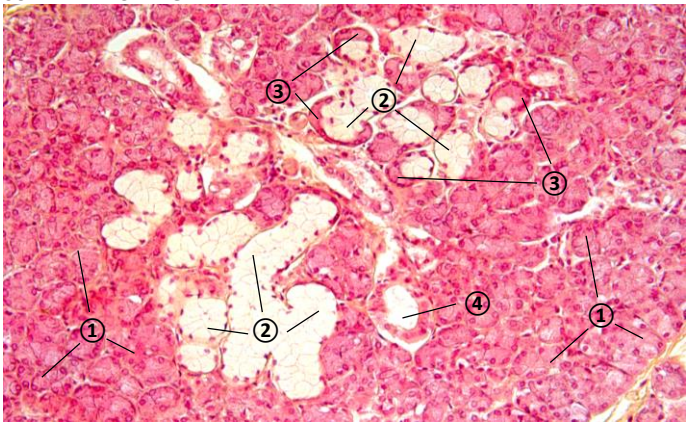
INTERLOBULAR DUCT



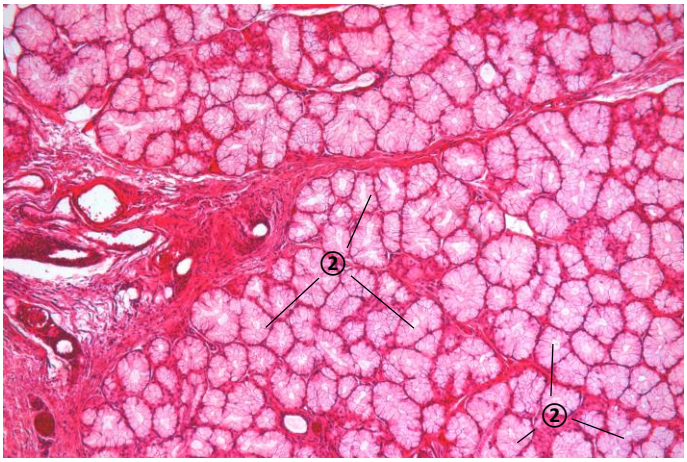
PAROTID



SUBMANDIBULAR GLAND



SUBLINGUAL GLAND



PANCREAS

- c.t. capsule, septa① with ducts and vessels
- exocrine compartment – serous acini②
- endocrine compartment – islets of Langerhans③

- **exocrine compartment**
- lobular parenchyma
- basophilic serous acini producing enzyme precursors (α-amylase, trypsin, lipase, etc.)
- secretion modulated by entero-endocrine system (e.g. cholecystokinin) and autonomic nervous system
- ductal system
- intercalated ducts with centroacinar cells (simple squamous to low cuboidal e.) → intralobular ducts④ (cuboidal e.) → interlobular ducts⑤ (cuboidal to columnar e.) → *d. pancreaticus* (*Wirsungi*) (pseudostratified to bilayered columnar e. with occasional goblet and enteroendocrine cells)
- accessory duct (*Santorini*) can persist
- striated ducts absent
- secretin-stimulated production of HCO_3^- and water in ducts (increase of pH to ~8)
- pancreatic stellate cells
- dispersed between acini
- myofibroblast phenotype, ECM secretion

- **endocrine compartment**
- islets of Langerhans③ (~10^6, ∅ 100-200 µm)
- cords (trabecules)⑥ of epithelial cells
- fenestrated capillaries⑦, c.t. capsule⑧ with thin septa
- blood from i. of Langerhans drained by acinar vascularizaton
- pancreatic hormones – preprohormones post-translationally modified (cleaved) to biologically functional peptides
- endocrine cells with secretory granules

Beta cells (β)	~70%	insulin
Alpha cells (α)	~20%	glucagon
Delta cells (δ)	~5%	somatostatin
PP-cells (γ)	<5%	pancreatic polypetide
Epsilon -cells (ε)	<1%	ghrelin

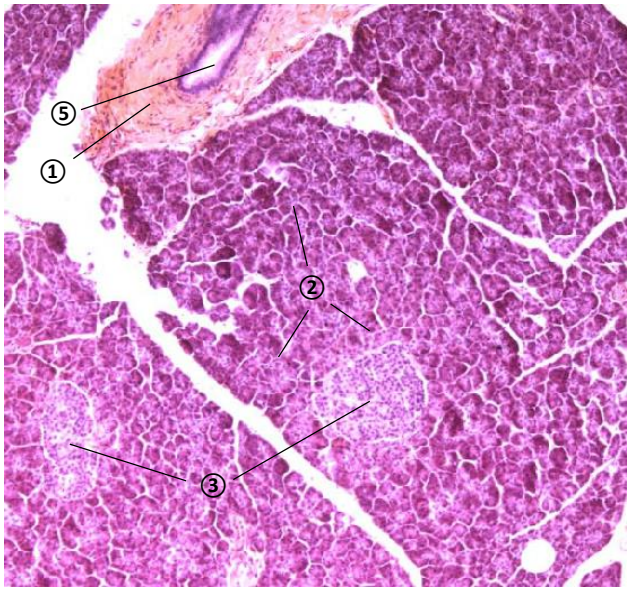
ENTEROENDOCRINE SYSTEM (DNES, APUD)

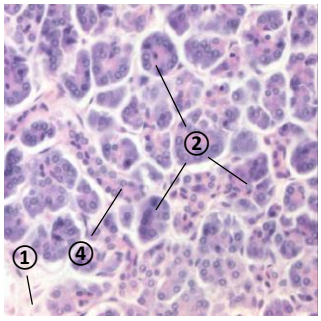
- endocrine cells producing gastro-intestinal hormones
- DNES and pancreas constitute gastro-entero-pancreatic (GEP) endocrine system
- located in epithelium or dispersed within glands
- slightly basophilic, argentaffine (argyrophilic) cells
- well developed smooth ER, apparent secretory granules

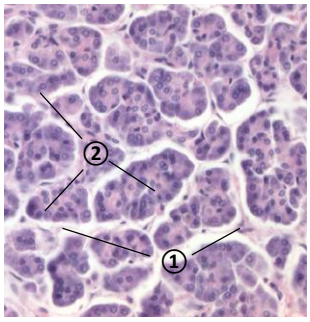
ULTRASTRUCTURAL CLASSIFICATION OF DNES CELLS

- **D-cells** (identical to D-cells of islets of Langerhans)
- pale cells, spherical granules (~350 nm)
- stomach, small intestine, hepatic and pancreatic ducts
- somatostatin
- **EC-cells** (enterochromaffin cells)
- conical cells, apical microvilli, at cell basis osmiophilic granules
- stomach, small and large intestine, gall bladder, bile ducts
- serotonin
- **ECL-cells** (EC-like cells)
- oval cells, large and variable cytoplasmic granules
- *fundus ventriculi*
- histamin
- **G-cells**
- conical cells, apical microvilli, secretory granules (~300 nm)
- *pars pylorica*, *duodenum*
- gastrin
- **I-cells** (CCK-cells)
- oval cells with irregular granules (~250 nm)
- small intestine
- cholecystokinin

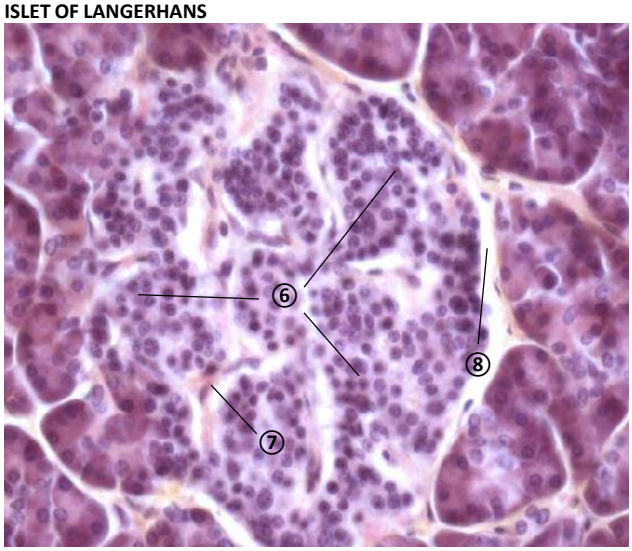
PANCREAS







ISLET OF LANGERHANS



- **K-cells**
- irregular granules (~350 nm)
- duodenum and small intestine generally
- GIP (gaster inhibitory protein)
- **L-cells** (EG-cells, similar to A-cells of islets of Langerhans)
- oval cells, spherical, osmiophilic granules (~250 nm)
- *gll. gastricae propriae*, small intestine, colon
- enteroglucagon
- **S-cells**
- large, oval cells, spherical granules (~200 nm)
- duodenum
- secretin

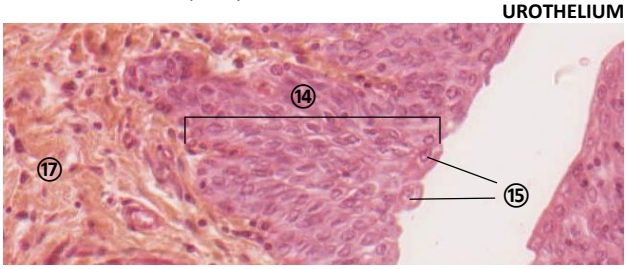
KIDNEY (*ren, nephros*)
- c.t. capsule, perirenal adipose tissue, rare interstitial c.t.
- renal parenchyma – *lobi renales*, medulla① (pyramids apically oriented to calyx of renal pelvis), *striae medullares corticis*②, cortex③ (between bases of medullar pyramids and capsula), cortical columns (*columnae renales Bertini*)
- **vascularization**
  - close association of vessels and tubules; two subsequent capillary systems: branches of *a. renalis* → *aa. interlobares* (entering *columnae renales*) → *aa. arcuatae* → *aa. interlobulares* (*aa. corticales radiatae*) → *vasa afferentia* → capillary glomerulus (1st capillary network) → *vasa efferentia* → peritubular cortical capillary network (2nd capillary network) (cortical nephrons) **OR** *vasa recta* and peritubular medullary capillary network (2nd capillary network) (juxtamedullary nephrons) → *vv. interlobulares* → *vv. arcuatae* → *vv. interlobares* → *v. renalis*

NEPHRON (renal corpuscle and tubule, ~1×10^6 per kidney)
- **renal corpuscle** (∅ 0.2 mm)
  - capillary glomerulus④, mesangium, parietal⑤ (simple squamous e.) and visceral⑥ sheets of Bowman's capsule, (podocytes), capsular (urinary) space⑦
  - vascular pole (*vas afferens et efferens*)
  - urinary pole (transition of urinary space to proximal tubule)
- blood-urine barrier
  - capillary endothelium with glycocalyx, *lamina rara subendothelialis*, *l. densa*, *l. rara subepithelialis*, pedicels of podocytes (slit diaphragm)
- **renal tubule**
  - proximal tubule⑨ (simple cuboidal e. with brush border) – *pars convoluta* (cortex) and *p. recta* (medulla)
  - **loop of Henle** – thin segment⑩ (simple squamous e.) → thick segment⑪ (simple cuboidal e.)
  - **distal tubule**⑫ – *pars recta* (medulla, simple cuboidal e.), *p. convoluta* (cortex, simple cuboidal e.), *macula densa* (simple columnar e.)
- endocrine juxtaglomerular apparatus: *macula densa*⑧ of distal convoluted tubule, extraglomerular mesangial cells, juxtaglomerular cells of *vas afferens*

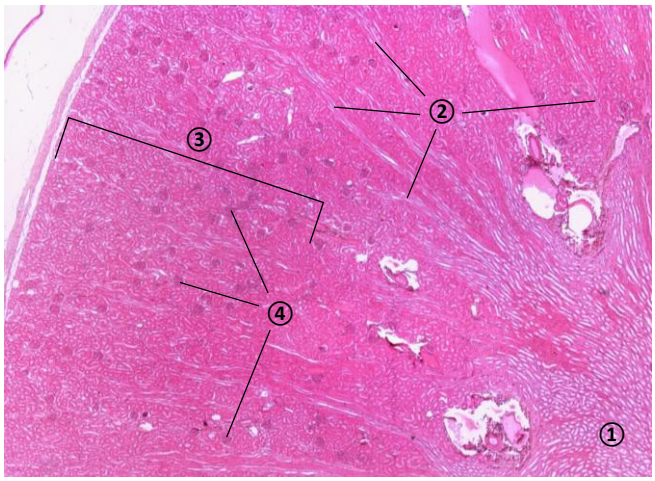
RENAL COLLECTING SYSTEM
- *ductuli colligentes*⑬ → *ductuli papillares* (*Bellini*) lined by principal and intercalated cells → *area cribrosa* → *calyx renalis* and *pelvis renalis* lined by urothelium
- **urothelium**⑭ (transitional epithelium)
  - volume flexibility, osmotic resistance
  - single layer of basal cells
  - 3-5 highly flexible layers of cuboidal → columnar cells
  - superficial layer of large umbrella cells⑮ covered by glycoprotein plaques similar to lipid rafts (uroplakins)

URETER (∅ 7 mm, length ~30 cm)
- *tunica mucosa*⑯
  - mucosal folds, stellate lumen lined by urothelium⑭
  - *l. propria m.*⑰ – loose collagen c.t. with elastic fibers
  - *l. muscularis m.* absent
- *t. muscularis*⑱
  - intercalated c.t. continuous with *l. propria m.*
  - inner longitudinal and outer circular layers of smooth muscle cells; in distal part – additional outer longitudinal layer
- *t. adventitia*⑲, partly *t. serosa*

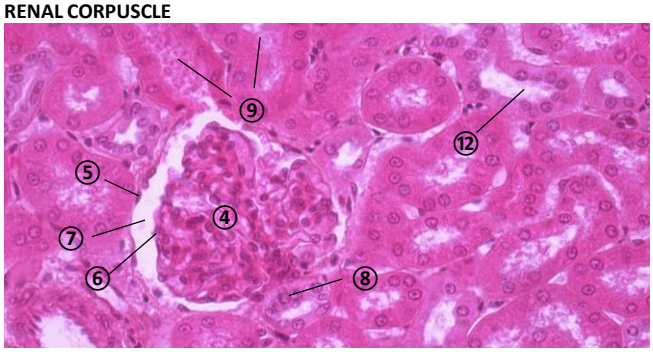
UROTHELIUM



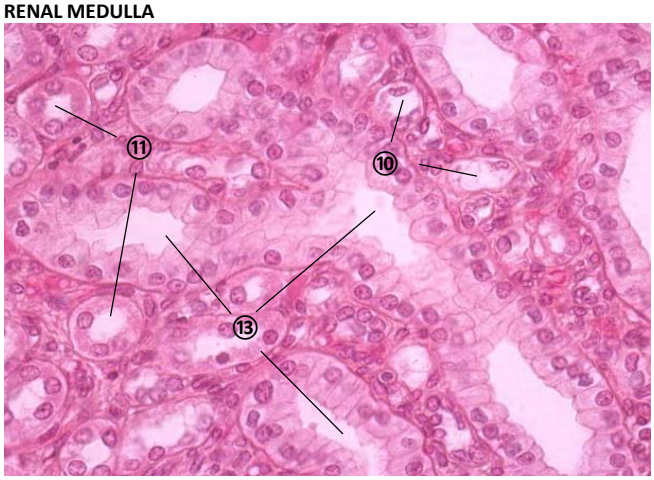
KIDNEY



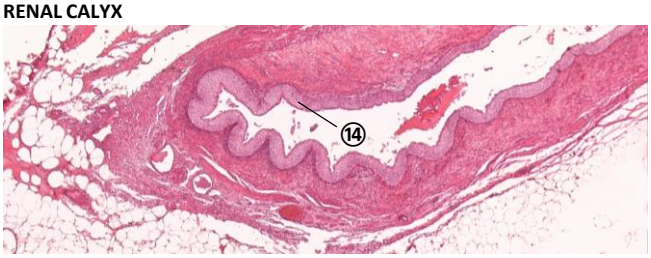
RENAL CORPUSCLE



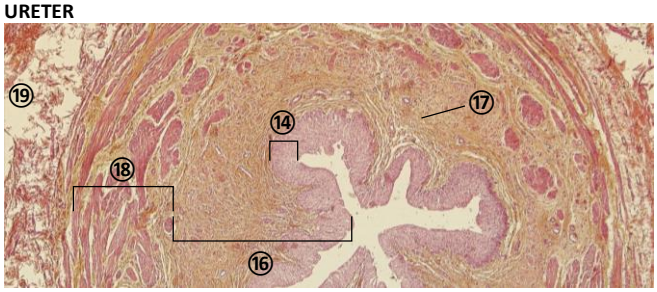
RENAL MEDULLA



RENAL CALYX



URETER

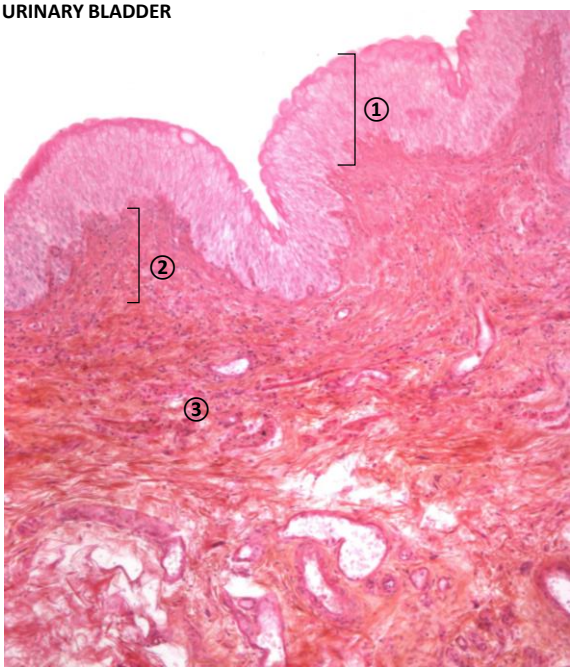


URINARY BLADDER (*vesica urinaria*)

- ***tunica mucosa***
- thick, flexible, folded into *rugae*, lined by urothelium①
- *l. propria m.*② continuous with *t. submucosa*
- rich capillary network, afferent nerve fibers, parasympathetic fibers
- *l. muscularis m.* absent
- ***t. muscularis externa***③ – *m. detrusor vesicae*
- ***t. adventitia*** – continuous with perivesicular adipose tissue
- ***t. serosa*** – fornix

URINARY BLADDER MUCOSA

URINARY BLADDER

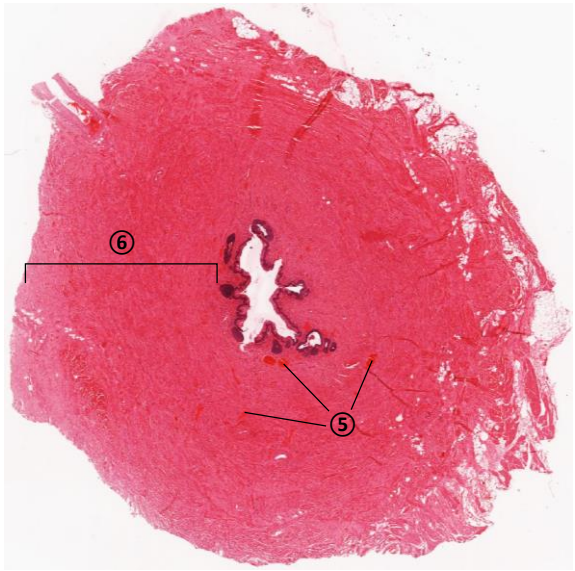


FEMALE URETHRA (↔ 2.5-4 cm)

- ***t. mucosa***④
- mucosa forms folds
- transitional e. → occasionally patches of pseudostratified columnar e. → stratified squamous nonkeratinized e. rich in glycogen
- occasionally *gll. urethrales* (*gll. periurethrales Littré*)
- rich venous plexus⑤ (similar to *corpus spongiosum urethrae*)
- ***t. muscularis***⑥
- inner longitudinal and outer circular layer of smooth muscle cells
- striated *m. sphincter urethrae* at urogenital diaphragm
- ***t. adventitia***

FEMALE URETHRA

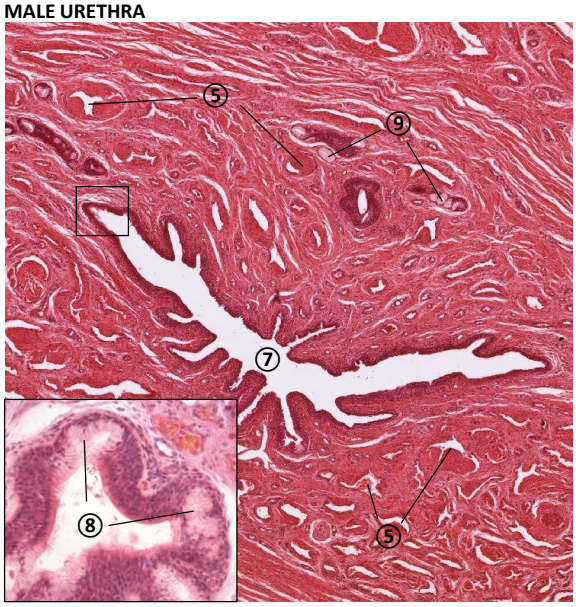
FEMALE URETHRA



MALE URETHRA⑦ (↔ 18-20 cm)

- ***t. mucosa***
- *pars intramuralis* (*praeprostatica*) → upper part of *pars prostatica*: urothelium; *p. prostatica* from *colliculus seminalis* → *p. diaphragmatica* and *p. cavernosa*: pseudo- and then stratified columnar e.; *fossa navicularis*: stratified squamous e.
- mucosal *lacunae urethrales* containing endoepithelial mucous glands (*gll. Morgagni*)⑧
- *l. propria m.* – loose collagen c.t. and elastic fibers, mucous tubuloacinar *gll. urethrales*⑨ (*Littré*), rich venous plexus⑤ (*corpus spongiosum urethrae*)
- ***t. muscularis externa***
- fully developed in *p. intramuralis* and *p. prostatica*
- in *p. cavernosa* continuous with *corpus spongiosum urethrae*

MALE URETHRA



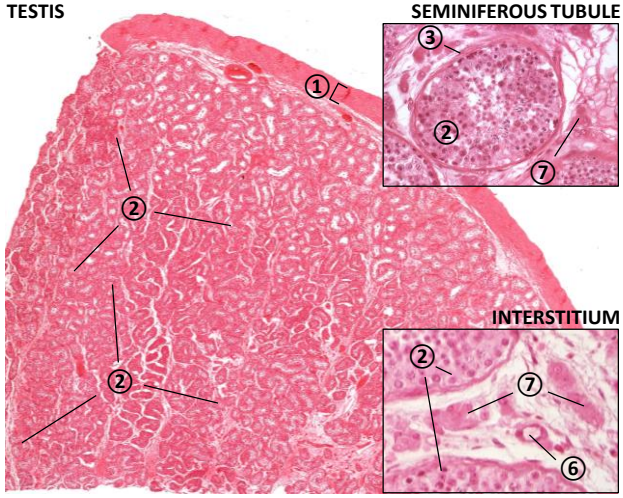
TESTIS

- c.t. capsule① – *tunica albuginea testis*, lined by *epiorchium* (*l. visceralis tunicae vaginalis testis*)
- *mediastinum testis*, *septula testis* → testicular lobules (~250)
- **convoluted seminiferous tubules** (*tubuli seminiferi contorti*)
  - ~600 per testis, ∅ 150-250 µm, ↔ 30-70 cm
  - spermatogenic (germinal) e.② (↔ 80 µm)
  - *l. propria*③ with collagen fibers and peritubular myofibroblasts
- Sertoli cells④ (sustentacular cells)
  - columnar cells with large, pale nuclei
  - membrane processes with junctional complexes
  - basement membrane⑤
  - hematotesticular barrier between basal and adluminal compartments
  - spermatogenic cells intercalated between Sertoli cells
- **interstitium**
  - loose collagen c.t. between seminiferous tubules
  - innervation, vascularization⑥
- Leydig cells⑦ (interstitial cells of Leydig)
  - large, polyhedral cells with eosinophilic cytoplasm, apparent nucleus, dominant sER, lipid droplets and other inclusions (Reinke's crystals, lipofuscin)
- **intratesticular ducts**: straight tubules (*tubuli recti*) → *rete testis*
- **spermatogenesis**
  - **mitosis** (in basal compartment)
  - stem spermatogonia (46, XY, 2n, 2C)
  - spermatogonia A → spermatogonia B⑧ (46, XY, 2n, 2C)
  - **meiosis I** (in adluminal compartment)
  - primary spermatocyte⑨ (46, XY, 2n, 4C)
  - secondary spermatocyte (23, X/Y, 1n, 2C)
  - **meiosis II**
  - spermatid (23, X/Y, 1n, 1C)
- **spermiogenesis**
  - maturation of round, radially symmetric, early spermatids⑩ into late spermatids⑪ and fully mature, motile spermatozoa
  - formation of acrosomal head cap⑫ from Golgi apparatus
  - hypercondensed nucleus⑬, proximal centriole in neck region (delivered to oocyte), distal centriole (basal body of axoneme)
  - mitochondria helically assembled in mid-piece⑭ (proximal part of flagellum) and aligned with axonemal complex
- **spermiation**
  - residual cytoplasmic bodies phagocyted by Sertoli cells
  - release of spermatozoa into lumen of seminiferous tubules

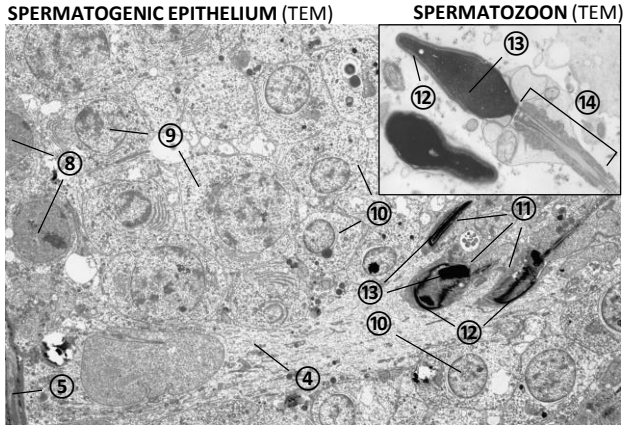
EPIDIDYMIS

- c.t. capsule⑮, interstitial c.t.
- ***ductuli efferentes***⑯ (*caput*)
  - *l. epithelialis m.* – alternations of tall ciliated columnar cells and resorptive cuboidal cells
  - loose collagen c.t. with myofibroblasts, abundant capillaries
- ***ductus epididymidis***⑰ (*corpus*, *cauda*, ↔ 4-6 m)
  - *l. epithelialis m.* – pseudostratified columnar e.⑱ with long stereocilia (modified microvilli)⑲
  - loose collagen c.t.⑳ with myofibroblasts (*caput*, *corpus*) or smooth muscle cells (*cauda*) with increasing thickness distally

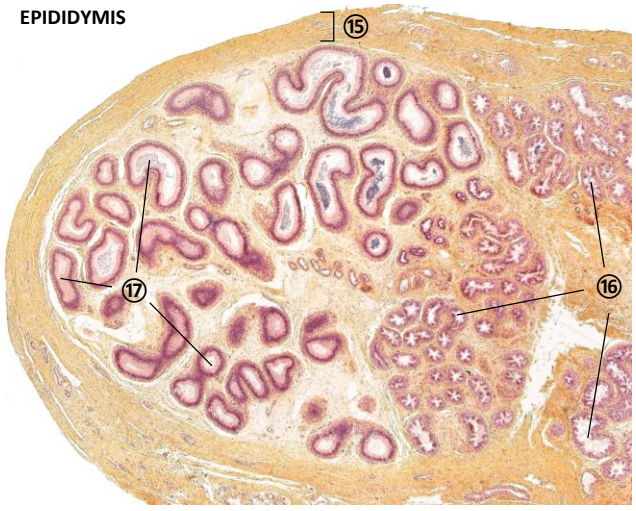
TESTIS



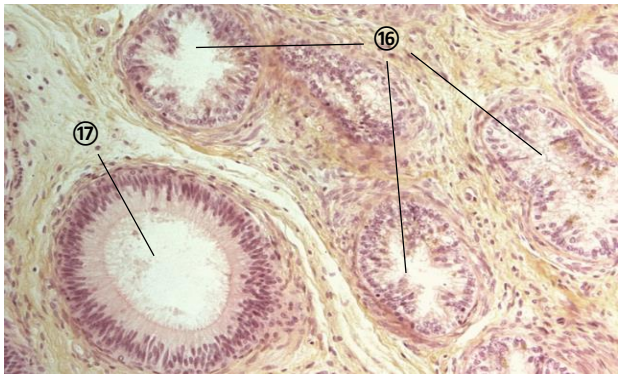
SPERMATOGENIC EPITHELIUM (TEM) **SPERMATOZOON** (TEM)



EPIDIDYMIS



EPIDIDYMIS



DUCTUS EPIDIDYMIDIS

FUNICULUS SPERMATICUS

- **c.t. capsule** (*tunica vaginalis testis et funiculi spermatici*)
- *ductus deferens*①, *a. testicularis*, *a. ductus deferentis*, *plexus pampiniformis*②, lymph vessels, nerves, *m. cremaster*③
- ***ductus*** (*vas*) ***deferens*** (∅ 3 mm, ↔ 40-45 cm)
  - ***tunica mucosa***
  - *l. epithelialis m.* – pseudostratified or simple columnar e. with stereocilia, in *ampulla d. deferentis* apparent mucosal folds④
  - thin *l. propria m.* with smooth muscle cells and elastic c.t.
  - ***t. muscularis***
  - spirally oriented smooth muscle cells illusively arranged to three layers, rich noradrenergic innervation
- ***t. adventitia*** loose collagen c.t. continuous with interstitial c.t.⑤

SEMINAL GLANDS (*gll. vesiculosae*, *vesiculae seminales*)

- paired tubular glands (↔ 10-15 cm), in caudal part, *ductus excretorius vesiculae seminalis* → *ampulla d. deferentis* → *d. ejaculatorius*
- *capsula fibrosa* – thin layer of dense collagen c.t.
- ***t. mucosa***
  - primary, secondary and tertiary folds⑥
  - *l. epithelialis m.* – simple or pseudostratified columnar e.
  - ~70% of ejaculate volume, rich in fructose and semenogelin, pH ~7.6
- ***t. muscularis***⑦
  - bundles of smooth muscle cells, rich innervation
- ***t. adventitia***
  - vascularized loose collagen c.t. continuous with interstitial c.t.

PROSTATE (*prostata*)

- *capsula fibrosa* – dense collagen c.t.
- ***gll. prostaticae***⑧
  - 30-50 branched tubuloacinar glands, drained by 15-30 *ductuli prostatici* to distal segment of *p. prostatica urethrae*
  - simple → pseudostratified columnar e.⑨ with basal and luminal cells (glandular, neuroendocrine)
  - secretion pH ~6.4, ~15-30% of ejaculate volume, rich in acid phosphatase, prostaglandins, PSA (prostate specific antigen)
  - lamellar, prostatic concrements⑩ (*corpora amylacea*)
- **fibromuscular stroma**⑪
  - dense collagen c.t. with elastic fibers and smooth muscle cells
  - rich innervation, vascularization

BULBOURETHRAL GLANDS (*gll. bulbourethrales*, *gll. Cowperi*)

- paired branched tubuloacinar mucous gland
  - homologous to female *gll. vestibulares maiores* (*gll. Bartholini*)
- *capsula fibrosa* – dense collagen c.t. → septa
- simple squamous → columnar glandular e. (apocrine secretion)
- ducts (↔ ~2.5 cm)
  - simple cuboidal → columnar e.
  - open to proximal part of *p. prostatica urethrae*

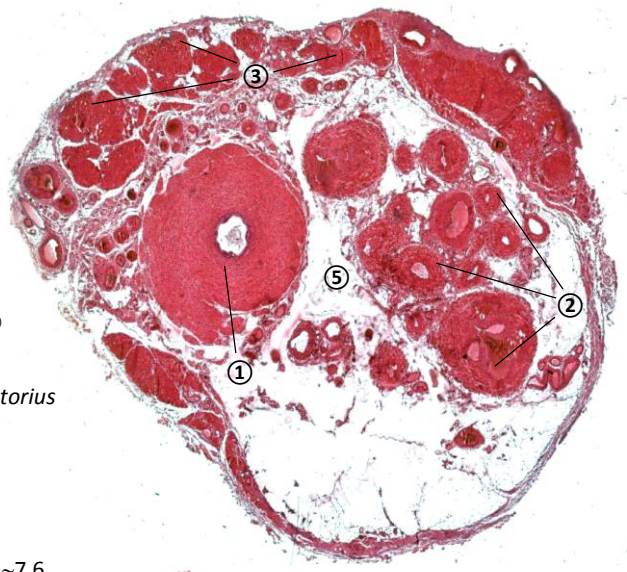
PENIS

- thin epidermis without adipocytes⑫
- *glans penis* covered by non-keratinized stratified squamous e.
- retractile skin fold (*praeputium penis*⑬)
  - sebaceous *gll. praeputiales* (Tyson's) producing *smegma praeputii*
  - glandopreputial lamella⑭ (development of *glans* and *praeputium*)
- ***tunica albuginea***⑮, *fascia penis*⑯
- **cavernous bodies**⑰ (*corpora cavernosa*)
  - endothelium-lined cavernae in c.t.- and smooth muscle-scaffold
  - continuous with *t. albuginea*
  - absent in *glans penis*
  - *a. profunda penis* → *aa. helicinae* with intimal cushions and valves
- ***corpus spongiosum urethrae*** (*penis*)⑱
  - dense venous plexus surrounding urethra⑲

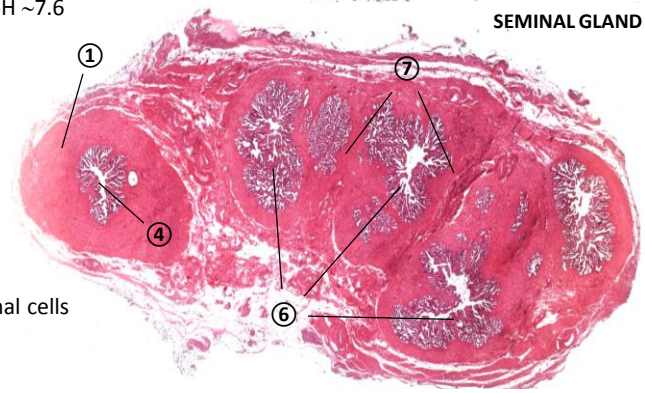
SCROTUM

- thin pigmented skin with sebaceous and sweat glands, hair follicles
- dermis with myofibroblasts (*tunica dartos)*
- *fascia spermatica ext.*, *m. cremaster*, *f. cremasterica*, *f. spermatica int.*, *periorchium* (*l. parietalis tunicae vaginalis testis*)

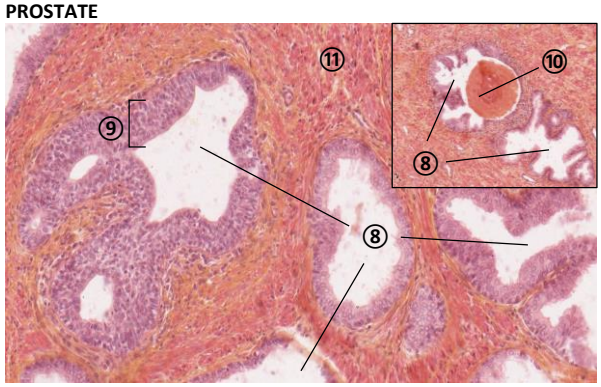
FUNICULUS SPERMATICUS



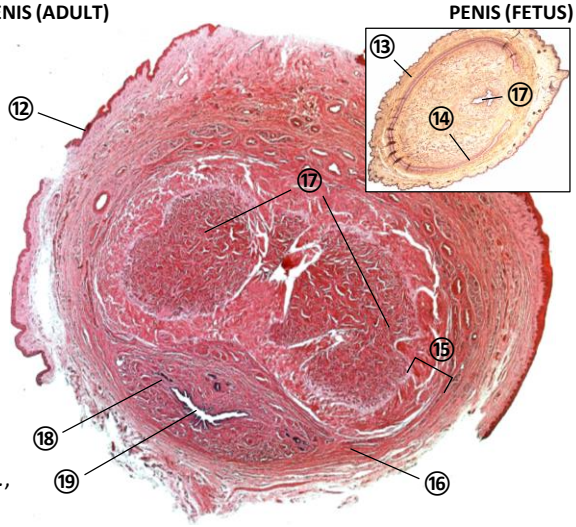
SEMINAL GLAND



PROSTATE



PENIS (ADULT) **PENIS (FETUS)**



OVARY (*ovarium*)
- surface covered by simple cuboidal e.①
- *tunica albuginea ovarii*② – dense collagen c.t.
- *cortex*③ – highly cellular c.t. stroma④, follicles and their derivatives
- *medulla*⑤ – loose collagen c.t., vascularization, innervation, interstitial endocrine cells
- **ovarian follicles**
- anatomical structures supporting oocyte development
  - oocyte (immature *ovum*)
  - follicular (granulosa) cells
  - thecal cells in late follicles

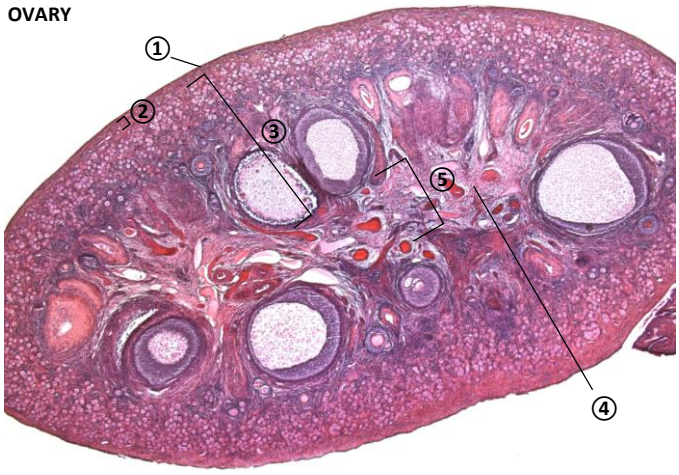
FOLLICULAR DEVELOPMENT
- **primordial follicle**⑥ (∅ 40-50 μm)
  - oocyte⑦ surrounded by simple squamous e.
- **primary follicle**⑧
  - unilaminar
  - ∅ 100 μm
  - simple cuboidal → columnar cells with basal lamina
  - *zona pellucida*
  - multilaminar⑨
  - multiple layers of follicular cells (*membrana granulosa*)
  - stromal cells form *theca folliculi*
- **secondary follicle**
  - *antrum folliculi*, *membrana granulosa*, *cumulus oophorus*
  - *theca folliculi interna* and *externa*
- **mature (Graafian) follicle** (∅ 1,5-2 cm)
  - *antrum folliculi* with *liquor folliculi*⑩ lined by *granulosa* cells⑪, *cumulus oophorus*⑫, *corona radiata*⑬, *theca folliculi int.*⑭ and *ext.*⑮
  - modified basal lamina of granulosa cells between *theca foliculli int.* and *membrana granulosa* (membrane of Slavjanski)

OOGENESIS
- **oogonia** (46, XX, 2n, 2C)
  - rapid proliferation in fetal period
  - interaction with follicular cells, formation of primordial follicles (finished before birth)
- **primary oocyte** (46, XX, 2n, 4C)
  - ∅ 25-30 μm
  - arrested in prophase of meiosis I (M I)
  - nucleolus, rER, GA
  - *zona pellucida*⑯
  - primordial, primary and secondary follicles
- **secondary oocyte** (23, X, 1n, 2C)
  - M I finished 36-48 hrs before ovulation,
  - first polar body extruded, centrioles absent
  - meiosis II (M II) initiated and arrested at metaphase II until fertilization
  - Graafian follicles
- **ovum** (mature oocyte) (23, X, 1n, 1C)
  - ∅ 120 μm
  - M II finished after fertilization, extrusion of second polar body, cortical reaction

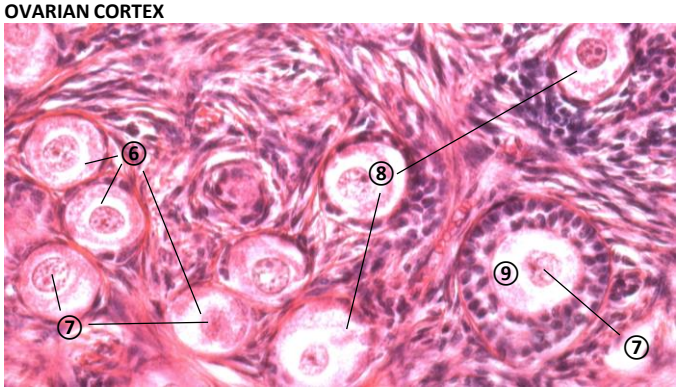
OVULATION
- LH dependent
- oocyte of dominant follicle finishes M I and enters M II
- *cumulus oophorus* and oocyte are released to liquor
- follicular wall, *t. albuginea* and surface e. breaks open
- myofibroblasts in *theca folliculi ext.* contract and release liquor with cumulus oophorus-oocyte complex
- non-fertilized oocyte degenerates in 24 hrs.

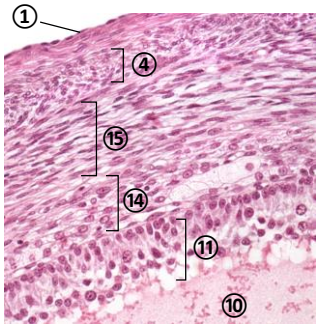
ATRESIA
- regression of immature follicles
- apoptosis of oocyte and granulosa cells, collapse of *antrum*, growth of c.t.

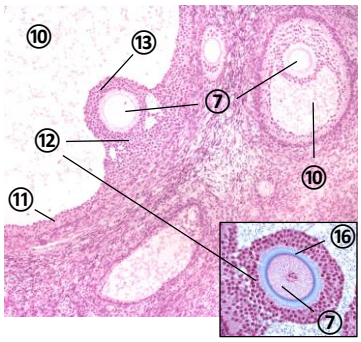
OVARY



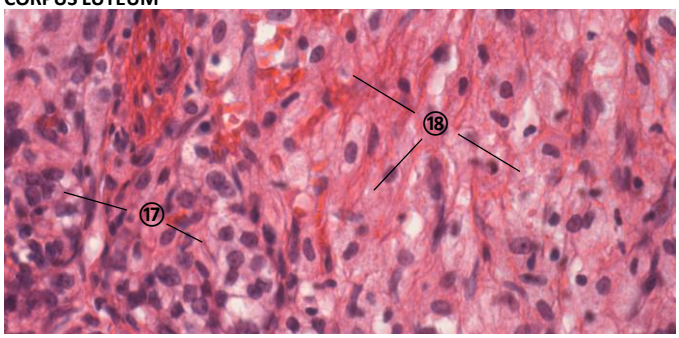
OVARIAN CORTEX







CORPUS LUTEUM



Time	Number of follicles
5th month i.u.	~7×10^6 oogonia
birth	~1×10^6 follicles
puberty	~400×10^3 follicles
menopausis	<1×10^3 follicles
ovulation	~400-450 follicles in life
atresia	>99,9%

CORPUS LUTEUM
- ***corpus luteum menstruationis***
  - temporary endocrine gland (12-14 days)
  - theca-lutein⑰ cells
  - granulosa-lutein⑱ cells
- ***corpus luteum graviditatis***
  - massive growth, 30 mm
  - active for 4-5 months, further its function is taken over by placenta
- ***corpus albicans***
  - luteolysis of *c. luteum* → c.t. scar

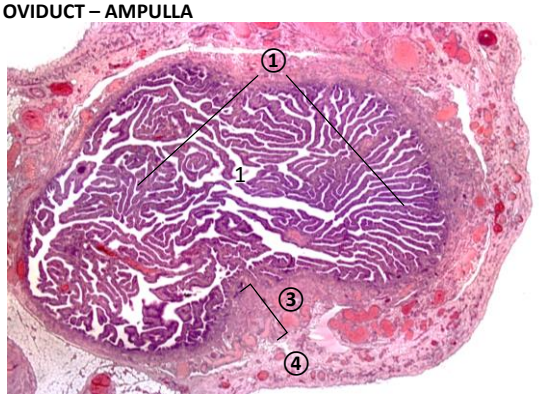
OVIDUCT (Fallopian tube, *tuba uterina, salpinx*)
- hollow muscular tube, ↔ 10-15 cm
- *fimbriae*, *infundibulum*, *ampulla*, *isthmus*, *pars uterina*
- ***tunica mucosa***
- mucosal folds dominant in *ampulla*①, less in *isthmus*②
- *l. epithelialis m.*
- simple columnar e.
- ciliated columnar cells
- secretory peg (intercalary) cells
- *l. propria m.* – loose collagen c.t.
- ***tunica muscularis***③
- two spiral layers of smooth muscle cells (peristaltics)
- ***tunica serosa***④
- loose collagen c.t. with rich vascularization
- mesothelium

UTERUS (*metra*, *hystera*)
- hollow muscular tube, ↔ 8 → 40 cm
- *fundus, corpus*, *isthmus*, *cervix uteri*

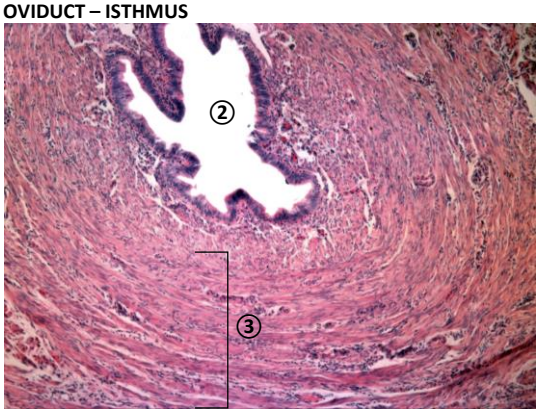
fundus et corpus uteri
- **endometrium** (*tunica mucosa*)
- *l. epithelialis m.* – simple columnar e.⑤
- *l. propria m.*⑥
- c.t. rich in collagen III fibers, abundant fibroblasts, tubular glands
- **basal layer** (*zona basalis*)⑦
- thickness ~0.5-1 mm
- hormone independent
- bases of tubular glands (*gll. uterinae*⑧)
- reepithelization of *z. functionalis* after menstrual phase
- **functional layer** (*zona functionalis*)⑨
- thickness ~1-4 mm (proliferative phase), ~5-7 mm (secretory phase)
- hormone dependent cyclic changes in *corpus* and *fundus*
- proliferative, secretory, ischemic, menstrual phase
- *pars compacta*⑩ and *p. spongiosa*⑪ develop in secretory phase
- in pregnancy: endometrium → *decidua*
- **myometrium** (*t. muscularis*)⑫
- thickness ~1.5 cm
- complex system of longitudinal, circular and oblique fibers
- in pregnancy: hyperplasia, hypertrofia (~50 → ~800 μm) of smooth muscle cells, distension of myometrium
- **perimetrium** (*t. serosa*)
- *t. serosa* covering *fundus*, *corpus* and *cervix*, *tela subserosa*

cervix uteri
- endocervix (*portio supravaginalis cervicis*)
- surrounded by **parametrium** (loose collagen c.t.), posteriorly by peritoneum
- endocervical canal (*canalis cervici uteri*)
- *plicae palmatae*
- simple columnar e.
- cervical tubular glands (→ occasional cysts, *ovula Nabothi)*
- ectocervix (*portio vaginalis cervicis*)
- squamo-columnar junction → stratified squamous e.

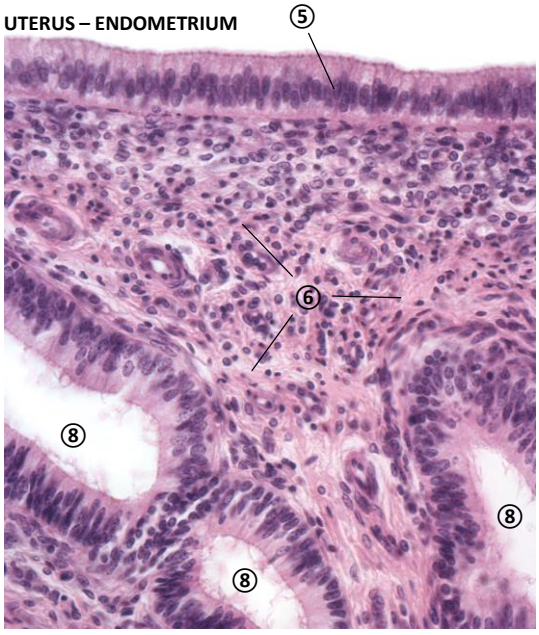
OVIDUCT – AMPULLA



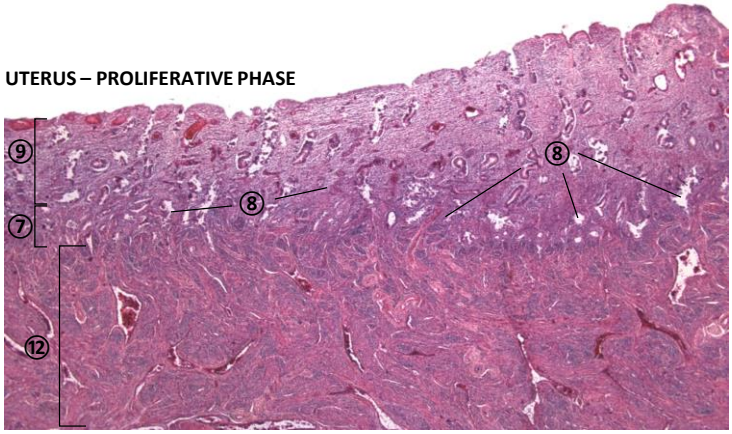
OVIDUCT – ISTHMUS



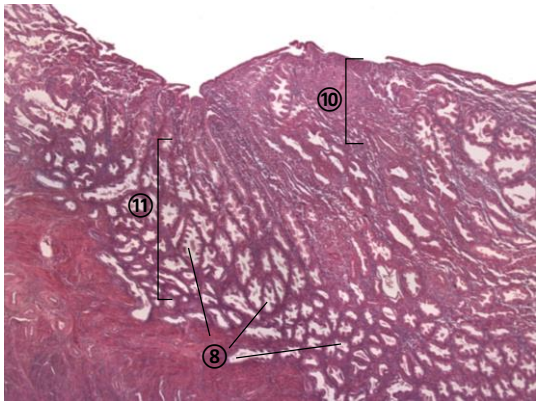
UTERUS – ENDOMETRIUM



UTERUS – PROLIFERATIVE PHASE



UTERUS – SECRETORY PHASE



VAGINA (*vagina*, *kolpos*)
- hollow, distensible fibromuscular tube, ↔ ~10 cm
- ***tunica mucosa***
- *l. epithelialis m.*
- non-keratinized stratified squamous e.①
- at *orificium ext. cervicis uteri* – stratified squamous e. of *p. vaginalis cervicis* → simple columnar e. of cervical canal (squamo-columnar junction)
- *stratum basale*, *parabasale*, *intermedium*, *superficiale* (proliferation → differentiation)
- hormone-dependent cyclic changes of e.
- glycogen② in differentiated cells
- dendritic (Langerhans) cells in *t. mucosa*
- cervical mucus, transudation of tissue fluid
- glands absent
- *l. propria m.*③
- loose collagen c.t.
- abundant venous plexus
- ***tunica muscularis***④
- thin, vascularized, rich intercalated c.t.
- ***tunica adventitia***

VESTIBULUM VAGINAE
- keratinized stratified squamous e.
- pair of *gll. vestibulares maiores* (*Bartholini*)
- tuboalveolar mucous glands
- homologous to male *gll. bulbourethrales* (*Cowperi*)
- ducts open bilaterally to *vestibulum* at inner posterior surface of *l. minora*
- *gll. vestibulares minores* (Skene's glands)⑤
- paraurethral glands open bilaterally to urethra or around urethral orifice
- homologous to male prostate

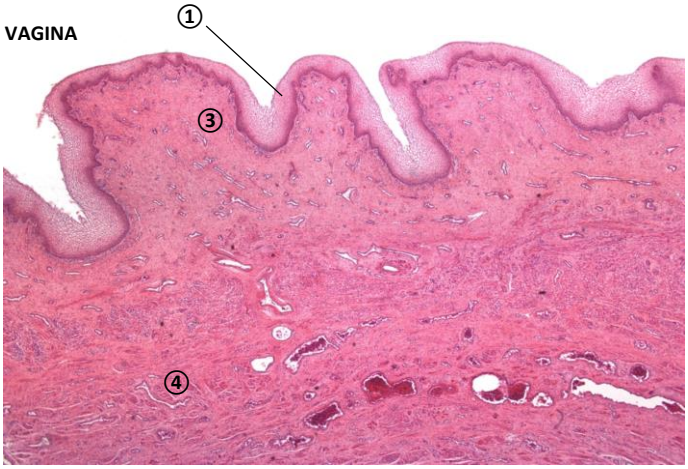
HYMEN
- thin fibrous membrane with collagen and elastic fibers
- stratified squamous e.
- free edge avascular, non-innervated

CLITORIS
- two erectile bodies similar to *corpora cavernosa penis*
- *glans clitoridis*
- stratified squamous e.
- sebaceous glands
- bulboid corpuscules (genital corpuscles, end-bulbs of Krause)

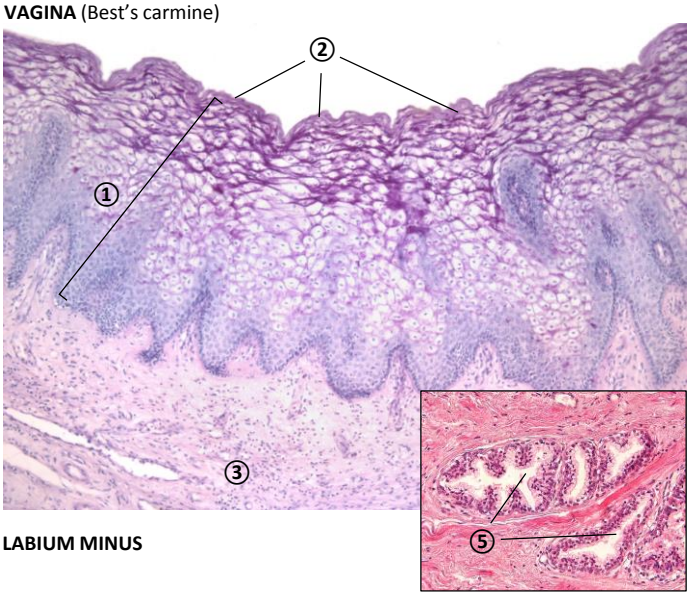
LABIA PUDENDI MINORA
- hairless surface lined by keratinized stratified squamous e. (epidermis)⑥
- loose collagen c.t rich in elastic fibers (dermis)⑦
- adipocytes rare or absent
- abundant nerve endings (Meissner's corpuscle type)
- sebaceous glands⑧

LABIA PUDENDI MAIORA
- skin folds homologous to scrotum
- loose collagen c.t (dermis) with adipocytes and smooth muscle cells (equivalent to *tunica dartos* of scrotum)
- outer surface – pigmented epidermis with hair follicles
- inner surface – smooth epidermis with sebaceous glands, similar to *labia minora*

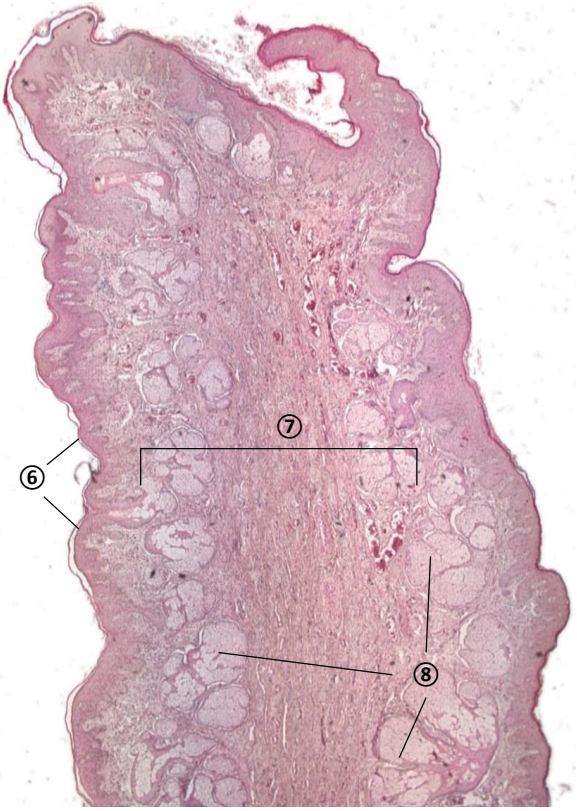
VAGINA



VAGINA (Best's carmine)



LABIUM MINUS



PLACENTA (*placenta*)
- temporary nutritive, metabolic and endocrine organ
- *discoidalis* (↔ 15-25 cm, thickness 2.5-4 cm, 500-600 g)
- *olliformis* (bowl-shaped)
- *hemochorialis* (perfused by maternal blood)

- ***pars fetalis placentae***
- chorionic plate① lined with amniotic ectoderm
- stem chorionic villi②
- derived from trophoblast and extraembryonic c.t.
- lined by syncytiotrophoblast or cytotrophoblast (Langhans cells) – simple cuboidal e.
- loose mesenchymal c.t., fibroblasts
- fetal capillaries
- smooth muscle cells
- macrophages (Hofbauer cells)
- terminal villi③
- structural units of *chorion frondosum* composed of stem villus and all associated free villi → **cotyledons** (~15-30)

- **intervillous space**④
- lacunae in eroded decidual tissue
- maternal blood from *aa. spirales* → endometrial veins
- syncytial knots of detached syncytiotrophopblast

- ***pars materna placentae***
- *decidua basalis*⑤ (*decidua* associated with *chorion frondosum*)
- large decidual cells rich in glycogen and lipids
- decidual septa and cotyledons → discrete units (placentomes)

- **placental (maternal-fetal) barrier**⑥
- endothelium and basal lamina of fetal capillaries⑦ in villus③
- loose mesenchymal c.t.⑧, cytotrophoblast⑨ (early pregnancy)
- syncytiotrophoblast⑩ and its basal lamina

- **endocrine function**
- progesterone and estrogens
- immune tolerance of fetus, support pregnancy
- human chorionic gonadotropin (hCG)
- maintains *corpus luteum*, immune tolerance of fetus
- human placental lactogen (chorionic somatomammotropin, hCS)
- metabolic effects similar to growth hormone
- many other immunoactive cytokines involved in establishment of pregnancy, maternal-fetal interactions and immunotolerance

UMBILICAL CORD (*funiculus umbilicalis*)
- cord (↔ 40-55 cm, ∅ 1 cm) between *p. fetalis placentae* and *umbilicus*

- ***aa. umbilicales***⑪ (2)
- from *a. illiacae internae* → *p. fetalis placentae*
- *membranae elasticae* (*interna* and *externa*) absent
- *tunica media* contains bundles of smooth muscle cells and intercalated c.t.
- *t. adventitia* absent

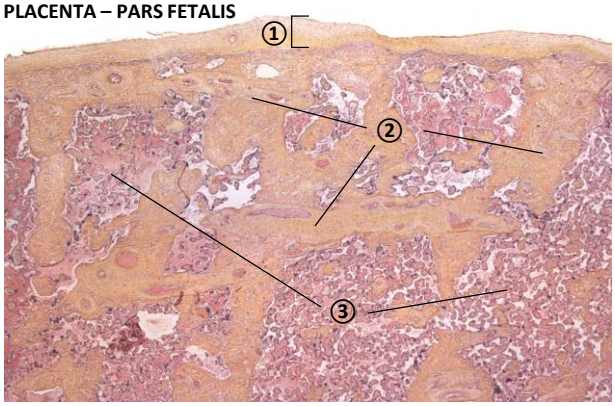
- ***v. umbilicalis***⑫ (1)
- from *p. fetalis placentae* → *v. portae* and *ductus venosus* (→ *v. cava inf.*)
- similar to muscular type artery
- thick and organized *t. media*
- *t. adventitia* and *vasa vasorum* absent

- **Wharton's jelly**⑬ (*substantia gelatinea funiculi umbilicalis*)
- stellate fibroblasts, occasionally macrophages, lymphocytes
- fine collagen network, large amount of amorphous ground substance (GAGs)

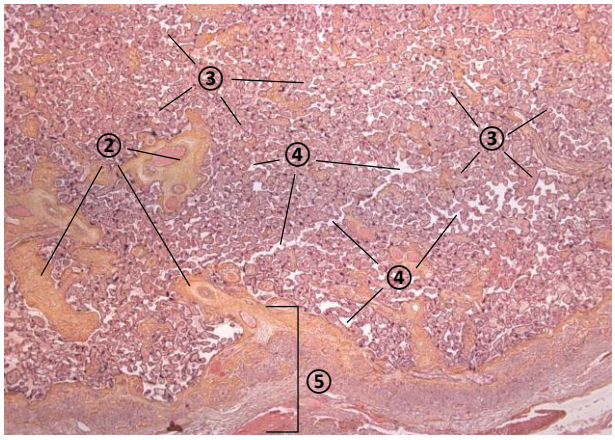
- ***ductus allantoideus***⑭ (*allantois*)
- rudimentary
- epithelial region or c.t. condensation between umbilical vessels

- **amniotic ectoderm**⑮

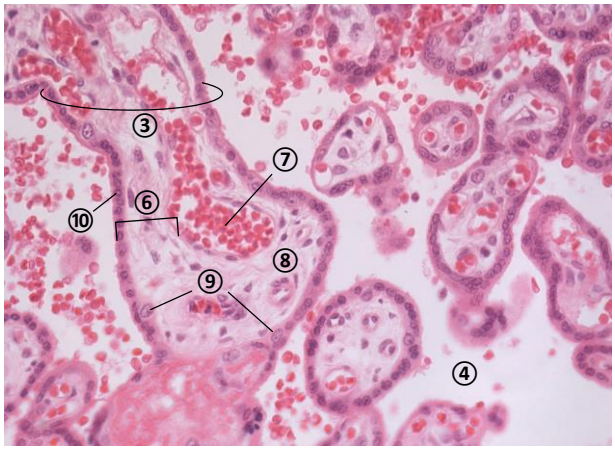
PLACENTA – PARS FETALIS



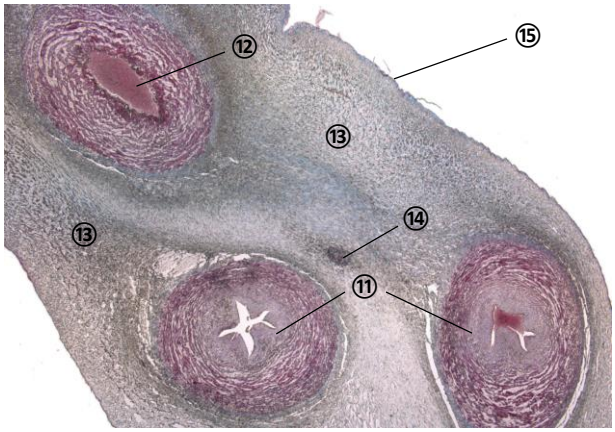
PLACENTA – PARS MATERNA



PLACENTAL BARRIER



UMBILICAL CORD



PITUITARY GLAND (*gl. pituitaria, hypophysis*)

- **neurohypophysis** (posterior pituitary)
  - neuroectodermal origin
  - *pars nervosa*①, *infundibulum*②
  - nonmyelinated axons and their synapses③
  - neuronal perikarya located in *ncl. supraopticus* and *ncl. paraventricularis* of hypothalamus
  - axonal transport of neurosecretory granules containing antidiuretic hormone (ADH, vasopressin) or oxytocin → neurohypophysis via *tractus hypothalamo-hypophysialis*
  - Herring's (neurosecretory) bodies – axonal dilatations, storage and release of hormones to capillary plexus
  - pituicytes④ (glial cells)
  - fenestrated capillaries

- **adenohypophysis** (anterior pituitary)
  - *pars distalis*⑤, *p. tuberalis*, *p. intermedia*⑥
  - epithelial cells in cords or clusters derived from roof of stomodeum (Rathke's pouch)
  - follicles in *p. intermedia* (embryonic rudiments)⑦
  - fenestrated capillaries
- **chromophilic cells**
- acidophilic cells⑧
  - somatotrophs – somatotropin (growth hormone, GH)
  - mammotrophs (lactotrophs) – prolactin (PRL)
- basophilic cells⑨
  - thyrotrophs – thyrotropin (thyroid stimulating hormone, TSH)
  - gonadotrophs – follicle stimulating hormone (FSH) and luteinizing hormone (LH)
  - corticotrophs – pro-opiomelanocortin prohormone cleaved to several biologically active peptides: e.g. adrenocorticotropic hormone (ACTH), β-lipotropin (β-LPA)
- **chromophobic cells**⑩
  - inactive (hormone depleted) or undifferentiated (progenitor) cells

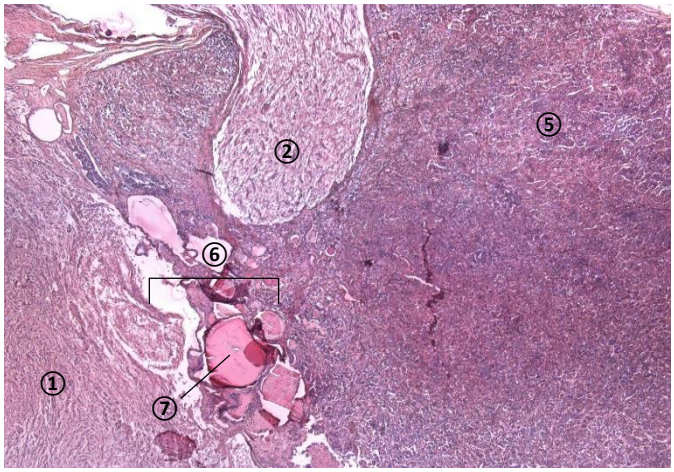
- **hypothalamic-pituitary axis**
  - neuroendocrine control of anterior pituitary secretions by hypothalamic releasing and inhibiting hormones (liberins and statins) from various hypothalamic nuclei

- **pituitary portal circulation**
  - fenestrated capillaries – hematoencephalic barrier not developed (neurohemal region)
- **adenohypophysis**: *a. carotis int.* → *aa. hypophysiales sup.* → primary capillary plexus in *eminentia mediana* receives neurosecretions from hypothalamus → *vv. portales hypophysiales* distribute neurosecretions → secondary capillary plexus in anterior lobe → *vv. hypophysiales* → cavernous sinuses → *vv. jugulares int.*
- **neurohypophysis**: *a. carotis int.* → *aa. hypophysiales inf.* → fenestrated capillaries → *vv. hypophysiales* → cavernous sinuses → *vv. jugulares int.*

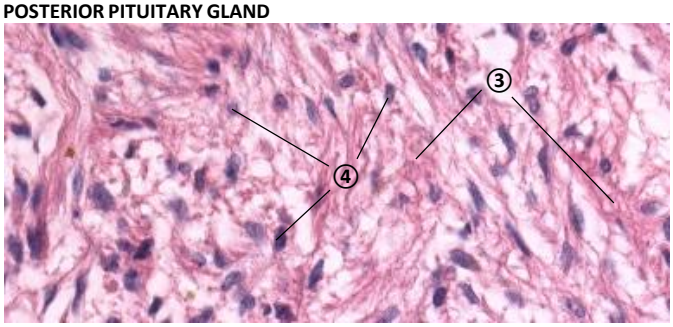
PINEAL GLAND (*gl. pinealis*, *corpus pineale*, *epiphysis cerebri*)

- *pia mater* capsule⑪, septa, lobular parenchyma⑫
- **pinealocytes**
  - neuroectodermal origin
  - large cytoplasmic processes associated with capillaries
  - secretory vesicles, abundant mitochondria
  - clustered within network of interstitial astrocytes
- complex neurosecretory function
  - diurnal rhythmic secretion of melatonin
- **interstitial cells**
  - modified astrocytes (~5% of cells)
- ***acervulus cerebri***⑬ (*corpora arenacea*)
  - calcified concrements of organic substances
  - number and size of concrements increase with age

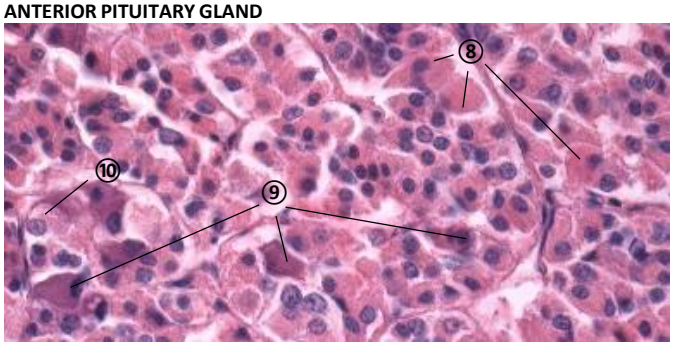
PITUITARY GLAND



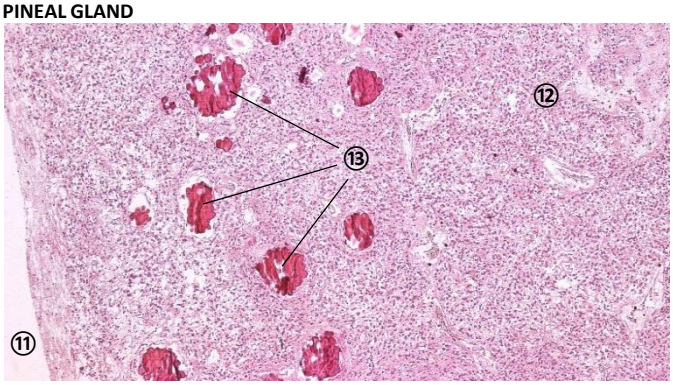
POSTERIOR PITUITARY GLAND



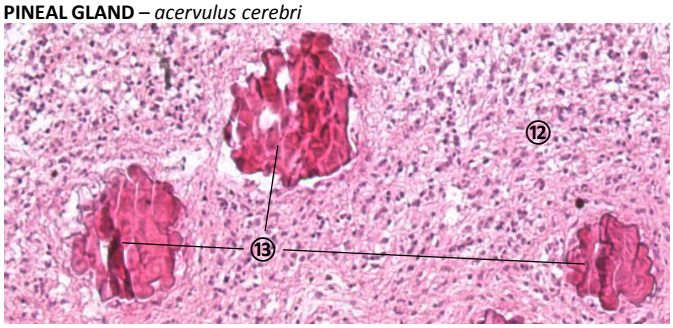
ANTERIOR PITUITARY GLAND



PINEAL GLAND



PINEAL GLAND – *acervulus cerebri*



THYROID GLAND (*gl. thyroidea*)

- two lobes connected by *isthmus*, anteriorly to trachea
- occasional *lobus pyramidalis* (embryonic rudiment of *d. thyreoglossus*)
- anastomozing *a. thyroidea sup*. and *a. thyroidea inf*. → rich venous plexus → *vv. thyroideae* → *v. jugularis int*. (*vv. thyroideae sup*. and *med*.) and *v. brachiocephalica sininistra* (*vv. thyroideae inf*.)

- **c.t. capsule** with septa → lobules

- **follicles**①
- round structures (~50-900 μm)
- lined with simple squamous to low columnar follicular e. cells② with basal lamina
- colloid③ storing secretory products
- surrounded by interstitial connective tissue④ (stroma) with rich plexus of fenestrated capillaries

- **follicular cells** (thyrocytes)
- height of e. dependent on synthetic activity
- well developed rER, GA, secretory pathway
- thyroglobulin, secreted into lumen (colloid)
- selective iodide uptake by Na^+/I^+ symport (NIS) and transport to colloid by Cl^-/I^- antiport (pendrin)
- in lumen oxidation of $2\ I^- \rightarrow I_2$ and iodination of thyroglobulin by thyroperoxidase (TPO) on microvilli of apical membrane
- endocytosis and proteolytic cleavage of iodinated thyroglobulin and secretion of T_3 and T_4 hormones to blood circulation
- synthesis and secretion of T_3 and T_4 hormones regulated by TSH of adenohypophysis
- embryonic origin from endoderm of pharynx (*ductus thyreoglossus*) between *tuberculum impar* and *copula*

- **parafollicular cells** (C-cells)
- pale-stained cells within follicular e. above basal lamina, but without direct contact with lumen, or in isolated clusters between follicles
- well developed GA, abundant secretory granules
- embryonic origin from neural crest
- calcitonin → bone matrix (↓ resorption)
- decrease of calcemia

PARATHYROID GLANDS (*gll. parathyroideae sup.* and *inf.*)

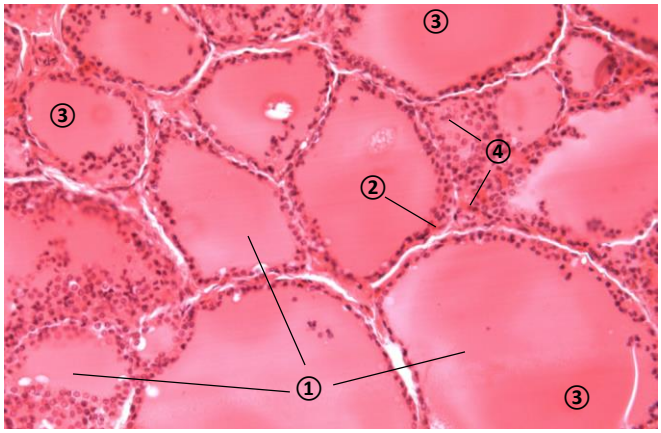
- four glands (40 mg each) located on back of thyroid
- c.t. capsule⑤ with thin septa, surrounded by adipose c.t.⑥
- microvascularization from *aa. thyroideae inf*.

- **chief** (principal) **cells**⑦
- small, numerous cells with weakly acidophilic cytoplasm
- dark, large nucleus
- abundant glycogen and secretory granules
- parathyroid hormone (PTH) → bone matrix (↑ resorption), renal distal convoluted tubules and intestinal e.
- increase of calcemia

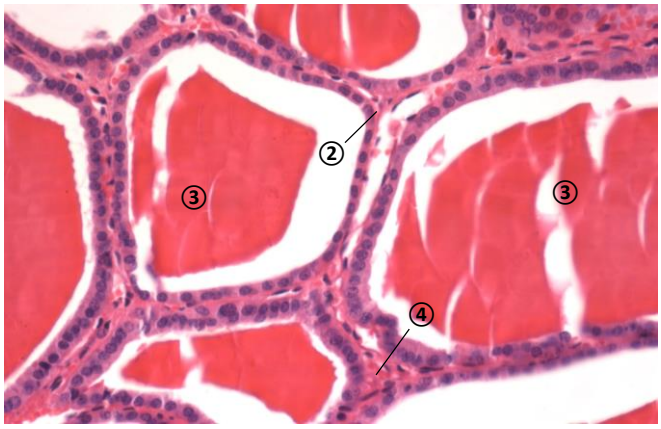
- **oxyphilic cells**⑧
- larger (~8-10 μm), polygonal cells, often in clusters
- pale to acidophilic cytoplasm, round nucleus
- number increases with age

- **adipocytes**⑨
- secretion of leptins

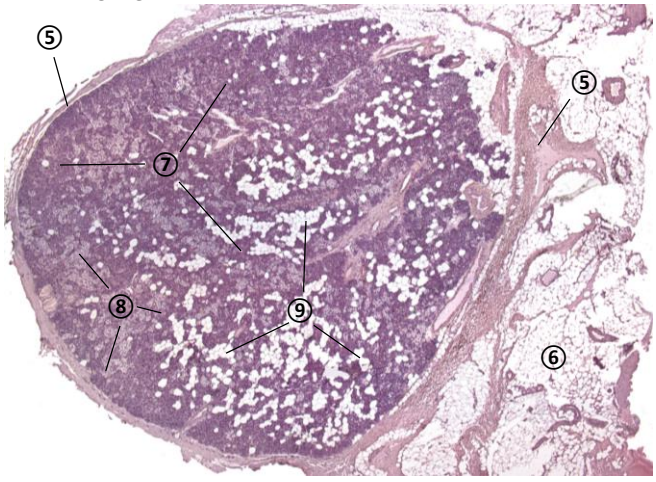
THYROID GLAND



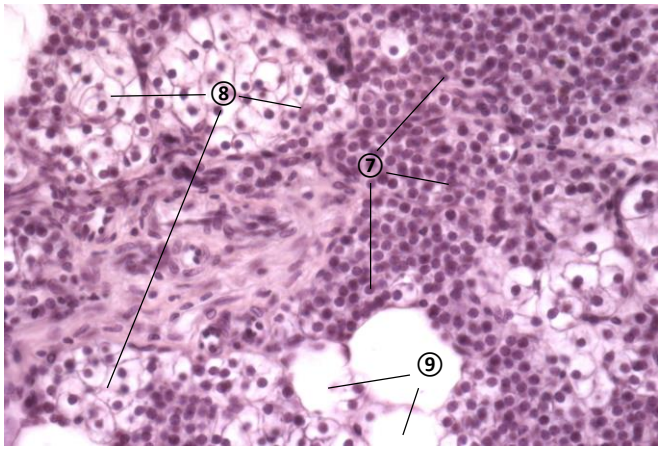
THYROID FOLLICLES



PARATHYROID GLAND



PARATHYROID GLAND



ADRENAL GLANDS (*gll. suprarenales*)
- c.t. capsule① and perirenal adipose tissue
- vascularization by branches of *a. phrenicae inf.* (→ *a. suprarenalis sup.*), aorta (→ *a. suprarenalis med.*) and *a. renales* (→ *a. suprarenalis inf.*)
- *aa. suprarenales* → anastomosing subcapsular arterial plexus → branches: 1) arterioles supplying capsule, 2) plexus of straight fenestrated capillaries in cortex, 3) arterioles supplying medulla → medullary venous sinusoids → medullary veins → *v. suprarenalis*

- **cortex**②
- dominant part of the suprarenal gland (80-90%)
- embryonic origin from coelomic e.
- organized into three distinct layers
- convoluted and straight cords of epithelial cells associated with fenestrated capillaries

- steroid-producing cells
- well developed sER③
- mitochondria with tubules④
- abundant lipid droplets⑤ with cholesteryl ester core (→ cholesterol source) in cytoplasm
- steroids released by diffusion from cytoplasm

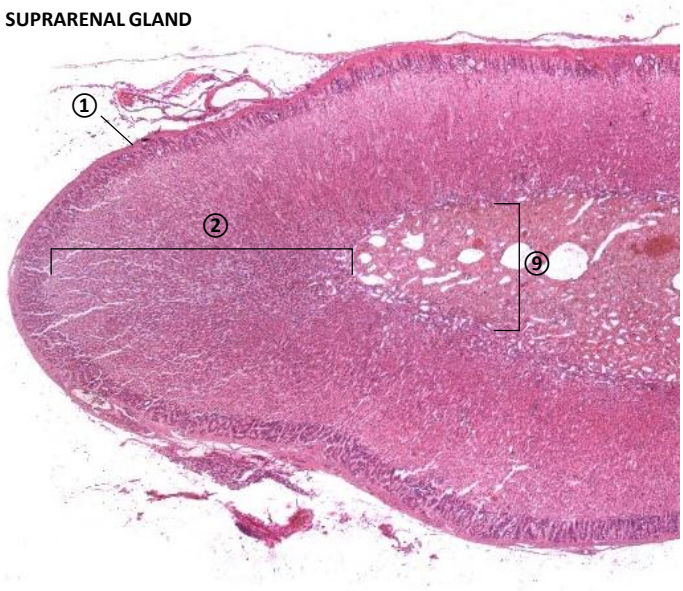
- *zona glomerulosa*⑥
- thin layer under c.t. capsule
- small cells in glomerular or cluster arrangements
- ACTH-independent regulation by renin-angiotensin system (angiotensin II)
- mineralocorticoids (e.g. aldosteron)

- *zona fasciculata*⑦
- dominant zone in cortex
- polyhedral cells in straight, radially-arranged cords
- lipid droplets in cytoplasm → foamy appearance of cells
- responsive to ACTH from adenohypophysis
- glucocorticoids (e.g. cortisol)

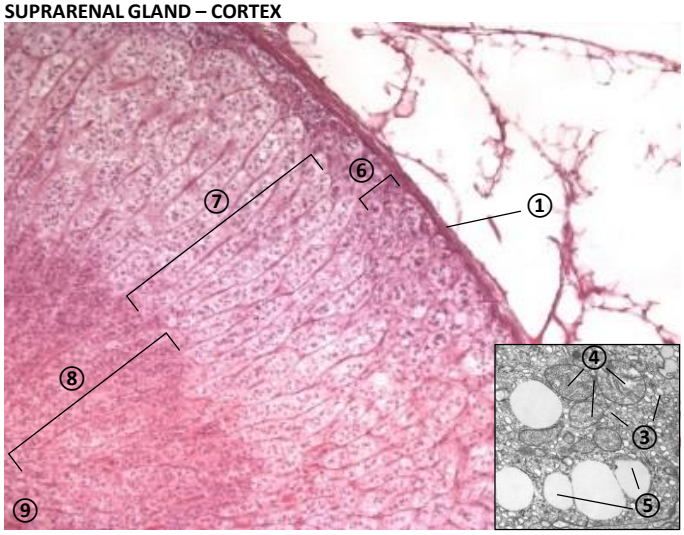
- *zona reticularis*⑧
- small, acidophilic cells in irregular, branched cords
- lipofuscin
- responsive to ACTH from adenohypophysis
- androgen precursors (e.g. dehydroepiandrosterone)

- **medulla**⑨
- chromaffine cells⑩
- sympathetic neuronal origin (neural crest)
- large epithelial-like cells in clusters or cords
- abundant secretory granules (150-300 nm)
- innervation by sympathetic preganglionic fibers
- synthesis of catecholamines (epinephrine, norepinephrine)
- network of reticular fibers
- dual blood supply
- from cortical plexus → medullary venous sinusoids
- from medullary arterioles → fenestrated capillaries (sinusoids)⑧ → medullary venous sinusoids

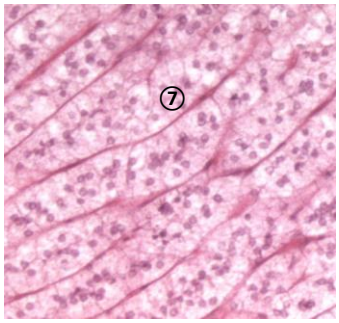
SUPRARENAL GLAND



SUPRARENAL GLAND – CORTEX

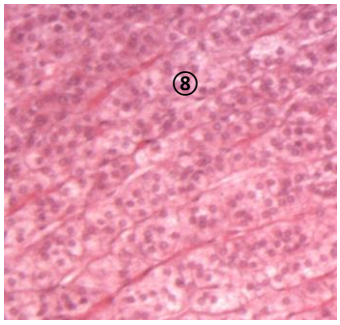


CORTEX – ZONA FASCICULATA

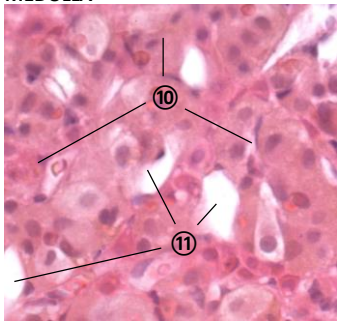


CORTEX – ZONA GLOMERULOSA

CORTEX – ZONA RETICULARIS



MEDULLA



TELENCEPHALON

- **gray matter** (*substantia grisea*)
  - *cortex cerebri* (surface)
  - cerebral nuclei (*ncl. caudatus*, *ncl. lentiformis*, *claustrum*, *ncl. amygdalae*)
- **white matter** (*substantia alba*)
  - mostly glial cells and myelinated axons

CEREBRAL CORTEX (*cortex cerebri*)

- neuronal perikarya and glial cells
- neuropil composed of unmyelinated axons, dendrites, synapses and processes of glial cells
- **allocortex** (1/12 of total cortex)
  - rhinencephalon
- **isocortex** (11/12 of total cortex)
  - thickness 1.5-5 mm, 0.2-0.25 m^2, 8-9×10^9 neurons
- **main types of neurons of isocortex**
  - pyramidal①
  - small stellate (or granular cells, ∅ 8-10 μm)
  - fusiform
  - interneurons (e.g. horizontal cells of Cajal, vertical cells of Martinotti)
- **nerve fibers**
- tangential
  - parallel to surface of hemispheres
  - five plexuses (plexus of Exner, band of Bechterew, external and internal band of Baillarger, deep tangential plexus)
- radial
  - intersecting tangential fibers
- **neuroglia**
  - astrocytes②, microglia, rare oligodendrocytes

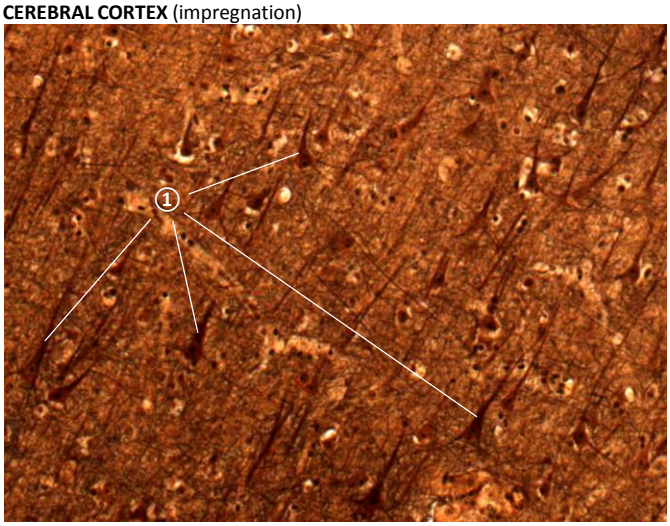
STRATIFICATION OF ISOCORTEX

- six layers (*laminae*) defined upon cytoarchitecture
- surface covered by *membrana limitans gliae superficialis* and *pia mater*③
- **I**. *lamina molecularis*
  - mostly glial cells and tangential fibers (plexus of Exner)
  - horizontal cells of Cajal
- **II**. *l. granularis ext.*
  - small stellate (granular) cells
  - tangential fibers (band of Bechterew)
- **III**. *l. pyramidalis*
  - various pyramidal cells, radial fibers
- **IV**. *l. granularis int.*
  - tangential myelinated fibers – external band of Baillarger
- **V**. *l. ganglionaris*
  - large pyramidal neurons (Betz cells)
  - internal band of Baillarger (collaterals of neurites of pyramidal cells)
- **VI**. *l. multiformis*
  - fusiform cells, small stellate (granular) cells, vertical cells of Martinotti
  - radial fibers, deep tangential plexus
  - continuous with white matter

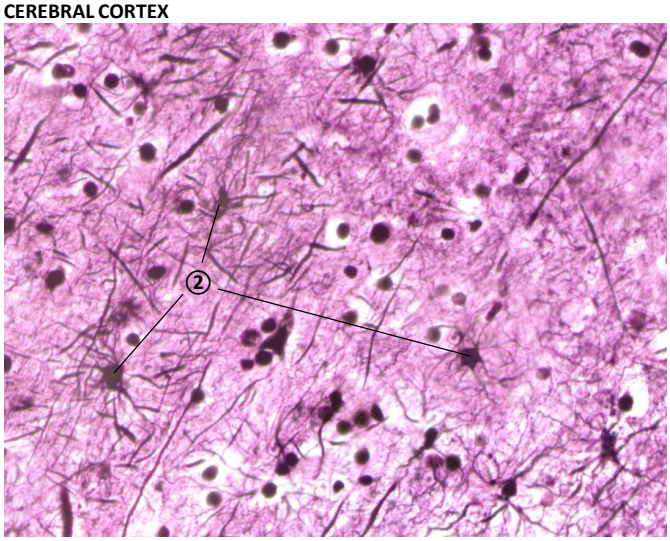
EXAMPLES OF CYTOARCHITECTONIC AND FUNCTIONAL DIFFERENCES OF ISOCORTEX

- **precentral (motor) area**
  - pyramidal cells prevailing
  - giant pyramidal Betz cells in *l. ganglionaris*
  - both granular layers very thin
  - lines of Baillarger absent
- **post-central (primary sensory) area**
  - both granular layers very thick
  - external band of Baillarger well marked
- **occipital (visual) area**
  - both granular layers very thick
  - both bands of Baillarger well marked

CEREBRAL CORTEX (impregnation)



CEREBRAL CORTEX



STRATIFICATION OF CEREBRAL ISOCORTEX

CEREBELLUM

- **gray matter**① (*substantia grisea*)
- *cortex cerebelli* (surface)
- cerebellar nuclei – areas in white matter (paired *ncl. dentatus*, *ncl. emboliformis*, *ncl. globosus*, *ncl. fastigii*)
- **white matter**② (*substantia alba*)
- mostly glial cells and myelinated fibers
- **efferent fibers**
- axons of Purkinje cells ending at dendrites and perikarya of cerebellar nuclei
- **afferent fibers**
- climbing fibers: synapses with perikarya and dendrites of Purkinje cells or basket cells
- mossy fibers: from vestibular nuclei, *medulla spinalis*, *pons varoli*, etc.; synapses with dendrites of granule cells in *s. granulosum* (*glomeruli cerebellares*)

CEREBELLAR CORTEX (*cortex cerebelli*)

- **stratification of cerebellar cortex**

I. *stratum moleculare*③ (*str. cinereum*)

- multipolar neurons (basket cells, stellate cells)
- dendritic arborizations of Purkinje cells
- collaterals of basket cells
- parallel fibers from granule cells in *str. granulosum*

II. *str. gangliosum*④ (*purkinjense*, *neuronorum pyriformium*)

- **Purkinje cells**⑤
- large, pear-shaped cells
- 1-2 large dendrites branching in a single plane in *str. moleculare,* axons terminate in cerebellar nuclei

III. *str. granulosum*⑥

- small (∅ 4-5 μm), intensively-stained neurons (granule cells, Golgi cells)
- axons bifurcate in *str. moleculare* (T-junction)
- **Bergman astroglia** (Golgi epithelial cell)
- modified protoplasmic astrocytes of *str. granulosum*
- processes run towards *str. moleculare*, to pia mater

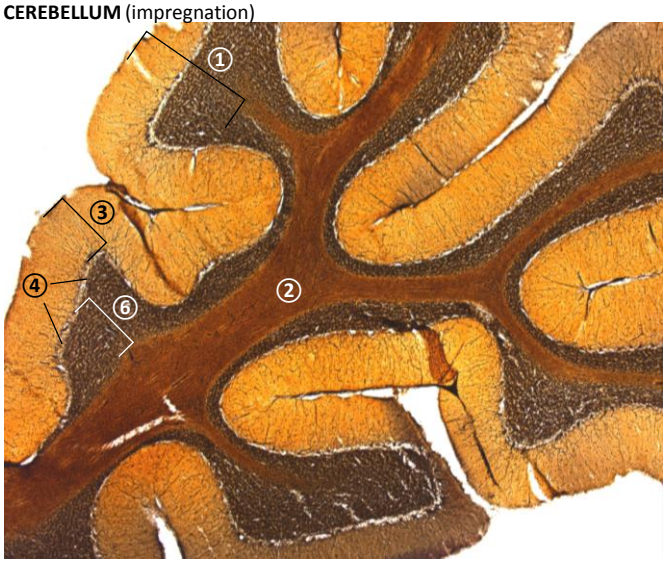
CHOROID PLEXUS (*plexus choroideus*)

- tufts of highly vascularised *pia mater* surrounded by ependymal cells
- project into brain ventricles
- cuboidal epithelial cells (ependyma)⑦
- gap junctions, interdigitations, microvilli
- inclusions (glycogen, lipid, pigments)
- absorption and production of cerebrospinal fluid
- hemato-liquor barrier
- loose c.t.⑧ – continuous with *pia mater*, vascularization⑨

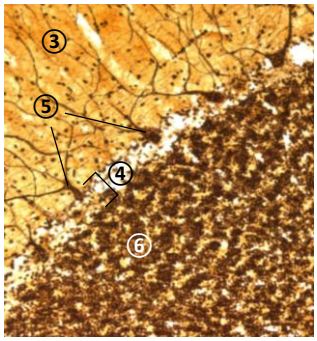
MENINGES CEREBRI

- **pachymeninx** (*dura mater*)
- dense irregular collagen c.t. with elastic fibers
- outer layer continuous with periost; in spinal cord epidural space between vertebral bodies and dura mater
- inner layer – epithelium-like arranged fibrocytes
- **leptomeninx** (*arachnoidea* and *pia mater*)
- *arachnoid*
- thin loose collagen c.t. membrane and layer of epithelioid squamous cells with *z. occludentes* and desmosomes (neurothelium) on *dura mater*-facing surface
- meningeal granules (arachnoid villi, *granulationes arachnoideales*) – folds of arachnoidea into subdural space (drainage of cerebrospinal fluid)
- avascular, no innervation
- *pia mater*
- thin loose collagen c.t. membrane with elastic fibers
- fibroblasts, histiocytes, mast cells, melanophores (myelencephalon)
- rich vascularization and innervation
- *membrana limitans piae*, *m. limitans gliae superficialis*

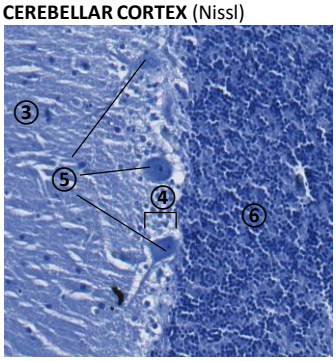
CEREBELLUM (impregnation)



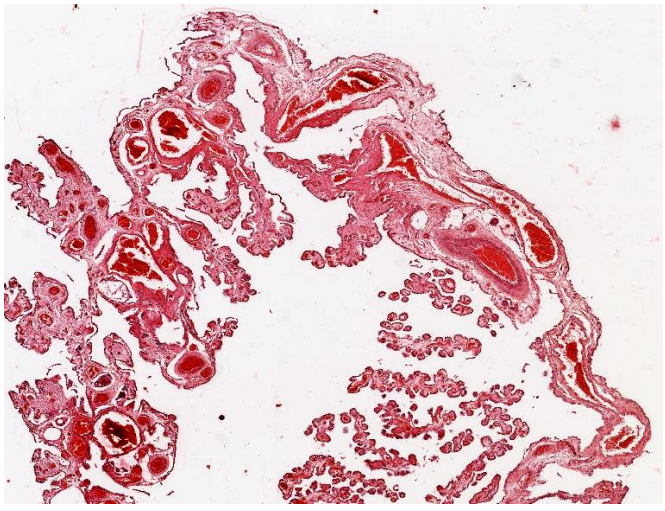
CEREBELLAR CORTEX



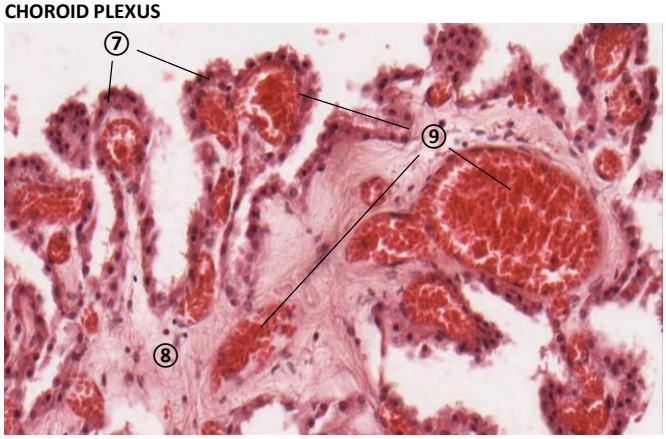
CEREBELLAR CORTEX (Nissl)



CHOROID PLEXUS



CHOROID PLEXUS



SPINAL CORD (*medulla spinalis*)

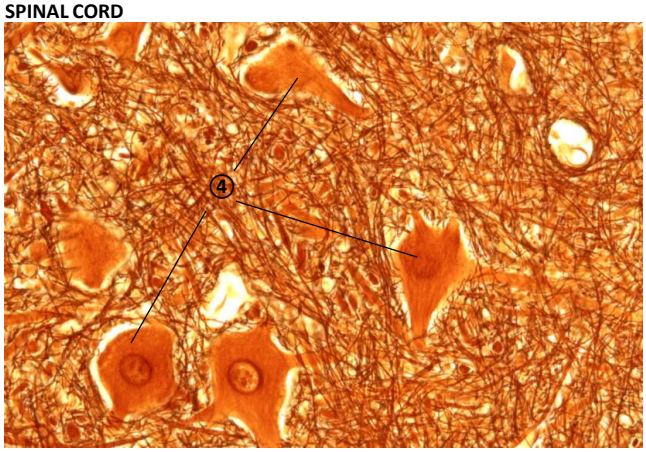
- ***pia mater***①
- **white matter**② (*substantia alba*)
- myelinated nerve fibers
  - endogenous
  - exogenous
  - longitudinal
  - transversal
- glial cells
  - oligodendrocytes
  - fibrous astrocytes (*membrana limitans gliae superficialis*)
- **gray matter**③ (*substantia grisea*)
  - multipolar neurons
  - protoplasmic astrocytes and microglia
- somatomotor neurons④
  - anterior horns (*nuclei motorii*)
  - star-shaped, large (>130 µm) perikarya
  - axons terminate via ventral spinal roots and spinal nerves at neuromuscular junctions
- visceromotor neurons
  - intermediate zone (*ncl. intermediolateralis*)
  - star- or spindle-shaped, small → medium-sized cells
  - preganglionic sympathetic neurons
  - axons terminate at autonomic ganglia
- sensory neurons
  - posterior horns
  - small → medium-sized neurons with processes of variable length
- interneurons
  - solitary throughout grey matter
  - various functions (e.g. associative, commisural)
- central commisure of gray matter with central canal
- **central canal**
  - lined by epithelium-like cells⑤ with microvilli and cilia (ependymocytes)

PERIPHERAL GANGLIA

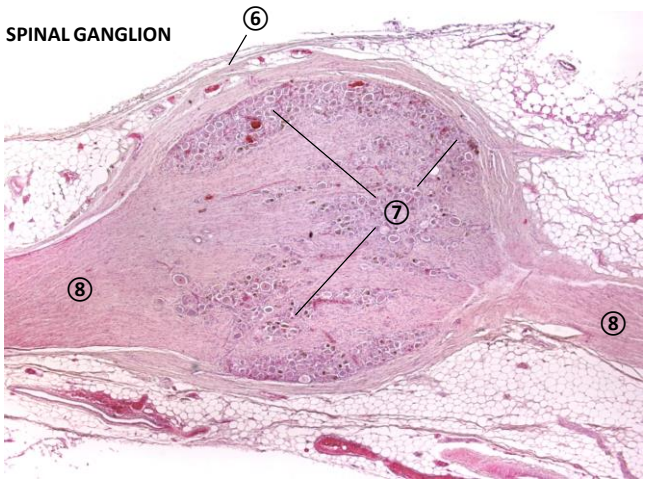
- lamellar c.t. capsule⑥, septa, rich vascularization
- large ganglionic cells⑦ and nerve fibers⑧
- lipofuscin⑨
- satellite cells⑩ (amphicytes) with basal lamina
- **spinal (sensory) ganglia**
- pseudounipolar neurons (15-110 µm)
  - large nucleus⑪ with apparent nucleolus
  - apparent Nissl's substance
  - stem process divides into dendritic branch (→ periphery) and axonal branch (→ central nervous system), T-junction
- preganglionic and postganglionic fibers
- **autonomic ganglia**
  - multipolar neurons with variable size and morphology
  - intramural ganglia (e.g. GIT wall) lack c.t. capsule
- **cochlear and vestibular ganglia** (*ggl. spirale cochleae* and *ggl. vestibuli*)
  - bipolar neurons

SPINAL CORD

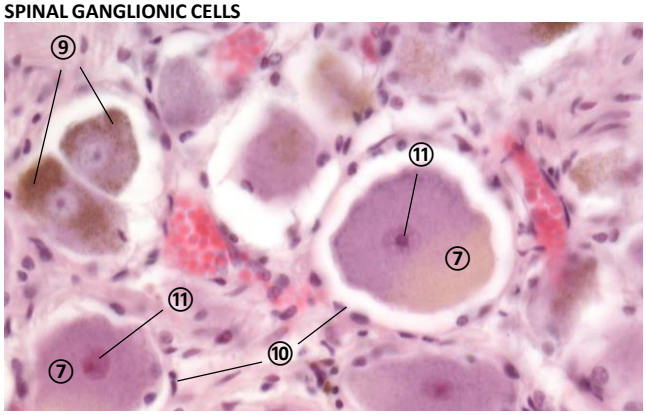
SPINAL CORD



SPINAL GANGLION



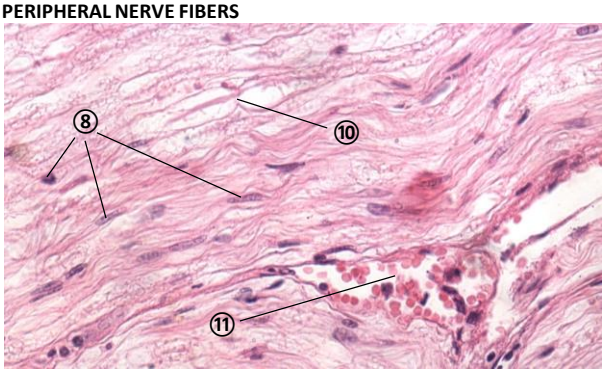
SPINAL GANGLIONIC CELLS



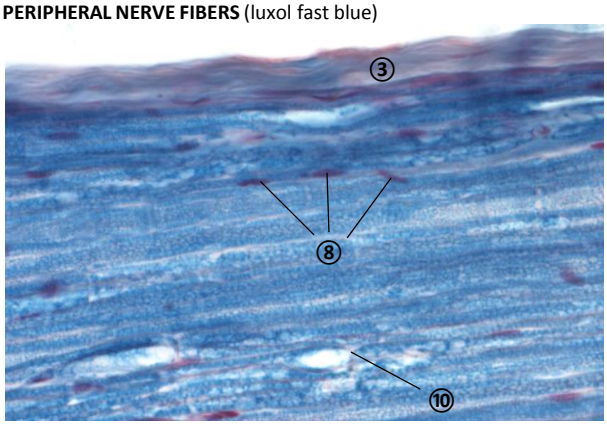
PERIPHERAL NERVES

- **epineurium**①
  - thick layer of dense irregular collagen c.t. externally covering whole nerve and nerve bundles②
  - longitudinal collagen and elastic fibers
  - fibroblasts and lymphocytes dispersed in c.t.
  - vascularization (*vasa nervorum*)
  - innervation (*nervi nervorum*)
- **perineurium**③
  - c.t. membrane with collagen and elastic fibers surrounding secondary nerve bundles within nerves
  - septa continuous with endoneurial c.t.
  - ~2-8 layers of epitheloid myofibroblast cells (perineural e.) with *z. occludentes* and gap junctions, basal lamina
  - hematoneural diffusion barrier
- **endoneurium**④
  - surrounding individual myelinated nerve fibers and primary nerve bundles
  - fine ECM with longitudinal collagen⑤ and reticular fibers produced by endoneurial fibroblasts
- **nerve fibers**
  - wavy course of peripheral nerve fibers (compared to CNS)
  - axons⑥ and dendrites arranged to primary and secondary bundles
  - myelin⑦ and/or Schwann sheath
  - Schwann cells⑧ with mesaxon⑨
  - nodes of Ranvier⑩
  - microvascularization in perineurial and endoneurial c.t.⑪
- **Obersteiner-Redlich zone**
  - transition zone between CNS (brainstem or spinal cord) and cranial or spinal nerves
  - changes in axonal ultrastructure
  - arachnoidea → perineural sheath
  - oligodendrocyte-type myelin (of central nervous type) → Schwann cell-type or peripheral myelin (in node of Ranvier)
  - termination of *membrana limitans gliae superficialis*

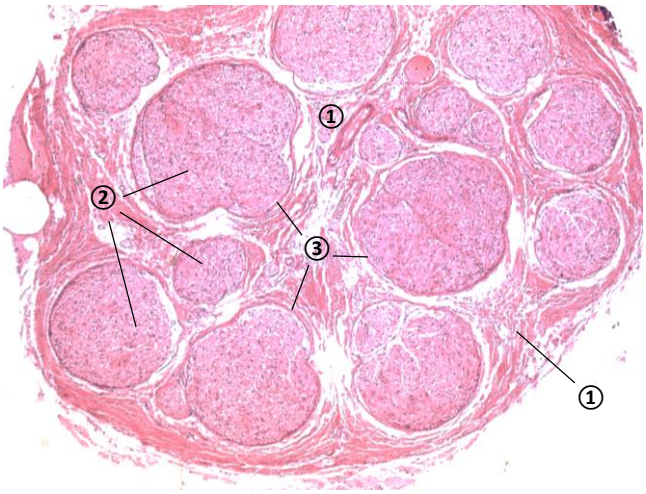
PERIPHERAL NERVE FIBERS



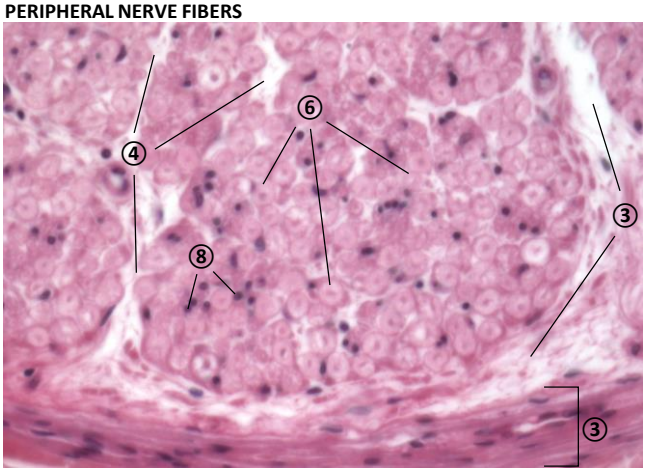
PERIPHERAL NERVE FIBERS (luxol fast blue)



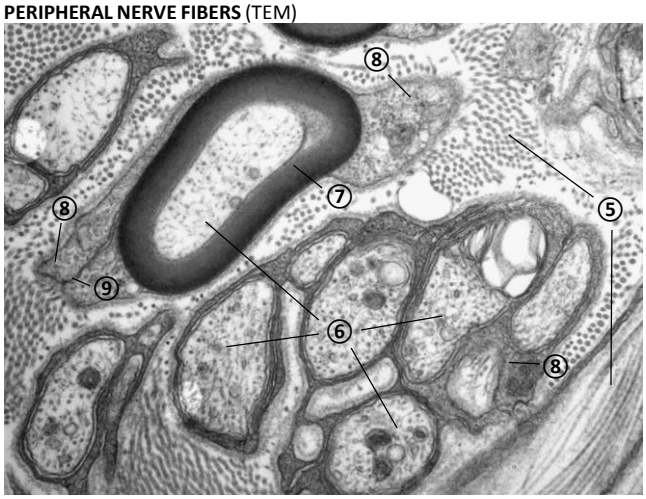
PERIPHERAL NERVE



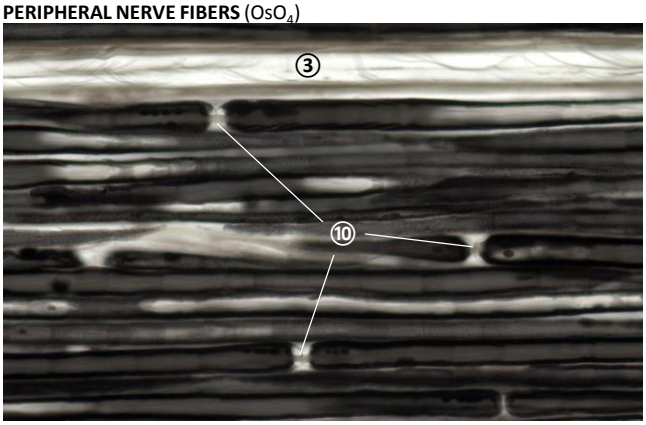
PERIPHERAL NERVE FIBERS



PERIPHERAL NERVE FIBERS (TEM)



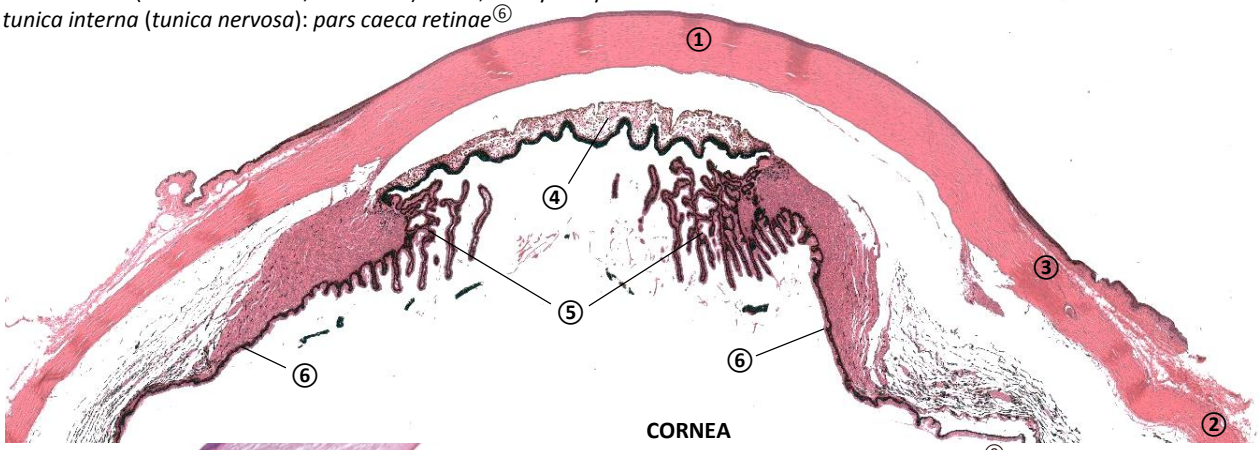
PERIPHERAL NERVE FIBERS (OsO_4)



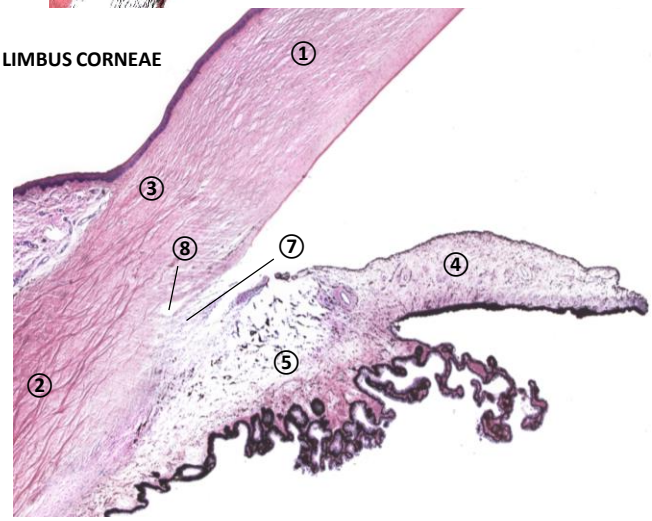
EYE (*bulbus oculi*)

- **eyebulb anterior segment**
- *tunica externa* (*tunica fibrosa*): *cornea*①, *sclera*②, *limbus corneae*③
- *tunica media* (*tunica choroidea, vasculosa*): iris④, ciliary body⑤
- *tunica interna* (*tunica nervosa*): *pars caeca retinae*⑥

ANTERIOR EYE SEGMENT



LIMBUS CORNEAE



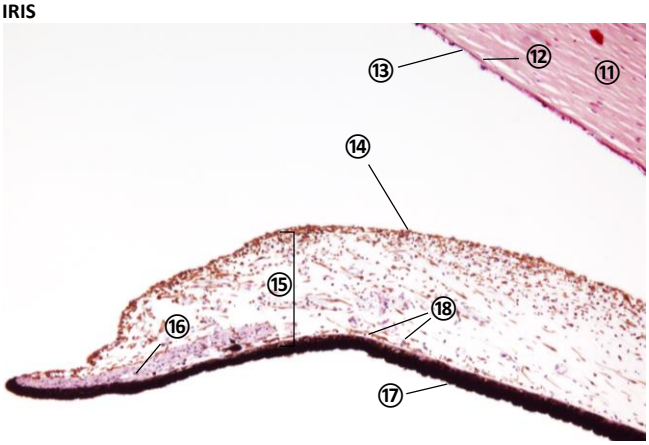
LIMBUS CORNEAE

- corneoscleral junction
- endothelium-lined **trabecular meshwork**⑦ (drainage of aqueous humor) → lymph vessel-like **scleral venous sinus**⑧ (canal of Schlemm) → *vv. anteriores ciliares*

IRIS

- discontinuous anterior layer⑭ of melanocytes and fibroblasts
- *stroma iridis*⑮
- gelatinous c.t., pigment cells with melanosomes, smooth muscle cells – *annular m. sphincter pupillae*⑯, vascularization
- posterior e.⑰
- myoepithelial *m. dilatator pupillae*⑱
- double layer of pigmented cells (*pars iridica retinae*)

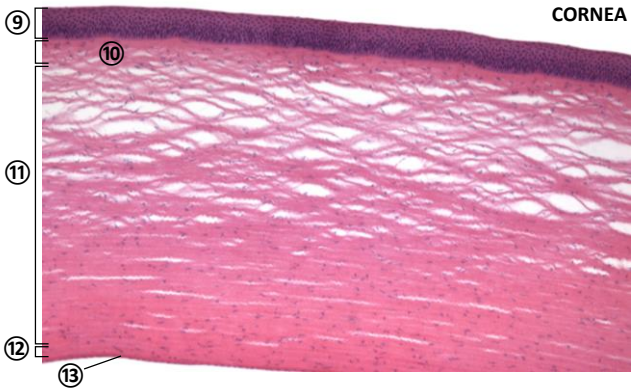
IRIS



CORNEA

- anterior stratified squamous e.⑨
- Bowman´s membrane⑩ – anterior limiting membrane
- transparent collagen stroma (*substantia propria cornae*)⑪
- Descemet´s membrane⑫ – posterior limiting membrane
- posterior simple squamous endothelium⑬
- rich innervation by sensory nerve fibers or ciliary nerves

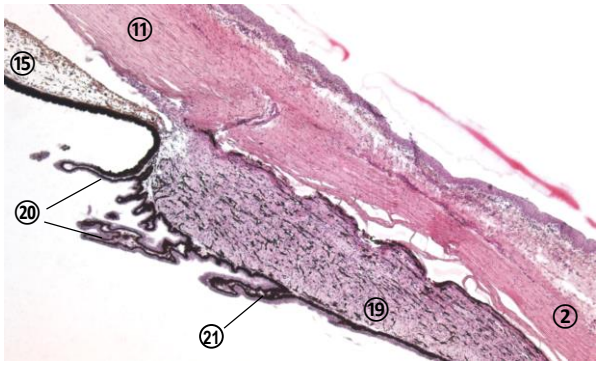
CORNEA



CILIARY BODY⑲ (*corpus ciliare*)

- ciliary muscle (*m. ciliaris*) – meridional, circular and radial smooth muscle fibers (lens accommodation)
- *processus ciliares* (*corona ciliaris*, *orbiculus ciliaris*)⑳
- ciliary e. (*pars ciliaris retinae*)㉑
- bilayered, basal layer – pigmented, melanin-rich cells
  superficial layer – non-pigmented cells
- production of aqueous humor

CILIARY BODY



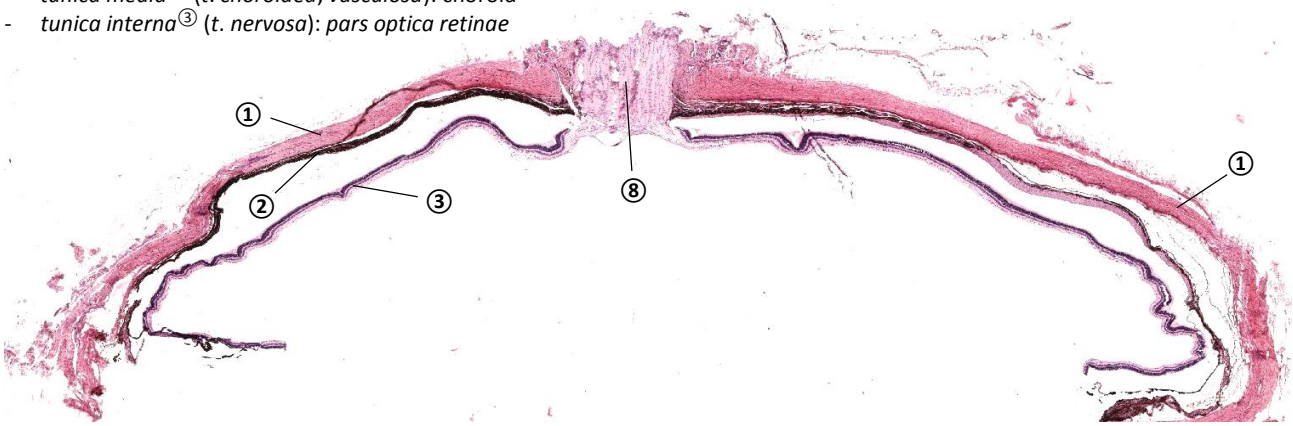
LENS (*lens cristallina*)

- ciliary zonule (zonule of Zinn), suspensory ligaments
- *capsula lentis*
- subcapsular anterior e. produces *capsula lentis* and secondary lens fibers
- lens fibers – long (~8-12 mm), hexagonal cells

EYE (*bulbus oculi*)

- **eyebulb posterior segment**
- *tunica externa*① (*t. fibrosa*): *sclera*
- *tunica media*② (*t. choroidea*, *vasculosa*): choroid
- *tunica interna*③ (*t. nervosa*): *pars optica retinae*

POSTERIOR EYE SEGMENT



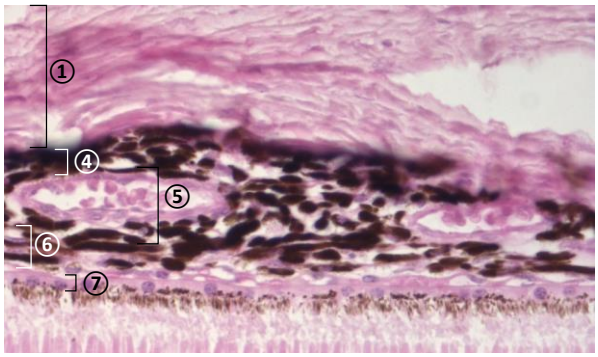
SCLERA

- dense irregular collagen c.t.

CHOROID (choroid coat)

- *lamina suprachoroidea*④
- avascular, collagen and elastic fibers, melanocytes, fibroblasts, chromatophores with melanin
- *l. vasculosa*⑤
- *aa. et vv. ciliares posteriores breves*
- *lamina choriocapillaris*⑥
- collagen and elastic c.t.
- capillary plexus (extremelly rich in *macula lutea*)
- *l. vitrea elastica*⑦ (Bruch´s membrane)
- ~1-2 μm, avascular, acellular
- composed of basal lamina of choroid endothelium, plexus of elastic fibers within two layers of collagen fibers, basal lamina of retinal pigment e.

CHOROID COAT



RETINA (*t. nervosa*)

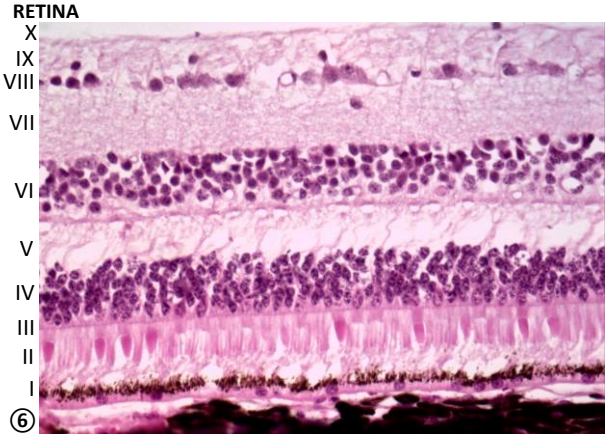
- neural structure derived from CNS
- vascularization
- branches of *a. centralis retinae* → blood supply of layers I-V
- capillaries from *aa. ciliares posteriores breves* in *l. choriocapillaris* → blood supply of layers VI-X
- ***pars optica retinae***

I. pigment e.
II. layer of rods and cones – peripheral part of photoreceptor cells
III. *membrana limitans externa* – distal end feet of Műller glial cells connected to photoreceptors by *zonulae adherentes*
IV. outer nuclear layer – nuclei of photoreceptor cells
V. outer plexiform layer – synapses of photoreceptor and bipolar neurons
VI. inner nuclear layer – perikarya of bipolar, horizontal and amacrine neurons, nuclei of Műller glial cells
VII. inner plexiform layer – synapses of bipolar and ganglion cells
VIII. ganglion cell layer – perikarya of multipolar neurons
IX. nerve fiber layer – axons of ganglion cells (→ *n. opticus*)
X. *membrana limitans interna* – basement membrane and extended processes of Műller glial cells

- specialized areas of photosensitive retina:
- *macula lutea*, *fovea centralis*, *discus nervi optici* ⑧

- ***pars caeca retinae***
- *pars ciliaris*
- *pars iridica*

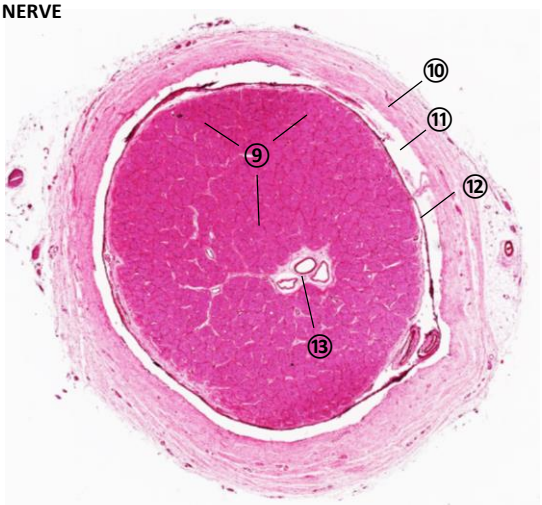
RETINA



OPTIC NERVE (*fasciculus opticus*)

- myelinated nerve fibers⑨ separated by glial sheaths
- *dura mater*⑩, *arachnoidea,* intervaginal space⑪, *pia mater*⑫, c.t. septa
- *porus opticus* in nerve axis⑬ with *a.* and *v. centralis retinae*

OPTIC NERVE



EYELID (*palpebra*)
- **skin** (ventral)
- thin epidermis①
- loose dermis, rich in elastic fibers
- dispersed small sweat and sebaceous glands
- eyelashes – hair follicles② at the eyelid margin
- small, sebaceous glands of Zeiss
- apocrine sweat glands of Moll (*gll. ciliares*)
- *m. arrector pili* absent
- ***pars palpebralis m. orbicularis oculi***③
- skeletal muscle
- **tarsus**④
- dense irregular collagen c. t. plate
- 25 (lower eyelids)-50 (upper eyelids) sebaceous Meibomian glands⑤ (*gl. tarseae Meibomi*) secreting lipidic film of *meibum*
- **palpebral conjunctiva** (dorsal)

CONJUNCTIVA
- thin, transparent mucous membrane lining conjunctival sac
- rich vascularization and innervation
- **palpebral conjuctiva**⑥ (*t. conjunctiva palpebrae*, eyelid conjunctiva)
- stratified columnar e.⑦ with single goblet cells⑧ or mucous cells clustered to small endoepithelial glands
- lymphoid infiltrations in *l. propria*
- **fornix**
- thick stratified columnar e.
- loose attachment of fornix collagen c.t. to orbital adipose c.t. → free movements of eyelid and eyebulb
- acccesory lacrimal glands of Krause
- **bulbar conjunctiva** (*tunica conjunctiva bulbi*, ocular)
- stratified columnar e.
- loose colagen c.t. with elastic fibers
- lymphoid infiltrations absent
- clusters of adipocytes in subconjunctival c.t.
- conjunctival e. at *limbus corneae* continuous with corneal e.

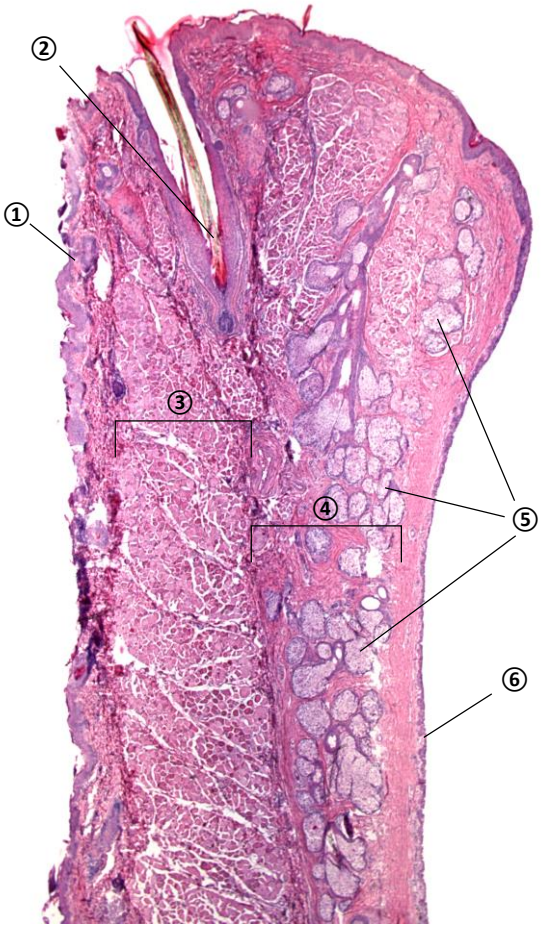
LACRIMAL GLAND (*gl. lacrimalis*)
- compound tubuloacinar gland similar to parotid
- alveoli and tubuli possess distinct lumen⑨
- pyramidal cells with apical secretory granules
- myoepithelial cells
- adipocytes⑩
- ~10-15 simple interlobular ducts lined by simple cuboidal e. → simple columnar e. opening to upper fornix
- typical intercalated and striated ducts absent
- serous, isotonic, lysozyme-rich fluid (tears)

LACRIMAL CANALS (*canaliculi lacrimales superior et inferior*, ↔ 8 mm)
- stratified squamous e.
- c.t. rich in elastic fibers
- lymphoid infiltrations

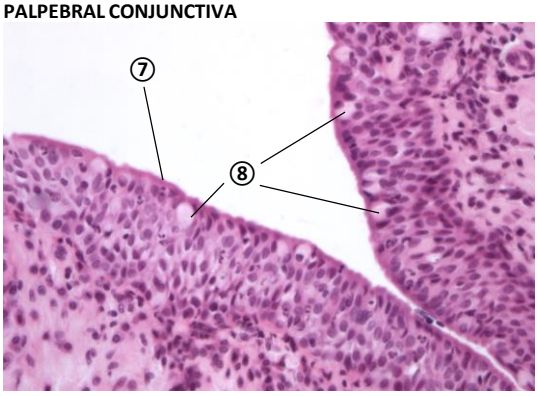
LACRIMAL SAC (*saccus lacrimalis*)
- dilated proximal end of nasolacrimal duct
- tall, stratified or pseudostratified columnar e. with goblet cells

NASOLACRIMAL DUCT (*ductus nasolacrimalis*)
- opens into the *meatus nasi inferior* (*plica lacrimalis*, *Hasneri*)
- tall stratified columnar e. → pseudostratified columnar e. with goblet cells
- c.t. rich elastic fibers
- lymphoid infiltrations
- venous plexus

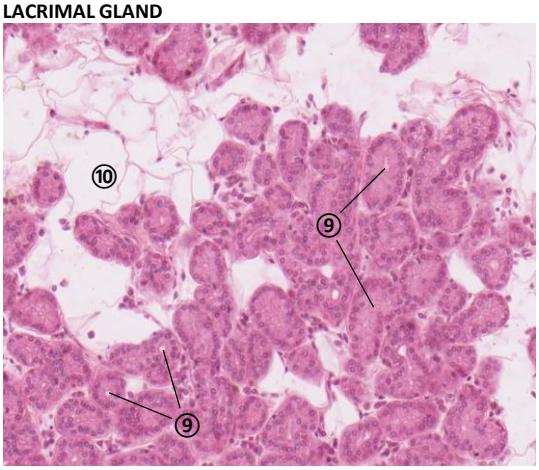
PALPEBRA



PALPEBRAL CONJUNCTIVA



LACRIMAL GLAND



EAR: AURICLE AND VESTIBULOCOCHLEAR APPARATUS

EAR (*auris*)

OUTER EAR (*auris externa*)

- **auricle** (*pinna*, *auricula*)
  - elastic cartilage①
  - epidermis② and dermis continuous with perichondrium
  - skin adnexa (fine hair follicles, eccrine sweat gll.)
- **external auditory meatus**
  - thin epidermis with coarse hairs (*tragi*) at meatus orifice
  - sebaceous and modified apocrine sweat gll. (*gll. ceruminosae*) in cartilagineous part; osseous part devoid of skin adnexa

MIDDLE EAR (*auris media*)

- **tympanic membrane** (*membrana tympanica*, *myrinx*)
  - *stratum cutaneum* – thin skin of external acoustic meatus
  - *str. fibrosum* – c.t. rich in collagen and elastic fibers
  - *str. mucosum* – continuous with mucosa of tympanic cavity
  - rich innervation, vascularization
- **tympanic cavity** (*cavum tympani*)
  - air-filled cavity
  - thin mucosa directly on periost, simple cuboidal e.
- **Eustachian tube** (*tuba auditiva*)
- *pars ossea*
  - mucosa of tympanic cavity
- *pars cartilaginea*
  - elastic cartilage and c.t.
  - mucosa of respiratory passages
  - seromucous glands, lymphatic follicles
  - *tonsilla tubaria* (Waldeyer's lymphatic ring)

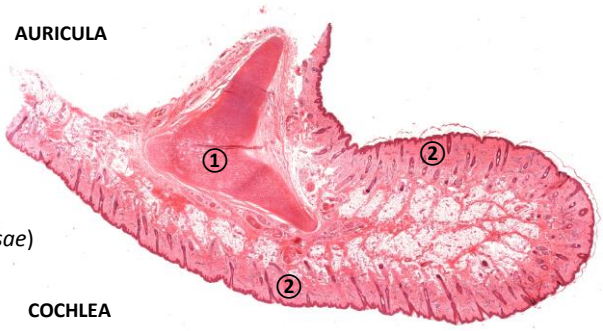
INNER EAR (*auris interna*)

- bony labyrinth
- *vestibulum*, semicircular canals, cochlea
- *spatium perilymphaticum* (perilymph)
- membranous labyrinth (endolymph)
- *pars statica labyrinthi membranacei* (vestibular system)
- *p. auditiva l.m.* (cochlear duct, *ductus cochelaris*)
- *ductus reuniens* (connection of *sacculus* and *d. cochlearis*)

COCHLEA

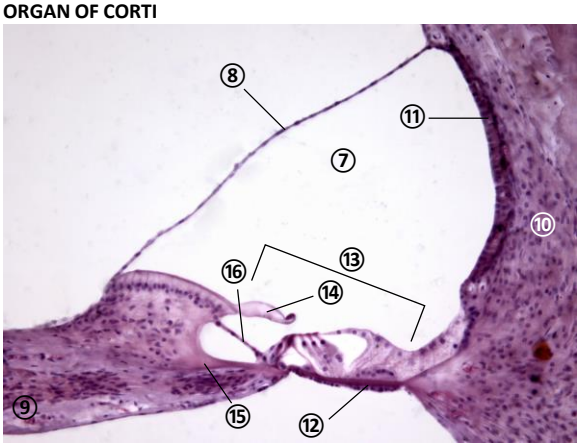
- *modiolus*③, helicotrema, *canalis spiralis cochleae*
- *ganglion spiralis cochleae*④
- ***scala vestibuli***⑤, ***scala tympani***⑥
- ***ductus cochlearis*** (*scala media*)⑦
  - *membrana vestibularis*⑧ (Reissner's membrane)
  - *lamina spiralis ossea*⑨, *ligamentum spirale*⑩
  - *stria vascularis*⑪, *membrana basilaris*⑫
  - diffusion barrier (*z. occludentes*)
- **organ of Corti**⑬
  - ***membrana tectoria***⑭
  - gelatinous acellular layer embedding stereocilia of hair cells
  - produced by interdental cells of spiral limbus
- **hair cells**
  - secondary sensory e.
  - stereocilia (4-8 µm)
  - inner hair cells – neurotransmission, single row
  - outer hair cells – electroacoustic amplification, 3-5 rows
- **supporting cells**
  - mostly columnar, tonofibrils
  - intercellular spaces
- **organ of Corti in close detail**
  - *sulcus spiralis internus*⑮ (e.⑯ often artifactually detached from basement membrane during sample processing)
  - inner phalangeal cells⑰, inner hair cells⑱
  - inner⑲ and outer pillar⑳ of Corti, tunnel of Corti㉑
  - space of Nuel㉒
  - outer hair cells㉓, outer phalangeal cells㉔ (Deiters' cells)
  - cells of Hensen㉕, Bottcher㉖ and Claudius㉗
  - e. of *sulcus spiralis externus*㉘

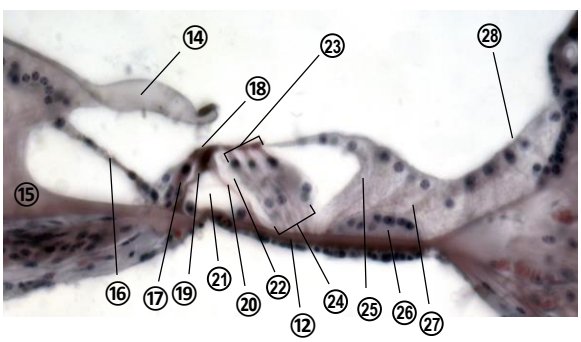
AURICULA



COCHLEA

ORGAN OF CORTI





VESTIBULAR SYSTEM

- simple squamous e. and extremely thin c.t.
- dendrites of neurons of *ganglion vestibulare* (*Scarpae*)
- ***utriculus***, ***sacculus***
  - sensory area – *macula utriculi et sacculi* (2-3 mm)
  - columnar supporting cells, sensory hair cells
  - gelatinous otolith membrane, aragonite crystals (otoliths/statoliths, ↔ 3-5 µm)
- **semicircular ducts** (*canales semicirculares*)
  - sensory area – *crista ampullaris*
  - columnar supporting cells
  - sensory hair cells with long stereocilia (30-40 µm) embedded in thick gelatinous layer (*cupula*)

SKIN (*cutis*)
- epidermis①, dermis②, hypodermis③
- thin and thick skin

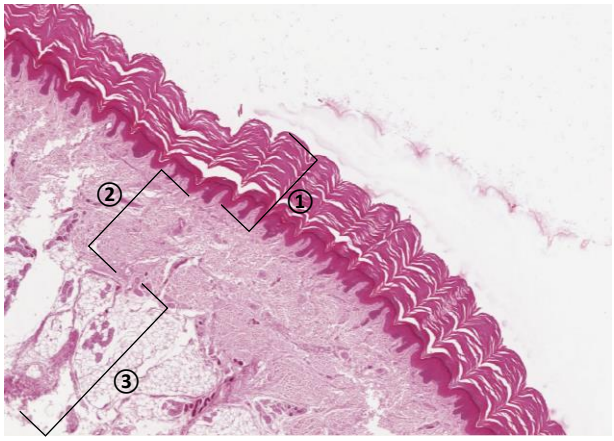
EPIDERMIS
- **keratinocytes**
- *stratum basale*④
- stem cells of epidermis
- *str. spinosum*⑤
- together with *str. basale* constitutes *str. germinativum*
- polyhedral cells entering differentiation (keratinization, cell junctions – desmosomes)
- *str. granulosum*⑥
- single layer in thin skin, 3-5 layers in thick skin
- keratohyaline granules (large, nonmembranous, proteins)
- lamellar granules (small, membranous, secreted lipoproteins)
- hydrophobic lipid envelope; loss of cell organelles
- free nerve endings
- *str. lucidum*⑦
- clear, translucent layer of non-viable keratinocytes
- thick skin only
- *str. corneum*⑧
- non-viable cells, without nuclei and other organelles
- keratin filaments embedded in a dense protein matrix
- *str. disjunctum* – detachment of non-viable cells (corneocytes)
- **melanocytes**
- mostly in *str. basale*
- melanin pigment in melanosomes; cytocrine secretion
- thin, long processes extending into *str. spinosum*
- **Langerhans cell**
- 2-8% of epidermal cells
- antigen presenting cells, mostly in *str. spinosum*
- **Merkel cells**
- tactile mechanoreceptors

DERMIS (*corium*)
- **papillary dermis** (*str. papillare*)
- loose collagen c.t. (collagen I and III fibers, ground substance)
- immune cells, vascular, lymphatic and neural plexus
- **reticular dermis** (*str. reticulare*)
- dense irregular collagen c.t. (collagen I)
- mechanical resistance

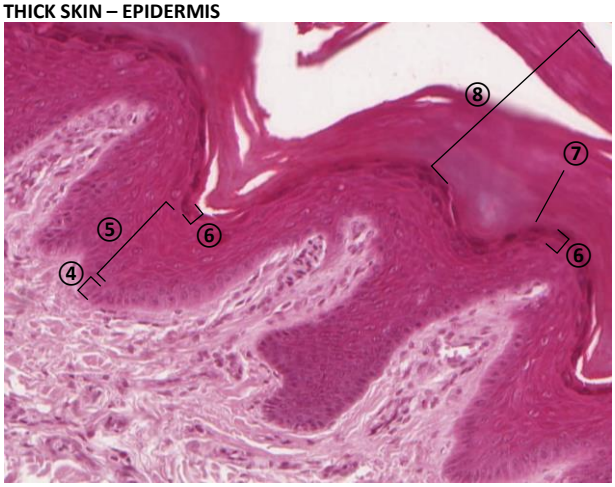
HYPODERMIS (*subcutis*)
- loose collagen c.t
- skin ligaments (*retinacula cutis*)
- abundant adipose tissue, lymphatic, vascular and neural plexus

RECEPTORS
- **mechanoreceptors**
- bulbous corpuscle (*corpusculum sensorium fusiforme*, *Ruffini*)
- hypodermis; stretch
- enlarged dendritic ending surrounded by perineurium
- lamellated corpuscles⑨ (*c. lamellosum*, *Vater-Pacini*)
- hypodermis; gross pressure changes, vibrations
- nerve endings, lamellae of modified Schwann cells, c.t. capsule
- tactile corpuscles (*c. tactus*, *Meissneri*)
- dermal papillae; light touch
- encapsulated, non-myelinated nerve endings
- lamellae of squamous supportive cells, c.t. capsule
- Merkel's discs (*meniscus tactus*)
- *str. basale* of epidermis; texture, pressure or static touch
- fingertips, lips, external genitalia, hair follicles
- non-capsulated, tactile Merkel (Merkel-Ranvier) cells associated with expanded (disc-like), intraepidermal nerve termini
- **thermoreceptors and nociceptors**
- free afferent nerve endings
- epidermis, dermis; pain
- bulboid corpuscle (*c. bulboideum*, end-bulb of Krause)
- skin and mucous membranes; low temperature, cold
- encapsulated nerve endings

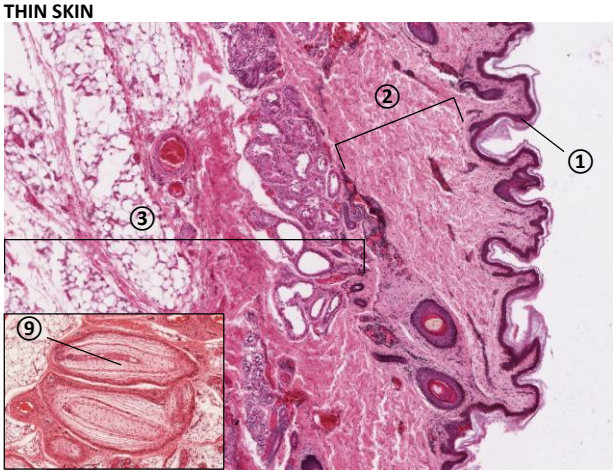
THICK SKIN



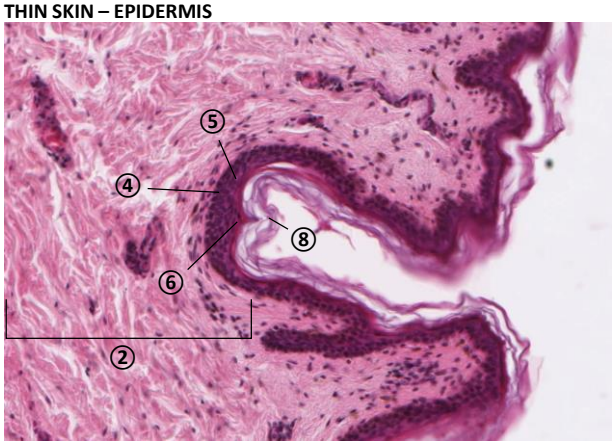
THICK SKIN – EPIDERMIS



THIN SKIN



THIN SKIN – EPIDERMIS



SKIN: SWEAT AND SEBACEOUS GLANDS, HAIR AND NAIL

ECCRINE SWEAT GLANDS (*gll. sudoriferae eccrinae*)
- tubular glands, merocrine secretion
- almost all skin, highest density in the thick skin
- **secretory segment**①
- single tubulus coiled into glomerulus
- dermis or hypodermis
- simple layer of secretory pyramidal cells
- dark cells (granules), light cells (glycogen, isotonic secretion)
- basement membrane
- myoepithelial cells
- **ductal segment**②
- dermis – bilayered cuboidal e.
- epidermis – intraepidermal canaliculus without epithelial lining

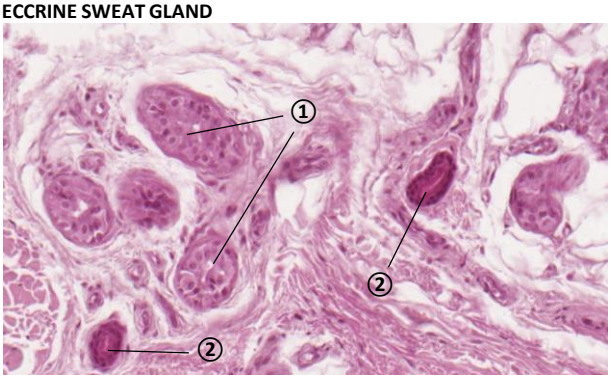
APOCRINE SWEAT GLANDS (*gll. sudoriferae apocrinae*)
- tubular glands, merocrine secretion
- axilla (*gll. sudoriferae axillares*), areola (*gll. areolares mammae*), pubic and perianal region (*gll. sudoriferae circumanales*)
- modified apocrine glands in external auditory meatus (*gll. ceruminosae*), eyelid (*gll. ciliares*), mammary gland
- **secretory segment**③
- dermis/hypodermis junction
- single tubulus coiled into glomerulus or straight (ciliary glands)
- large lumen, variable height of e.
- secretory e. cells with granules, pigment, lipid inclusions
- myoepithelial cells
- ducts open to the infundibulum of hair follicles

SEBACEOUS GLANDS④ (*gll. sebaceae*)
- alveolar glands, holocrine secretion
- all skin, except for thick skin, lipid rich *sebum*
- **secretory segment**
- dermis
- mitotically active cells on periphery of alveolus
- differentiation, accumulation of lipid droplets, pycnosis
- disintegration of cells and release of secretion
- **ductal segment**
- ducts open to the infundibulum of hair follicles or freely
- stratified squamous e.

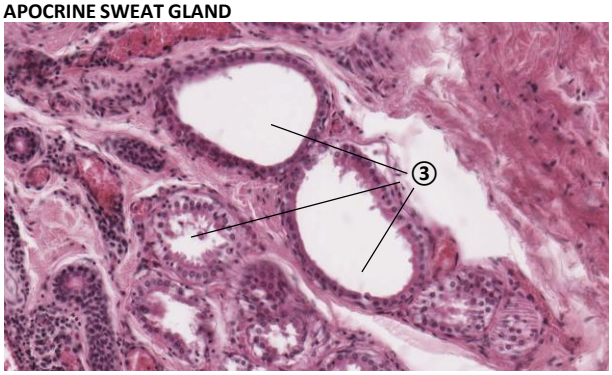
HAIR⑤
- **hair shaft** (*scapus pili*)
- medulla⑥ – discontinuous, loose keratinized cells, air spaces
- cortex⑦ – long, dense, keratinized cells, melanosomes (pigment)
- cuticle⑧ – overlapping, squamous shingle-like keratinized cells
- **hair follicle with hair root** (*folliculus et radix pili*)
- epithelial root sheaths⑨ (inner and outer), c.t. sheath⑩
- similar to the hair shaft but not yet keratinized
- **hair bulb**⑪ (*bulbus pili*)
- expanded part of hair root – proliferating matrix cells, melanocytes
- **hair papilla**⑫ (*papilla pili*)
- dermal c.t with capillary loop
- fibroblasts paracrine regulating hair cycle (anagen, katagen, telogen)
- **hair follicle infundibulum**
- upper segment of follicle, from entrance of sebaceous gland duct to follicular orifice
- ***m. arrector pili*** – smooth muscle cells

NAIL
- **nail plate**⑬ – keratinized epidermal cells (*stratum corneum unguis*), lunula
- **nail root**⑭ – proximal part of nail plate under skin fold
- **nail bed**⑮
- nail matrix (*str. germinativum unguis*) continuous to nail bed epidermis and *hyponychium*⑯
- *eponychium*⑰ – extension of *str. corneum* of epidermis on nail plate mostly from proximal epidermal fold

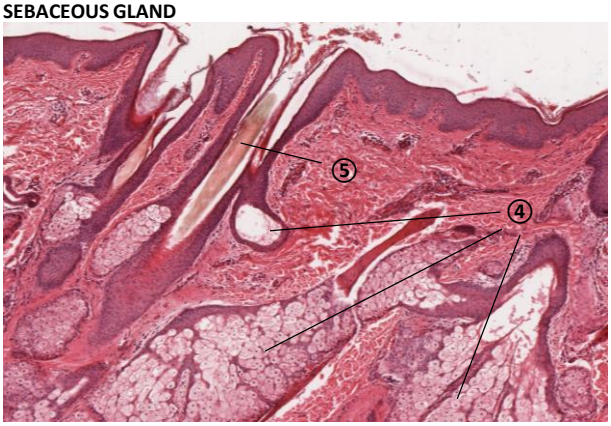
ECCRINE SWEAT GLAND



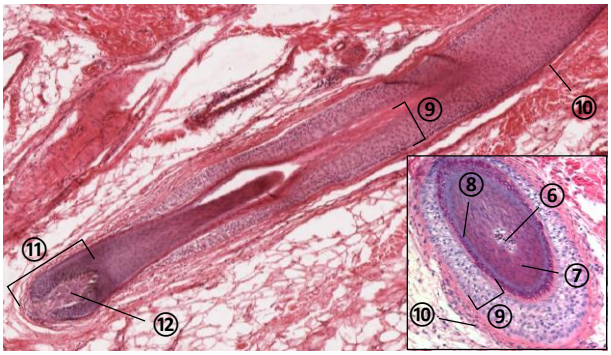
APOCRINE SWEAT GLAND



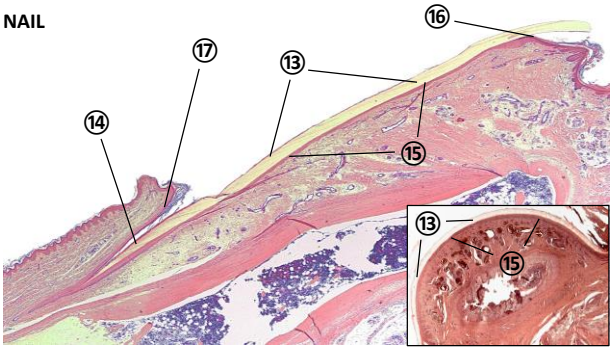
SEBACEOUS GLAND



HAIR



NAIL



MAMMARY GLAND (*gl. mammae*, *gl. lactifera*)

- **body of breast** (*corpus mammae*)
- 15-20 tubuloalveoar glands① in lobes (*lobi mammae*)
  - apocrine and merocrine secretion
- embedded in adipose and c.t. stroma
  - ligaments of Cooper
  - interlobular c.t.②, dense, less cellular, with adipose foci
  - intralobular c.t.③, loose, highly cellular, rich vascularisation, lymphoid infiltrations

- **ductal structure**
- *pori lactiferi* on *papilla mammae*
  - openings of *ductus lactiferi*
  - stratified squamous e.
- lactiferous sinus (*sinus lactiferus*)
  - dilatation of *ductus lactiferus*
  - bilayered cuboidal to columnar e.
- *ductus lactiferus* (↔ 2-4 cm)④
  - single excretory duct of every lobe
  - simple cuboidal e.
  - continuous layer of myoepithelial cells on basal lamina
- terminal canaliculus
  - cuboidal secretory cells
  - myoepithelial cells

- **secretory alveoli**⑤
  - fully developed during pregnancy and lactation
  - minor changes during menstrual cycle
  - involution after lactation period or upon climacterium

- **inactive mammary gland** (*mamma non lactans*, non-secretory)
- in males or prior puberty – few solid epithelial buds in c.t.
- in puberty (prior 1st pregnancy)
  - branching morphogenesis of duct system
  - secretory alveoli absent or as epithelial buds only
- after lactation period
  - few inactive secretory alveoli
  - increase of interlobular c.t. and adipocytes

- **active mammary gland** (*mamma lactans,* secretory, in lactation)
- well developed secretory alveoli⑤
  - proliferation during pregnancy (estrogen, progesteron, prolactin)
- secretory alveolar cells⑥
  - often binucleated (~30%)
  - lipid droplets in cytoplasm → apocrine secretion
  - secretory vesicles (lactose, kasein) → merocrine secretion
  - ion transport (e.g. K^+), transcytosis (IgA)
  - incomplete basal layer of myoepithelial cells⑦ on basal lamina
- lobes separated by incomplete septa⑧; interlobular c.t. reduced

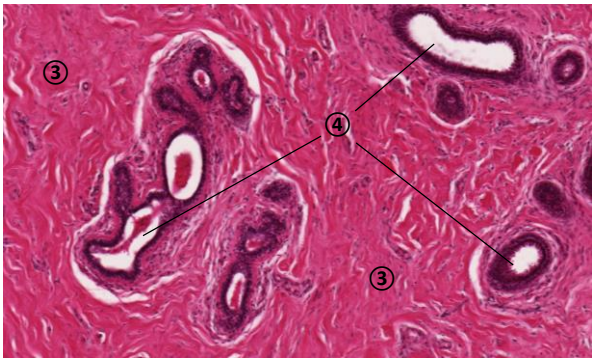
- **mammary milk**
  - isotonic solution of ions (K^+, I^+, phosphate), proteins (~ 1%), lipids (~ 4%) and lactose (~ 7%) in water (~ 88%)
- colostrum – rich in proteins, immunoglobulins, cytokines, etc.

- **involution of mammary gland**
- postlactational involution
  - apoptosis of redundant alveolar cells
  - reduction of secretory alveoli to prepregant state
  - increase of interlobular c.t.
- lobular involution during climacterium
  - irreversible regression of secretory cells
  - remodelling of c.t. stroma, increase of adipose tissue

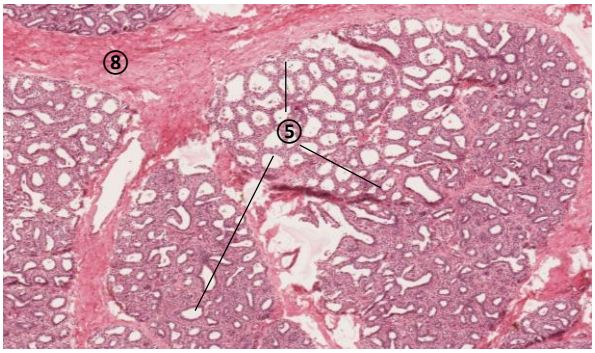
- **mammary papilla** (nipple) and **areola** (*papilla et areola mammae*)
  - pigmented thin skin with *pori lactiferi*
  - papillar c.t. rich in smooth muscle cells, adipocytes absent
  - multibranched free nerve endings and sensory skin adnexa
- *areola mammae*
  - periareolar apocrine sweat glands of Montgomery (*gll. areolares mammae*)
  - eccrine sweat glands, sebaceous glands, hair follicles

INACTIVE MAMMARY GLAND

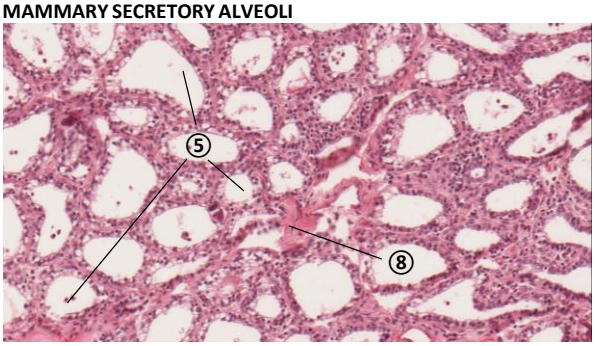
LACTIFEROUS DUCT



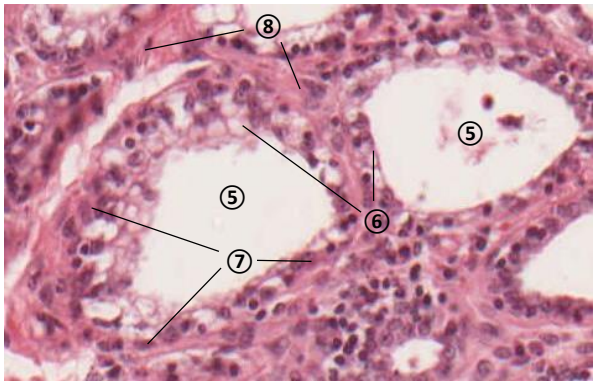
ACTIVE MAMMARY GLAND



MAMMARY SECRETORY ALVEOLI



MAMMARY ALVEOLAR EPITHELIUM



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Published by Masaryk University Press, Žerotínovo nám. 617/9, 601 77 Brno, Czech Republic
First electronic edition, 2020
ISBN 978-80-210-9671-4