

Lesson I. Part II. Cell Biology

Kazan Federal University

2023

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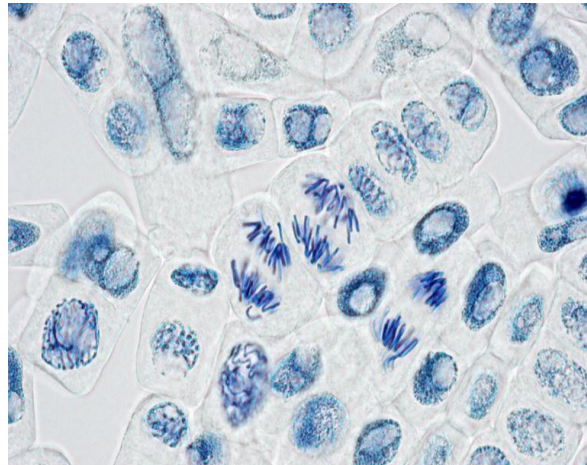
Cell biology. General information

Cell biology (cytology) is a branch of biology that studies the structure, function and behavior of cells. Modern cell biology is based on **cell theory**, the main provisions of which are as follows:

1. All living organisms are composed of one or more cells
2. The cell is the most basic unit of life
3. All cells arise only from pre-existing cells



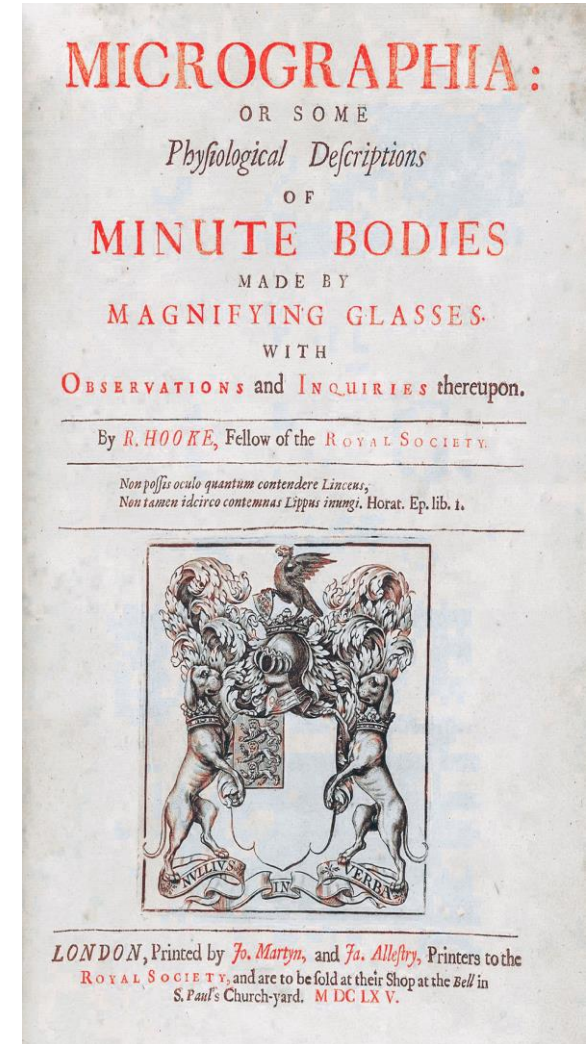
Bacterial cells



Plant cells



Animal cells



Micrographia by Robert Hooke, 1665

Cell biology. General information

Cell is the basic structural, functional, and biological unit of all organisms. Cells consist of cytoplasm enclosed within a membrane, which contains many biomolecules such as proteins, lipids, carbohydrates and nucleic acids.

Compartmentalization is a phenomenon of particular importance in cell biology. All types of membrane organelles may be considered as distinct **compartments**, each with special properties and functions. Cellular compartmentalization allows cells to optimize the efficiency of the processes that occur within organelles.



Detailed model of the inner space of a human cell

Types of cells

Eukaryotic cell
(Animalia, Plantae, Fungi)

Size

5 - 100 μm

Nucleus

Present

Membrane organelles

Present

Cytoskeleton

Well developed

Prokaryotic cell
(Bacteria, Archea)

Size

0.1 - 5.0 μm

Nucleus

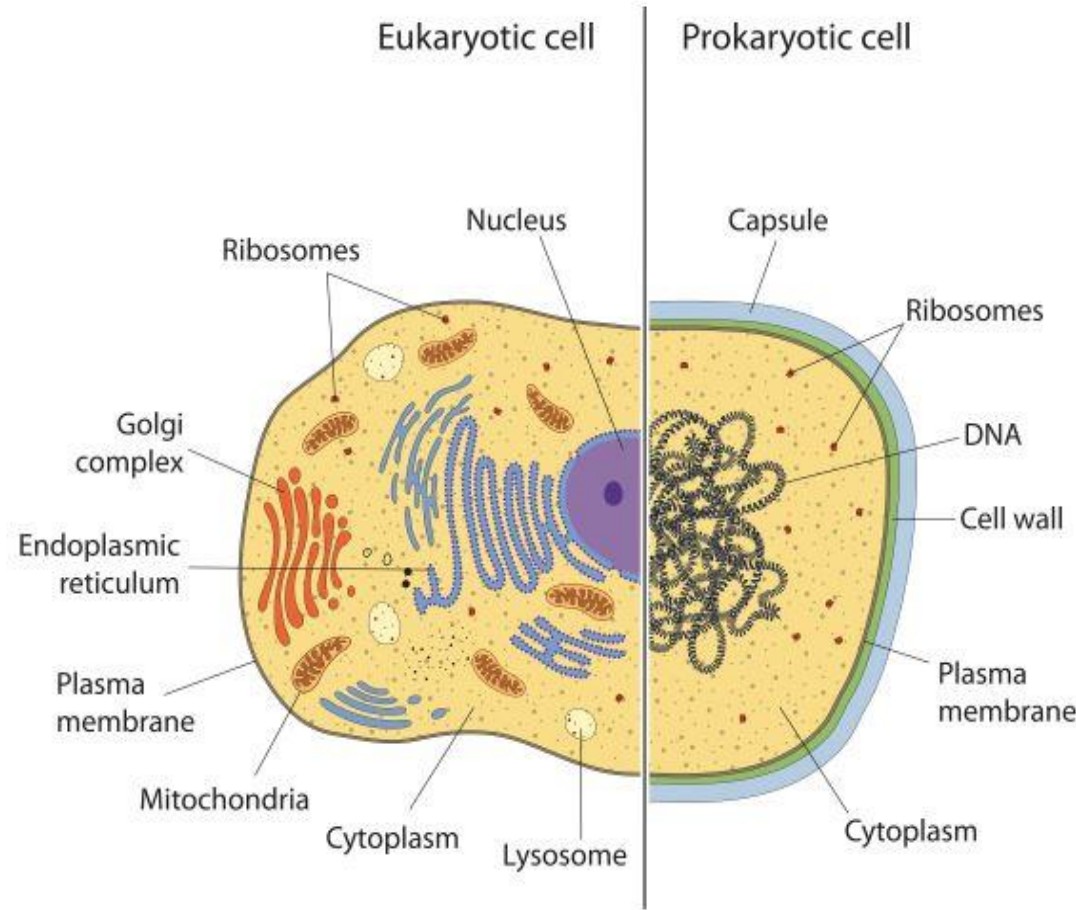
Absent

Membrane organelles

Absent

Cytoskeleton

Poorly developed



Structural components of cells

Eukaryotic cell

(example of animals)

Cell membrane

Cytoplasm

Nucleus

Ribosomes

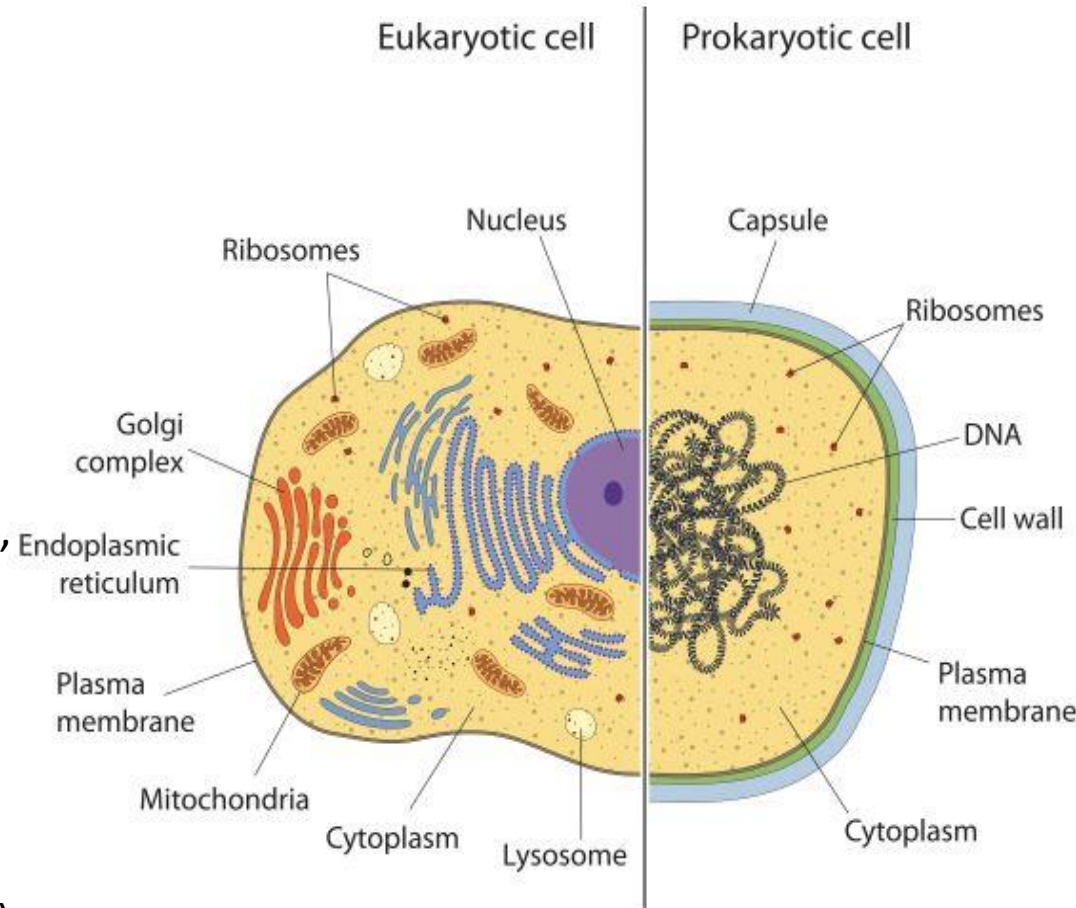
Single membrane-bound organelles

(endoplasmic reticulum, Golgi apparatus, lysosome, vacuole, etc.)

Double membrane-bound organelles
(mitochondria)

Cytoskeletal structures (microfilaments, microtubules, etc.)

Appendages (flagella, cilia, microvilli etc.)



Prokaryotic cell

(example of bacteria)

Capsule

Cell wall

Cell membrane

Cytoplasm

Nucleoid

Ribosomes

Appendages (flagella, pili, fimbriae, etc.)

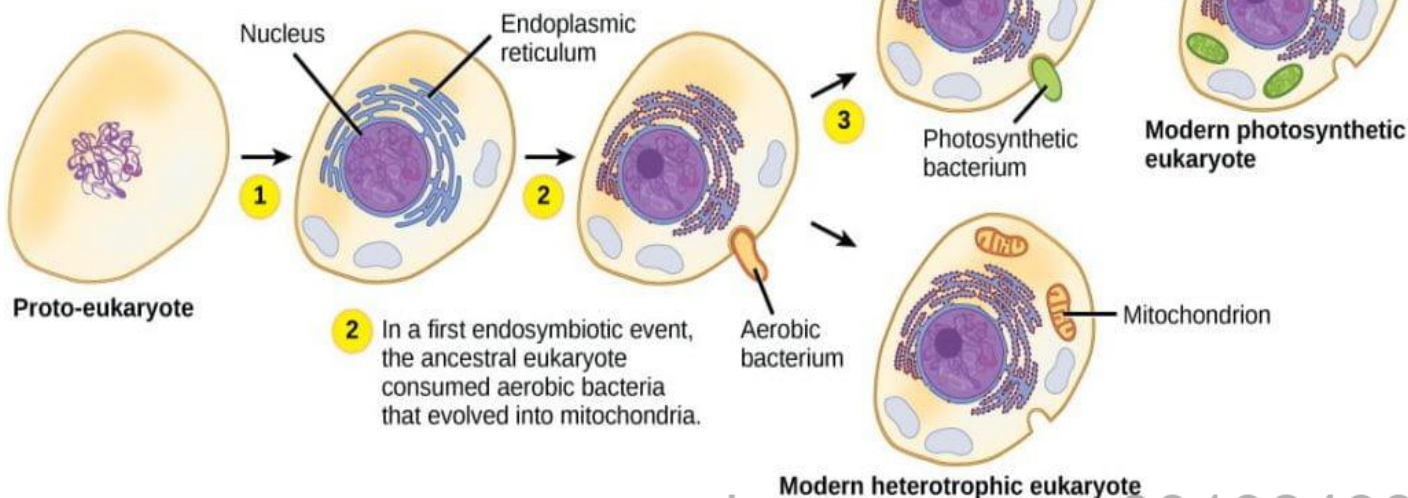
Origin of eukaryotic cells

Endosymbiotic theory (symbiogenesis) is the leading evolutionary theory of the origin of eukaryotic cells from prokaryotic organisms. The theory holds that mitochondria, plastids such as chloroplasts, and possibly some other organelles of eukaryotic cells are descended from formerly free-living prokaryotes (more closely related to bacteria than archaea) taken one inside the other in endosymbiosis.

The ENDOSYMBIOTIC THEORY

1 Infoldings in the plasma membrane of an ancestral prokaryote gave rise to endomembrane components, including a nucleus and endoplasmic reticulum.

3 In a second endosymbiotic event, the early eukaryote consumed photosynthetic bacteria that evolved into chloroplasts.

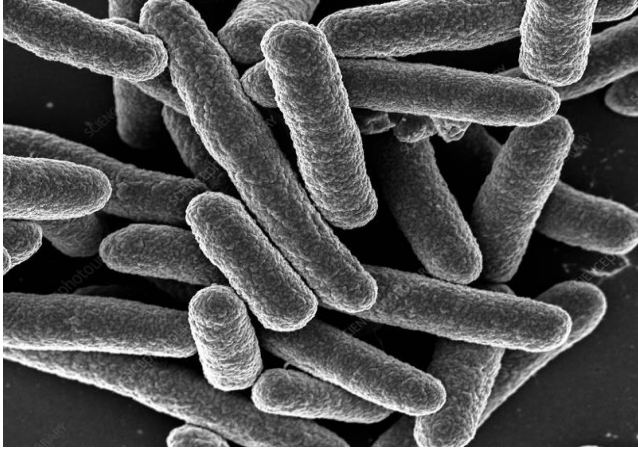


Cyanobacteria

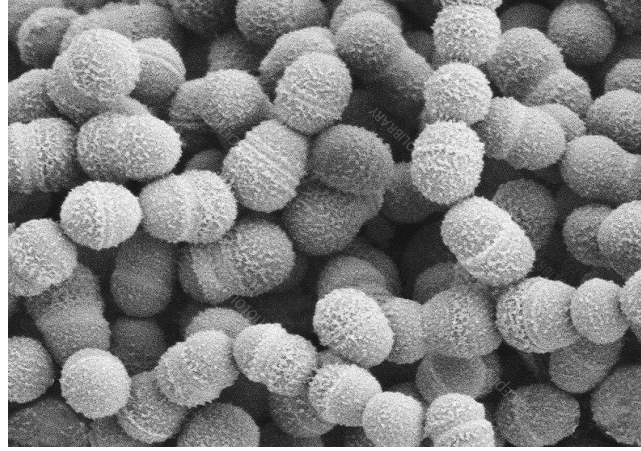


Chloroplasts in plant cells

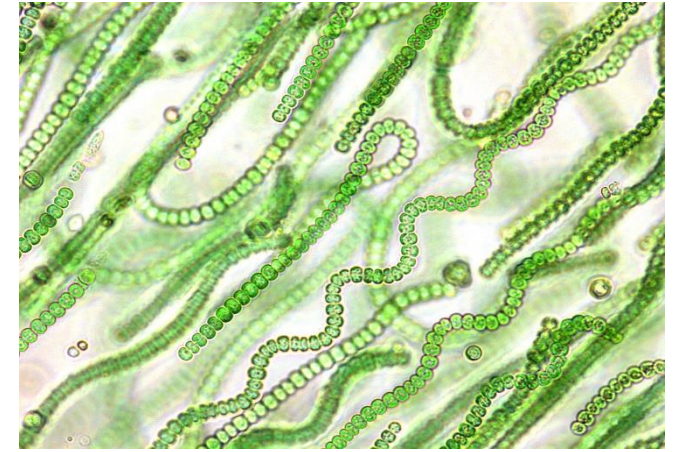
Diversity of prokaryotic cells



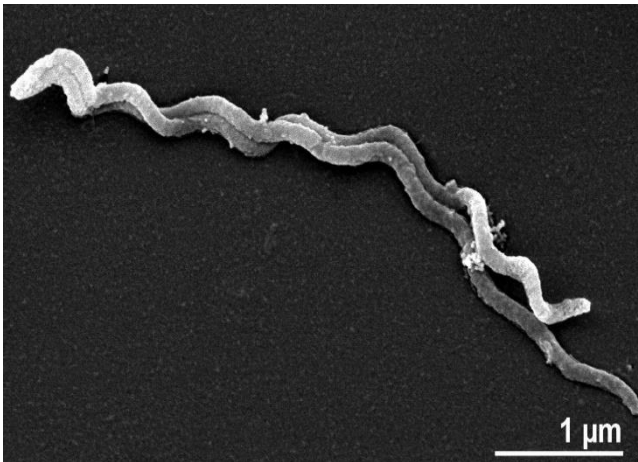
Escherichia coli
(Bacteria)



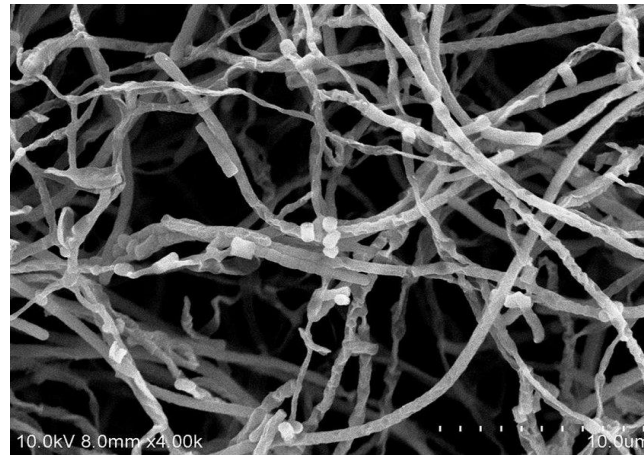
Streptococcus salivarius
(Bacteria)



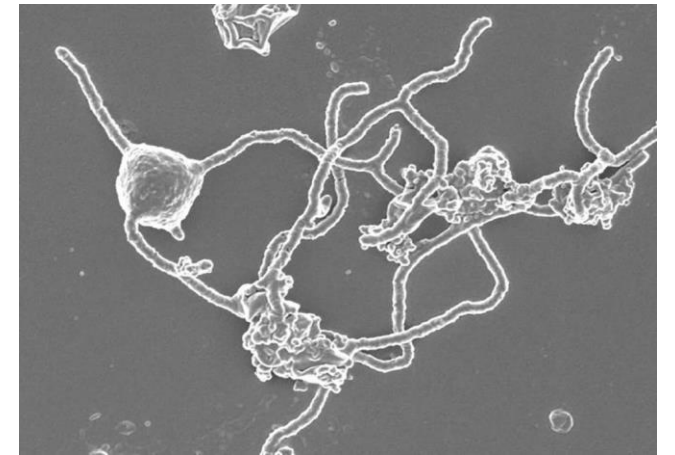
Nostoc caeruleum
(Bacteria)



Spirochaeta africana
(Bacteria)



Streptomyces pluripotens
(Bacteria)

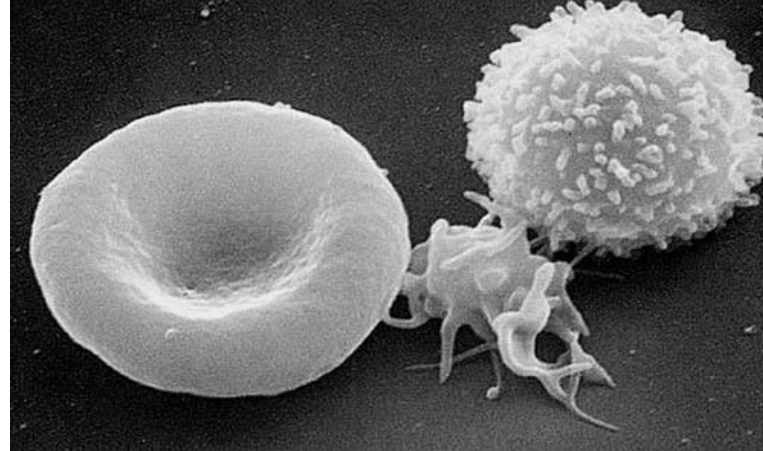


Prometheoarchaeum syntrophicum
(Archaea)

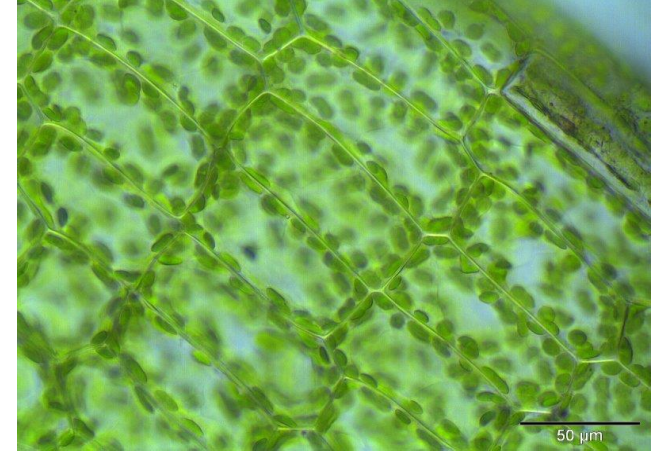
Diversity of eukaryotic cells



Arcella vulgaris
(Protist)



Human blood cells



Epidermal cells of *Rhizomnium punctatum*
(Plantae)



Euplotes crassus
(Protist)



Euglena viridis
(Protist)

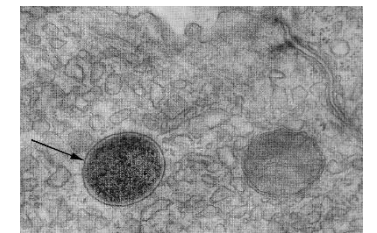
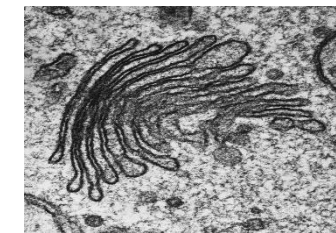
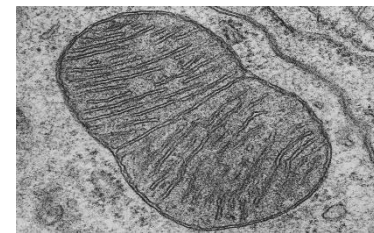
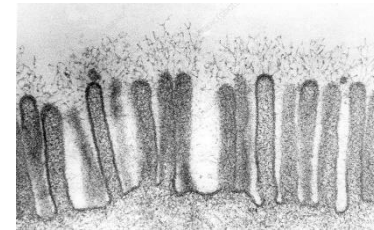
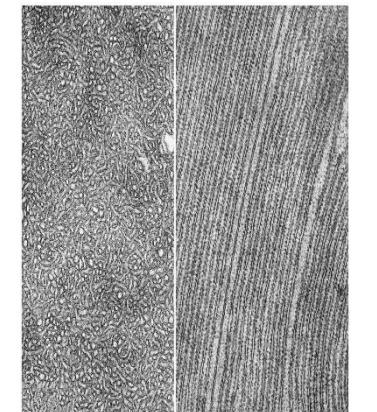
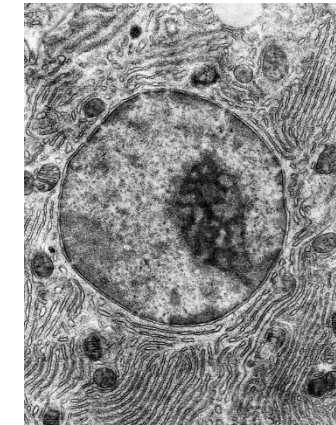
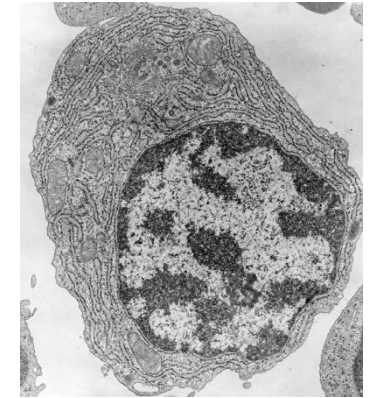


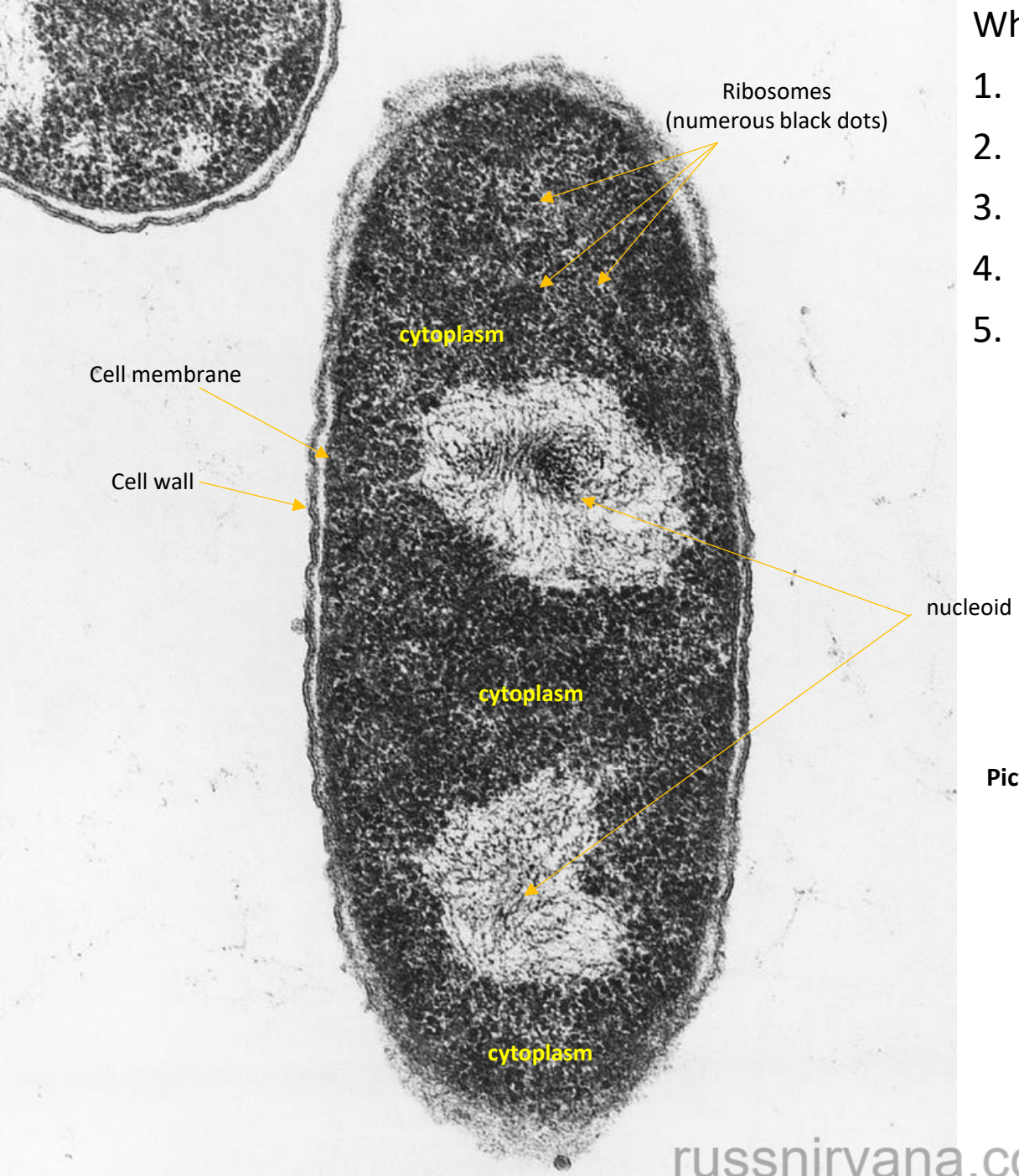
Hyphae of *Penicillium spinulosum*
(Fungi)

Classwork

You have to draw pictures from the following electron micrographs:

1. **General structure of prokaryotic cell (*Escherichia coli*)**
2. **General structure of eukaryotic cell (human lymphocyte)**
3. **Nucleus**
4. **Endoplasmic reticulum**
5. **Golgi apparatus**
6. **Lysosomes**
7. **Mitochondrion**
8. **Surface of the animal cell**

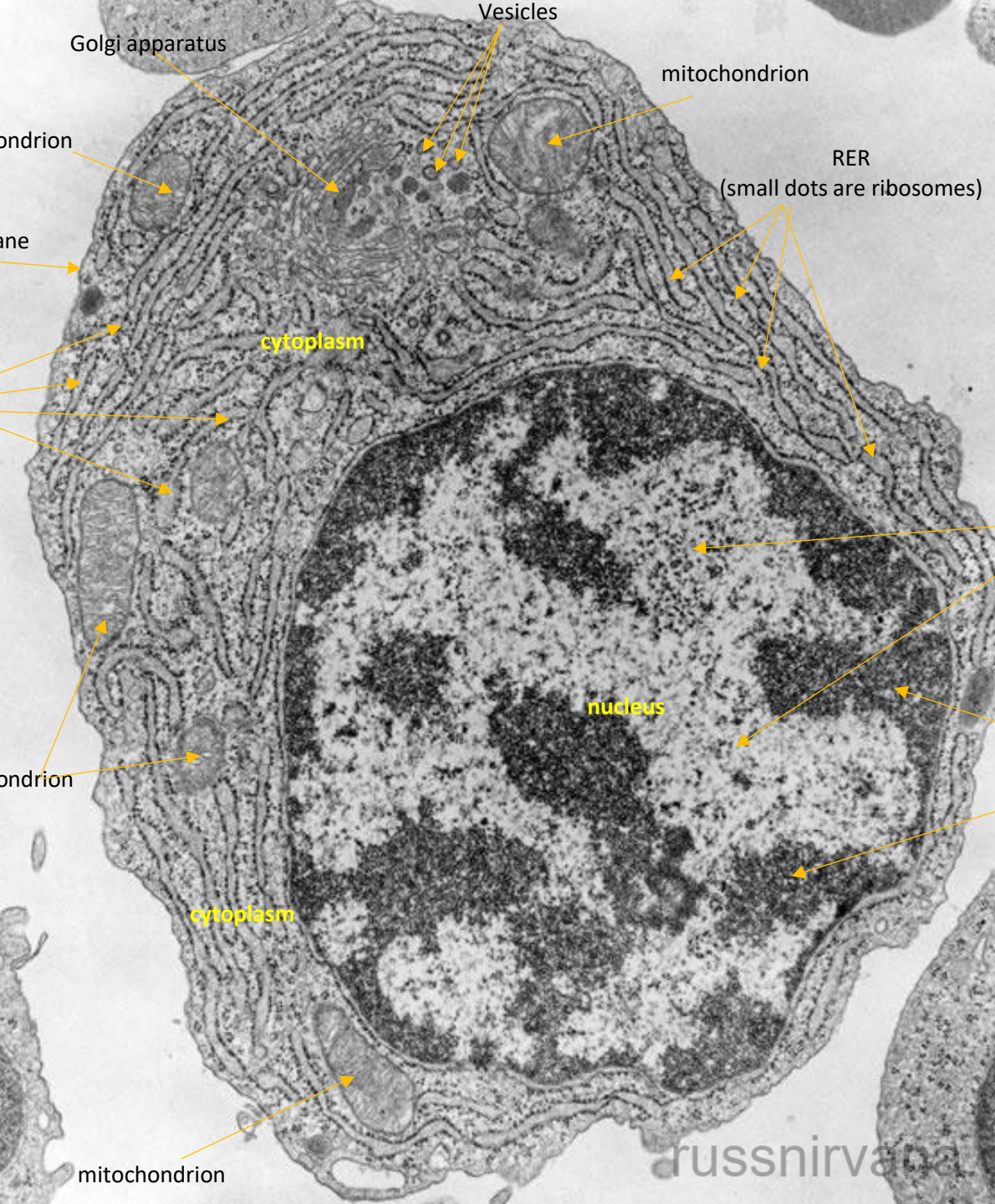




What should be marked:

1. cell wall
2. cell membrane
3. cytoplasm
4. ribosomes
5. nucleoid

Picture 1: General structure of prokaryotic cell
(*Escherichia coli*, TEM micrograph)



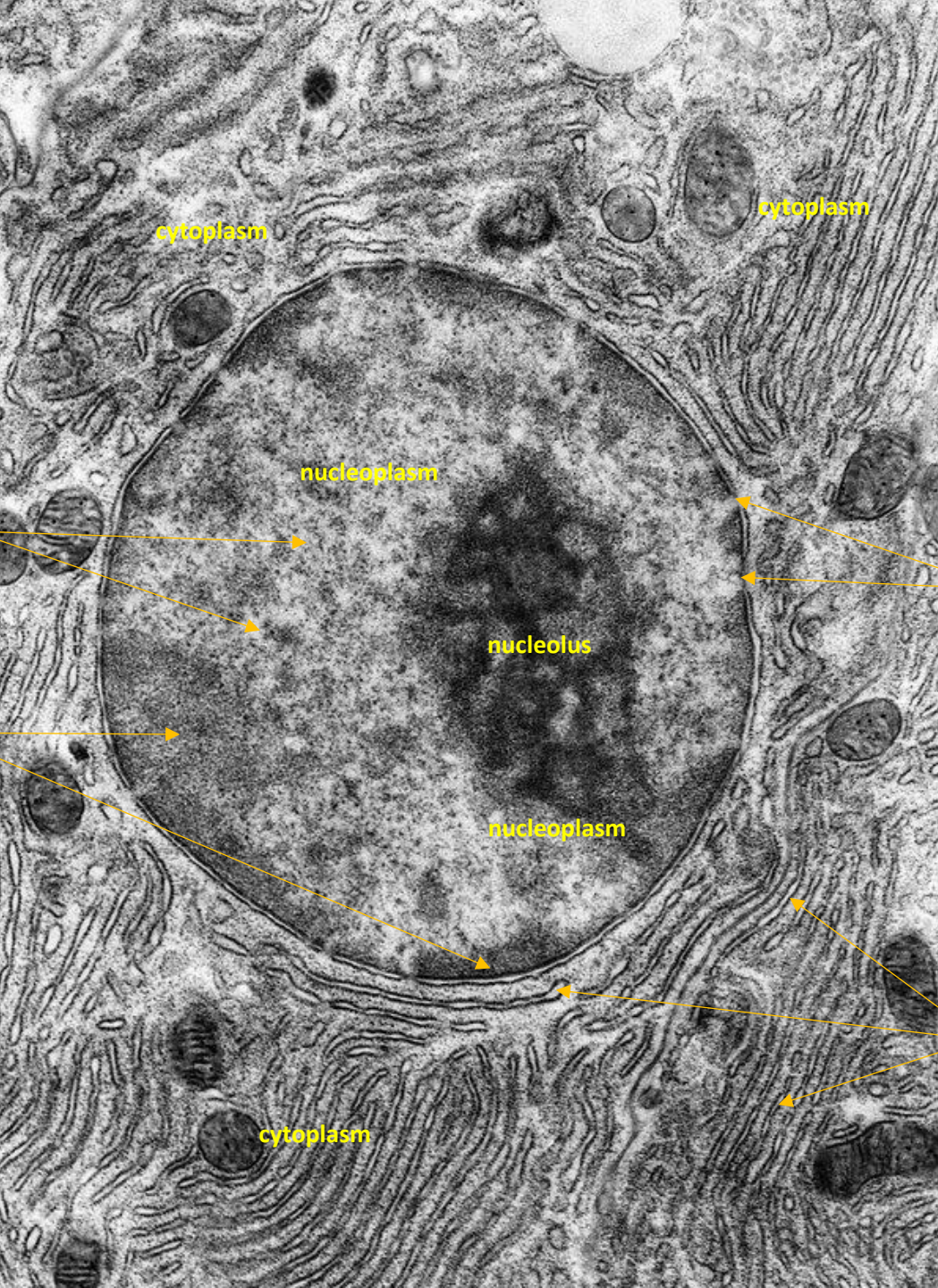
What should be marked:

1. cell membrane
2. cytoplasm
3. nucleus (+ euchromatin and heterochromatin)
4. rough endoplasmic reticulum (+ ribosomes)
5. Golgi apparatus (+ vesicles)
6. mitochondria

Euchromatin (electron-light areas)

Heterochromatin (electron-dense areas)

**Picture 2: General structure of eukaryotic cell
(human lymphocyte, TEM micrograph)**



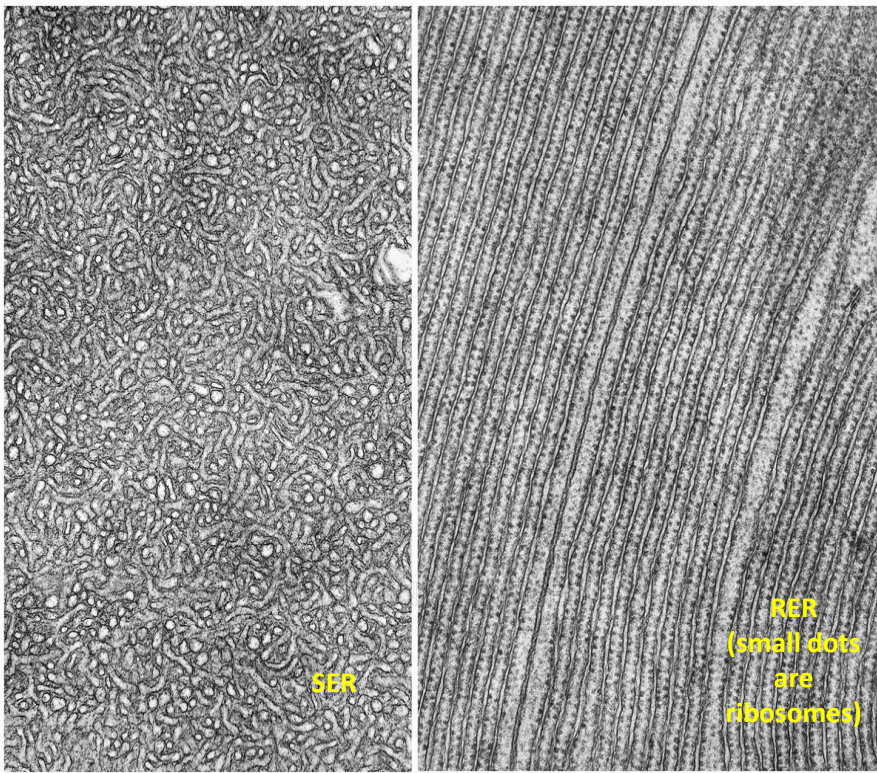
What should be marked:

1. nuclear membrane with pores
2. nucleoplasm (+ euchromatin and heterochromatin)
3. nucleolus
4. cytoplasm
5. rough endoplasmic reticulum (+ ribosomes)

Pores in
nuclear
membrane

**Picture 3: Nucleus
(TEM micrograph)**

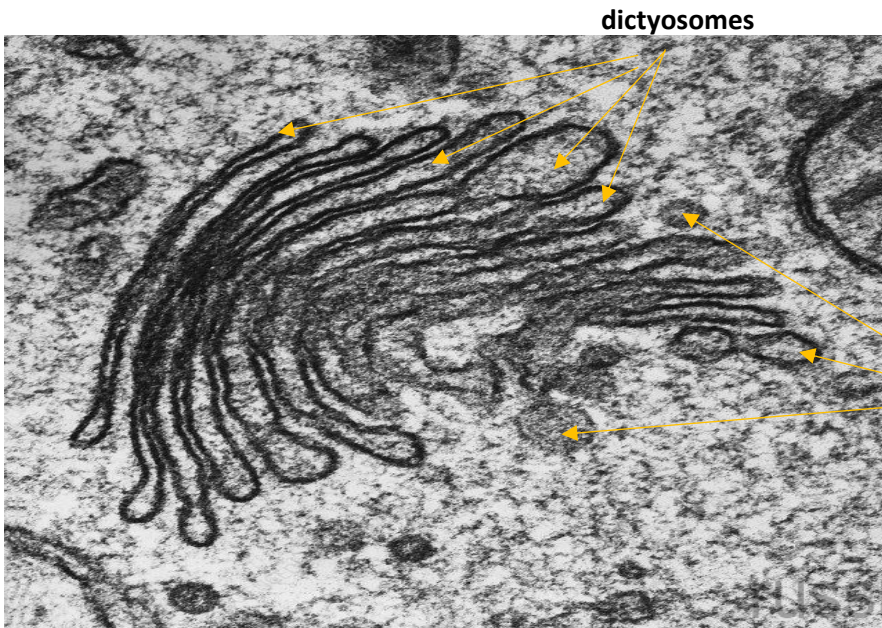
RER
(small dots are
ribosomes)



What should be marked:

1. rough endoplasmic reticulum (+ ribosomes)
2. smooth endoplasmic reticulum

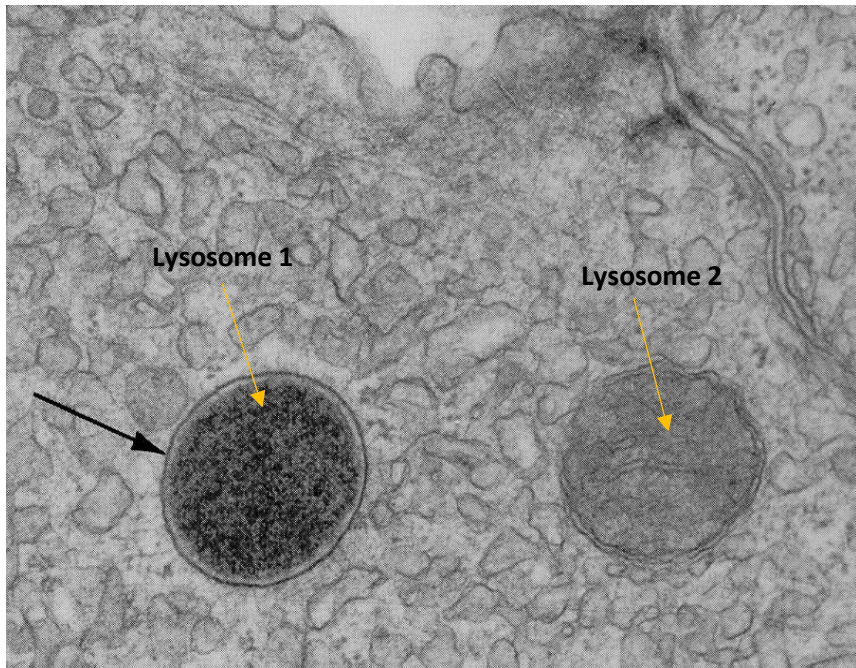
Picture 4: Endoplasmic reticulum
(TEM micrograph)



What should be marked:

1. dictyosomes
2. vesicles

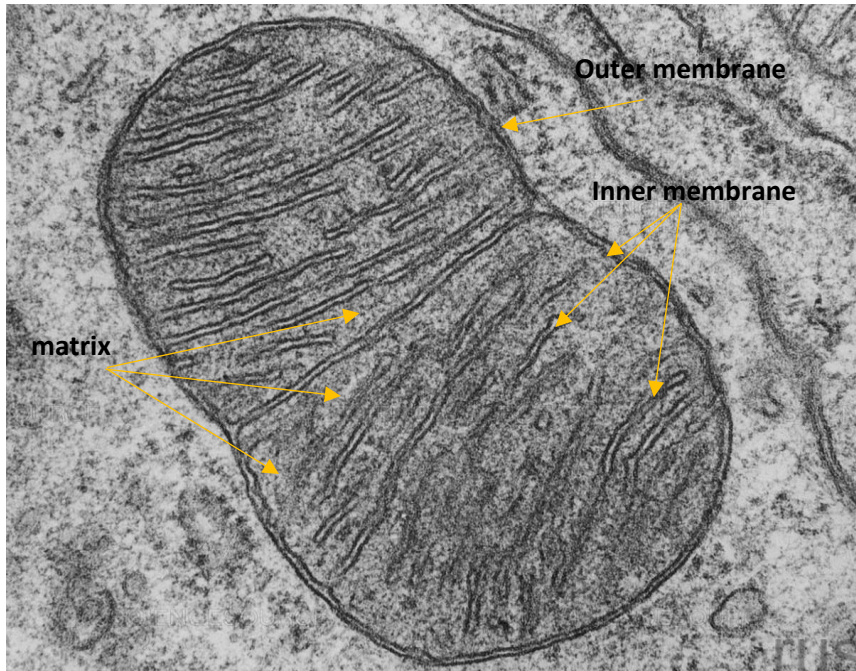
Picture 5: Golgi apparatus
(TEM micrograph)



What should be marked:

1. two lysosomes

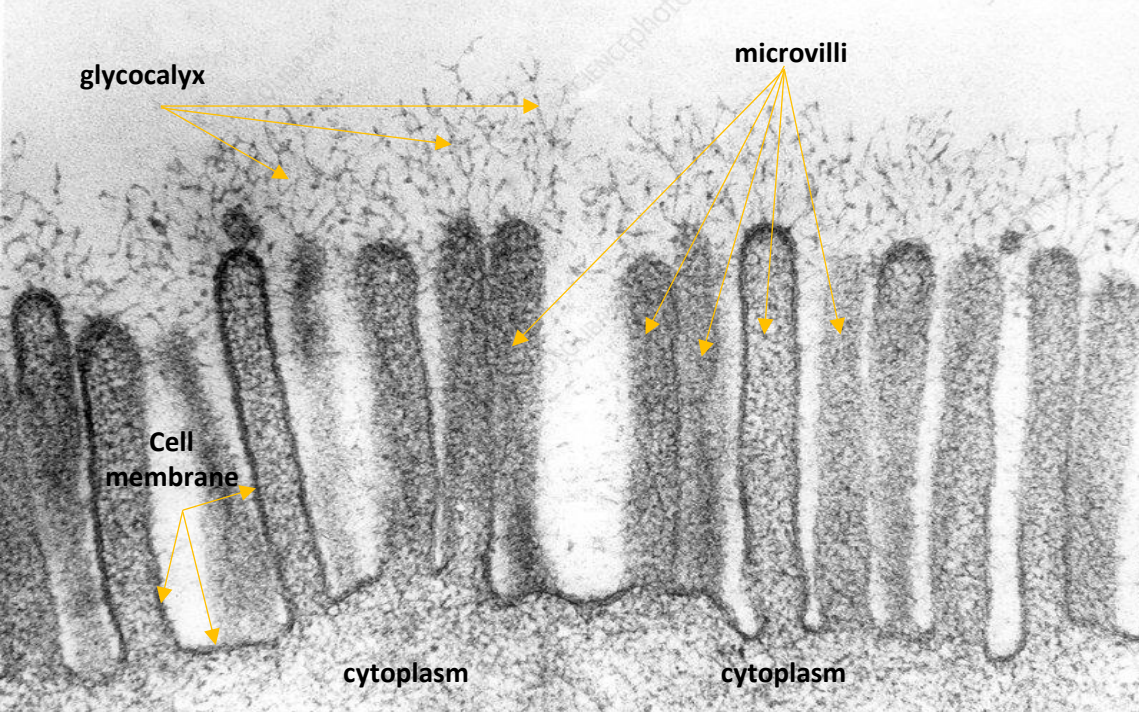
Picture 6: Lysosomes
(TEM micrograph)



What should be marked:

1. outer membrane of mitochondrion
2. inner membrane of mitochondrion (+ cristae)
3. matrix of mitochondrion

Picture 7: Mitochondrion
(TEM micrograph)

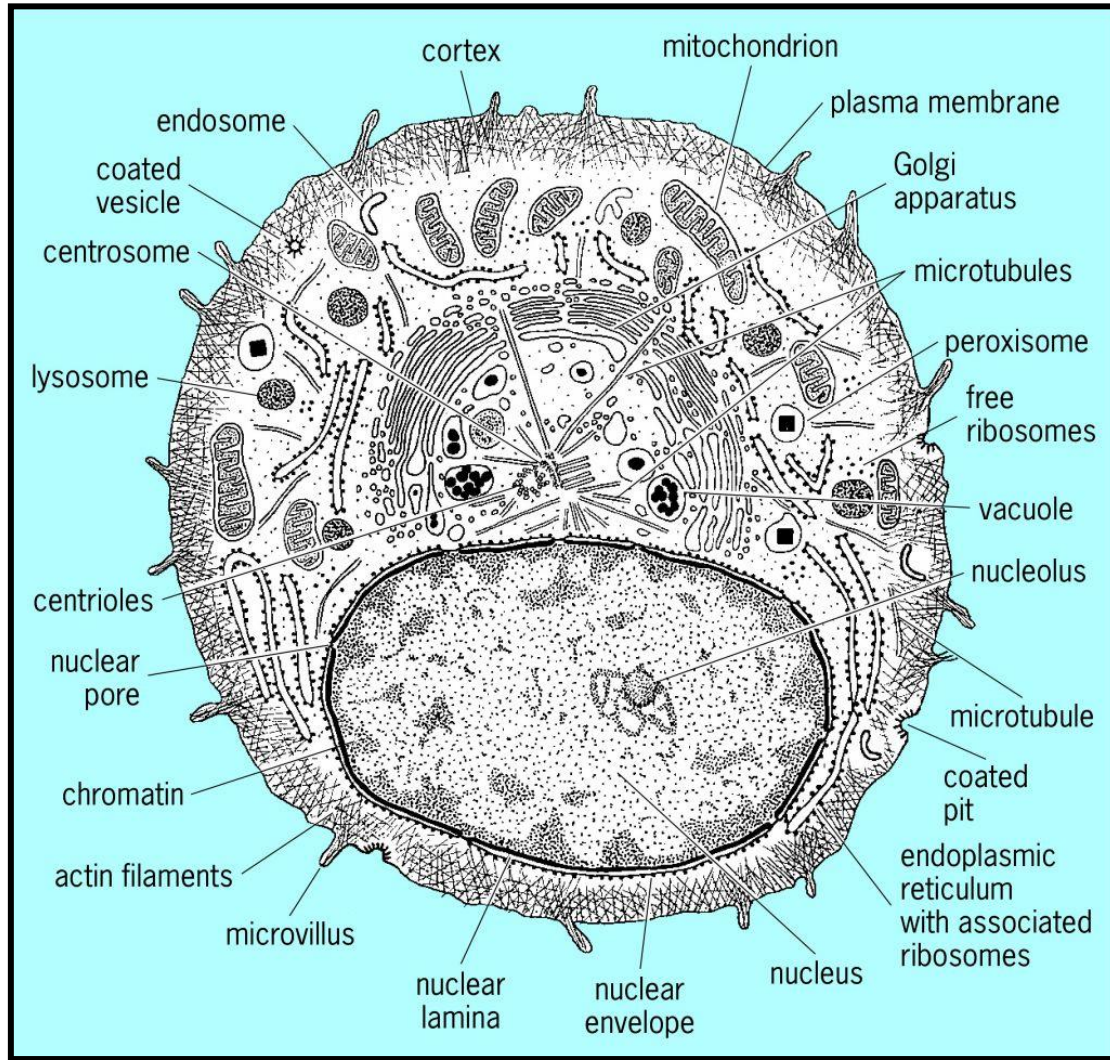


What should be marked:

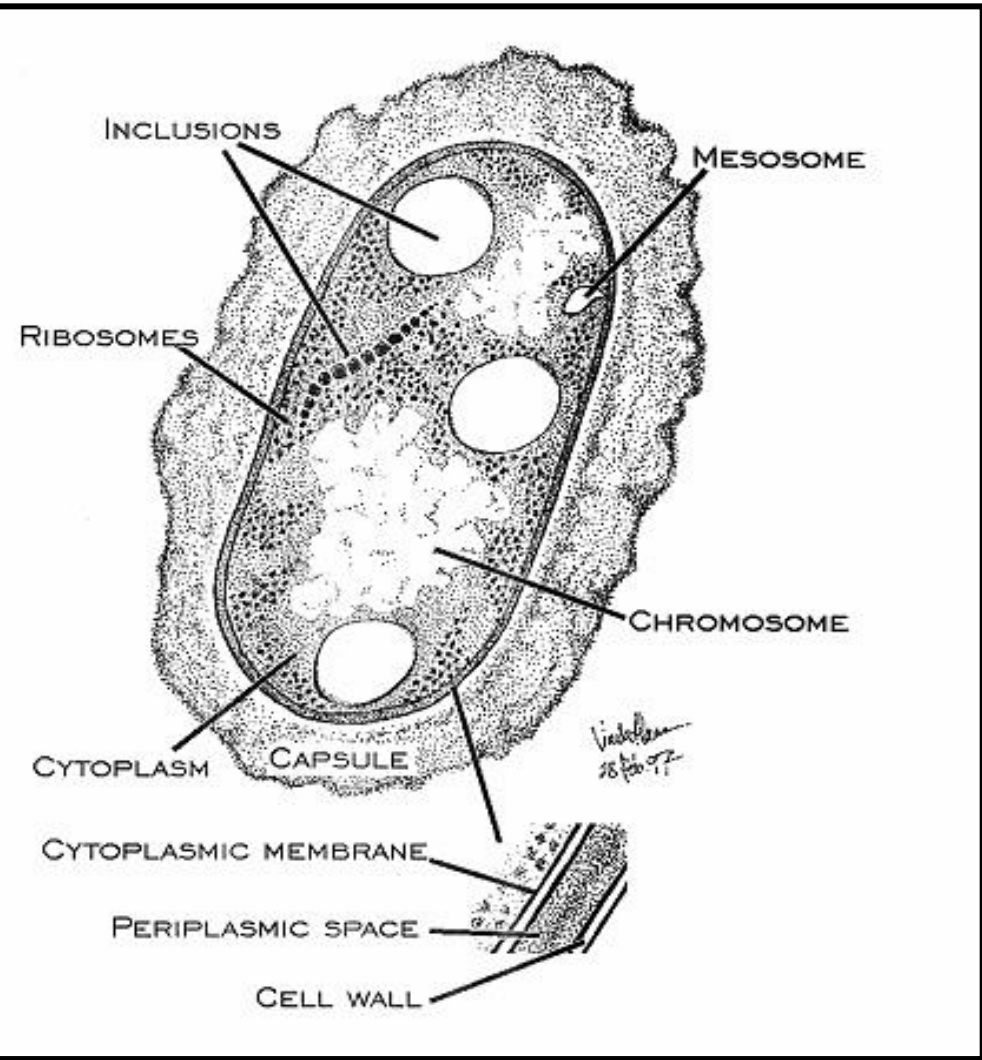
1. cell membrane
2. microvilli
3. glycocalyx
4. cytoplasm

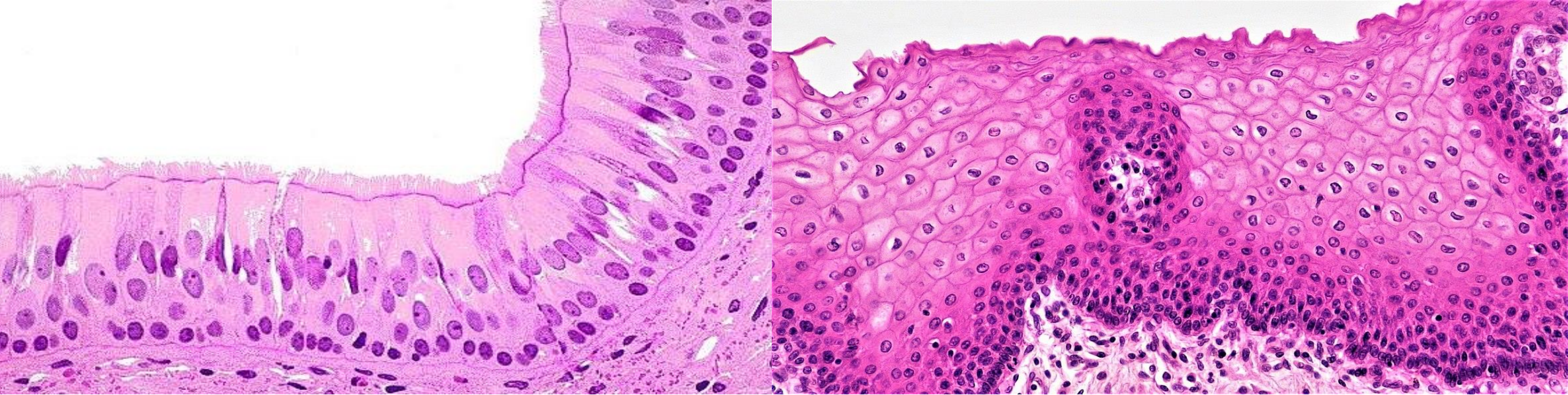
Picture 8: Surface of the animal cell (TEM micrograph)

Generalized animal cell



Generalized bacterial cell





Lesson II. Epithelial tissue

Kazan Federal University

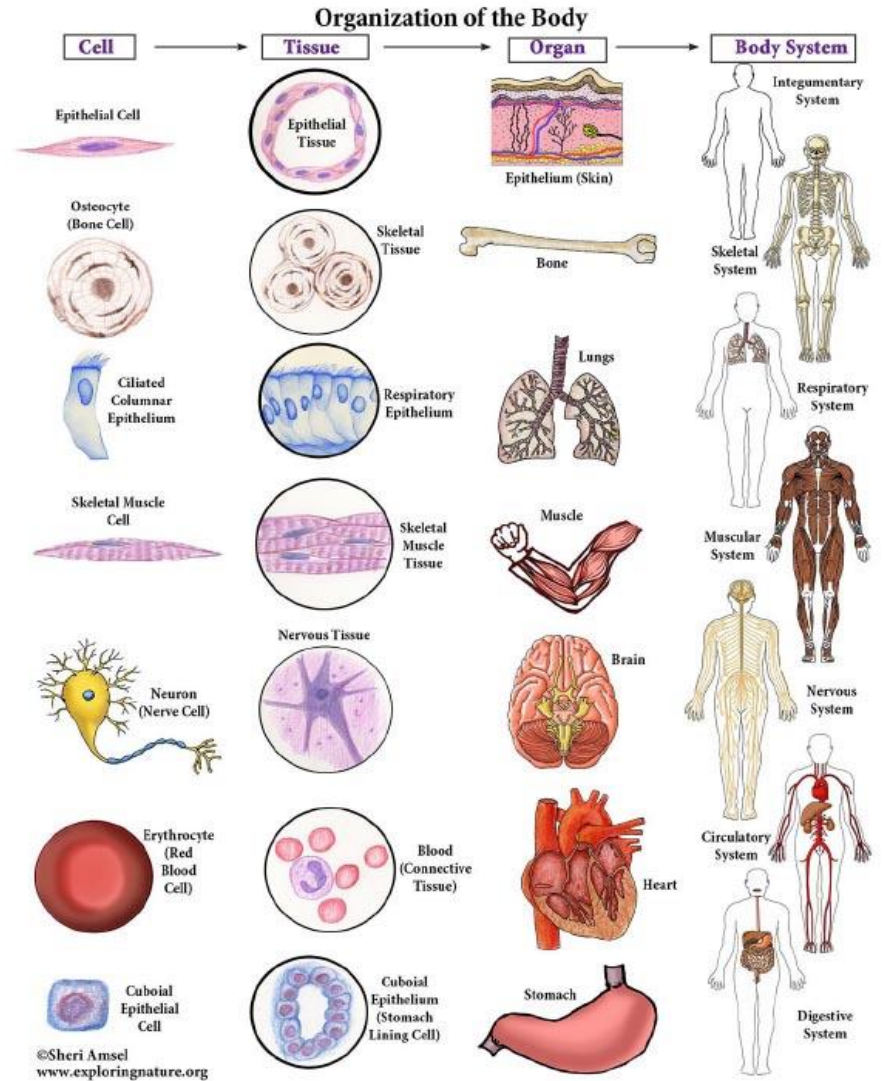
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Definition of tissue

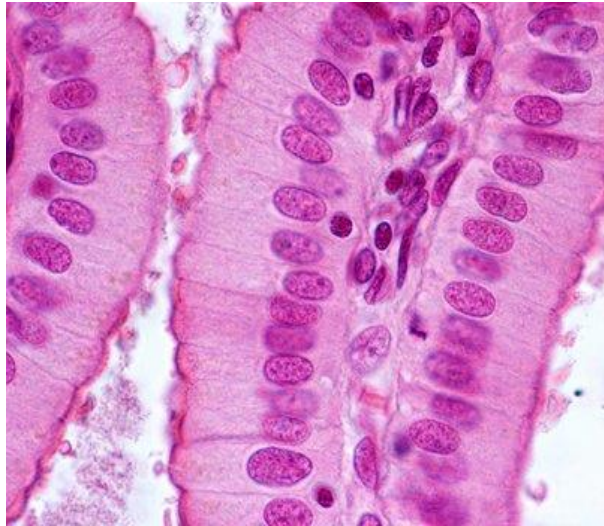
Tissue is an ensemble of similar cells and their extracellular matrix from the same origin that together carry out a specific function. Organs are then formed by the functional grouping together of multiple tissues.

In biology, **tissue** is a cellular organizational level between cells and a complete organ.

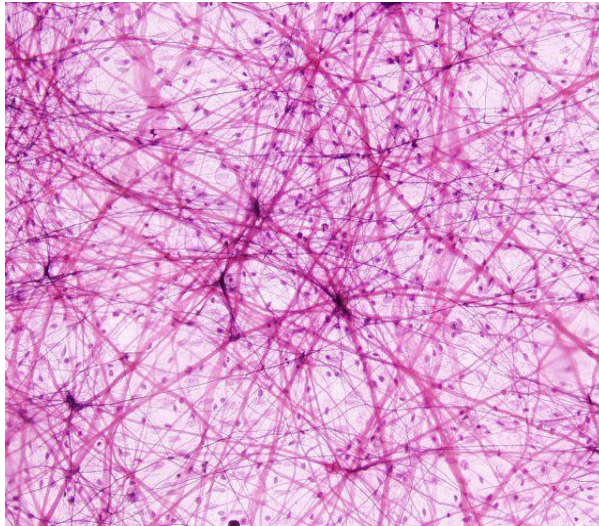


Types of tissues

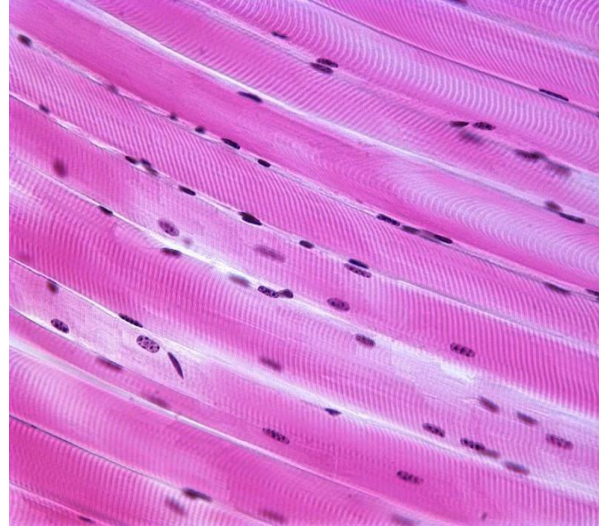
Epithelial tissue



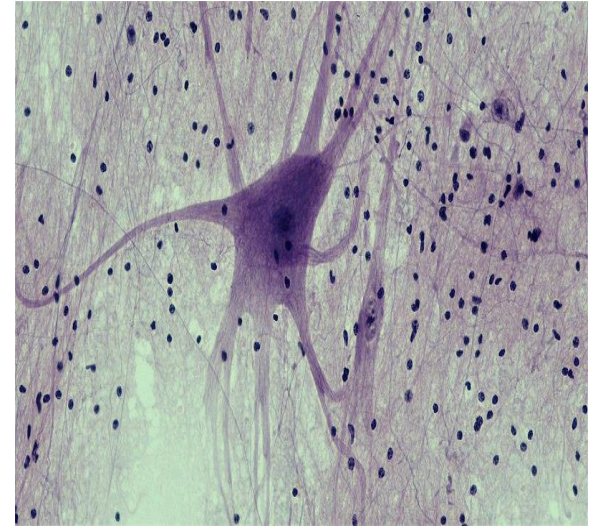
Connective tissue



Muscle tissue



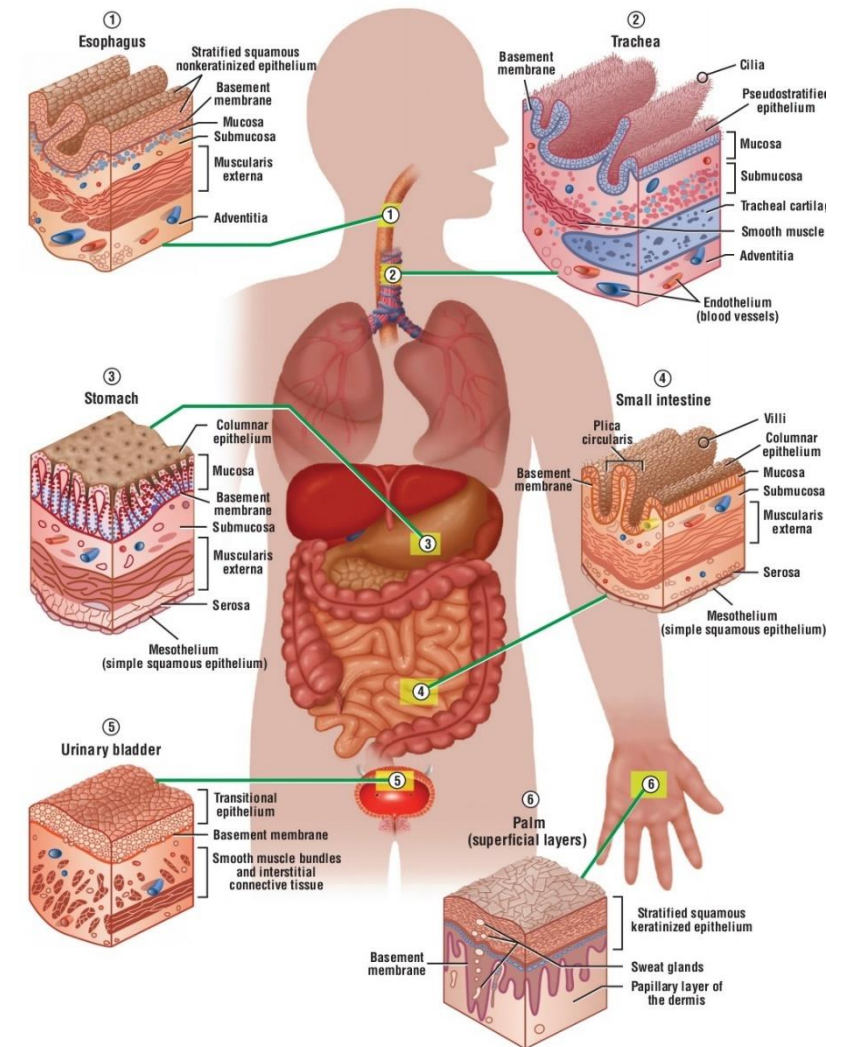
Nervous tissue



Epithelial tissue

Epithelial tissue forms boundaries between different compartments in body, and nearly all substances must pass through the epithelium. It lines the outer surfaces of organs and blood vessels throughout the body, as well as the inner surfaces of cavities in many internal organs. Epithelial tissue is composed of cells laid together in sheets with the cells tightly connected to one another.

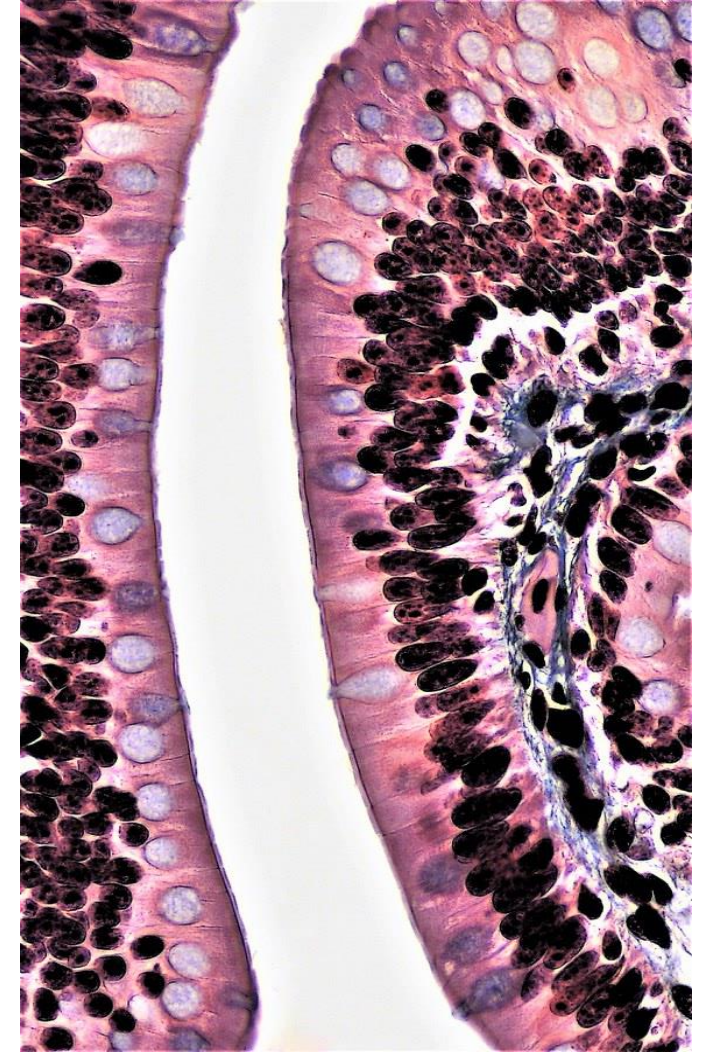
Epithelial tissues perform a variety of functions that include protection, secretion, absorption, excretion, filtration, diffusion, and sensory reception.



Epithelial tissue

Main characteristics of epithelia:

1. Epithelia have structural and functional **polarity**
2. In epithelial tissues **cell junctions** are especially abundant
3. Epithelial cells have almost no free **extracellular matrix (ECM)**
4. Epithelia are anchored to a **basement membrane**
5. Epithelial layers are **avascular**, but **innervated**. Nutrients are delivered by diffusion
6. Most epithelial cells renew continuously by **mitosis**
7. Epithelial tissue develops from the **ecto-, endo-** and **mesoderm**

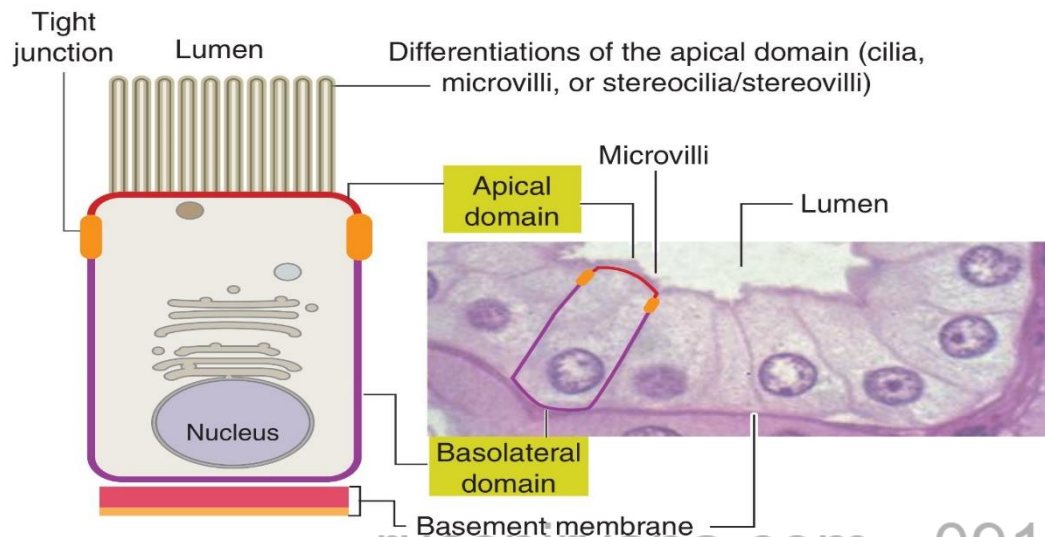


Simple columnar epithelium of intestine

Cells in epithelium

The **polarity** of the epithelium is manifested in the special structure of their cells. Two regions can be distinguished in epithelial cells:

- 1) **Apical domain** is exposed to the lumen or external environment. It has structures for the protection of the epithelial surface (e.g. cilia) or absorption of substances (e.g. microvilli)
- 2) **Basolateral domain** links neighboring cells to each other and to the basement membrane with special junctions. It facilitates directional transport functions prevented from trespassing the sealing junctions.

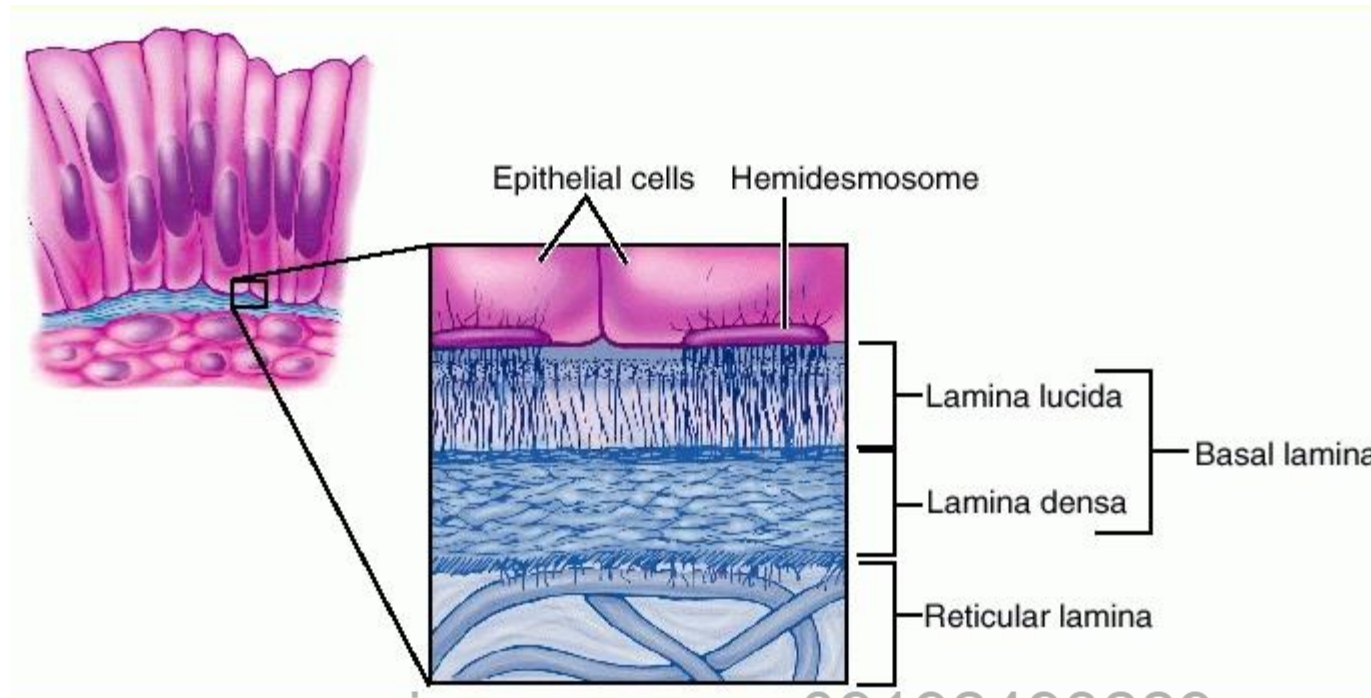


Ciliated epithelium of oviduct

Extracellular matrix in epithelium

The basement membrane is form of extracellular matrix that underlies all epithelia. It provides structural support to epithelia and forms a mechanical connection between epithelia and underlying connective tissue. The basement membrane also regulates the metabolism, proliferation, survival and differentiation of epithelial cells.

The basement membrane consists of two components: **the basal lamina** and **the reticular lamina**.



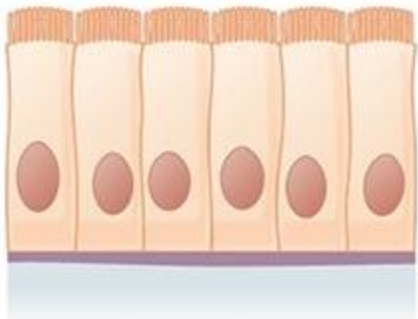
Types of epithelial tissues



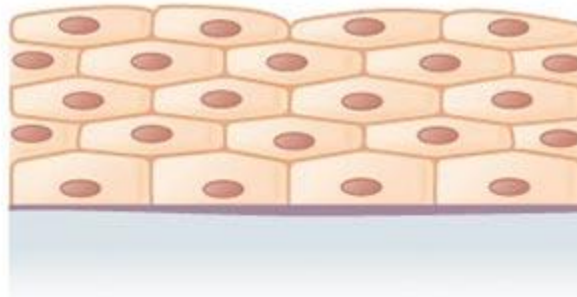
Simple squamous epithelium



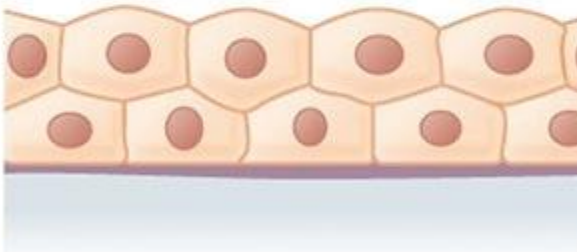
Simple cuboidal epithelium



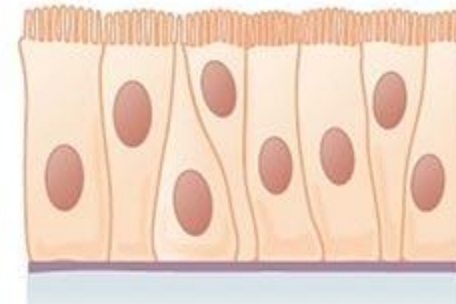
Simple columnar epithelium



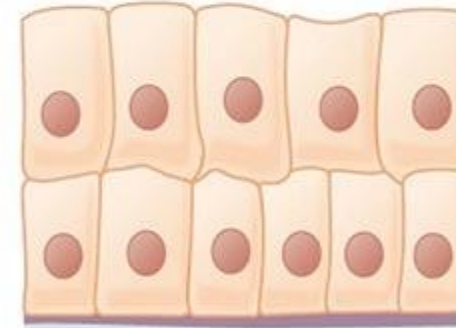
Stratified squamous epithelium



Stratified cuboidal epithelium



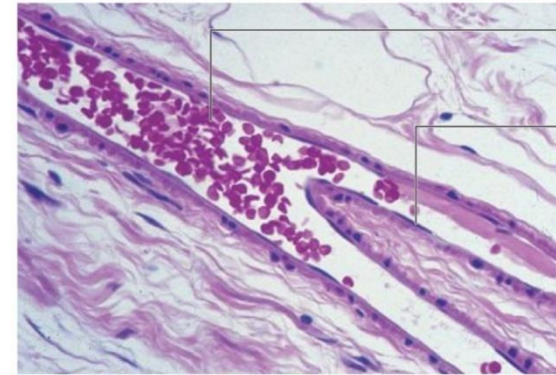
Pseudostratified columnar epithelium



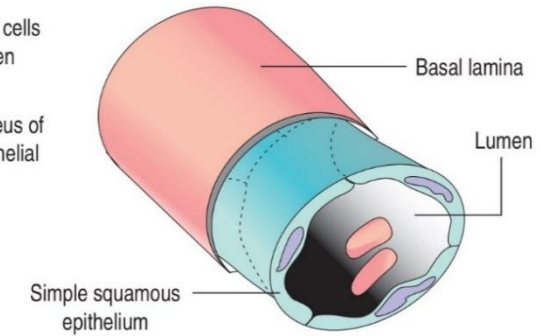
Stratified columnar epithelium

Simple epithelium

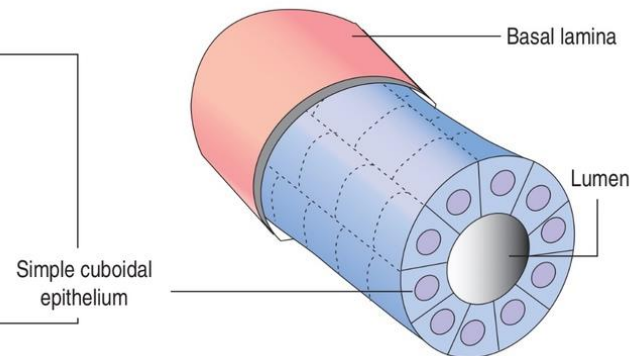
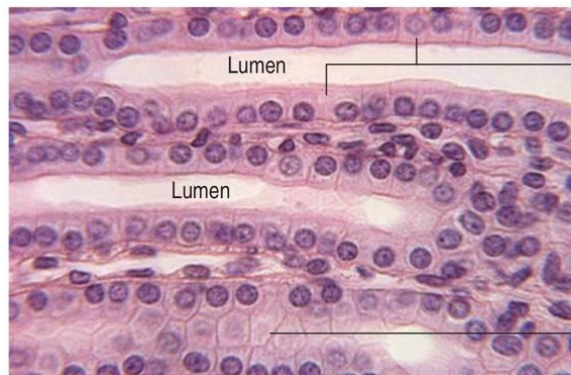
Simple epithelium is a single layer of cells with every cell in direct contact with the basement membrane that separates it from the underlying connective tissue.



Red blood cells in the lumen
Flat nucleus of an endothelial cell



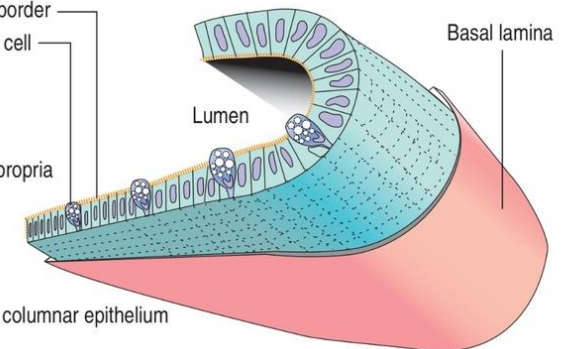
Simple squamous epithelium (endothelium)



Simple cuboidal epithelium (collecting tubule, kidney)



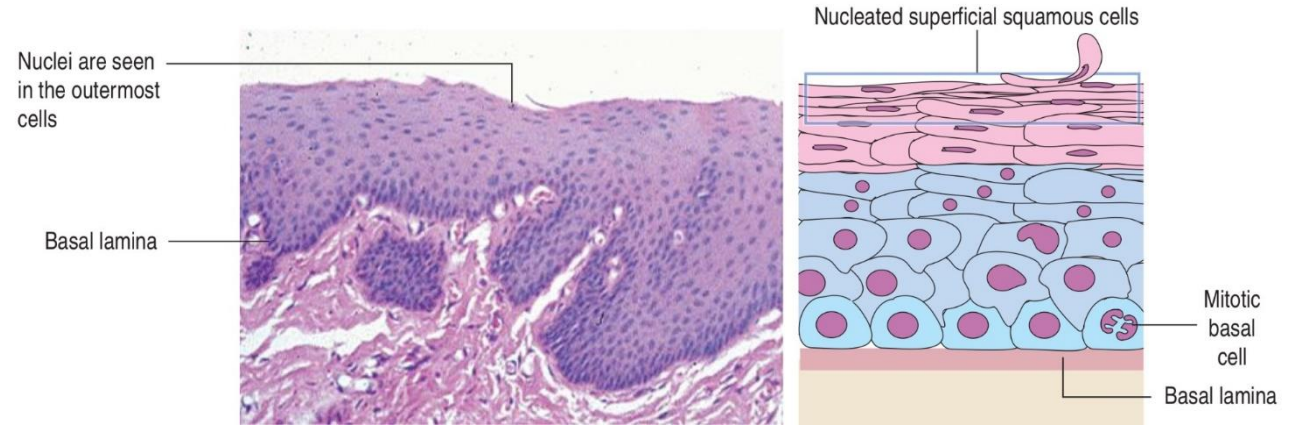
Brush border
Goblet cell
Lamina propria
Simple columnar epithelium



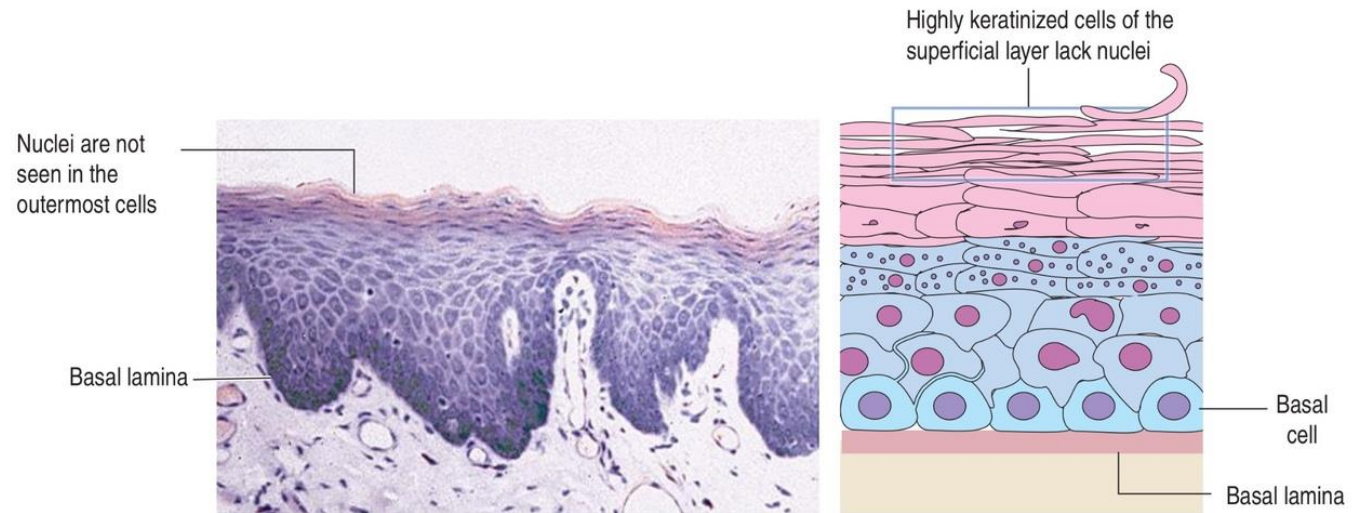
Simple columnar epithelium (small intestine)

Stratified epithelium

Stratified epithelium differs from simple epithelium in that it is multilayered. Cells flatten as the layers become more apical, though in their most basal layers, the cells can be squamous, cuboidal, or columnar.



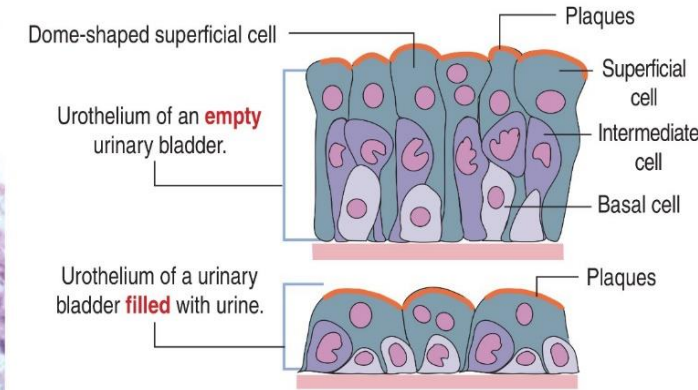
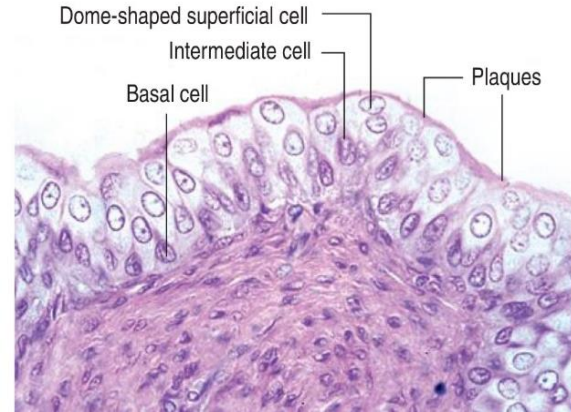
Stratified squamous epithelium with moderate keratin (esophagus)



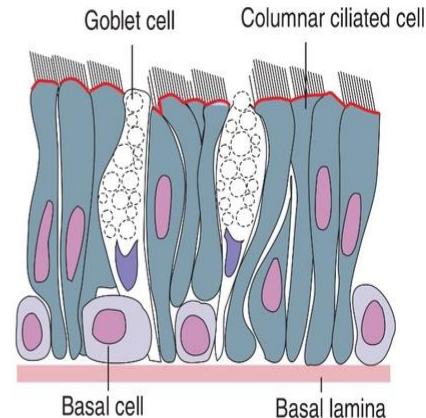
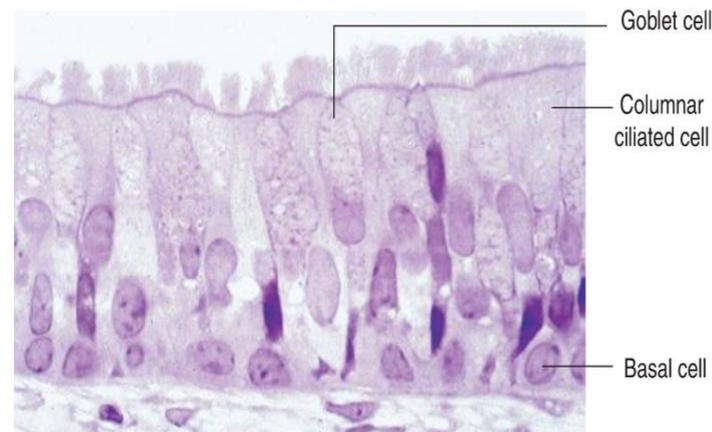
Stratified squamous epithelium with abundant keratin (epidermis)

Pseudostratified epithelium

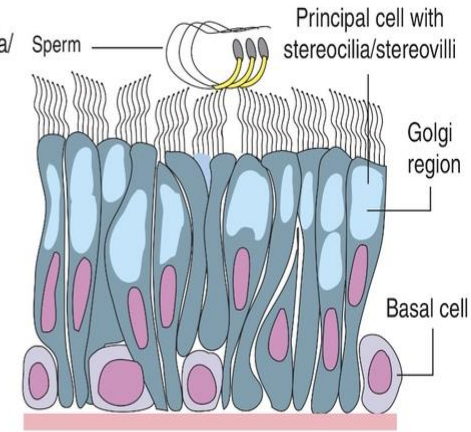
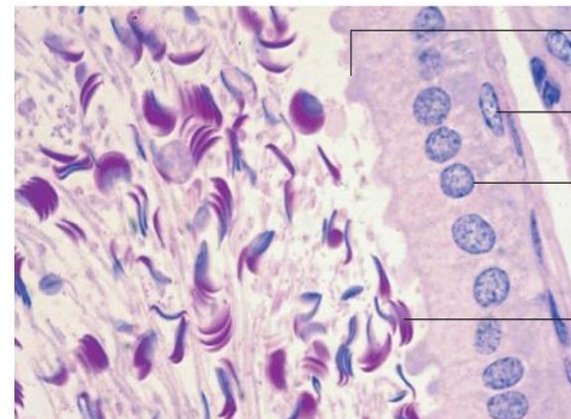
Pseudostratified epithelium consists of columnar epithelial cells whose nuclei appear at different heights, giving the misleading impression that the epithelium is stratified when the cells are viewed in cross section.



Urothelium (urinary bladder)

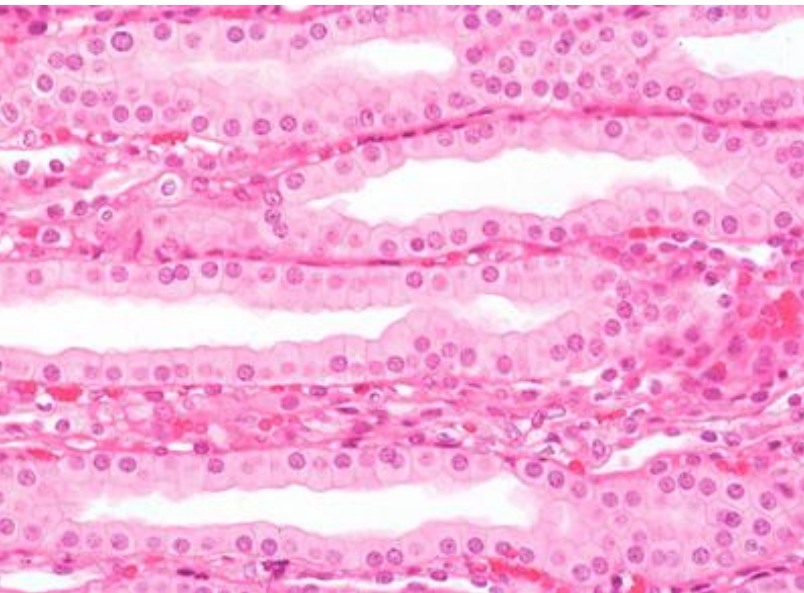


Pseudostratified columnar epithelium with cilia (trachea)

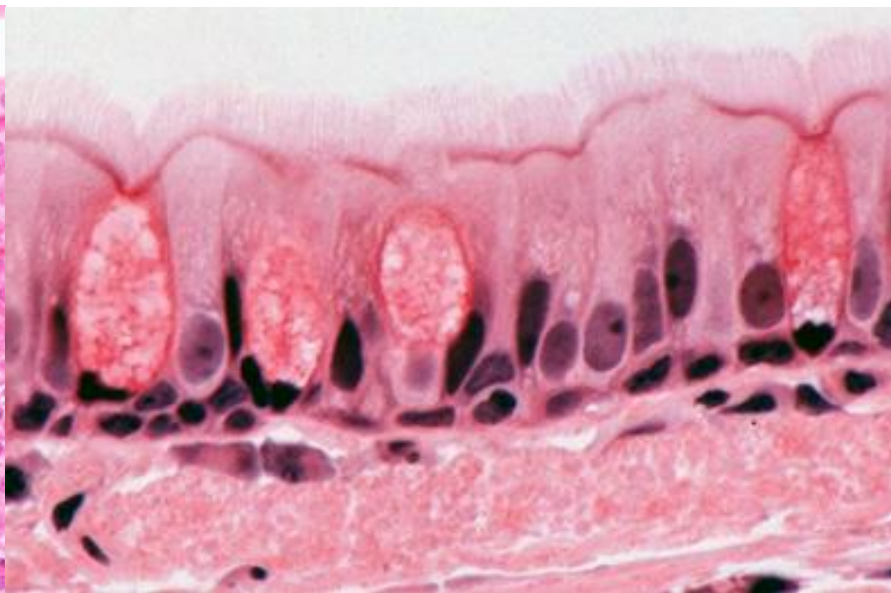


Pseudostratified columnar epithelium with stereocilia (epididymis)

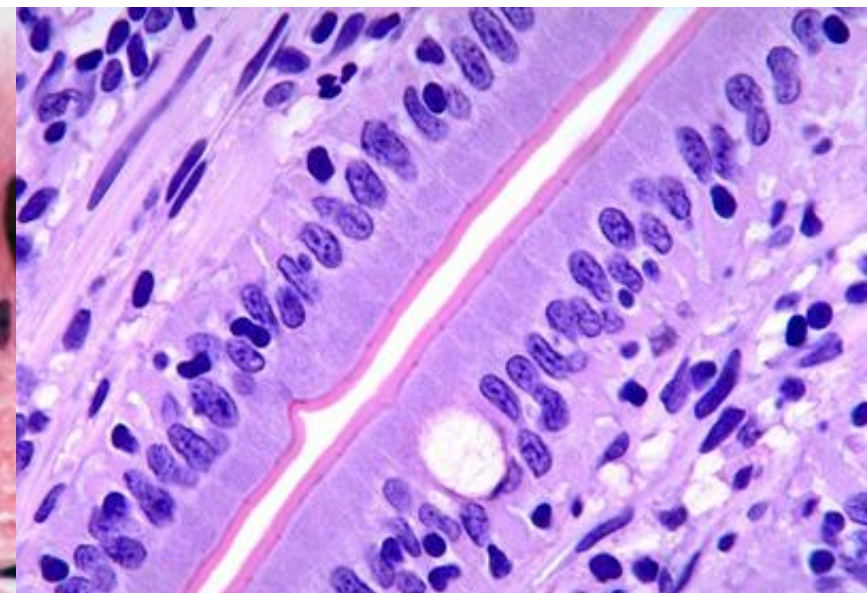
You have 6 pictures on the next slides. You have to determine what types of epithelium these pictures correspond to.



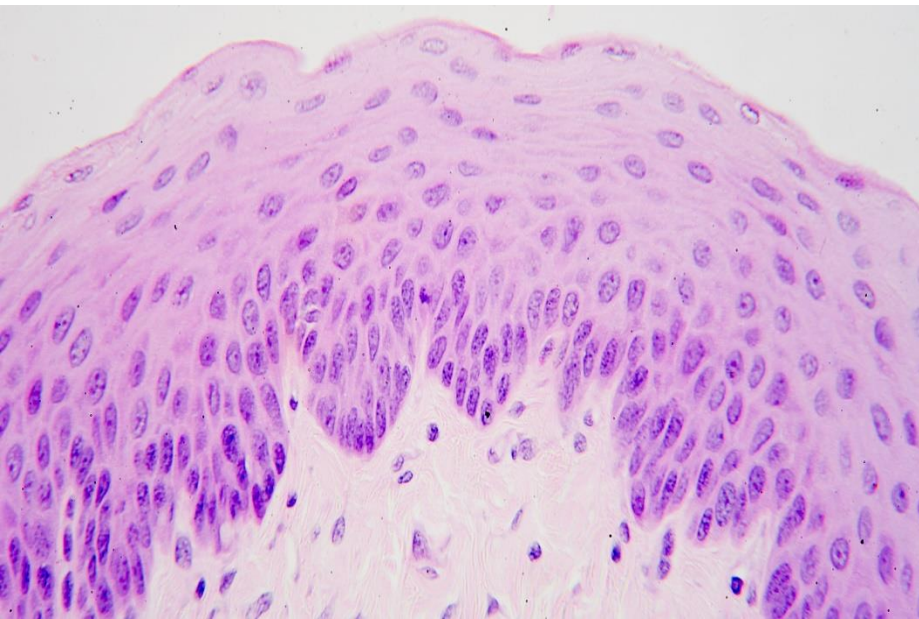
Picture 1



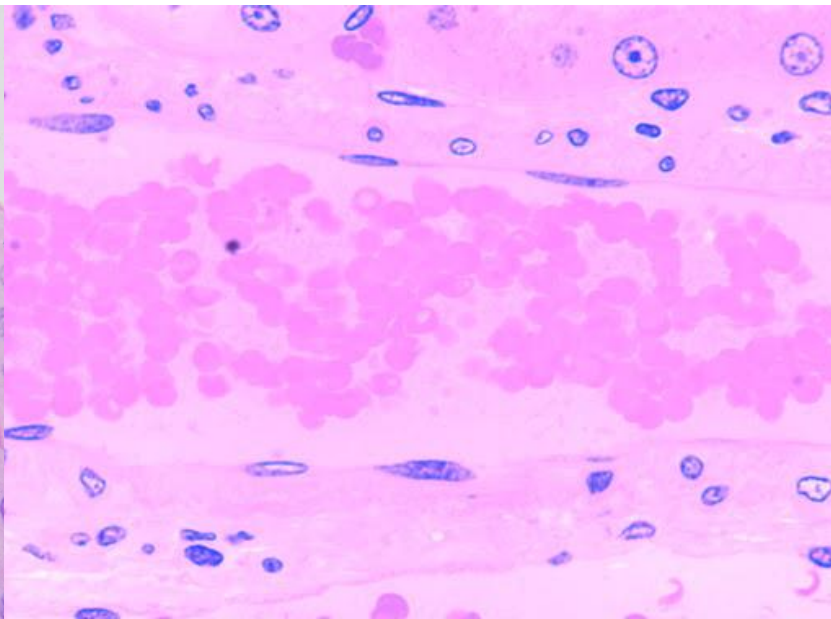
Picture 2



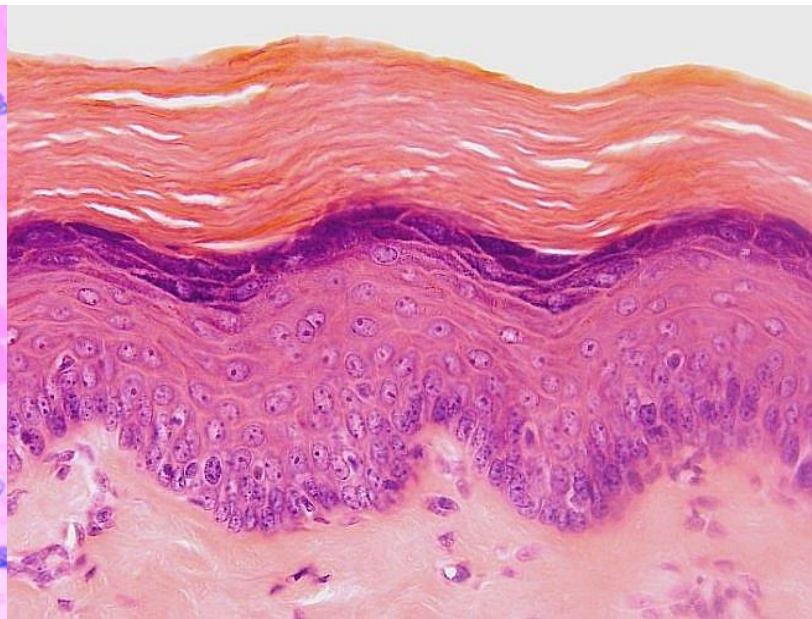
Picture 3



Picture 4



Picture 5

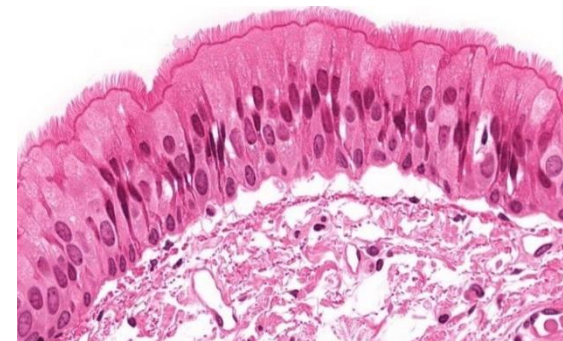
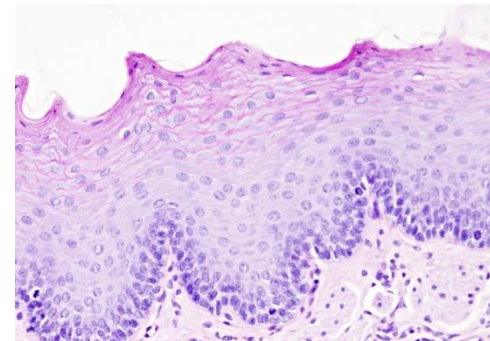
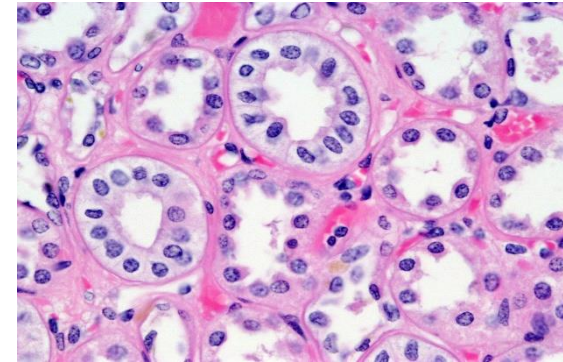
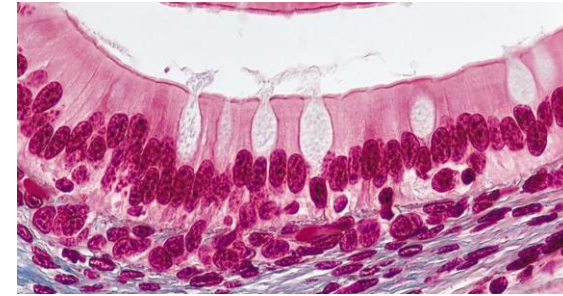


Picture 6

Classwork

You have to draw pictures from the following micrographs:

1. **General structure of epithelial cell (small intestine)**
2. **Simple columnar epithelium (small intestine)**
3. **Simple cuboidal epithelium (renal tubule)**
4. **Stratified squamous non-keratinized epithelium (esophagus)**
5. **Pseudostratified columnar ciliated epithelium (trachea)**

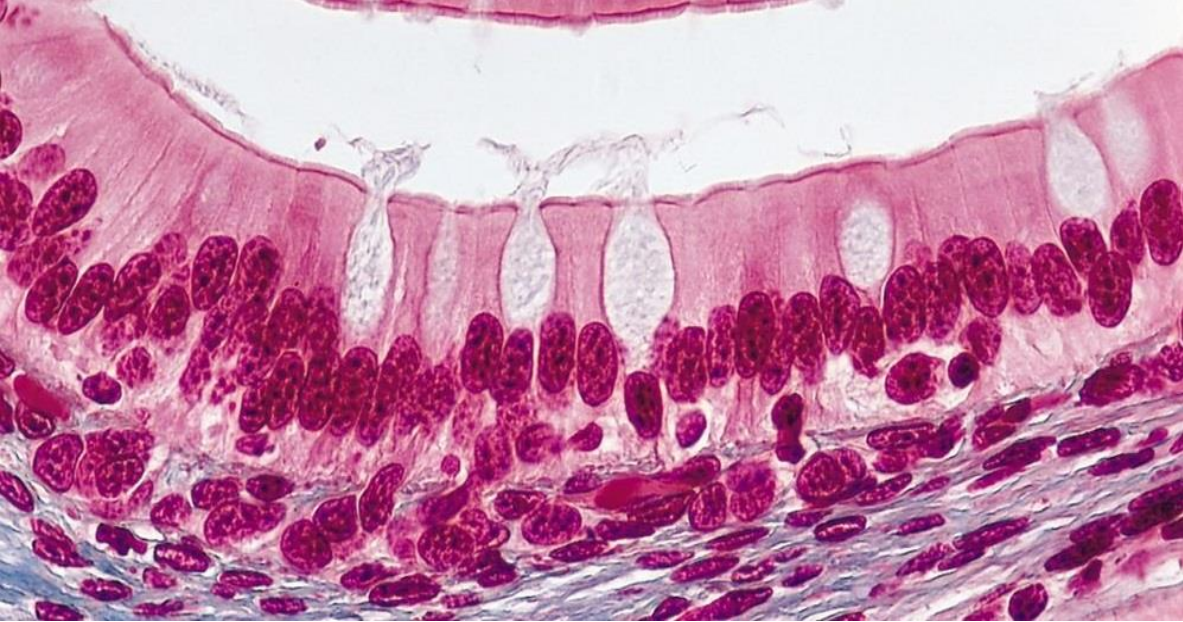




What should be marked:

1. Apical domain of the cell
2. Basolateral domain of the cell
3. Microvilli
4. Nucleus
5. Mitochondria
6. Vesicles
7. Basement membrane
8. Lumen of intestine

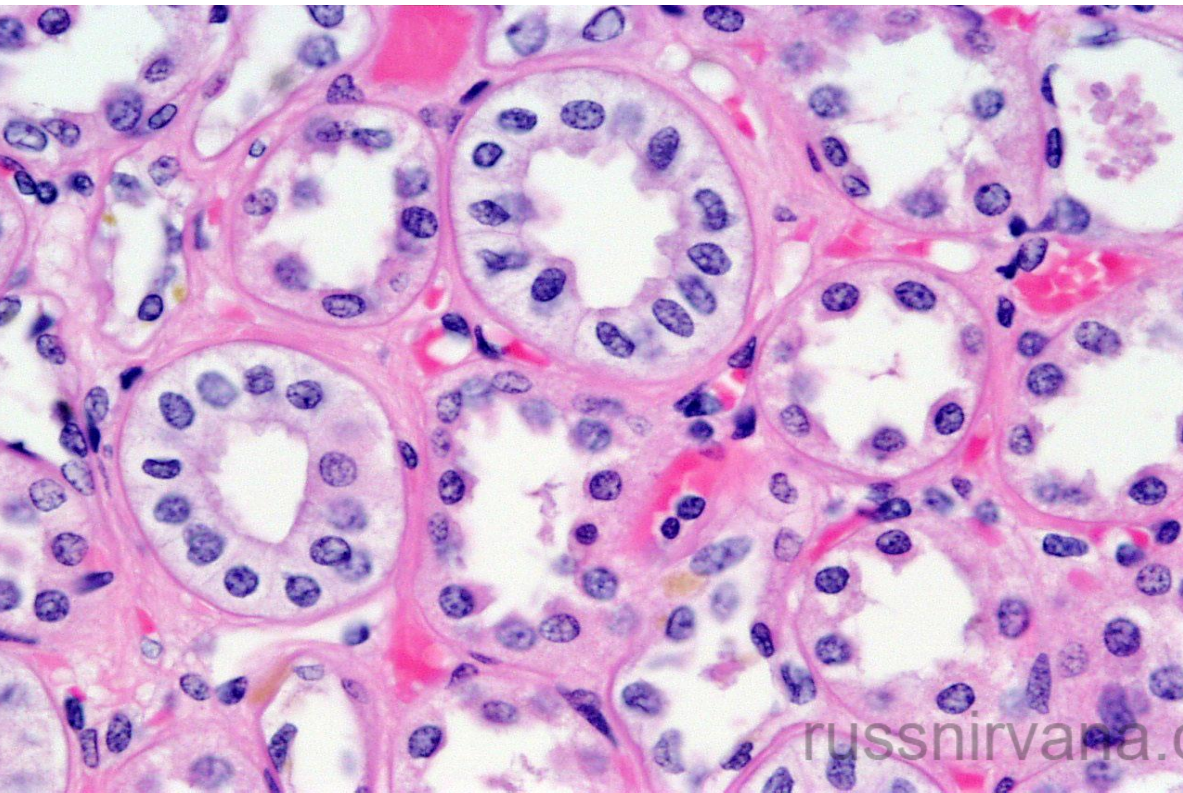
Picture 1: General structure of epithelial cell in small intestine (TEM micrograph)



What should be marked:

1. Absorptive cells
2. Goblet cells
3. Microvilli
4. Nuclei
5. Basement membrane
6. Lumen of intestine

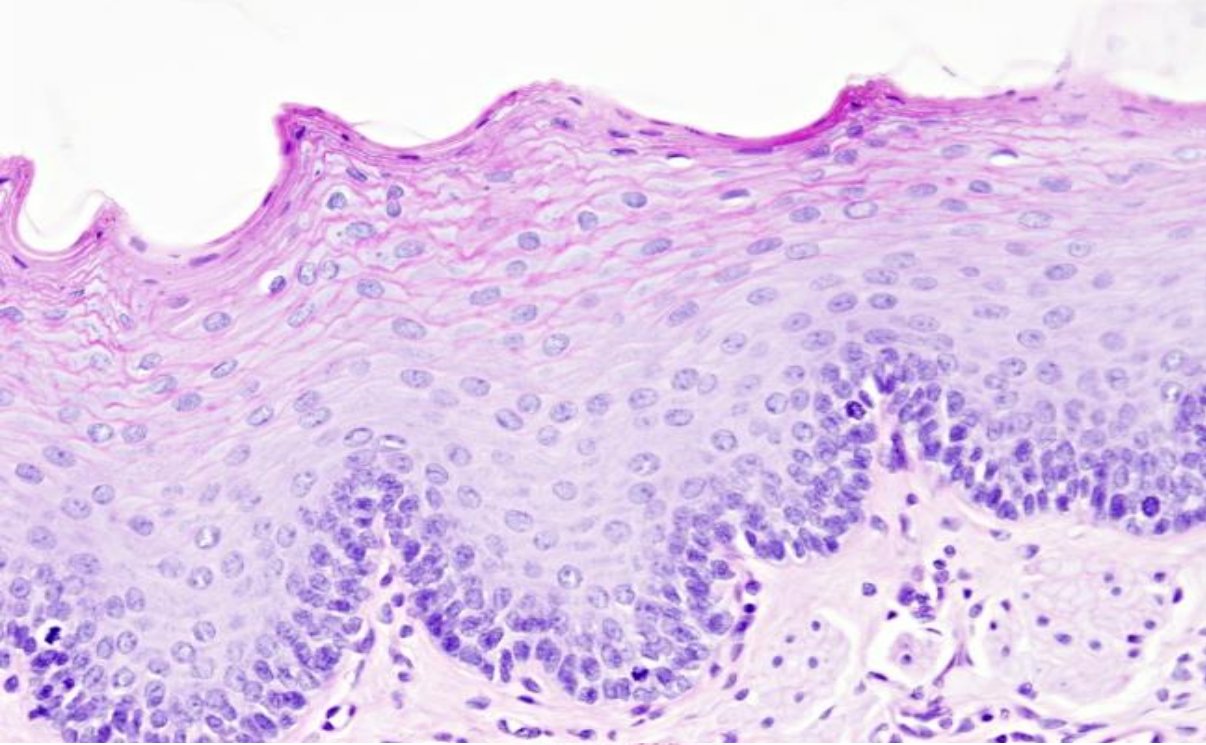
Picture 2: Simple columnar epithelium in small intestine (light micrograph, Mallory's stain)



What should be marked:

1. Renal cells
2. Nuclei
3. Basement membrane
4. Lumen of renal tubule

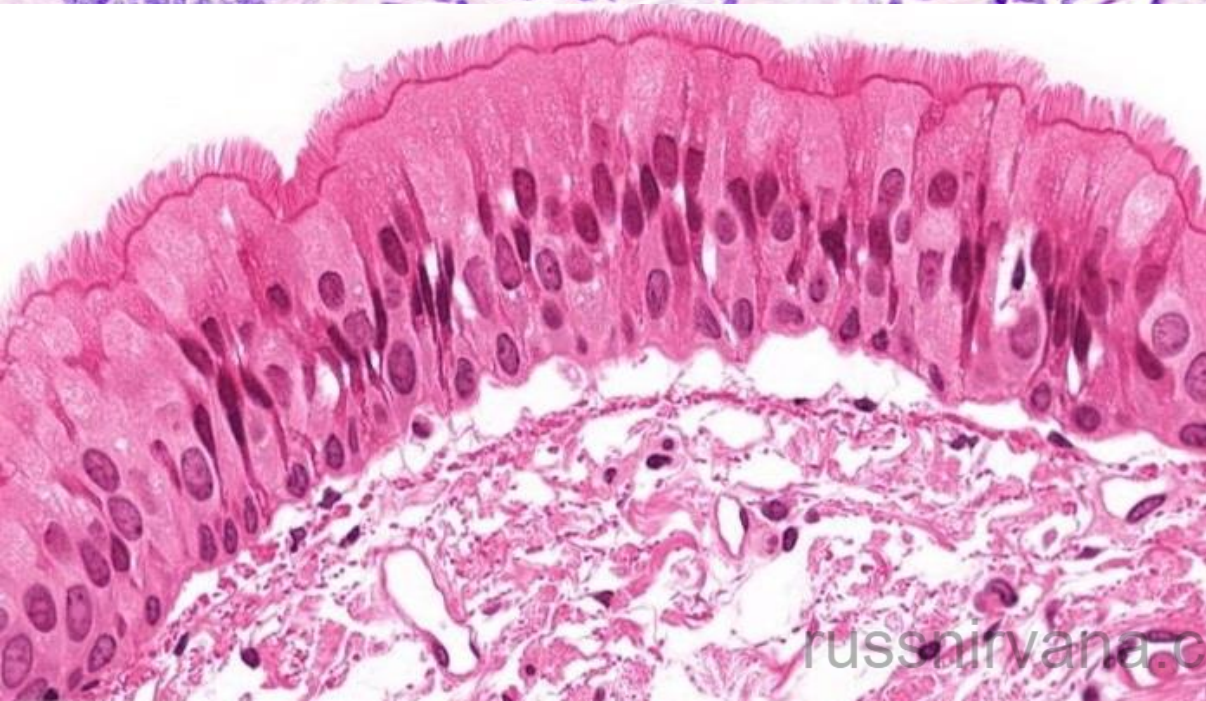
Picture 3: Simple cuboidal epithelium in renal tubules (light micrograph, hematoxylin-eosin stain)



What should be marked:

1. Stratum spinosum (intermediate and superficial cells)
2. Stratum basale (basal cells)
3. Nuclei
4. Basement membrane
5. Lumen of esophagus

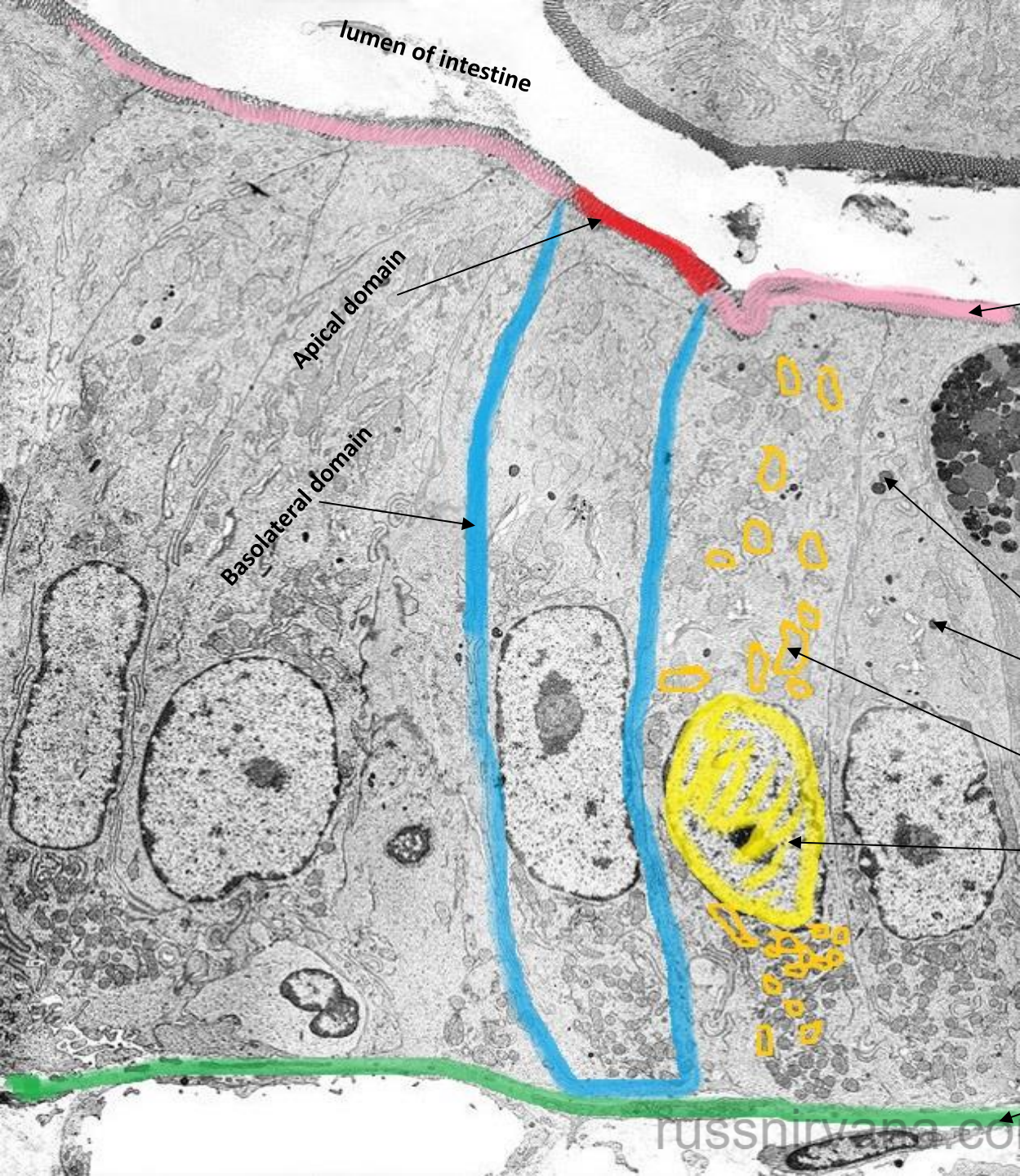
Picture 5: Stratified squamous non-keratinized epithelium in esophagus
(light micrograph, hematoxylin-eosin stain)



What should be marked:

1. Columnar ciliated cells
2. Basal cells
3. Cilia
4. Nuclei
5. Basement membrane
6. Lumen of trachea

Picture 5: Pseudostratified columnar ciliated epithelium in trachea
(light micrograph, Mallory's stain)



lumen of intestine

Apical domain

Basolateral domain

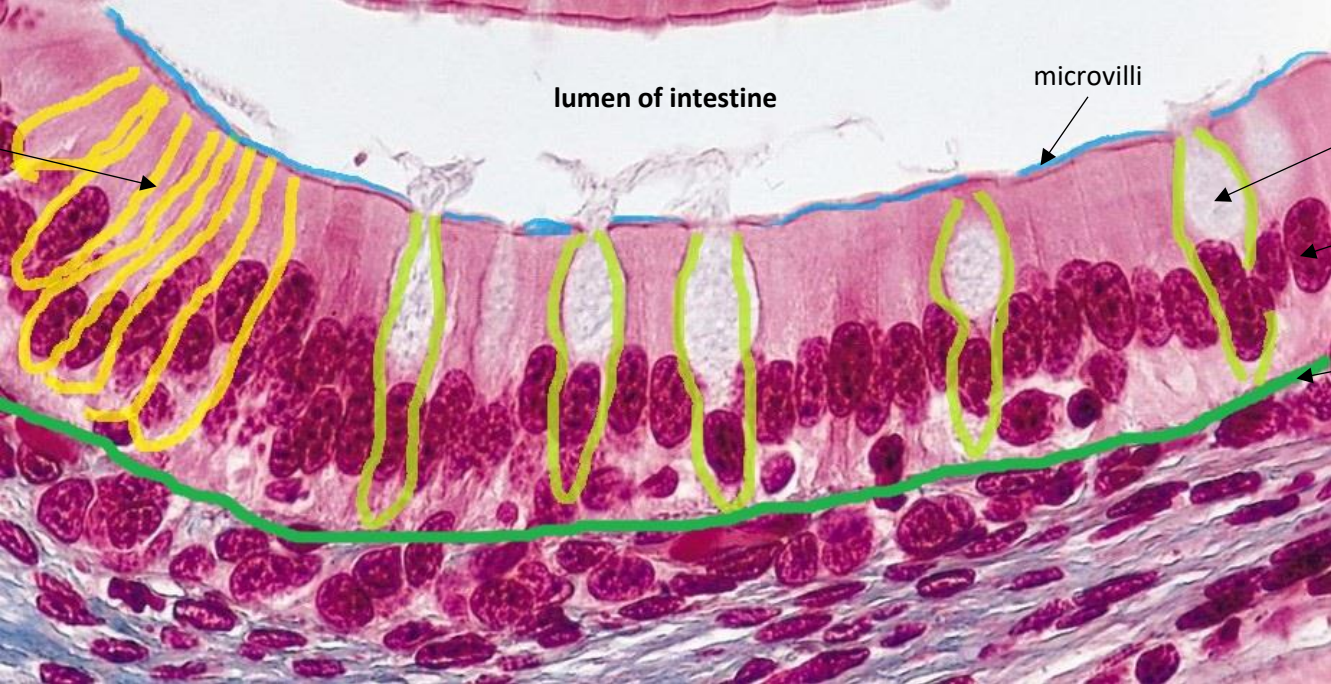
microvilli

vesicles

mitochondria

nucleus

Basement membrane



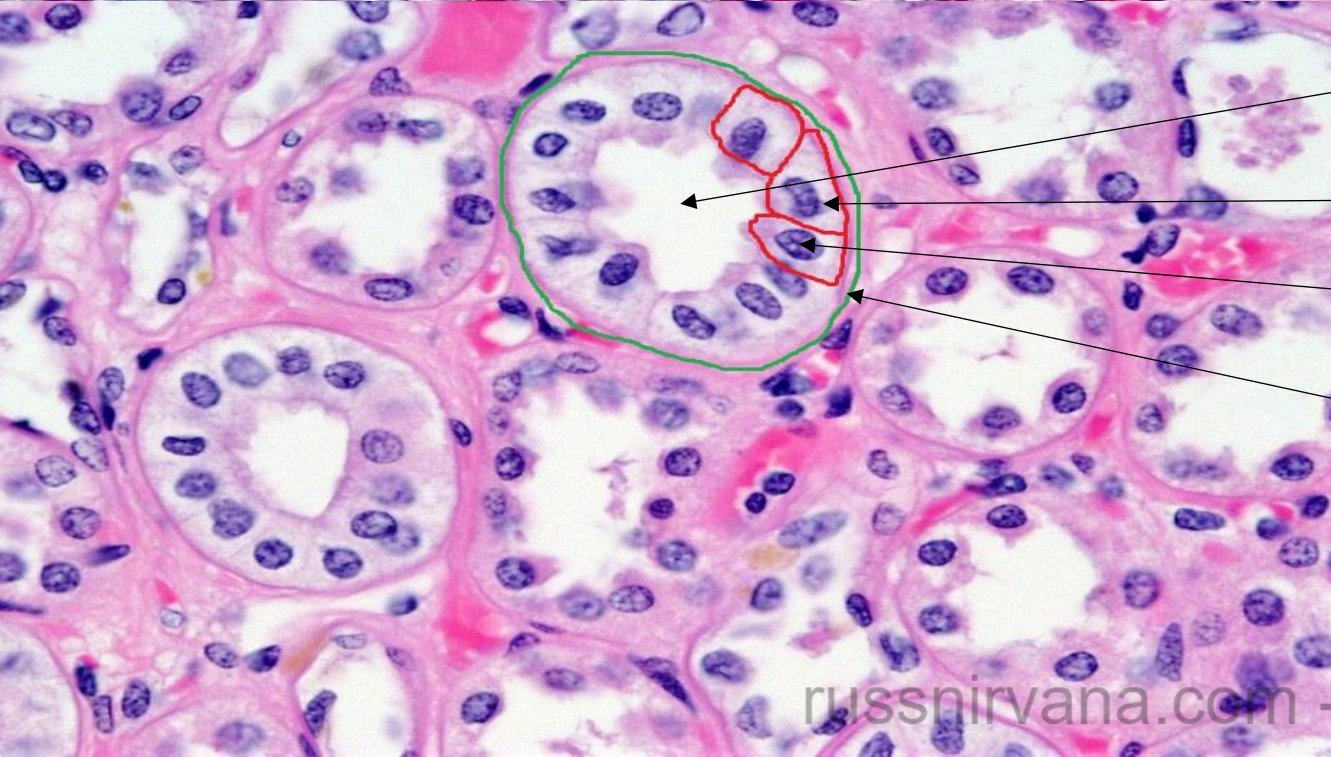
lumen of intestine

microvilli

goblet cells

nucleus

basement membrane

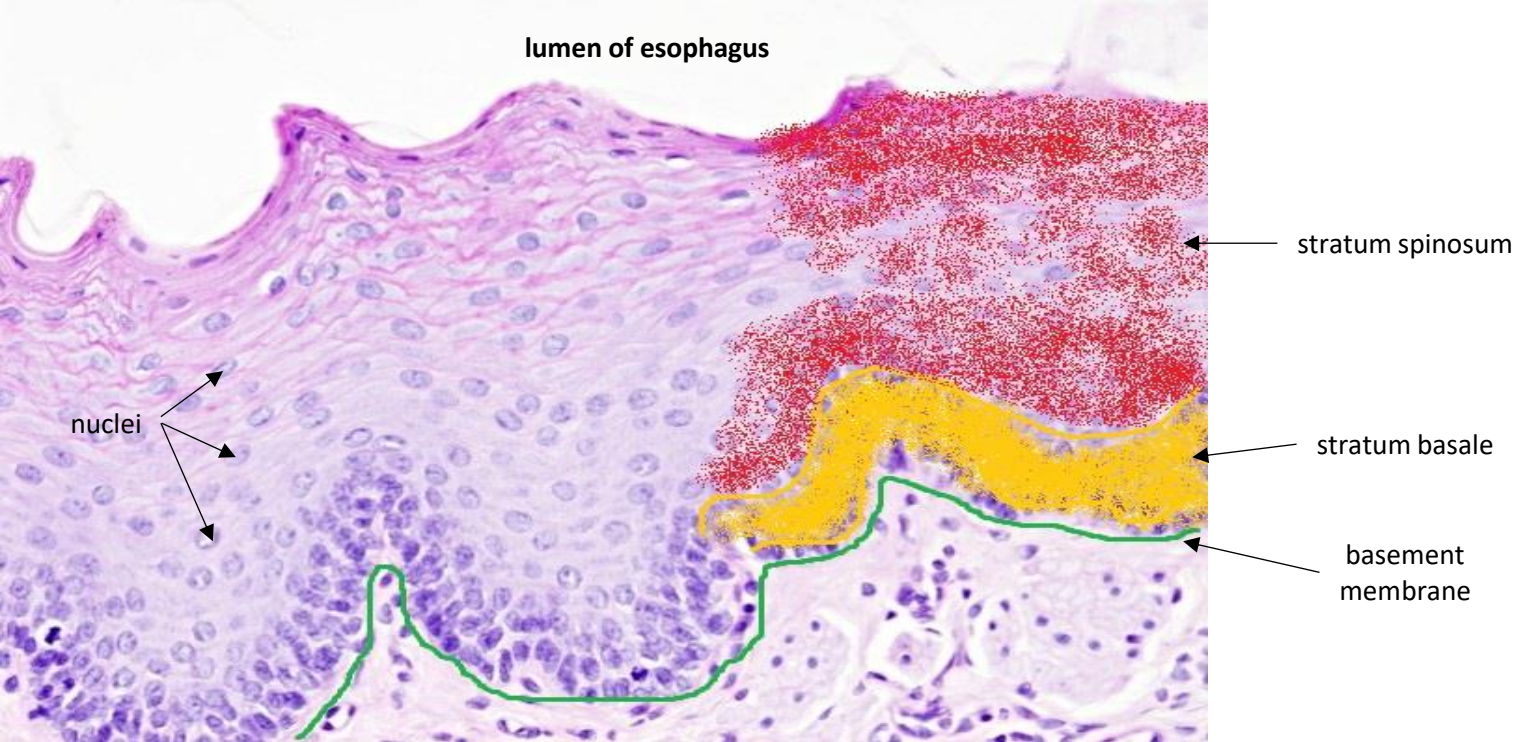


lumen of renal tubule

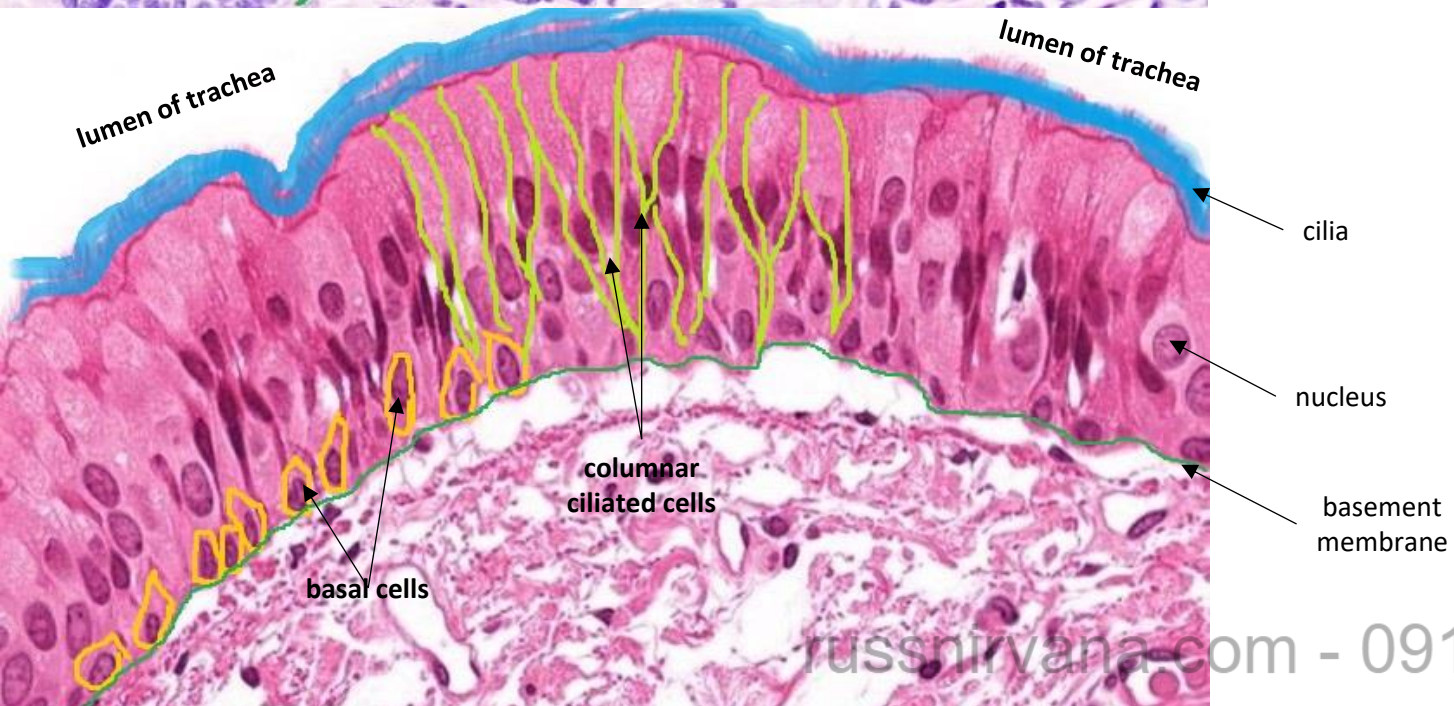
renal cells

nucleus

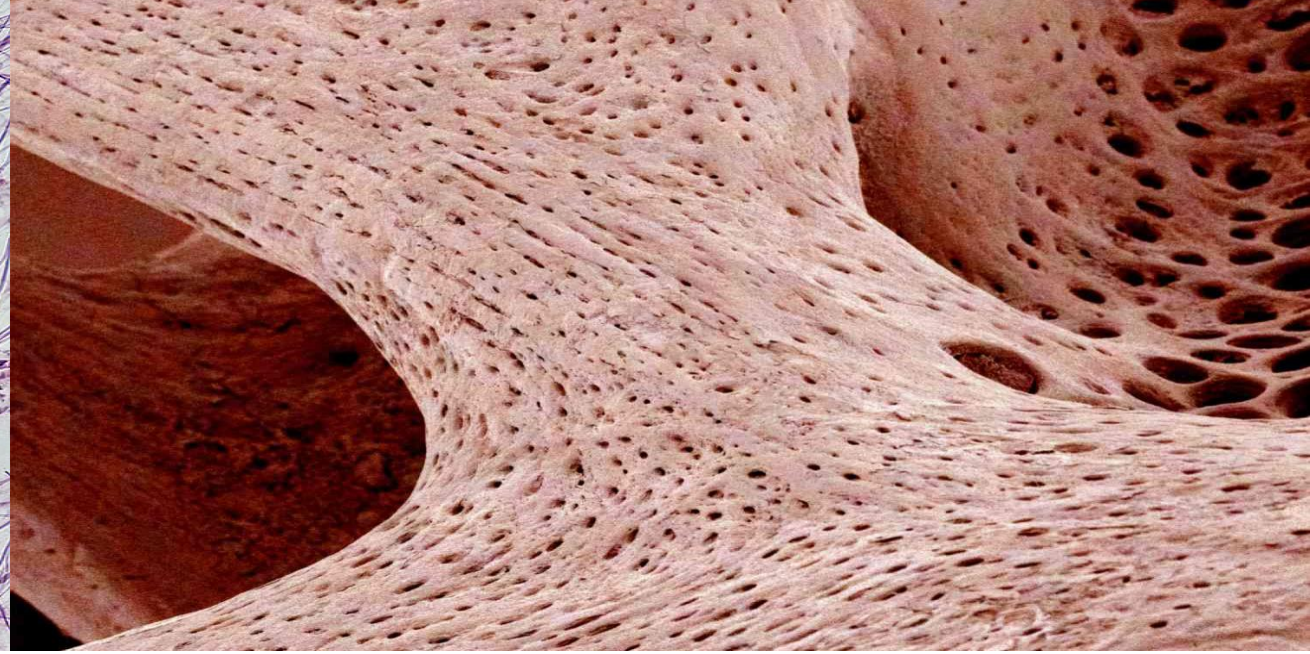
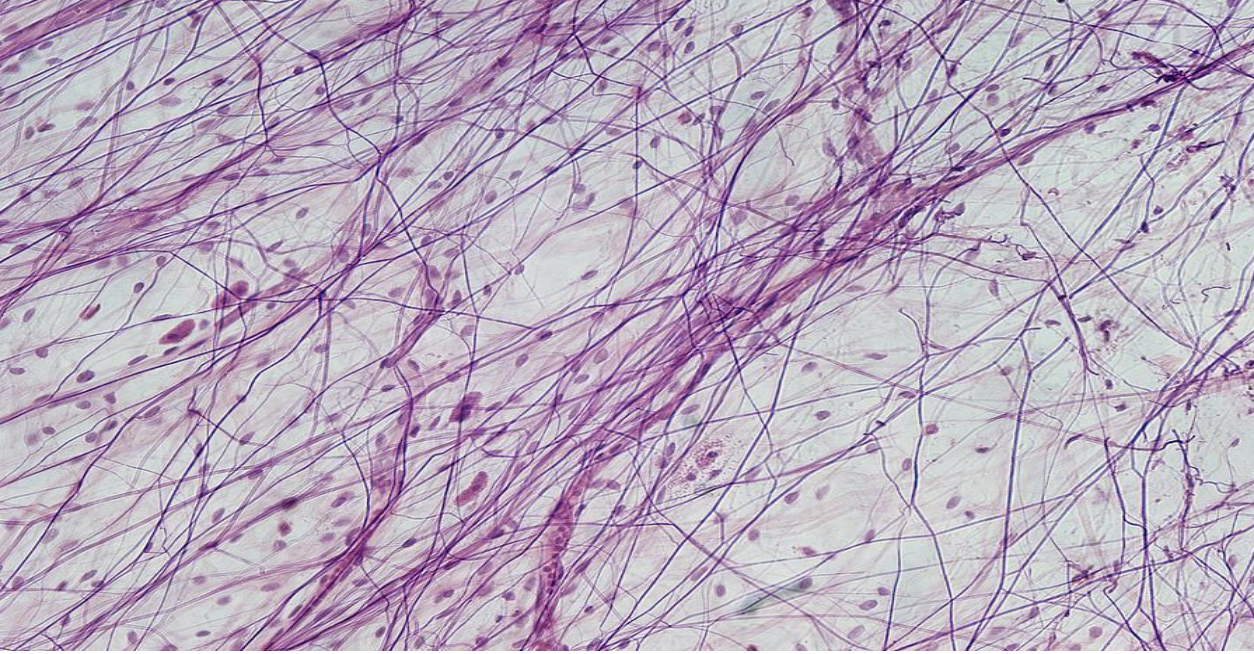
basement membrane



We can't see basement membrane in this photo, but you have to show it in your drawing as line under basal surface of epithelium



We can't see basement membrane in this photo, but you have to show it in your drawing as line under basal surface of epithelium



Lesson III. Connective tissue

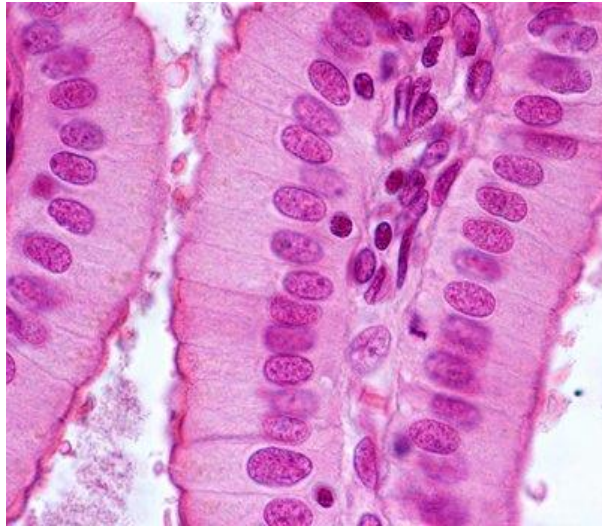
Kazan Federal University

2021

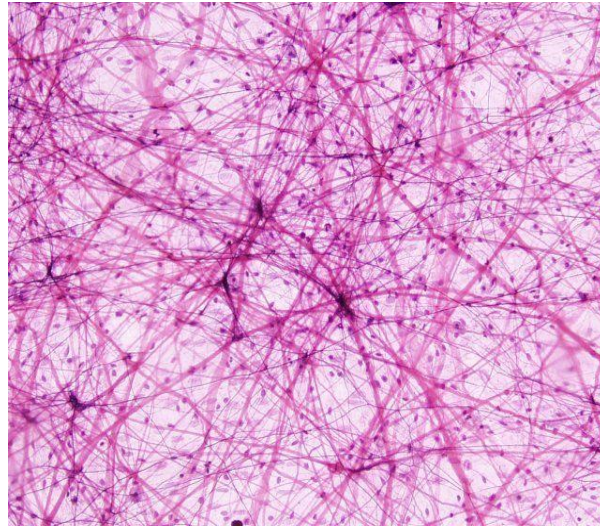
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Types of tissues

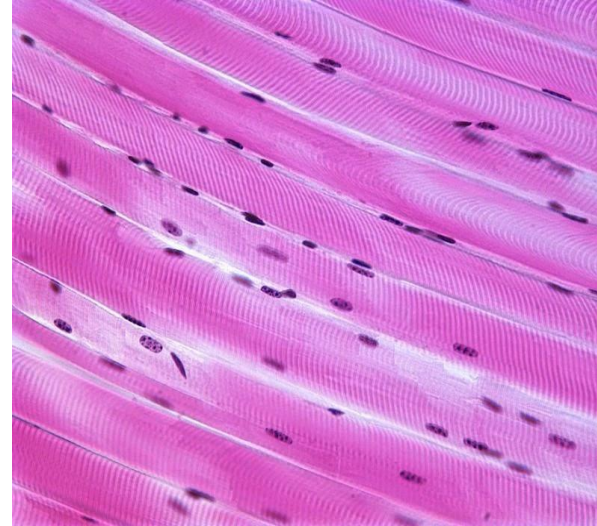
Epithelial tissue



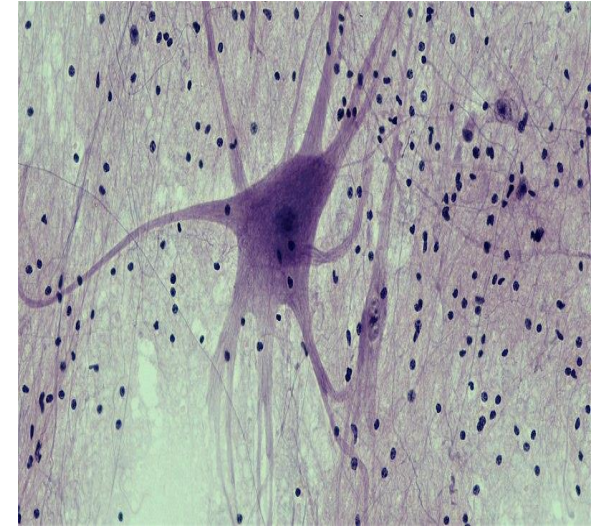
Connective tissue



Muscle tissue



Nervous tissue

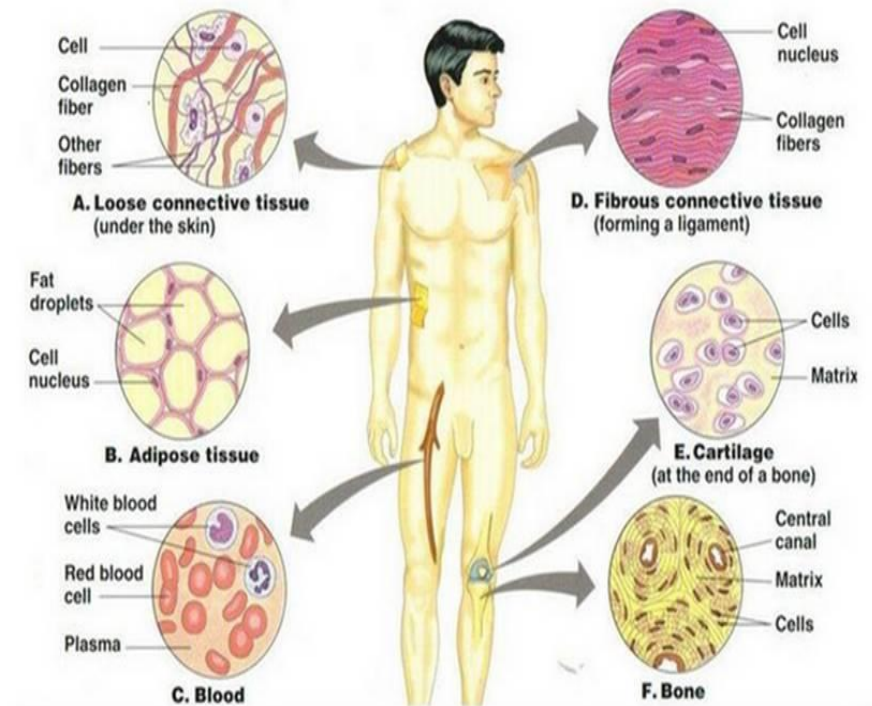


Connective tissue

Connective tissue supports and physically connects other tissues and cells together to form the organs of the body. The interstitial fluid of connective tissue gives metabolic support to cells as the medium for diffusion of nutrients and waste products. Unlike the other tissue types (epithelium, muscle, and nerve), which consist mainly of cells, the major constituent of connective tissue is the **extracellular matrix (ECM)**.

Connective tissue has a wide variety of functions that depend on the types of cells and extracellular matrix. It has important roles in binding and supporting, protecting, insulating, storing reserve fuel and transporting substances within the body.

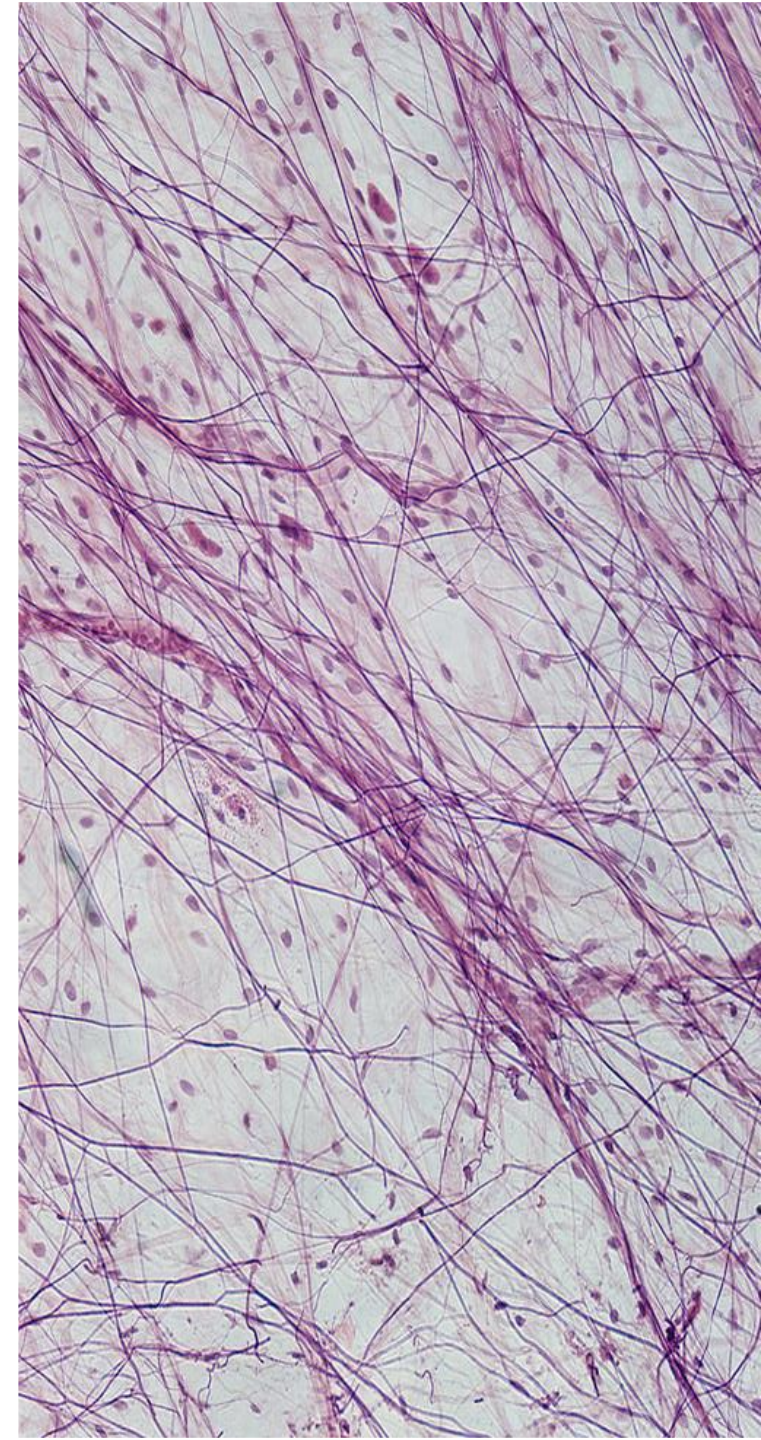
Connective tissue



Connective tissue

Main characteristics of connective tissue:

1. Connective tissue is the most abundant and widely distributed of the primary tissues
2. Connective tissue has three main components: **cells**, **fibers** and **ground substance**. Together the ground substance and fibers make up the **extracellular matrix**
3. Connective tissue is usually **vascular** and **innervated**. It can have various levels of vascularity.
4. Most connective tissue cells renew continuously by **mitosis**
5. Connective tissue develops from the **mesoderm**



Types of connective tissue

Ordinary connective tissue

Special connective tissue

Loose

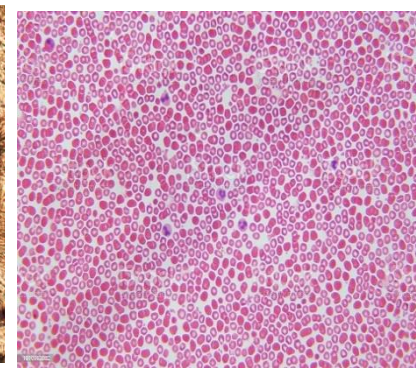
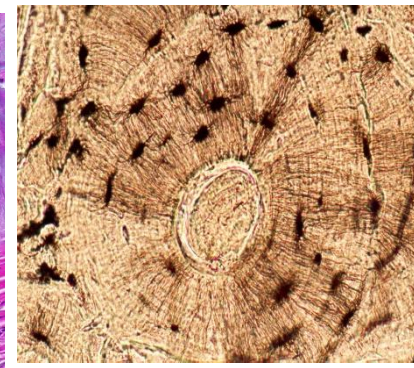
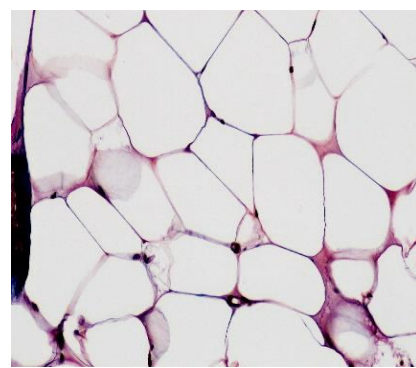
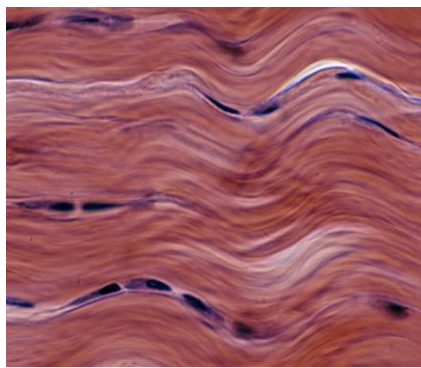
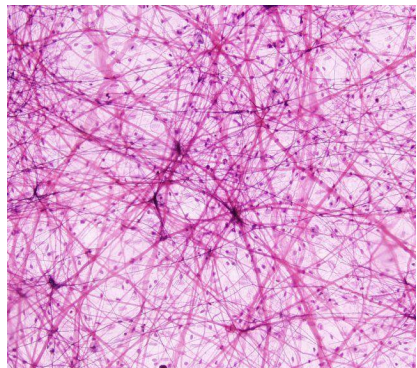
Dense

Adipose

Cartilage

Bone

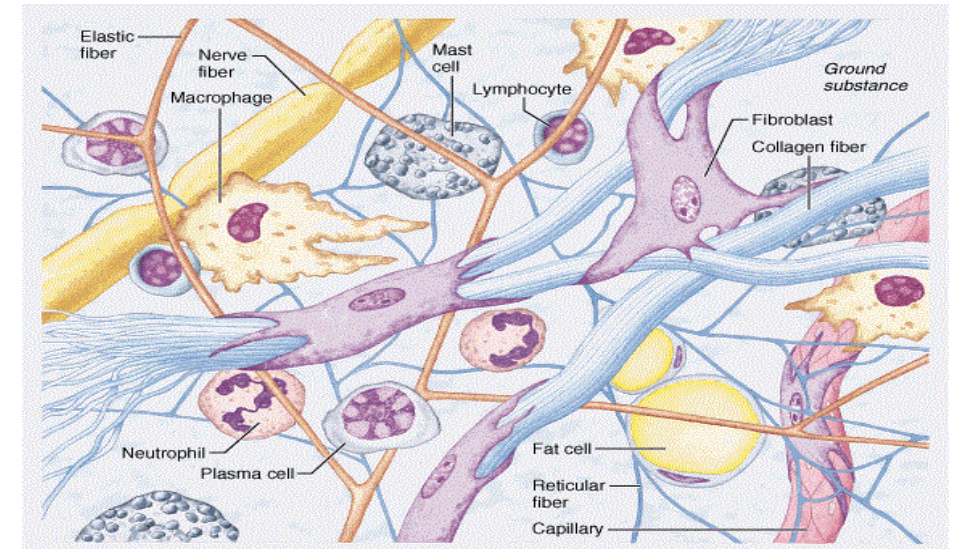
Blood



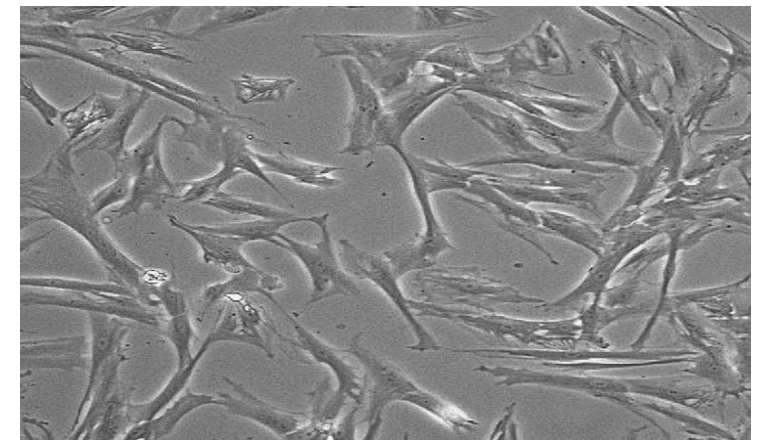
Cells in ordinary connective tissue

Cells in ordinary connective tissue are widely separated from each other by the extracellular matrix. They include relatively stationary cells (**fibroblasts, adipocytes**) and motile migrating cells (**mast cells, macrophages, monocytes, lymphocytes, plasma cells, eosinophils**).

The most common cells are **fibroblasts** - large, flattened cells with elliptical nuclei. The cell shape often appears stellate with long cytoplasmic processes. Fibroblasts produce and maintain most of the tissue's extracellular components.



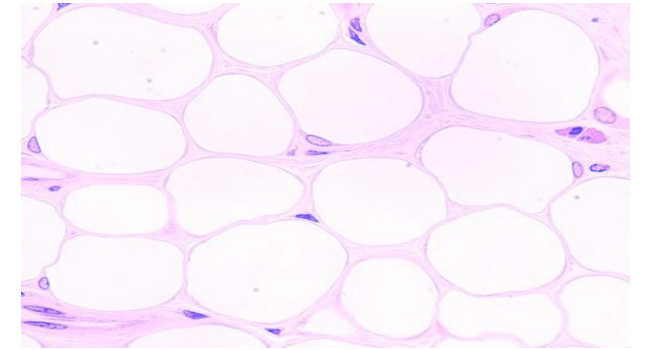
Cell types of loose connective tissue



Fibroblasts

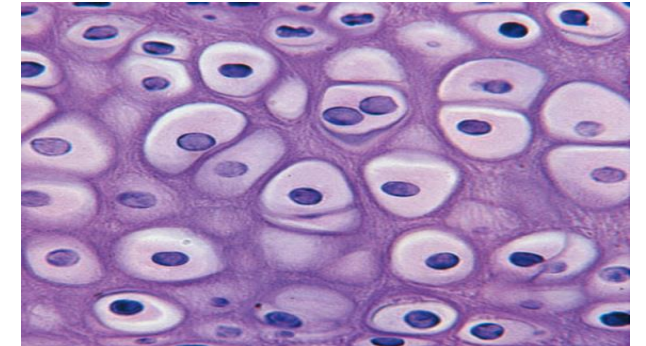
Cells in special connective tissue

Adipocytes are the cells that form the adipose tissue, and they have the ability of synthesizing and storing large lipid droplets in the cytoplasm. Adipocytes are usually found in large and dense groups .



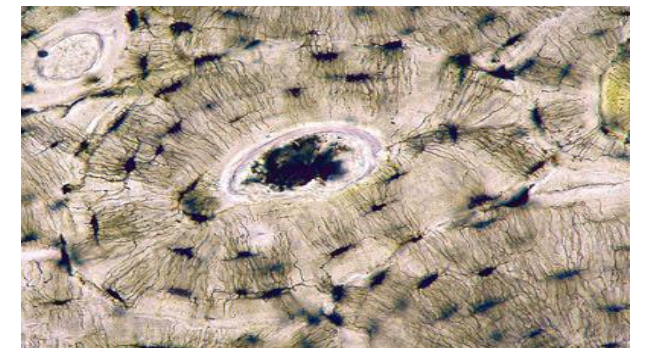
Adipocytes

Chondrocytes form the cartilage tissue, they are usually found in couples or tetrads (**isogenous groups**) and located in extracellular matrix cavities (**lacunae**). Unlike osteocytes, chondrocytes are not connected by cytoplasmic processes.



Chondrocytes

Osteocytes are the most abundant cell type in the bone. They are locked in extracellular matrix cavities (**lacunae**) and connected to each other by cytoplasmic extensions, which form tunnels (**canaliculi**) inside extracellular matrix.



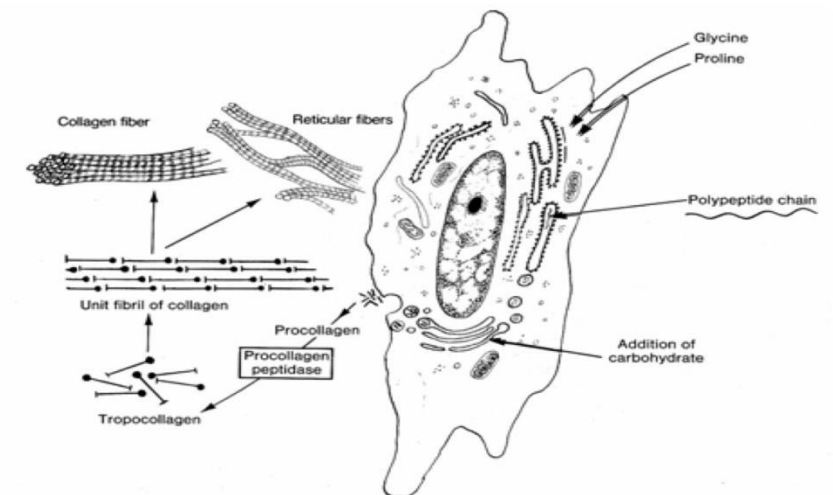
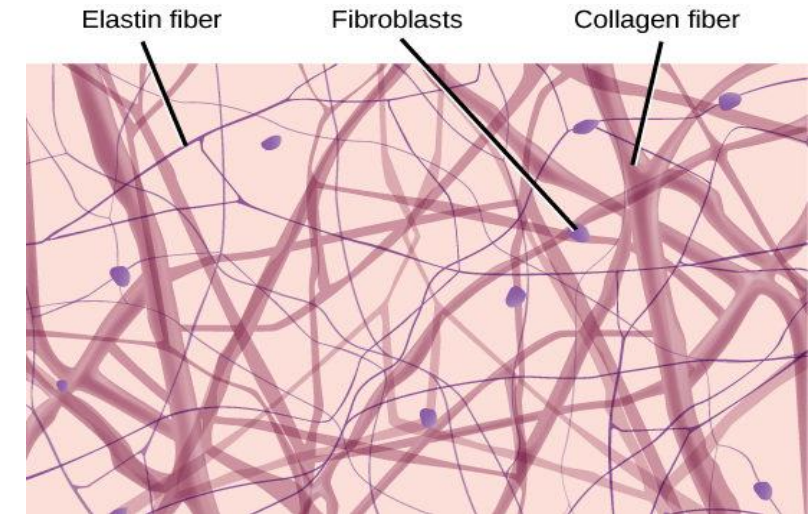
Osteocytes

Extracellular matrix in connective tissue

Extracellular matrix consists of different combinations of **fibers** and **ground substance**. The type and proportion of components in the ECM set the structural, mechanical and biochemical properties of the different connective tissues.

Ground substance is amorphous material in which cells and fibers are embedded. It is a complex of anionic, hydrophilic organic molecules (carbohydrates or complexes of proteins and carbohydrates). Water in ground substance allows the exchange of nutrients and metabolic wastes between cells.

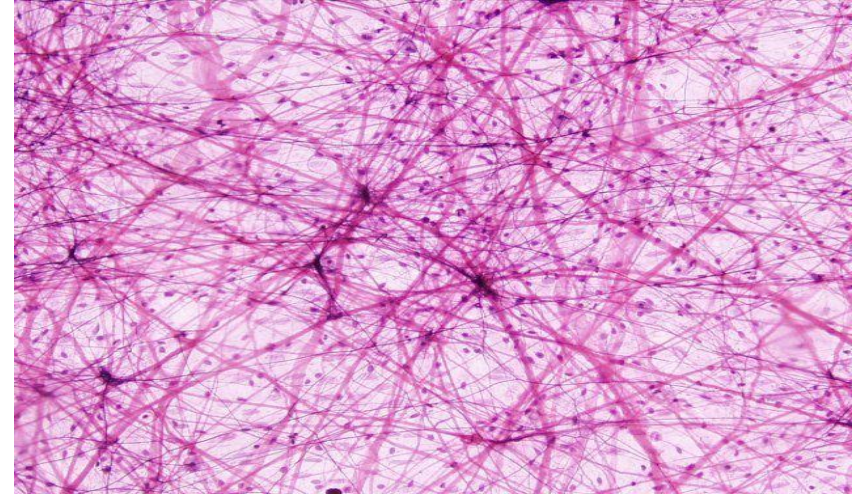
The fibrous component are elongated structures formed from proteins that polymerize after secretion from fibroblasts. The tree main types of fibers include **collagen**, **reticular** and **elastic fibers**.



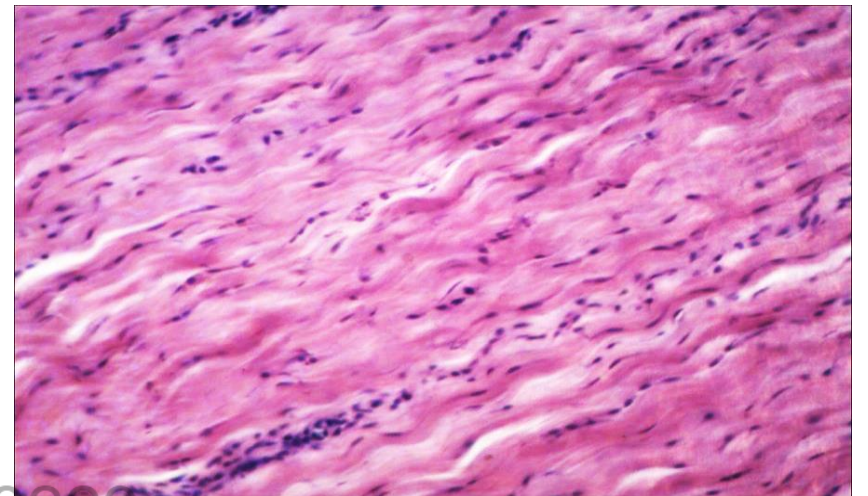
Formation of collagen by fibroblast

Ordinary connective tissue

Loose connective tissue contains cells, fibers and ground substance in roughly equal parts. Collagen fibers predominate, but elastic and reticular fibers are also present. With high or moderate amount of ground substance, loose connective tissue has a delicate consistency, it is flexible and not very resistant to stress.



Dense connective tissue has similar components, but with fewer cells and a clear predominance of collagen fibers over ground substance. The abundance of collagen here protects organs and strengthens them structurally.

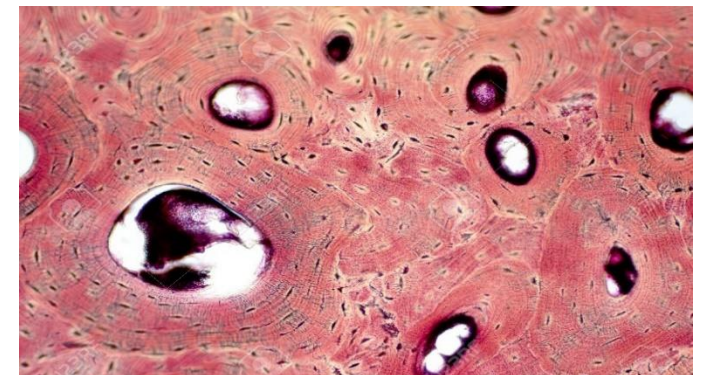
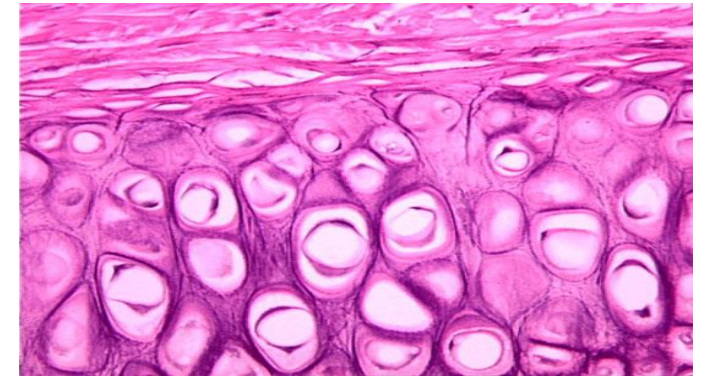
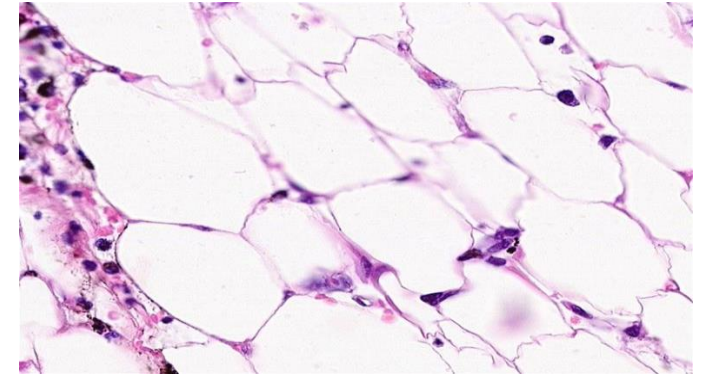


Special connective tissue

Adipose is a connective tissue that functions as the major storage site for lipids. It has very little ECM and tightly clustered cells.

Cartilage is avascular tissue in which the ground substance of ECM is abundant and of a firmly gelled consistency that endows this tissue with unusual rigidity and resistance to compression. In this tissue metabolites and nutrients can diffuse through the water in matrix to reach the cells. Cartilage is enclosed by the **perichondrium**, a dense fibrous layer.

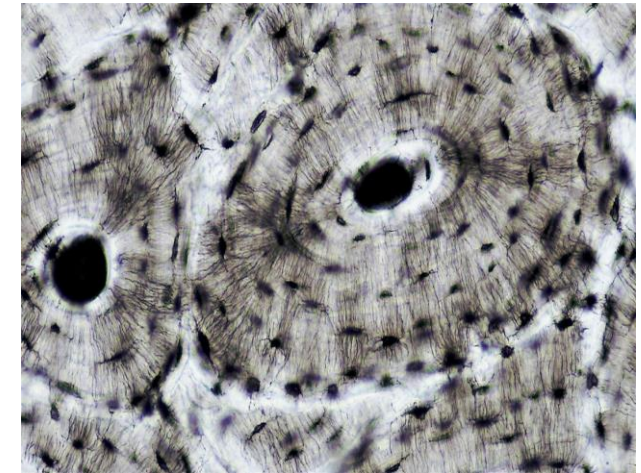
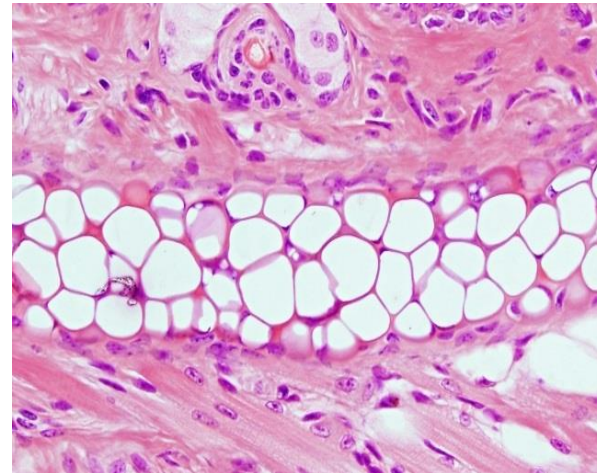
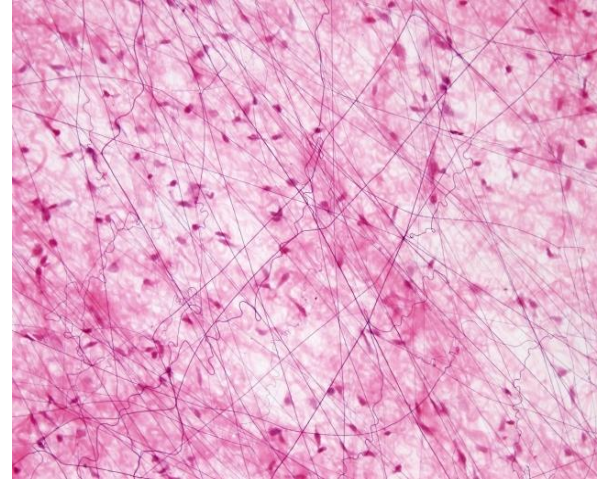
Bone is vascular tissue with high mineralization of the ECM, which forms a dense, hard substance with high tensile, weight-bearing and compression strength. A fundamental characteristic of bone is the arrangement of ECM into regular layers (**lamellae**). Blood vessels passing through the **Haversian channel** supply bone tissue.



Classwork

You have to draw pictures from the following micrographs:

1. **General structure of fibroblast cells**
2. **Loose connective tissue**
3. **Elastic cartilage tissue**
4. **Compact bone tissue**

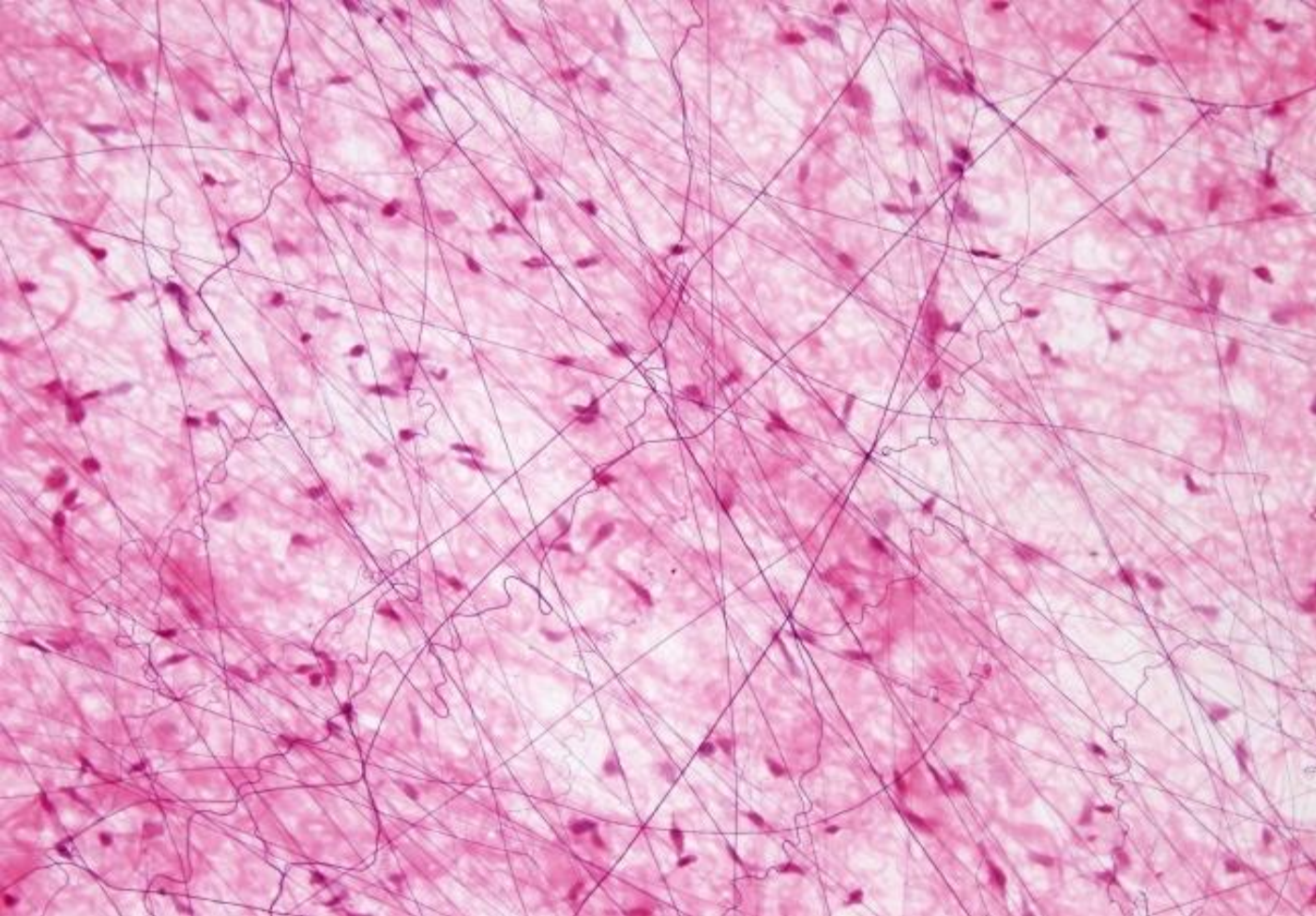




What have to be labeled:

1. Nucleus
2. Nucleoli
3. Vesicles
4. Cellular processes

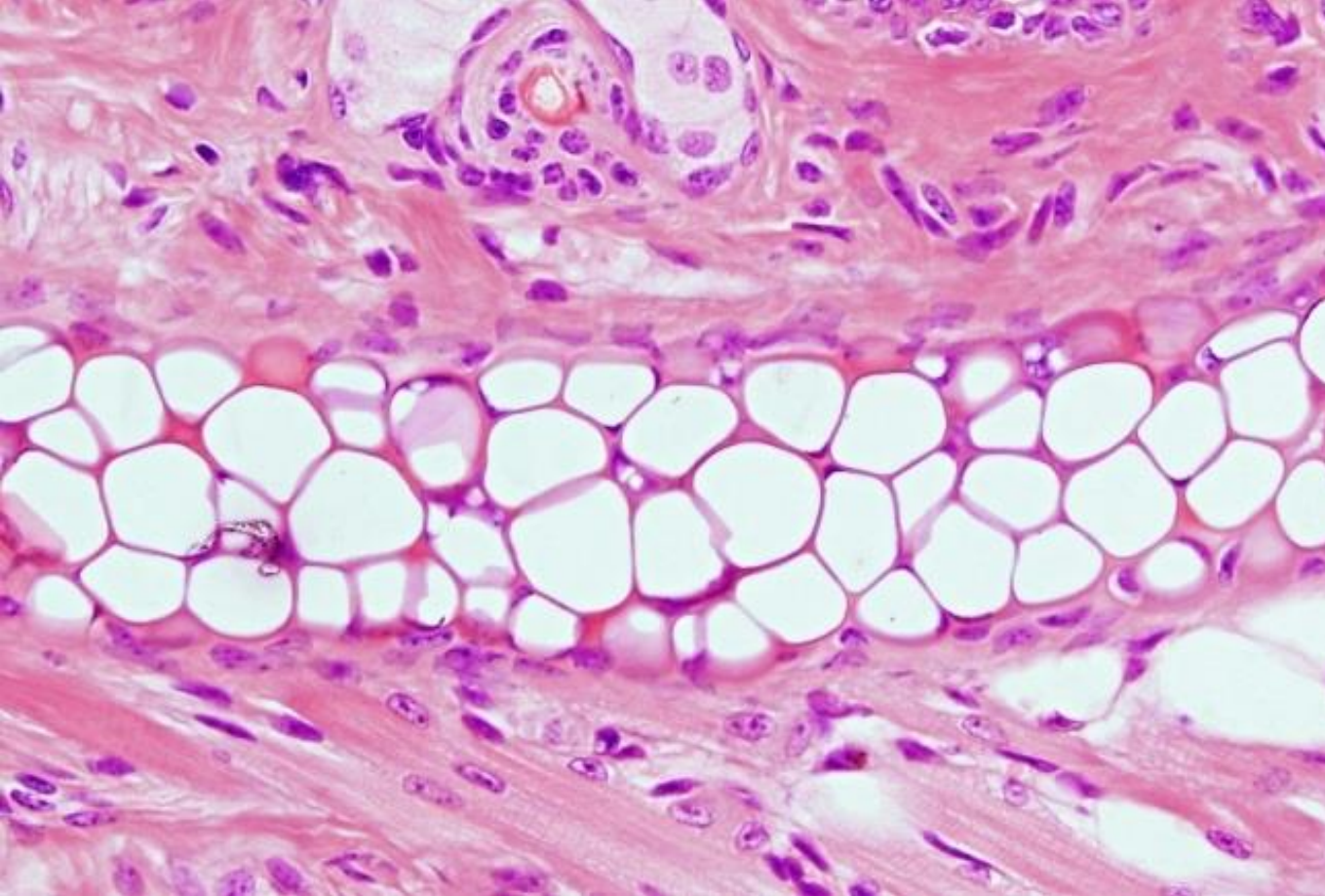
**Picture 1: General structure of fibroblast cells
(light micrograph, without staining)**



What have to be labeled:

1. Fibroblasts
2. Elastic fibers
3. Collagen fibers

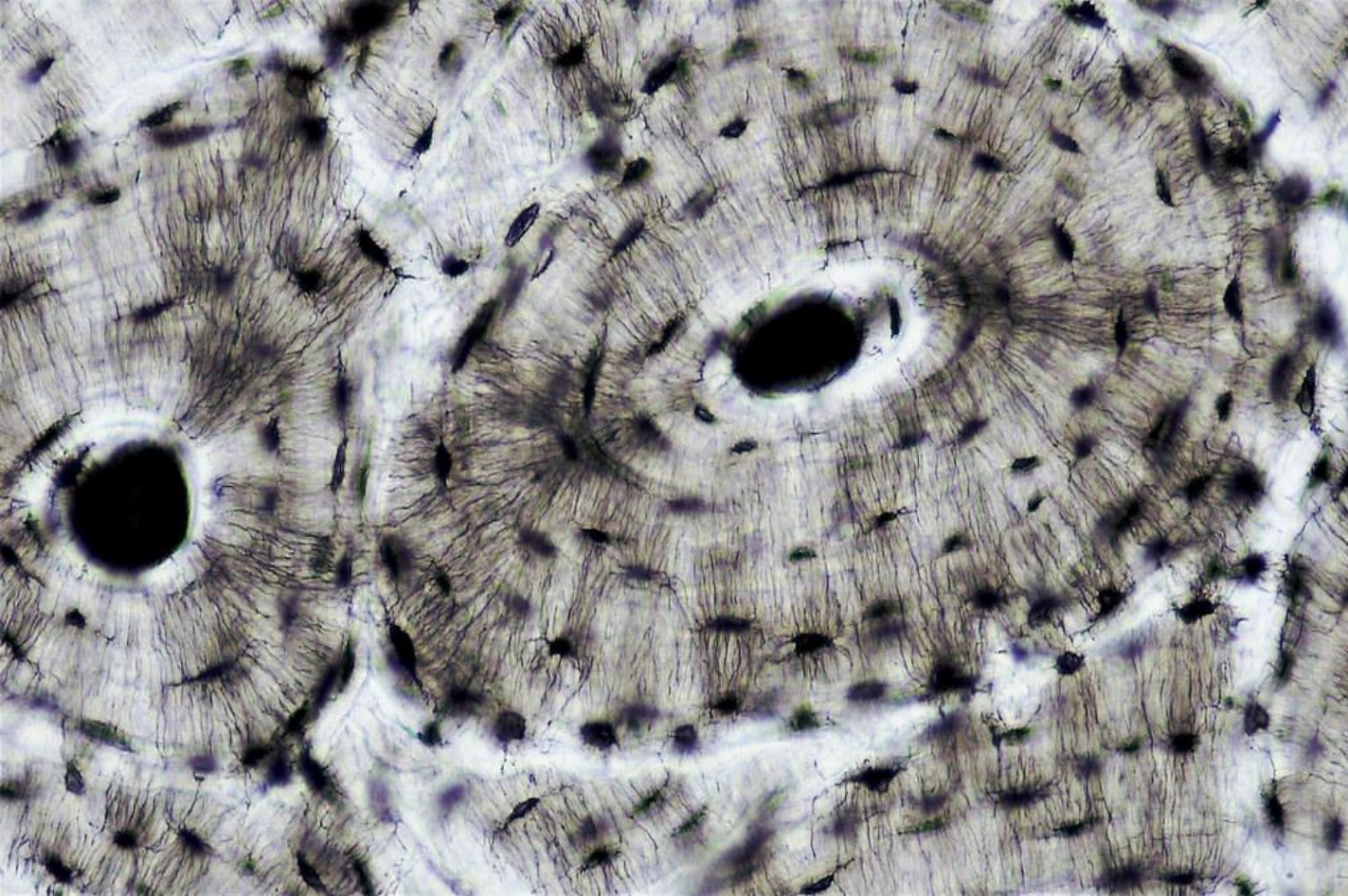
**Picture 2: Loose connective tissue
(light micrograph, hematoxylin-eosin stain)**



Picture 3: Elastic cartilage tissue
(light micrograph, hematoxylin-eosin stain)

What have to be labeled:

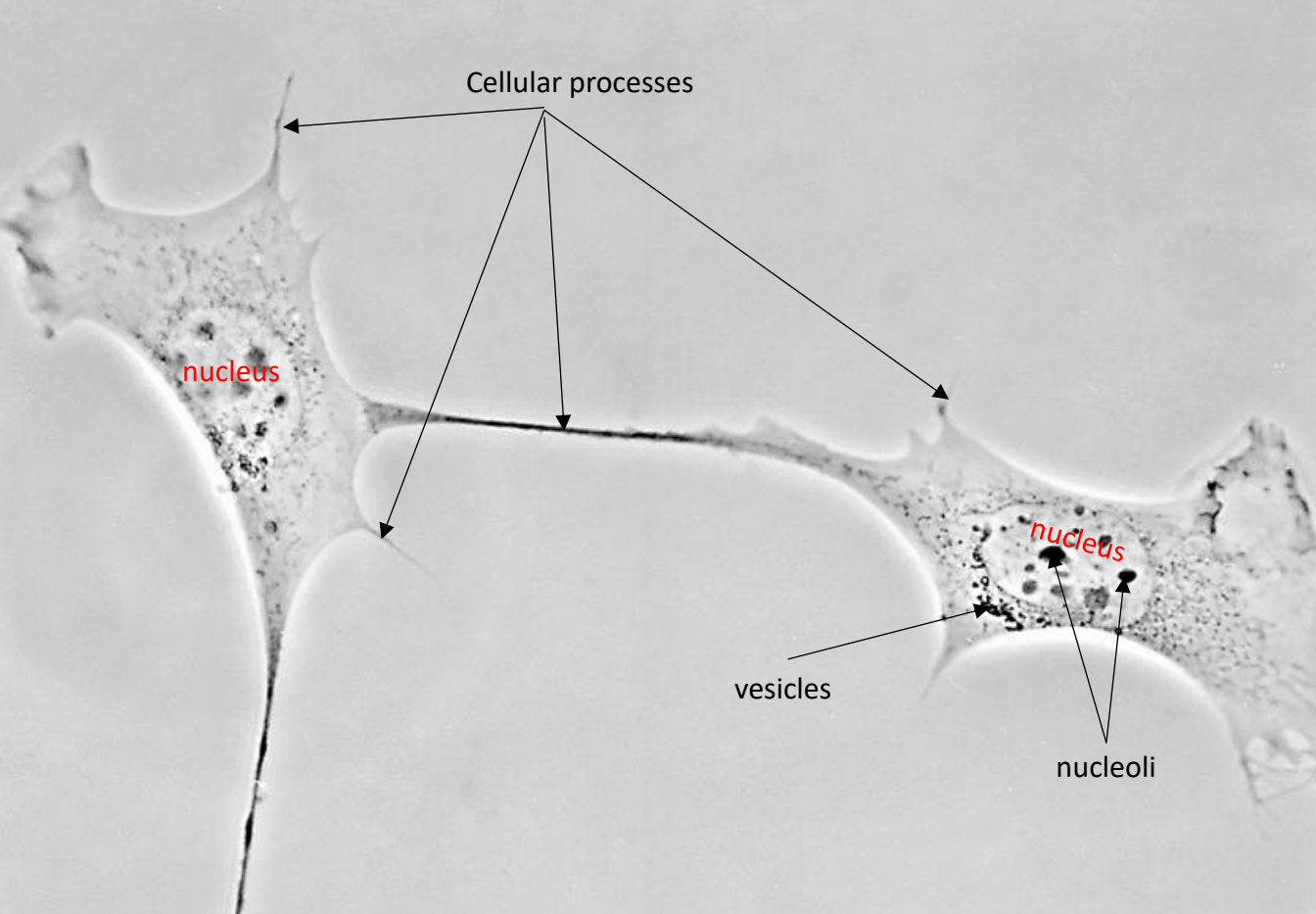
1. Chondrocytes (isogenous groups)
2. Lacunae
3. Perichondrium

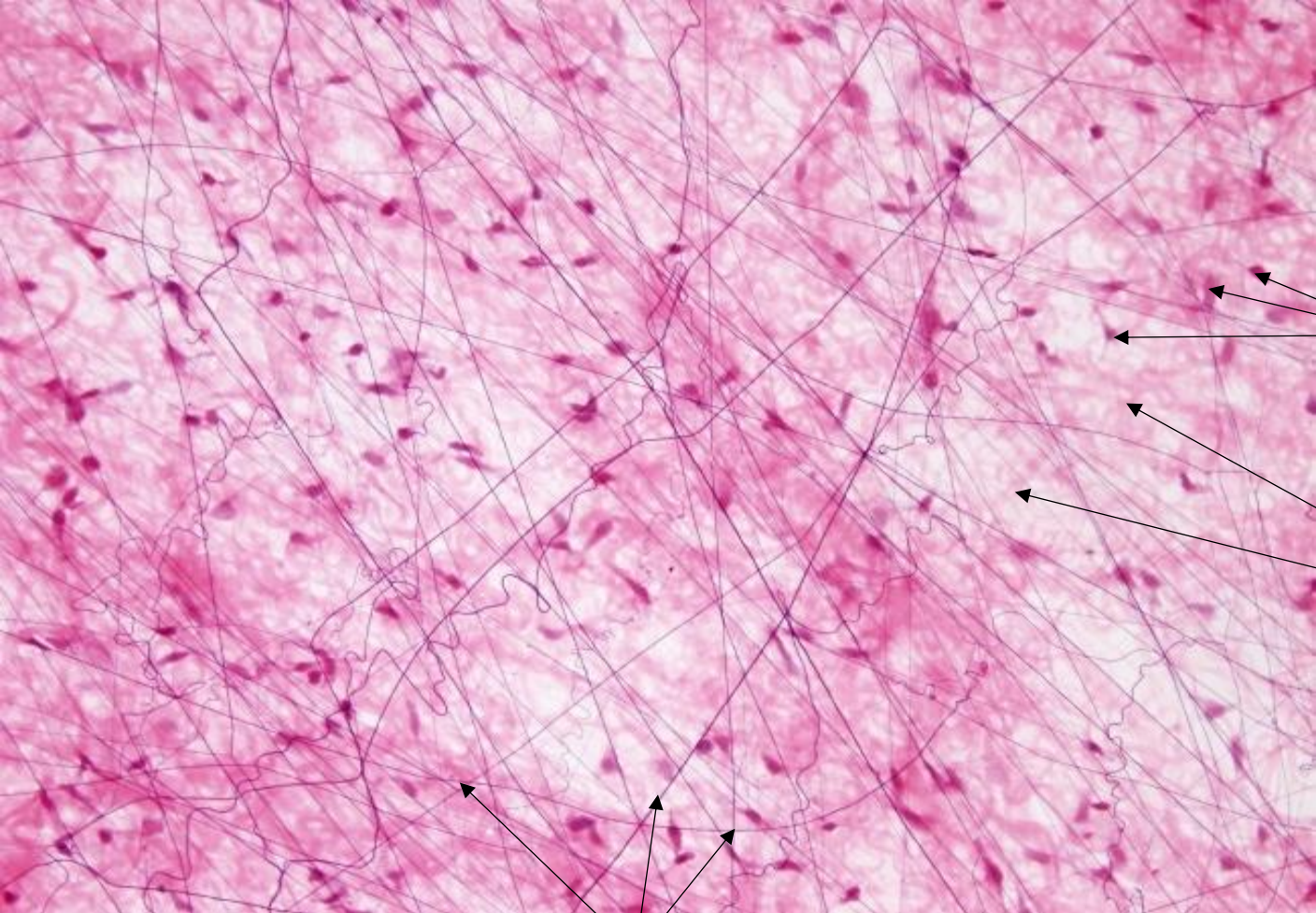


**Picture 4: Compact bone tissue
(light micrograph, without staining)**

What have to be labeled:

1. Osteon
2. Osteocytes (lacunae)
3. Cellular processes (canaliculi)
4. Lamellae
5. Haversian channel

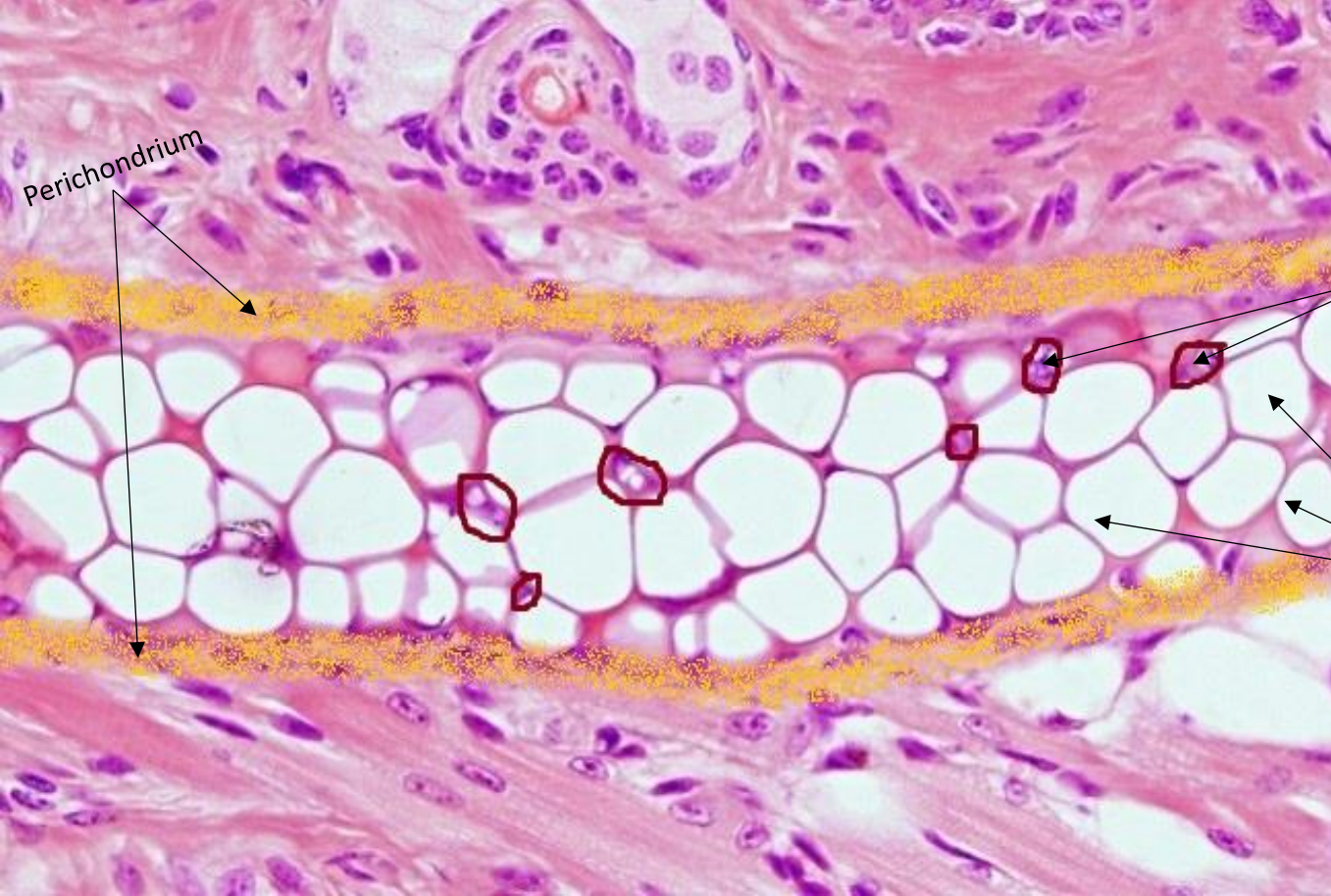




Fibroblasts (pink cells)

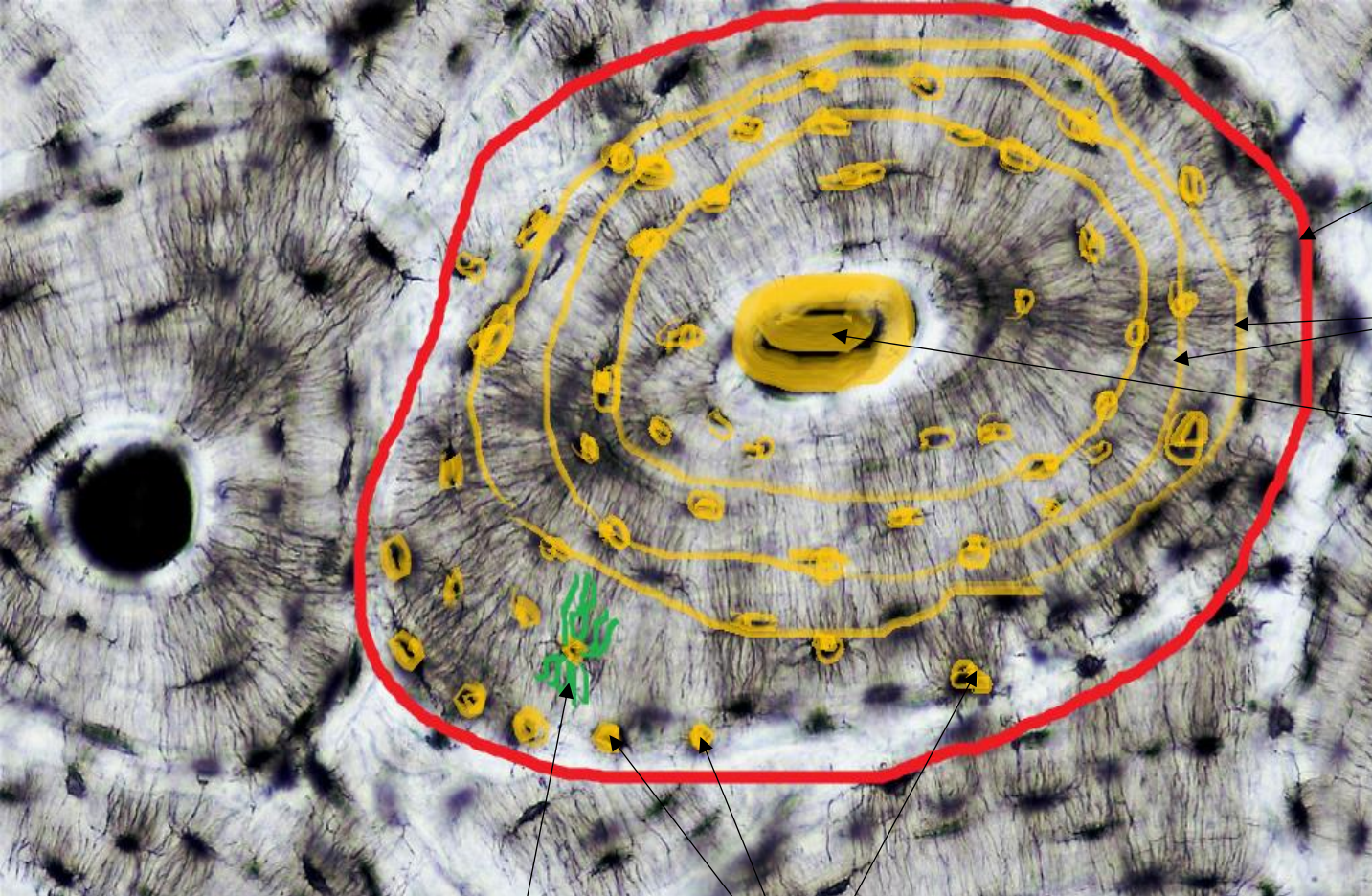
Collagen fibers (pink thick fibers)

Elastic fibers (purple thin fibers)



Isogenous groups
(2-4 chondrocytes)

Lacunae



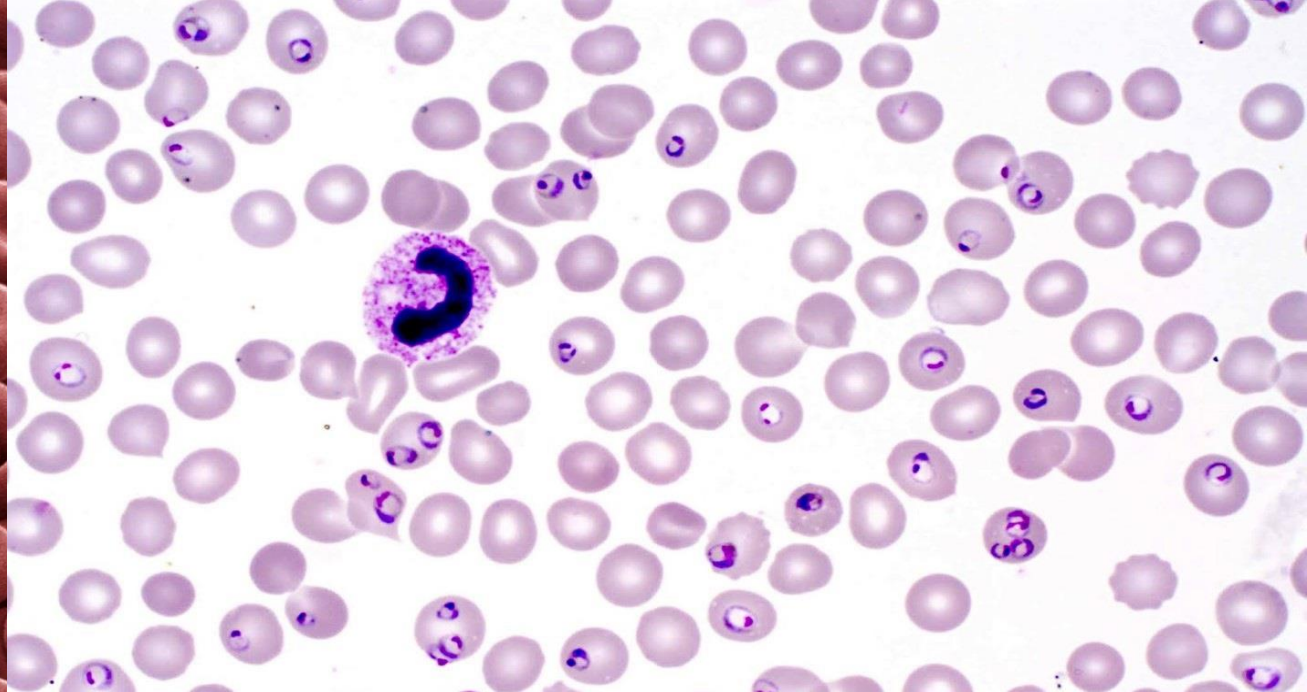
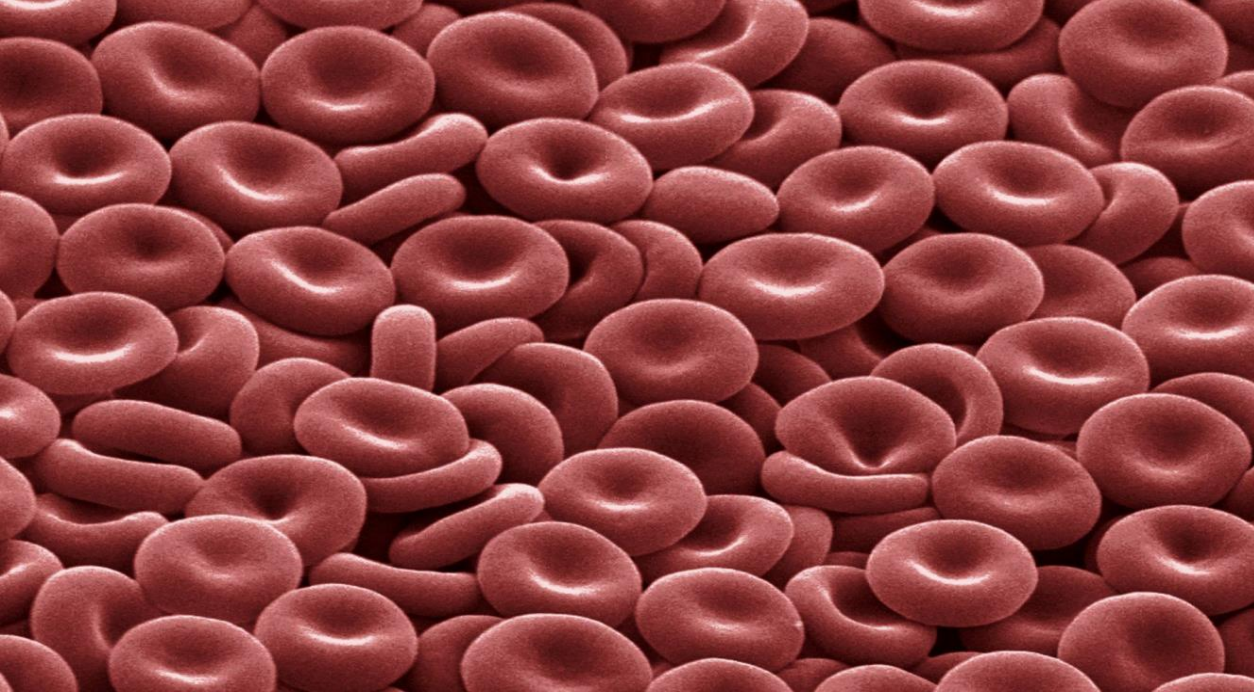
Osteon

Lamellae

Haversian channel

Cellular processes
(canaliculi)

Osteocytes (lacunae)



Lesson IV. Blood tissue

Kazan Federal University

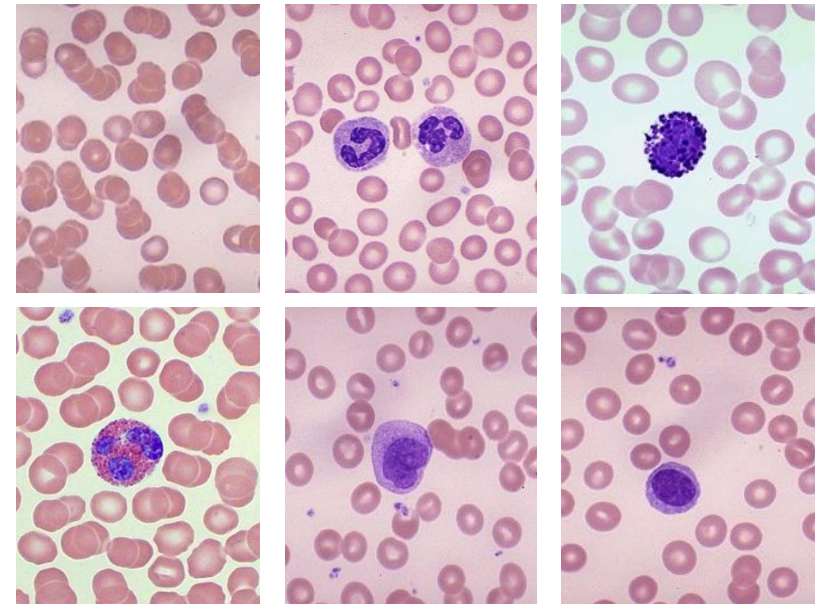
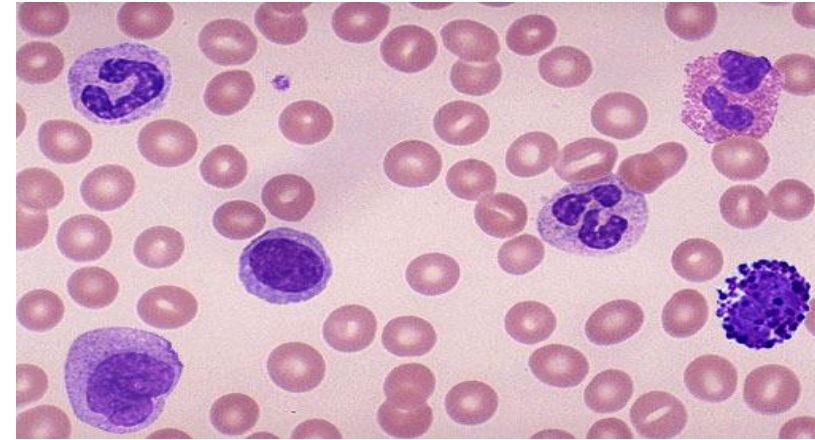
2023

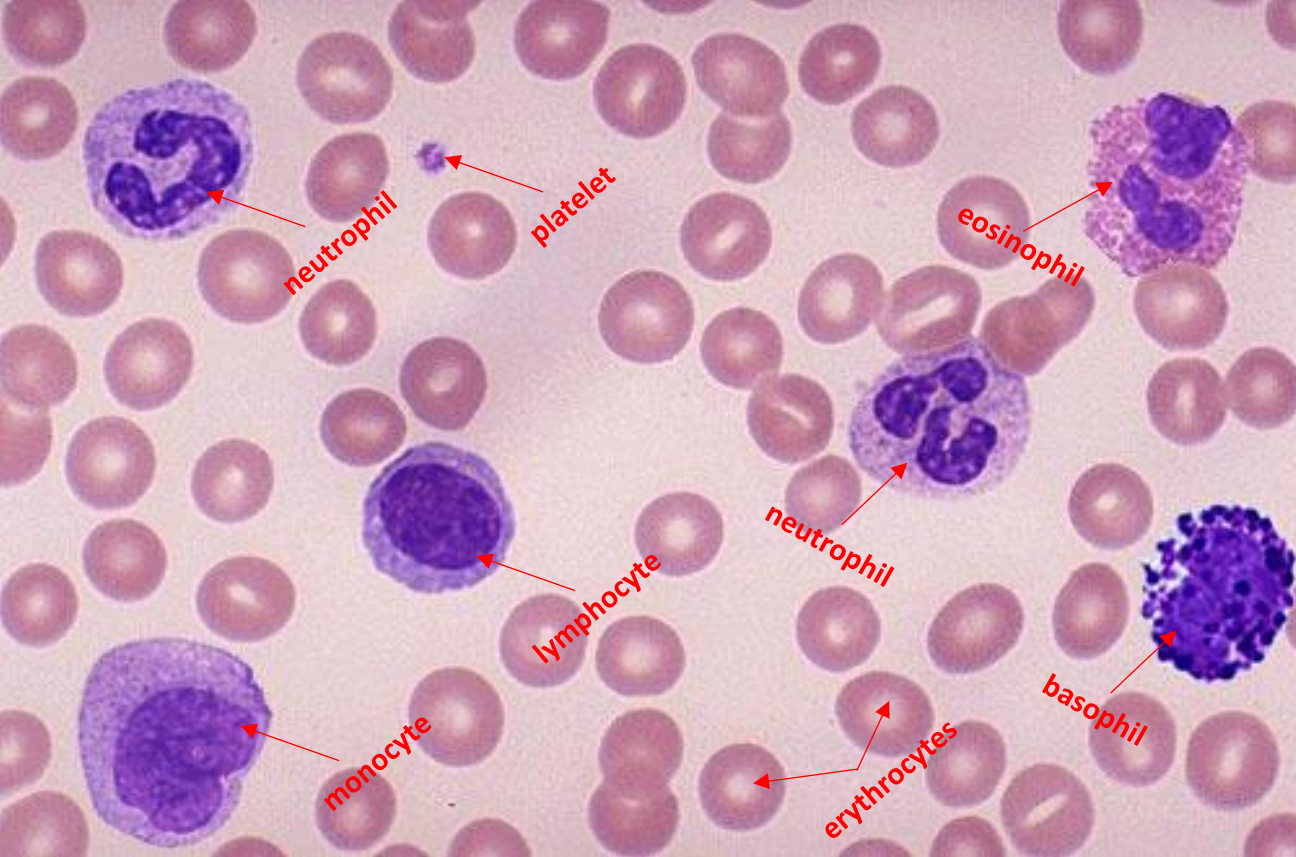
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Classwork

You have to draw pictures from the following micrographs:

1. **Formed elements of blood**
2. **Erythrocyte**
3. **Neutrophil**
4. **Basophil**
5. **Eosinophil**
6. **Monocyte**
7. **Lymphocyte**

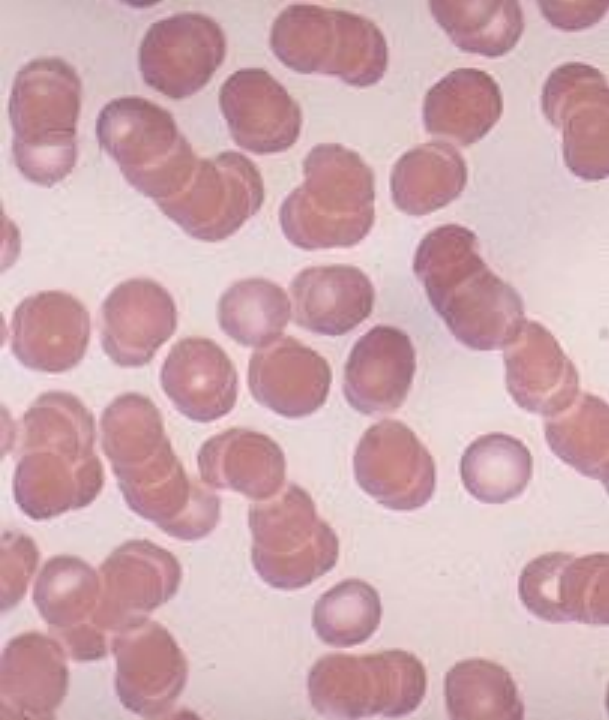




**Picture 1: Formed elements of blood
(Romanowsky - Giemsa staining)**

What should be marked:

- 1) Erythrocytes
- 2) Platelet
- 3) Neutrophil
- 4) Eosinophil
- 5) Basophil
- 6) Monocyte
- 7) Lymphocyte



What should be marked:

- 1) Cytoplasm

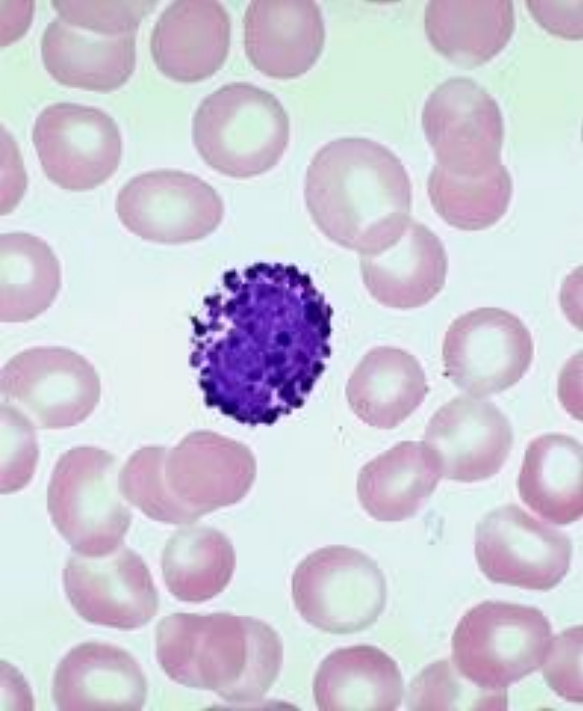
Picture 2: Erythrocyte
(Romanowsky - Giemsa staining)



What should be marked:

- 1) Multilobed nucleus
- 2) Cytoplasm
- 3) Specific granules (neutrophilic)

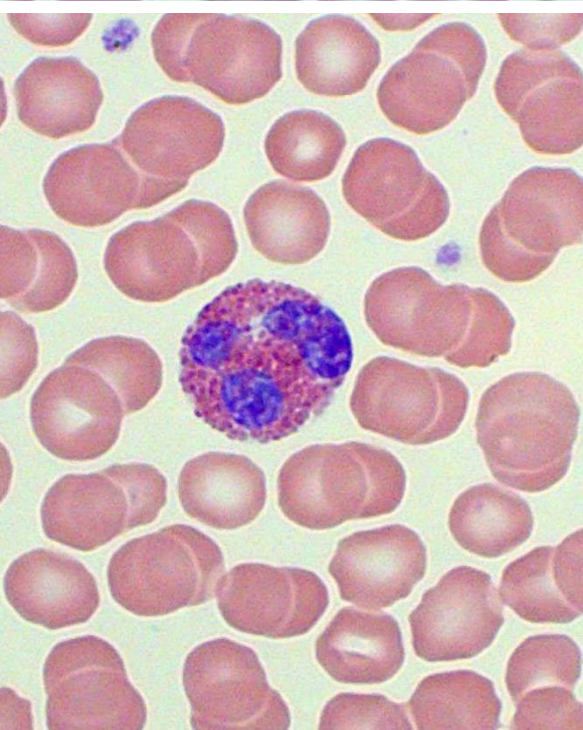
Picture 3: Neutrophil
(Romanowsky - Giemsa staining)



What should be marked:

- 1) Bilobed nucleus
- 2) Cytoplasm
- 3) Specific granules (basophilic)

Picture 4: Basophil
(Romanowsky - Giemsa staining)



What should be marked:

- 1) Bilobed nucleus
- 2) Cytoplasm
- 3) Specific granules (eosinophilic)

Picture 5: Eosinophil
(Romanowsky - Giemsa staining)



What should be marked:

- 1) Kidney-shaped nucleus
- 2) Cytoplasm

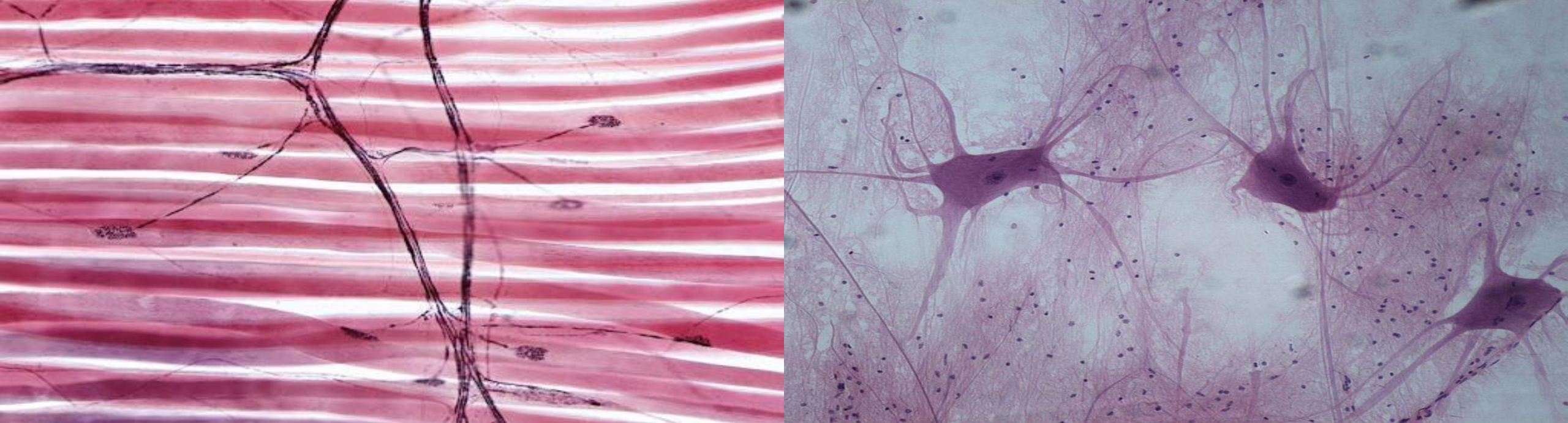
Picture 6: Monocyte
(Romanowsky - Giemsa staining)



What should be marked:

- 1) Round nucleus
- 2) Cytoplasm

Picture 7: Lymphocyte
(Romanowsky - Giemsa staining)



Lesson V. Muscle tissue. Nervous tissue

Kazan Federal University

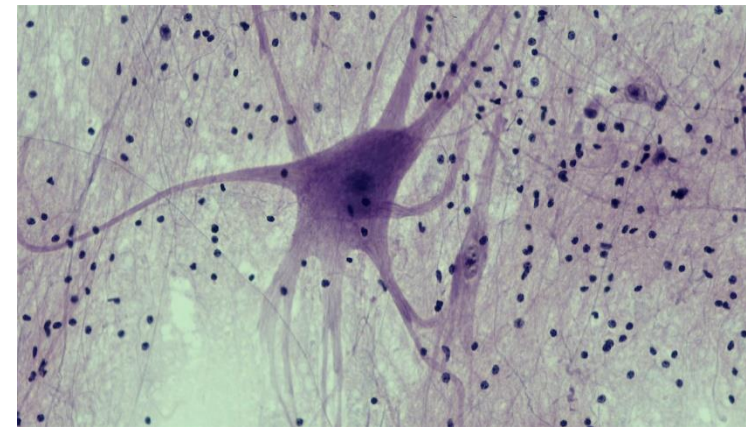
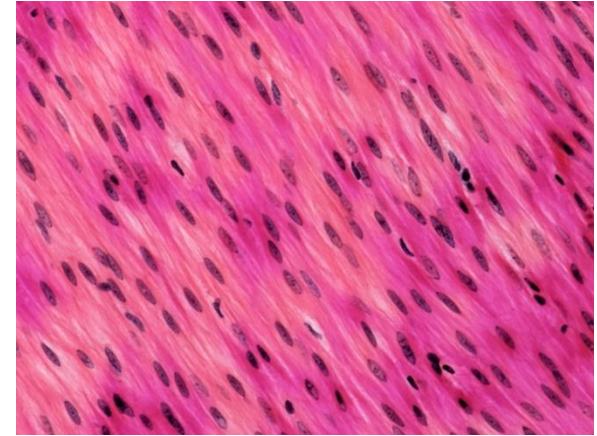
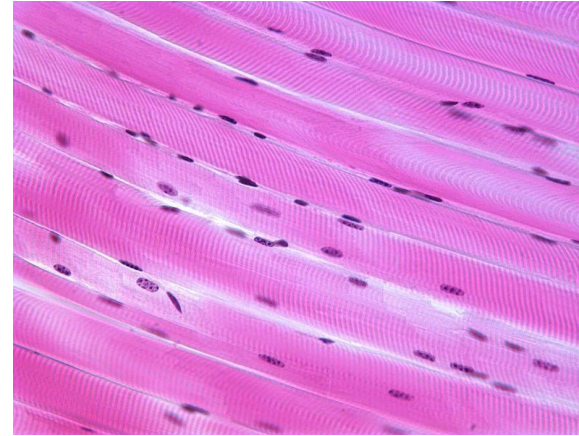
2023

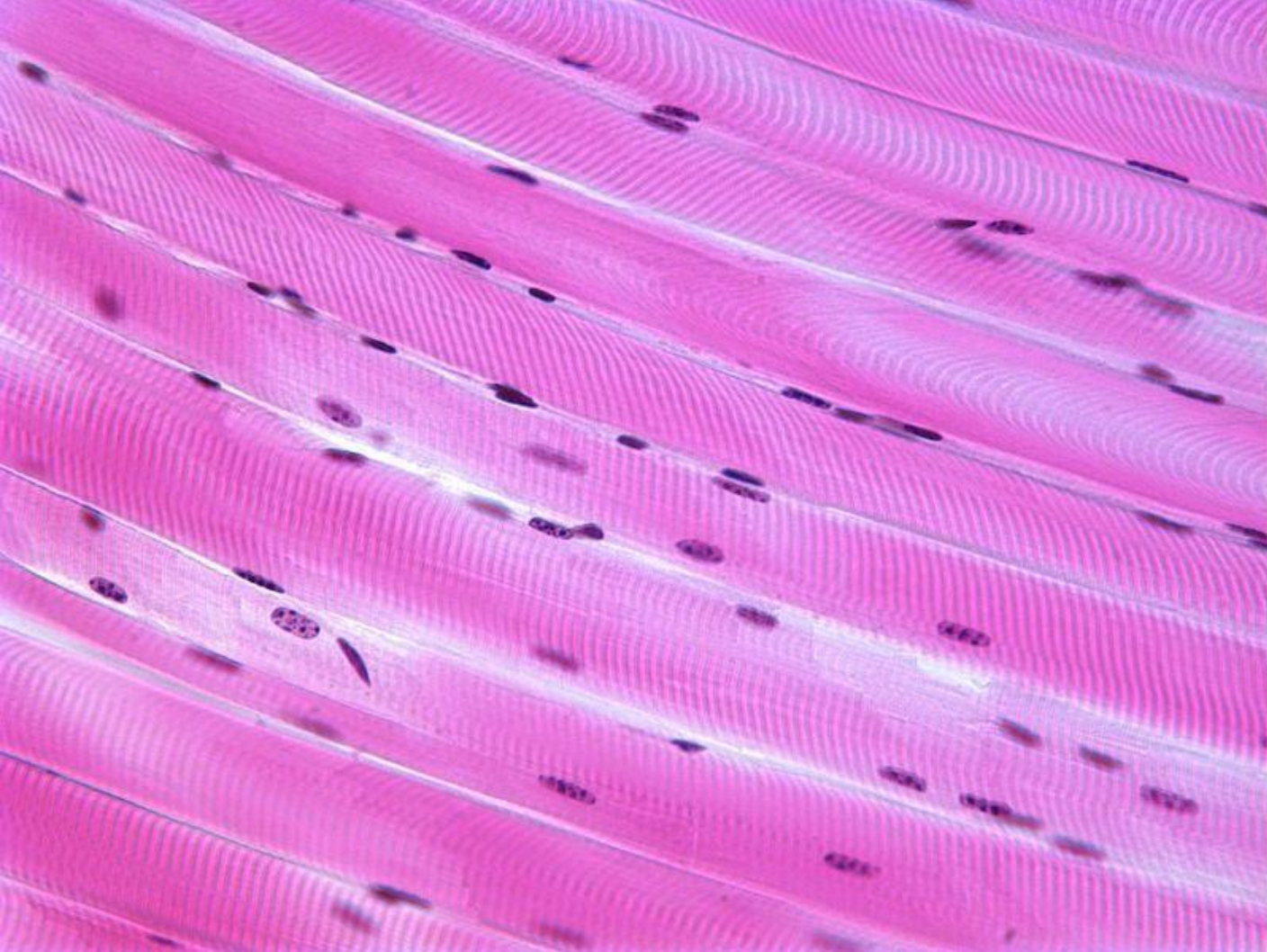
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Classwork

You have to draw pictures from the following micrographs:

1. **Skeletal muscle tissue**
2. **Smooth muscle tissue**
3. **Nervous tissue in spinal cord**

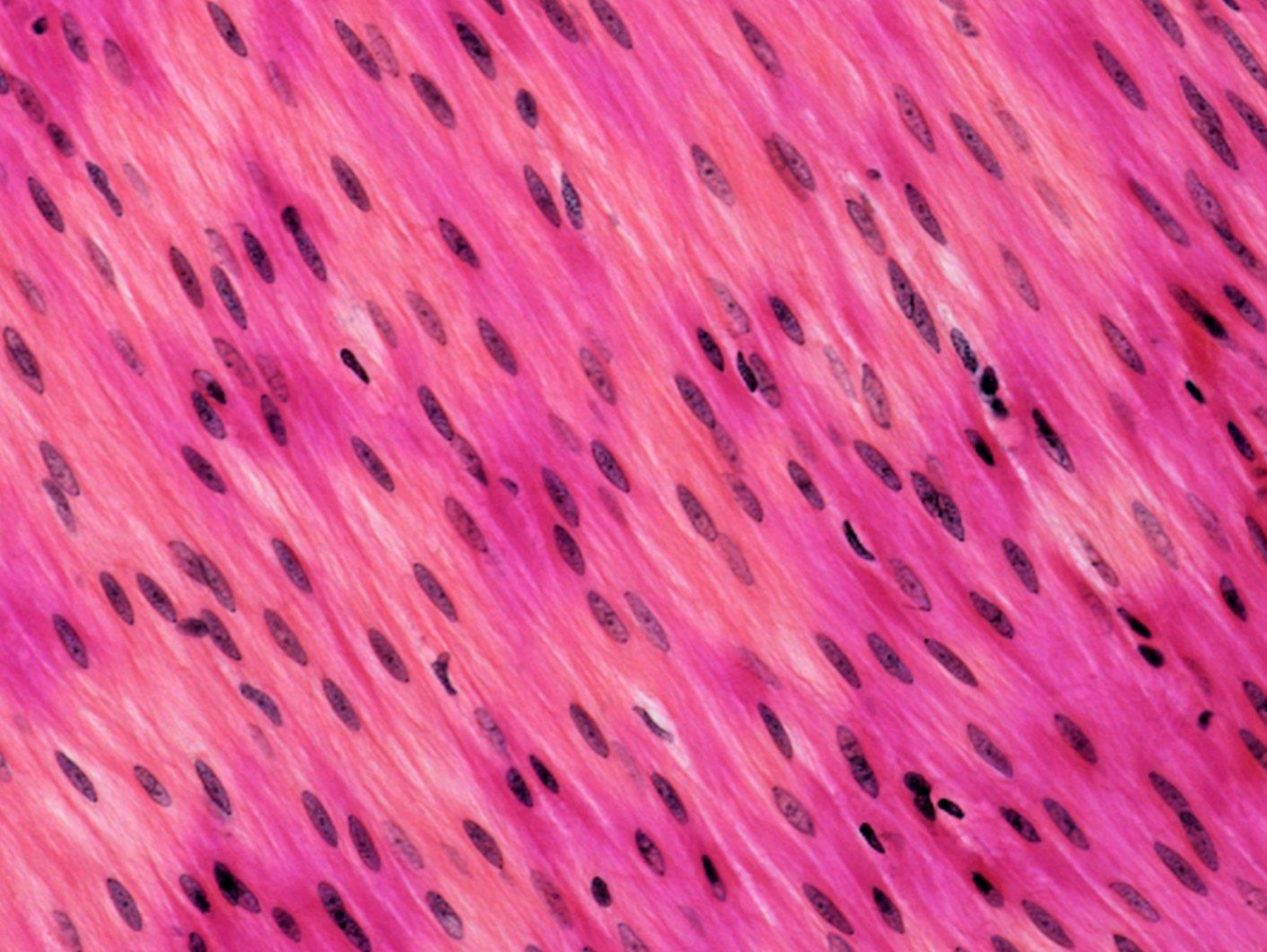




What should be marked:

1. Muscle fibers
2. Nuclei of muscle fibers
3. Striations (myofibrils)
4. Endomysium

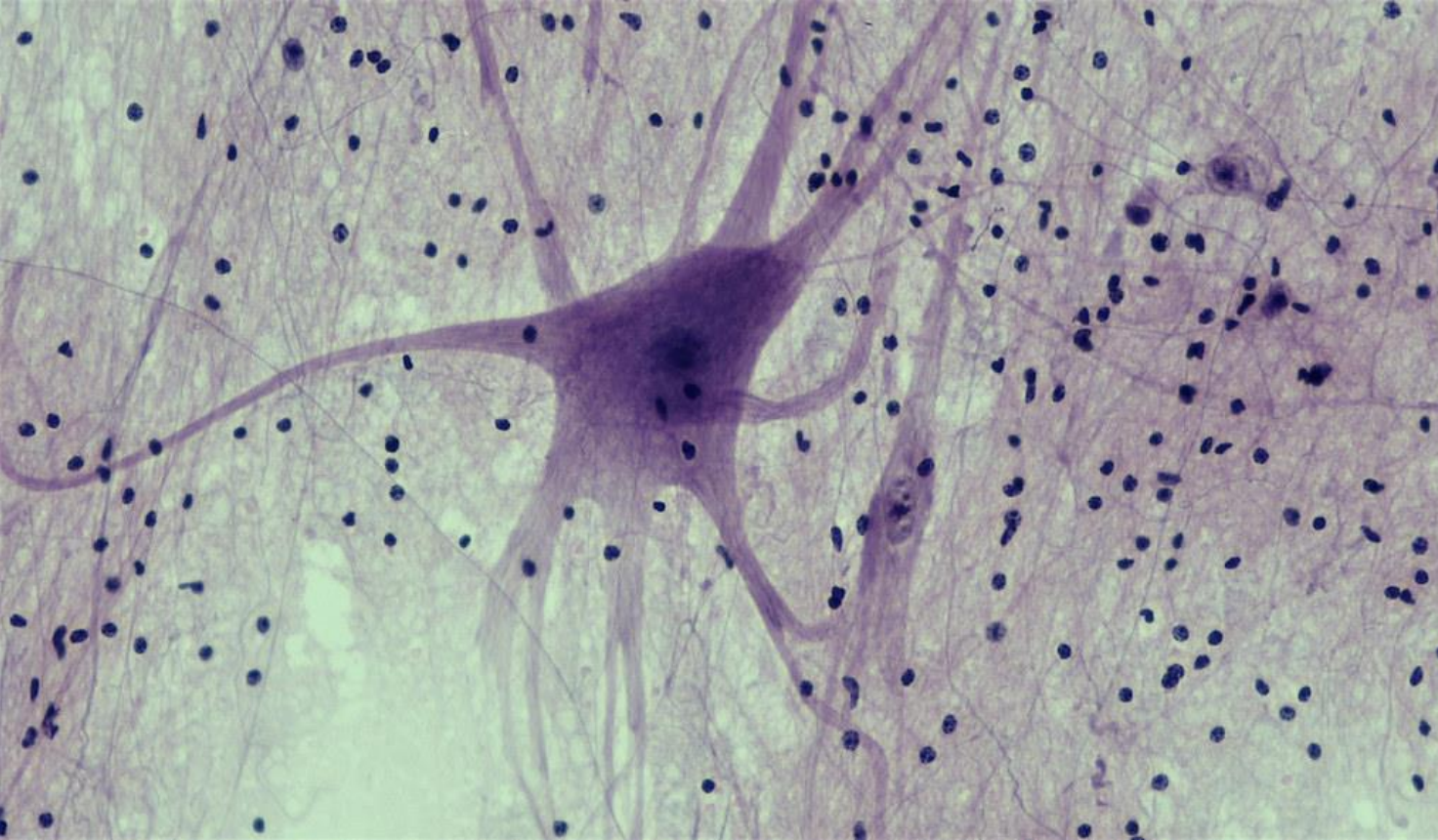
**Picture 1: Skeletal muscle tissue
(light micrograph, hematoxylin-eosin stain)**



What should be marked:

1. Muscle cells
2. Nuclei of muscle cells

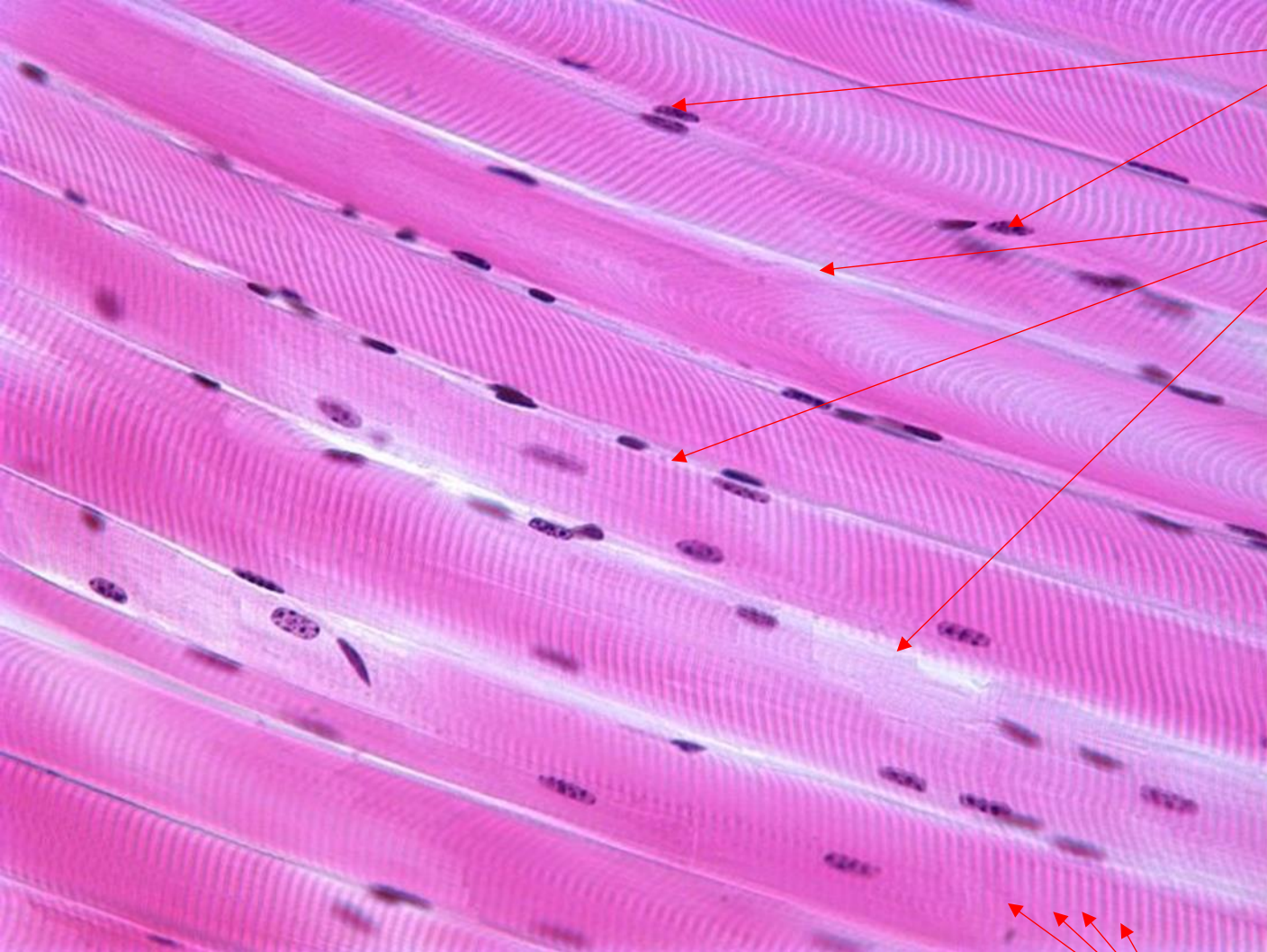
**Picture 2: Smooth muscle tissue
(light micrograph, hematoxylin-eosin stain)**



What should be marked:

1. Neuron
2. Neuronal nucleus
3. Neuronal soma
4. Axon
5. Dendrites
6. Glial cells

**Picture 3: Nervous tissue in spinal cord
(light micrograph, Nissl stain)**

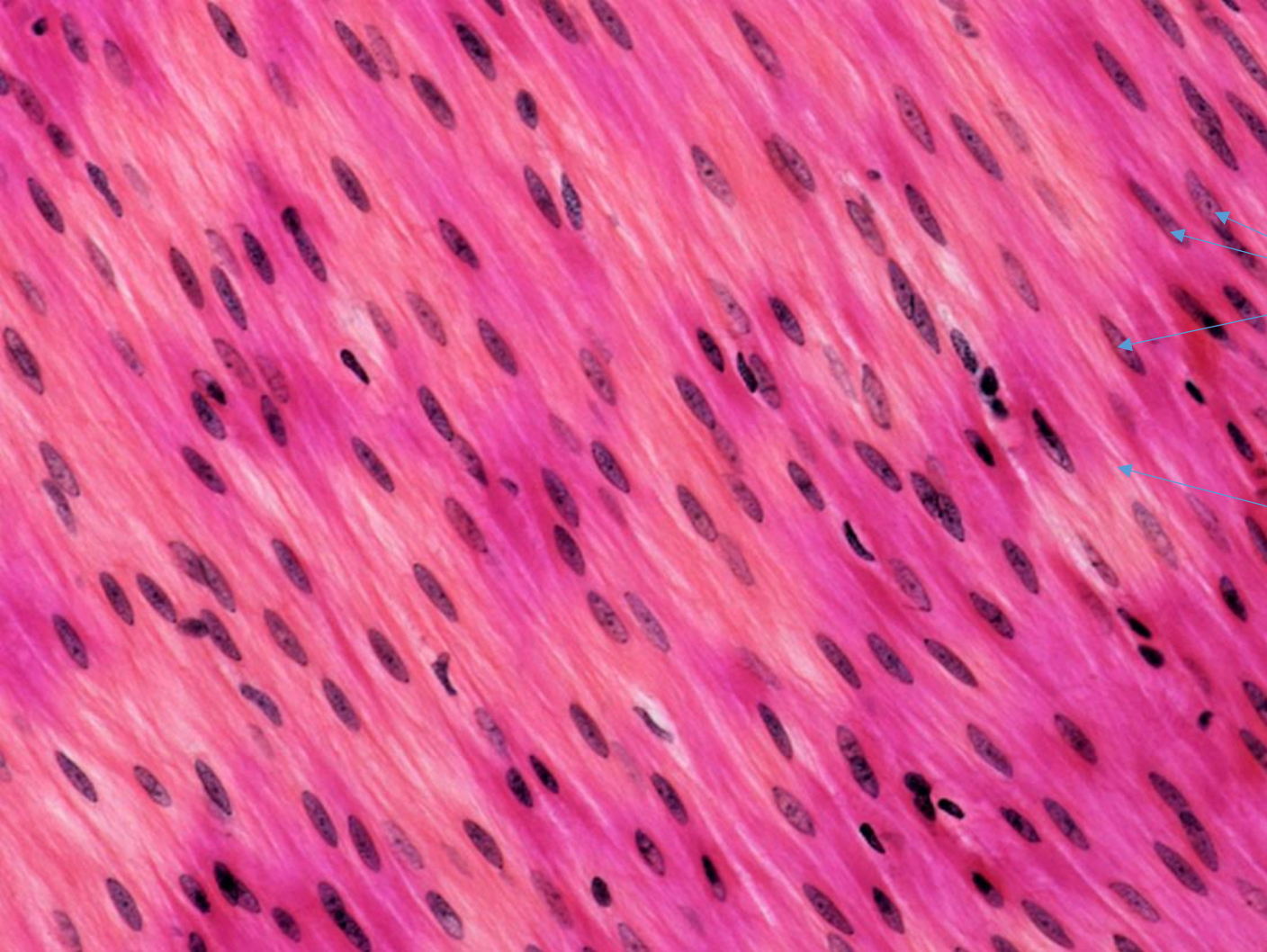


nuclei of muscle fibers

endomysium

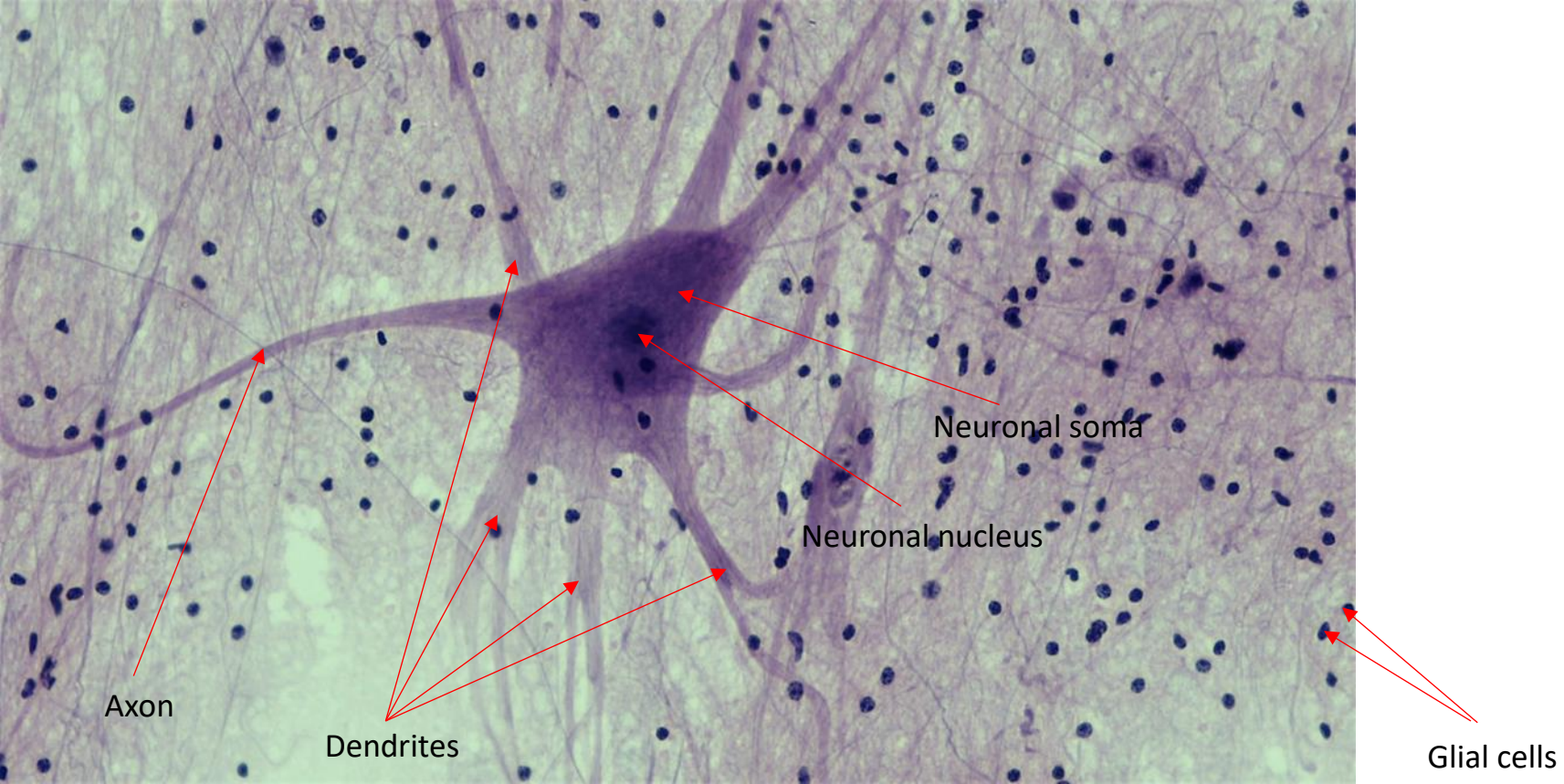
Muscle fibers

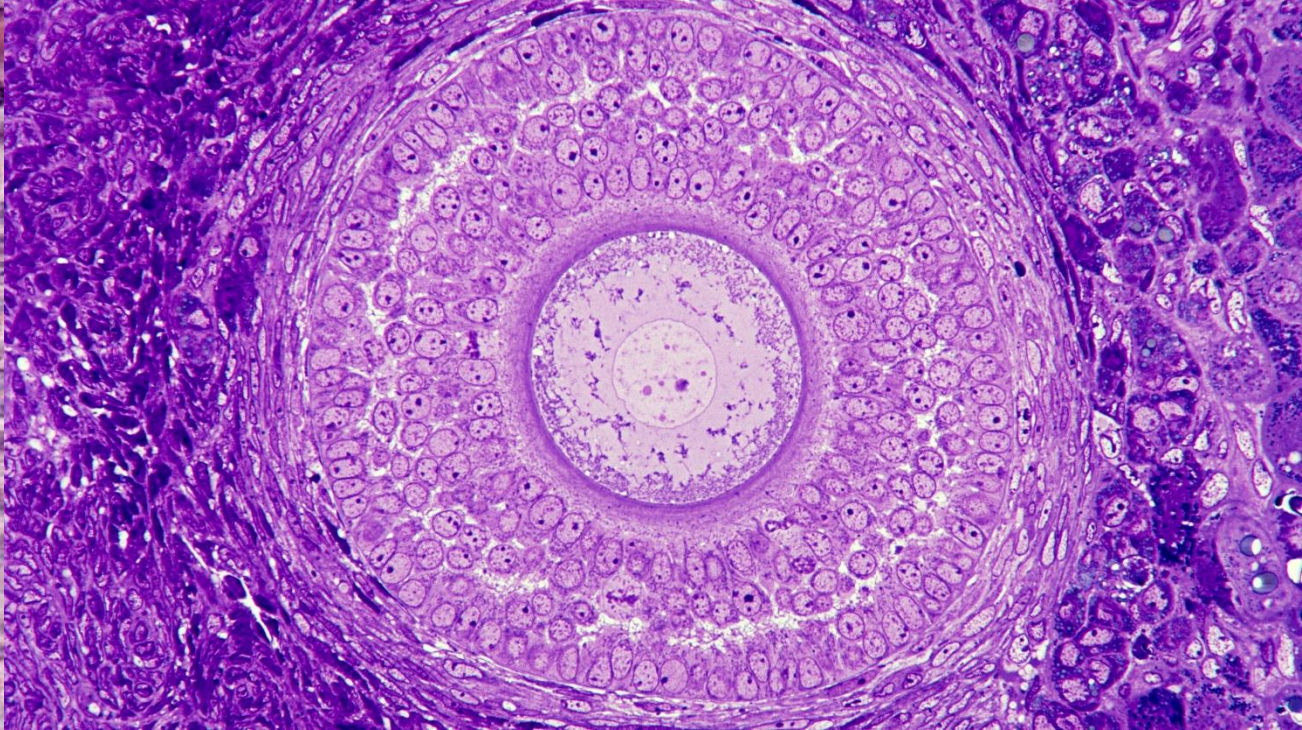
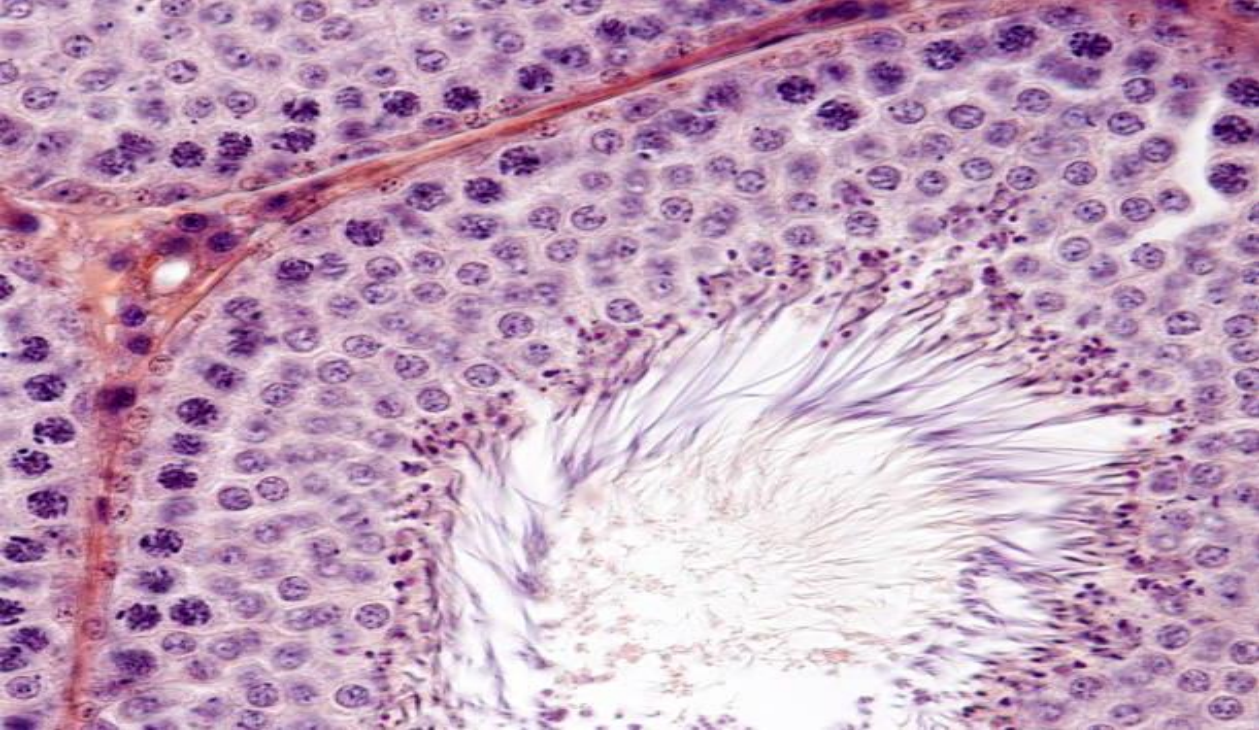
Striations (myofibrils)



Nuclei of muscle cells

muscle cells





Lesson VI. Spermatogenesis. Oogenesis

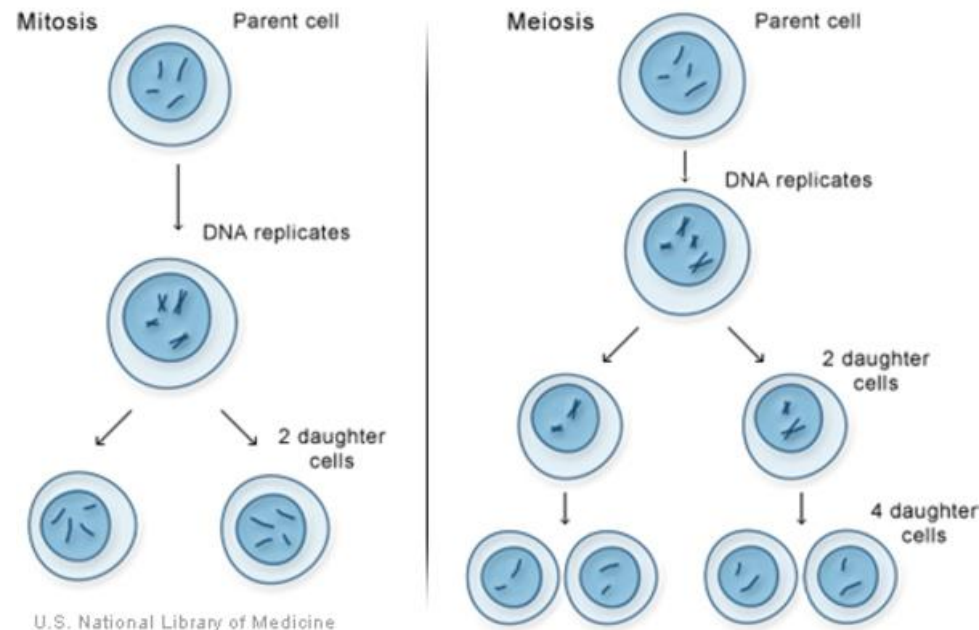
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Gametogenesis

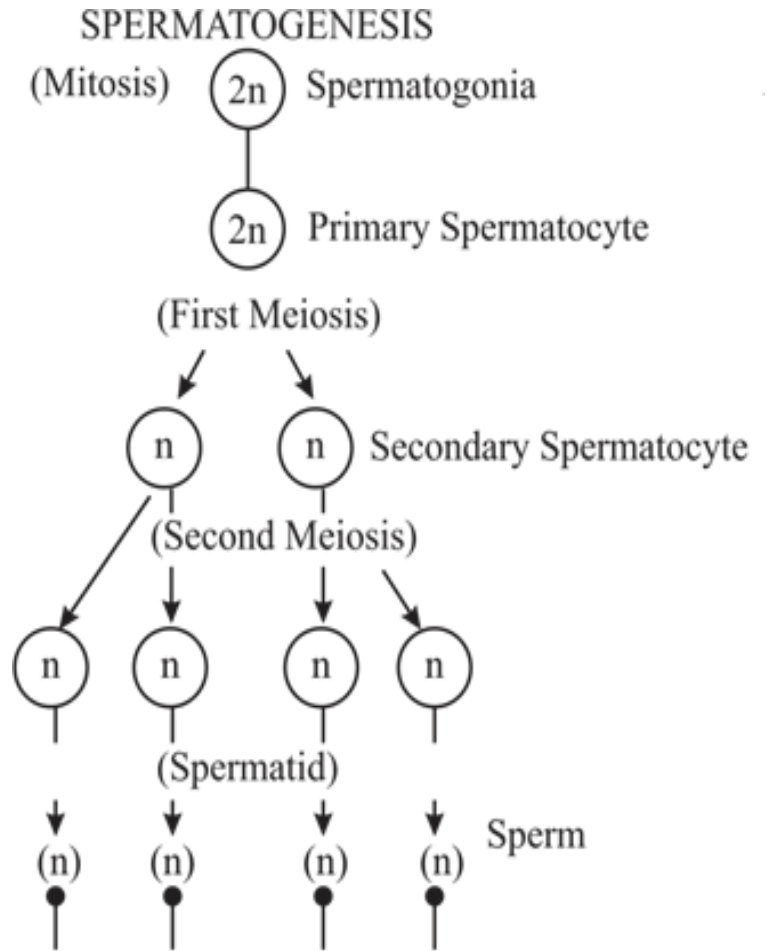
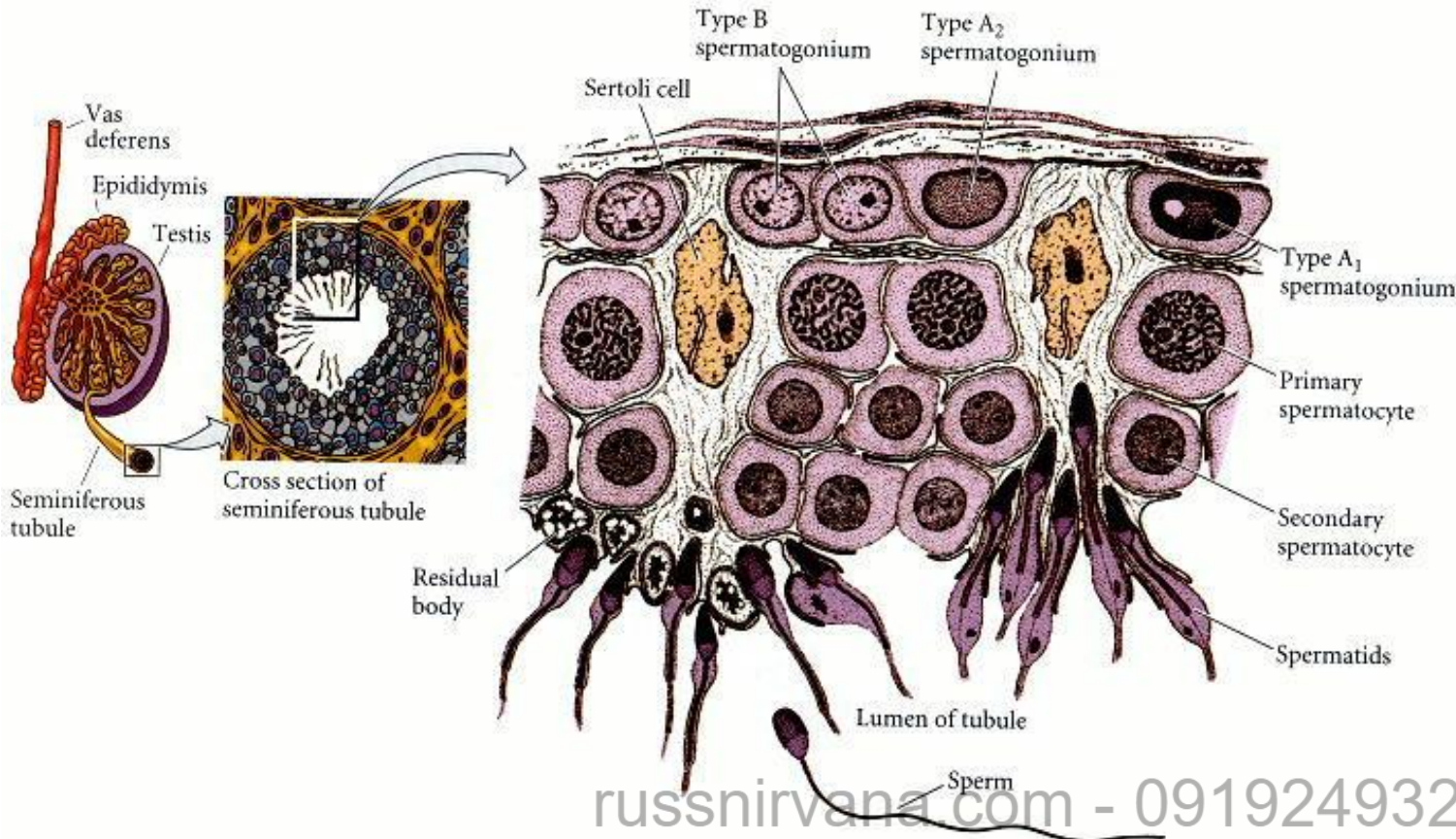
Gametogenesis is the production of gametes from haploid precursor cells. In animals two morphologically distinct types of gametes are produced (male and female) via distinct differentiation programs, **spermatogenesis** and **oogenesis**. Animals produce a tissue that is dedicated to forming gametes, called the germ line. Individual germline cells are called germ cells. During the process of gametogenesis, a germ cell undergoes meiosis to produce haploid cells that directly develop into gametes. Hence, in animals, meiosis is an integral part of gametogenesis.



U.S. National Library of Medicine

Spermatogenesis

Spermatogenesis is the origin and development of the sperm cells within the male reproductive organs. Spermatogenesis starts in the germinal epithelium of the testes. Testes are composed of numerous thin tightly coiled tubules known as the seminiferous tubules; the sperm cells are produced within the walls of the tubules.



Spermatogenesis

The development of a mature sperm cell takes place in two main steps, **spermatocytogenesis** and **spermiogenesis**.

Spermatocytogenesis is the process by which a spermatogonium develops into a spermatid. During this process, the number of chromosomes is halved through meiosis. It involves the following stages:

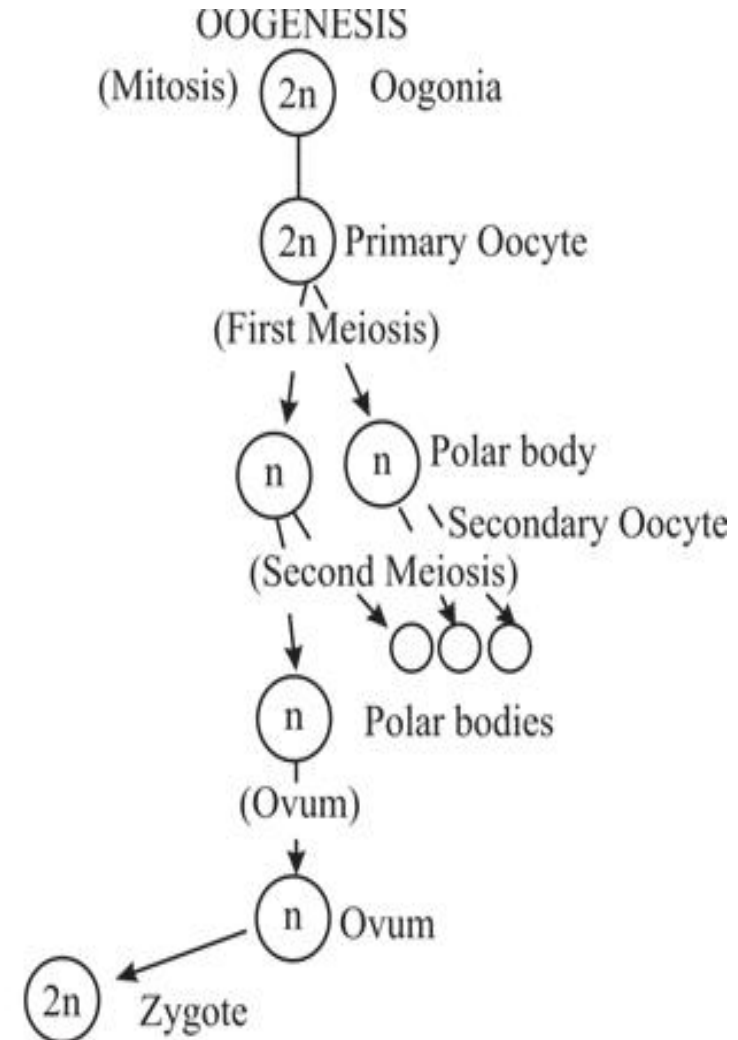
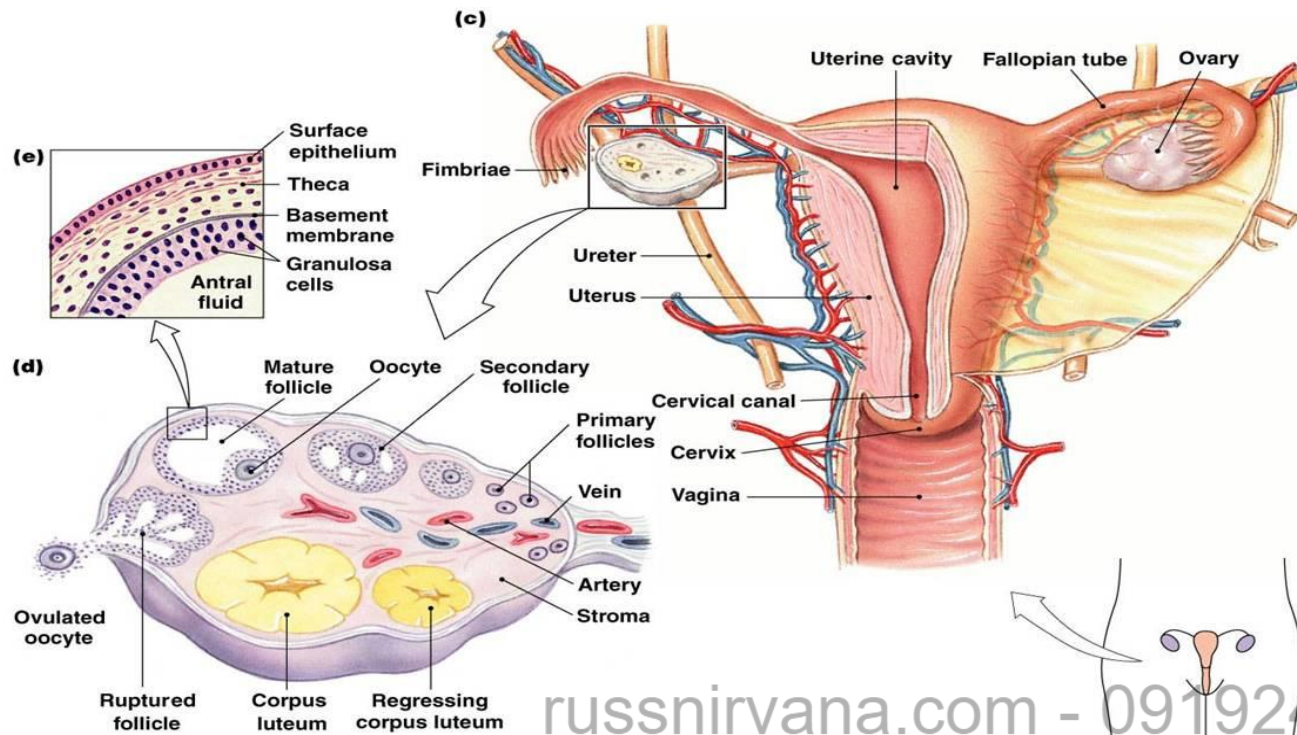
- Spermatogonia rest on the basement membrane of the seminiferous tubule and divide mitotically to produce more spermatogonia and primary spermatocytes. The spermatogonia remain in the basal compartment while the spermatocytes are located in the adluminal compartment.
- Primary spermatocytes are located in the middle region of the seminiferous tubule, within the adluminal compartment. These cells have a prolonged prophase that gives rise to the first meiotic division.
- Secondary spermatocytes are the product of the first meiotic division. They have 23 pairs of chromatids. This stage is short-lived and ends with the second meiotic division.
- Spermatids are the haploid products of meiosis. They remain connected to one another by cytoplasmic bridges. These bridges result from incomplete cytokinesis and allow for synchronous maturation.

Spermiogenesis is the process by which a spermatid matures into a spermatozoan . This process involves several steps:

- The acrosome , containing hydrolytic enzymes, develops and comes to overlie the dense, elongated nucleus.
- A flagellum grows out of the pole opposite the acrosome, facing the tubular lumen. This flagellum is a modified cilium that develops from the centrioles of the spermatid.
- Mitochondria become arranged around the flagellum.
- The bulk of the cytoplasm is cast off as a residual body , leaving only a thin rim of cytoplasm around the nucleus. Sertoli cells consume the residual body.
- The final maturation of sperm occurs in the epididymis, where the cells gain the ability to move. They gain the ability to fertilize the egg through the process of capacitation , which occurs in the female reproductive tract.

Oogenesis

Oogenesis is the origin and development of the ova within the female reproductive organs. Oogenesis starts in the germinal epithelium of ovaries, which gives rise to the development of ovarian follicles, the functional unit of the ovary. Oogenesis differs from spermatogenesis in several ways. Whereas the gamete formed by spermatogenesis is essentially a motile nucleus, the gamete formed by oogenesis contains all the materials needed to initiate and maintain metabolism and development.



Oogenesis

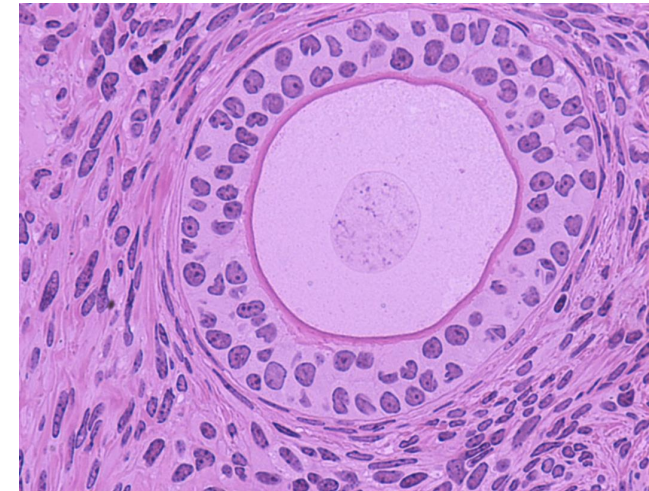
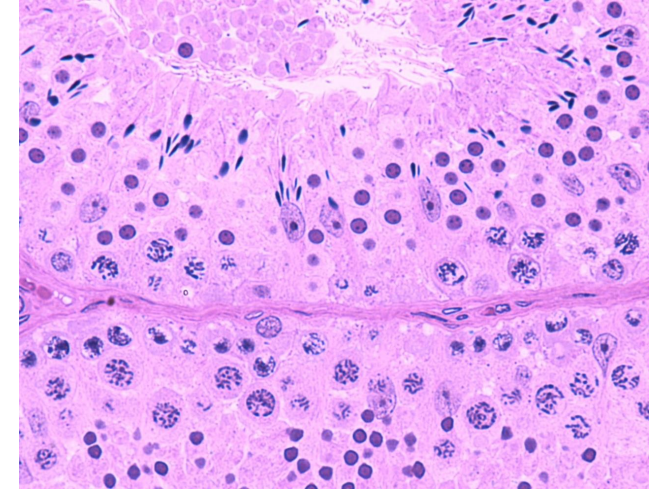
There are several developmental stages that precede the maturation and release of the ovum. All of these occur within the cortex of the ovary:

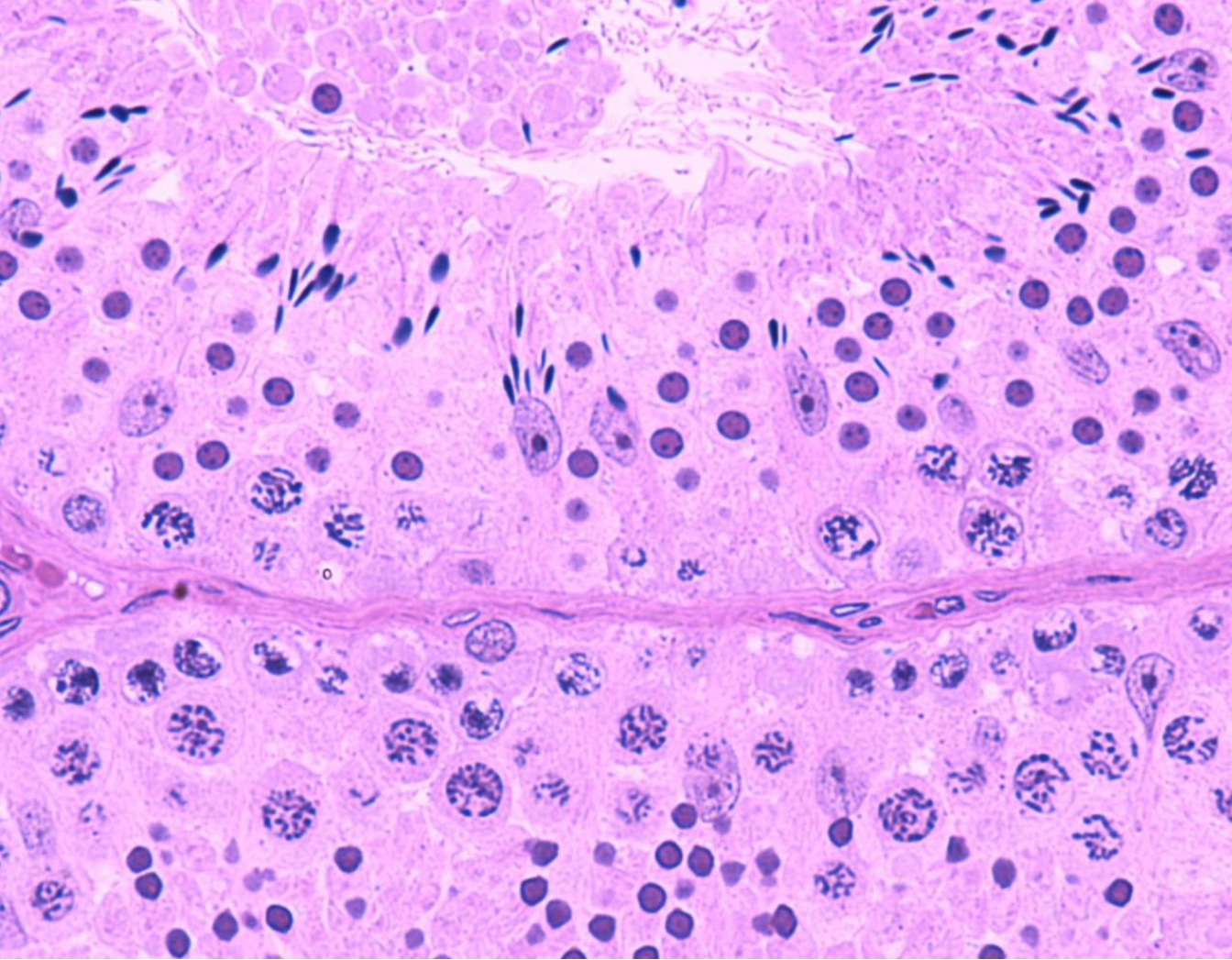
- Oogonia are small, diploid germ cells that migrate to the ovarian cortex and multiply by mitosis. Some of these cells develop the potential to become mature female gametes and become primordial follicles. This occurs during the first few months of gestation.
- Primordial follicles consist of a primary oocyte surrounded by a layer of squamous follicular cells. The oocytes in these follicles undergo arrest before the completion of the first stage of meiosis, and therefore have double the genetic material of the oogonia (4N). This arrest continues until a female reaches sexual maturity.
- After puberty, a few primordial follicles develop into primary follicles with each ovarian cycle. Like its primordial follicle precursor, the early primary follicle is encapsulated by a single layer of cuboidal epithelial cells. With continued development, this lining becomes stratified epithelium composed of cuboidal granulosa cells surrounded by an outer layer of squamous theca cells. The primary oocyte grows and becomes encased in an acellular layer of proteoglycans and glycoproteins known as the zona pellucida. This layer separates the developing oocyte from the surrounding granulosa cells.
- As the follicle continues to develop, the oocyte is displaced from its center by the accumulation of the liquor folliculi in the developing follicular antrum. The formation of the antrum represents the transition to a secondary follicle. A group of cells known as the cumulus oophorus develops between the oocyte and the zona granulosa. The zona granulosa produces estrogen, whereas the theca interna produces androstenedione that is converted to estrogen by the enzyme aromatase in the granulosa cells. The outer theca externa has no known function.
- With continuing hormonal stimulation, the first meiotic division is completed and a Graafian follicle develops. In this process, the primary oocyte becomes a secondary oocyte (2N) and the first polar body is formed. In this follicle, the oocyte is surrounded by the zona pellucida and a group of cells known as the corona radiata, which is derived from the cumulus oophorus. The follicle has a large fluid-filled antrum and is enveloped by follicular cells comprising the zona granulosa, as well as internal and external theca cells.
- Upon ovulation, the Graafian follicle bursts and the ovum, composed of the oocyte, zona pellucida, and corona radiata is expelled into the peritoneal cavity near the oviduct. The second meiotic division and formation of the second polar body does not occur until fertilization.

Classwork

You have to draw pictures from the following micrographs:

1. **Spermatogenesis in seminiferous tubule**
2. **Oogenesis in primary ovarian follicle**

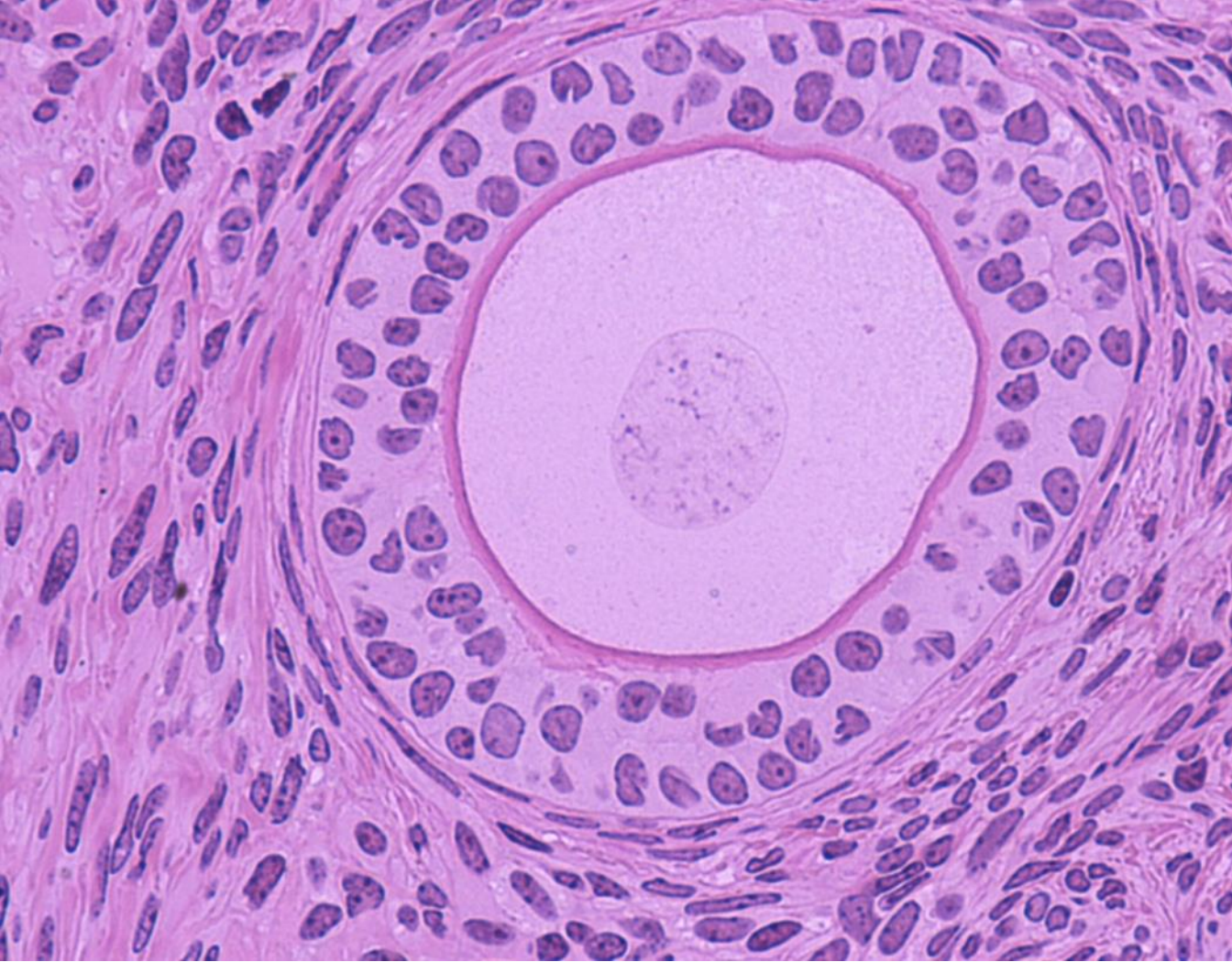




**Picture 1: Spermatogenesis in seminiferous tubule
(light micrograph, hematoxylin-eosin stain)**

What should be marked:

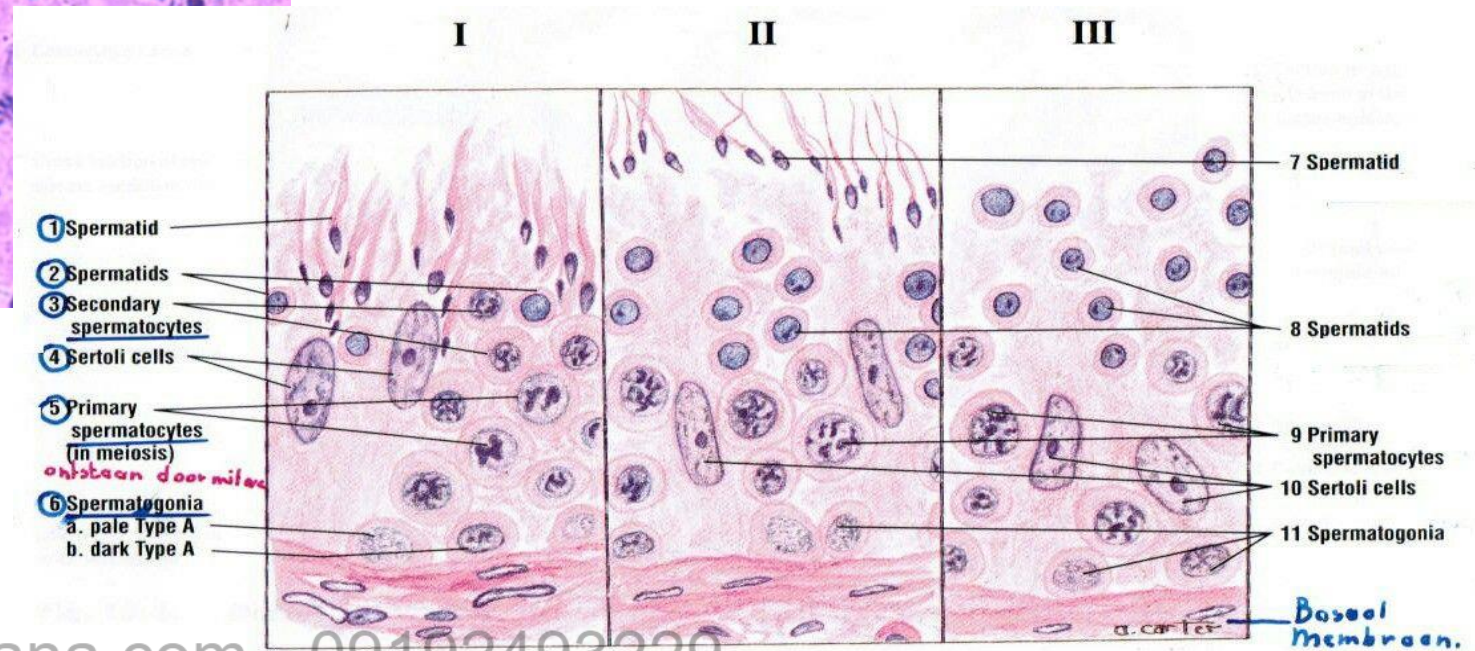
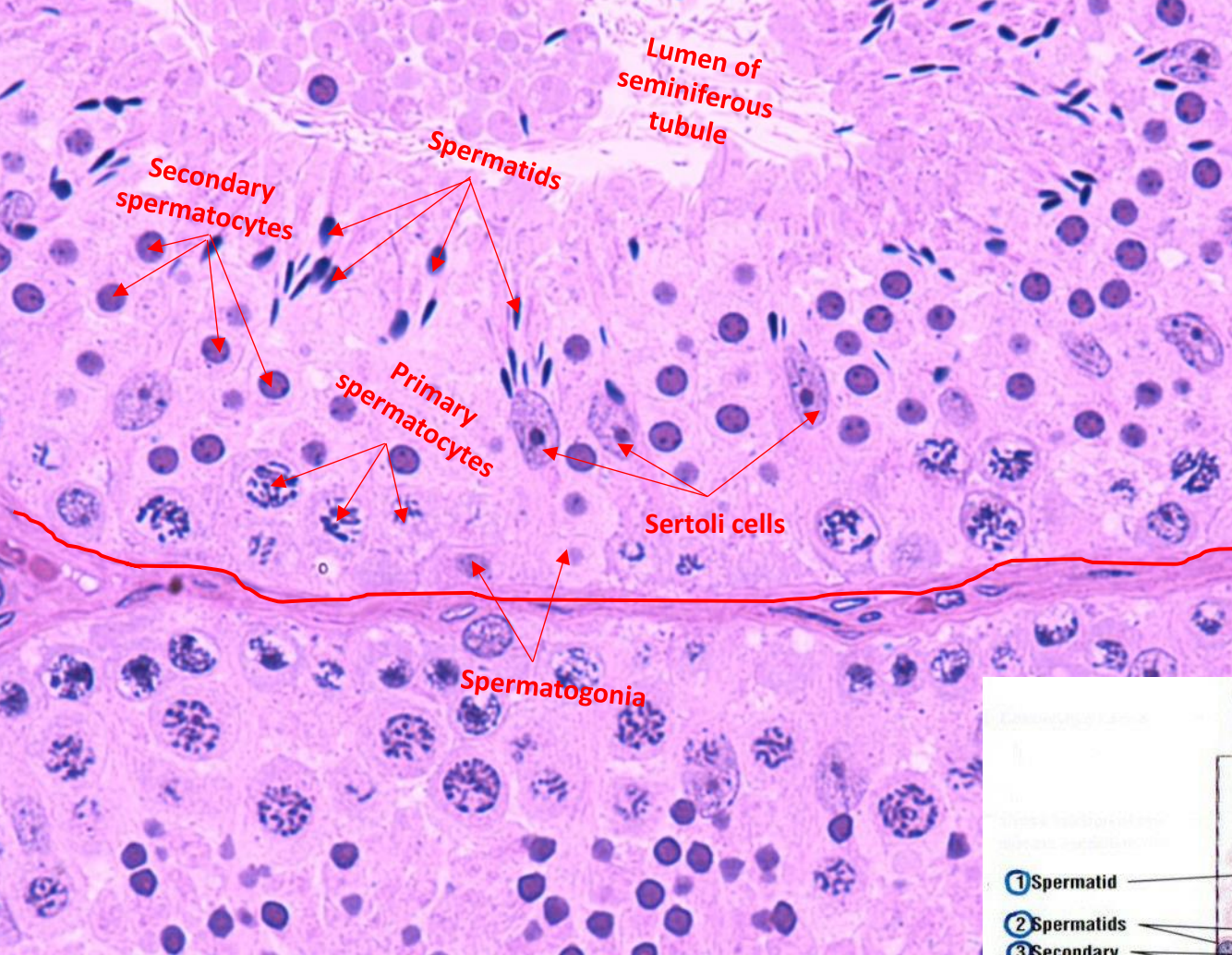
1. Spermatogonia
2. Primary spermatocytes
3. Secondary spermatocytes
4. Spermatids
5. Sertoli cells
6. Basement membrane
7. Lumen of seminiferous tubule



What should be marked:

1. Oocyte
2. Germinal vesicle (nucleus)
3. Zona pellucida
4. Zona granulosa (follicular cells)
5. Basement membrane

**Picture 2: Oogenesis in primary ovarian follicle
(light micrograph, hematoxylin-eosin stain)**



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Fig. 18-4 Primate Testis: Stages of Spermatogenesis. Stain: hematoxylin-eosin. High magnification.



oocyte

zona
pellucida

zona granulosa
(follicular cells)

basement
membrane



Lesson VII. Embryogenesis

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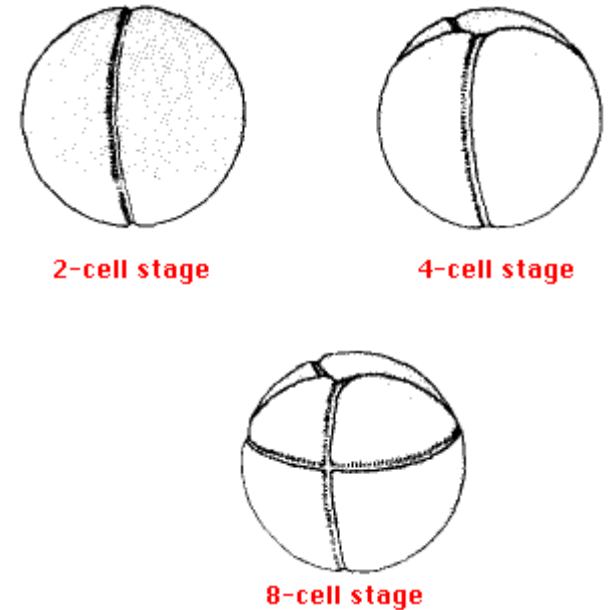
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Cell cleavage

The zygote nucleus undergoes a series of mitoses, with the resulting daughter nuclei becoming partitioned off, by cytokinesis, in separate, and ever-smaller, cells. The **first cleavage** occurs shortly after the zygote nucleus forms. A furrow appears that runs longitudinally through the poles of the egg, passing through the point at which the sperm entered and bisecting the gray crescent. This divides the egg into two halves forming the **2-cell stage**. The **second cleavage** forms the **4-cell stage**. The cleavage furrow again runs through the poles but at right angles to the first furrow. The furrow in the **third cleavage** runs horizontally but in a plane closer to the animal than to the vegetal pole. It produces the **8-cell stage**.

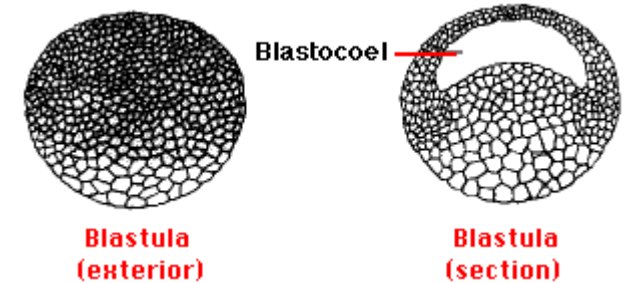
The next few cleavages also proceed in synchrony, producing a 16-cell and then a 32-cell embryo. However, as cleavage continues, the cells in the animal pole begin dividing more rapidly than those in the vegetal pole and thus become smaller and more numerous. By the next day, continued cleavage has produced a hollow ball of thousands of cells called the blastula. A fluid-filled cavity, the blastocoel, forms within it.

During this entire process there has been no growth of the embryo. In fact, because the cells of the blastula are so small, the blastula looks just like the original egg to the unaided eye. Not until the blastula contains some 4,000 cells is there any transcription of zygote genes. All of the activities up to now have been run by gene products (mRNA and proteins) deposited by the mother when she formed the egg.



Blastulation

At the end of cleavage the solid ball of cells give rise to **blastula** which consists of a number **blastomeres**. The characteristic features of the blastula stage are the presence of a well defined cavity called the **blastocoel**. This is the beginning of the primary body cavity. The process of the formation of blastula is called **blastulation**. The blastula of frog is called amphiblastian as the cavity is confined to only the animal pole. The vegetal pole however is composed of a solid mass of non-pigmented yolky cells. In the thirty two cell stage, the blastula consists of a single layer of cells and is called the early blastula. The pigmented cells (**micromeres**) are found in the anterior half while the yolky **macromeres** are present in the posterior half. As has been already pointed out, the blastocoel lies entirely in the anterior half. The blastula of frog is hollow and has a very well developed blastocoel. It is said to be a coeloblastula. As segmentation proceeds, the number of cells in the blastula increase; so also the blastocoel. The floor of the blastocoel is flat while its top portion is arched. The roof is made up of three to four layers of pigmented micromeres while the floor is formed by yolky macromeres. Between the micromeres and the macromeres and along the equator is found a group of cells which are intermediate in size (between macromeres and micromeres). These cells constitute the germ ring. The germ ring is formed in the region of the grey crescent.



Gastrulation

Gastrulation is the process of formation of hollow gastrula from blastula. It involves dynamic movement and rearrangement of blastomeres. Such movements of blastomeres along specific paths during gastrulation are called as morphogenetic movements. Three types of morphogenetic movements can be found.

Invagination: Invagination is an active infolding of blastomeres. During invagination, few blastomeres near grey crescent are pushed inward to form a slit or groove. The opening of this groove is called as blastopore and the cavity is called as gastrocoel or archenteron. The blastopore gradually assumes a crescentic shape. Finally it becomes circular. The region dorsal to the blastoporal opening is called the 'dorsal lip'. The lower edge may be called the 'ventral lip'. Due to enlargement of archenteron, blastocoel is gradually reduced.

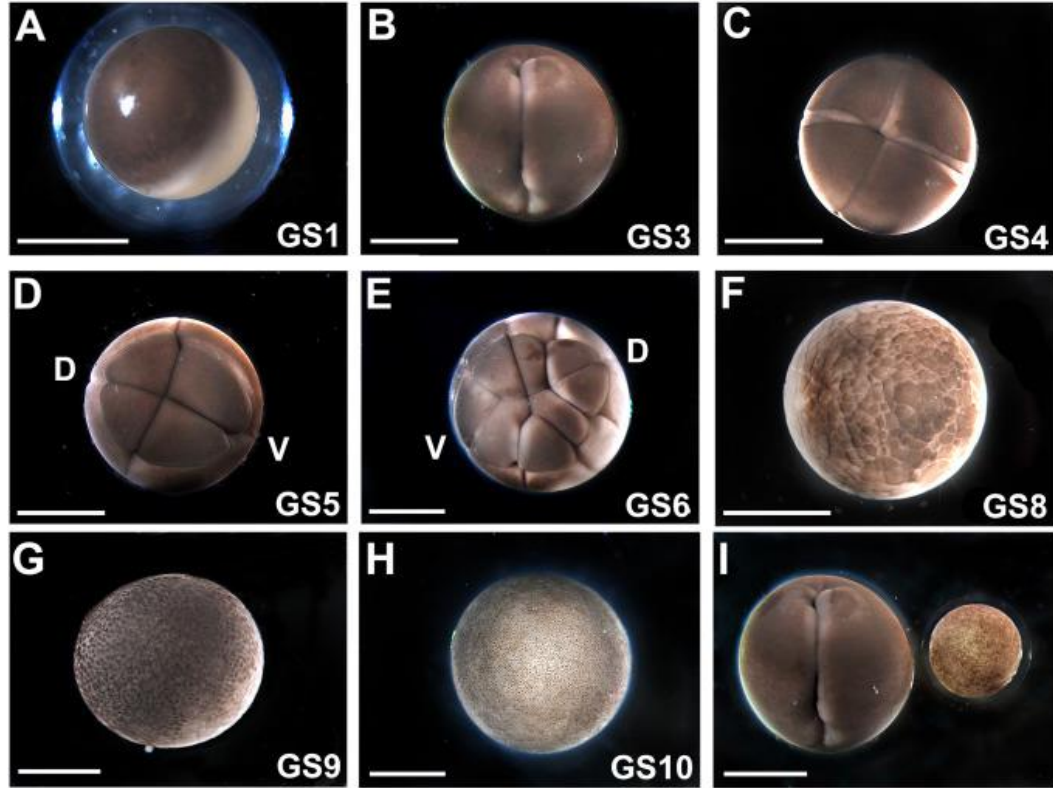
Involution: Involution is the process of rolling in movement of blastomeres. During this process the micromeres multiply and migrate to the dorsal lip of blastopore and roll inside or turn into the archenteron and arrange themselves on the roof of the archenteron. Involution is completed by convergence and divergence. During this, the micromeres multiply rapidly and move towards the blastoporal end, process called convergence. Thus converged cells in the blastopore start to involute slowly and diverge towards the roof of the archenteron. This process is called as divergence. Thus involuted cells develop into chordamesoderm. The archenteron gradually widens which pushes the blastocoel narrow. The crescentic blastopore becomes complete circle.

Epiboly: Epiboly means growth of one layer of cells over another. During epiboly, micromeres of animal pole divide rapidly and move over the macromeres of vegetal pole. This layer forms ectoderm. As a result of these morphogenetic movements, three primary germ layers are formed. The cells which cover the gastrula externally form ectoderm. Those involuted cells into the roof of archenteron give rise to mesoderm and cells of sides and floor of the archenteron will develop into endoderm.

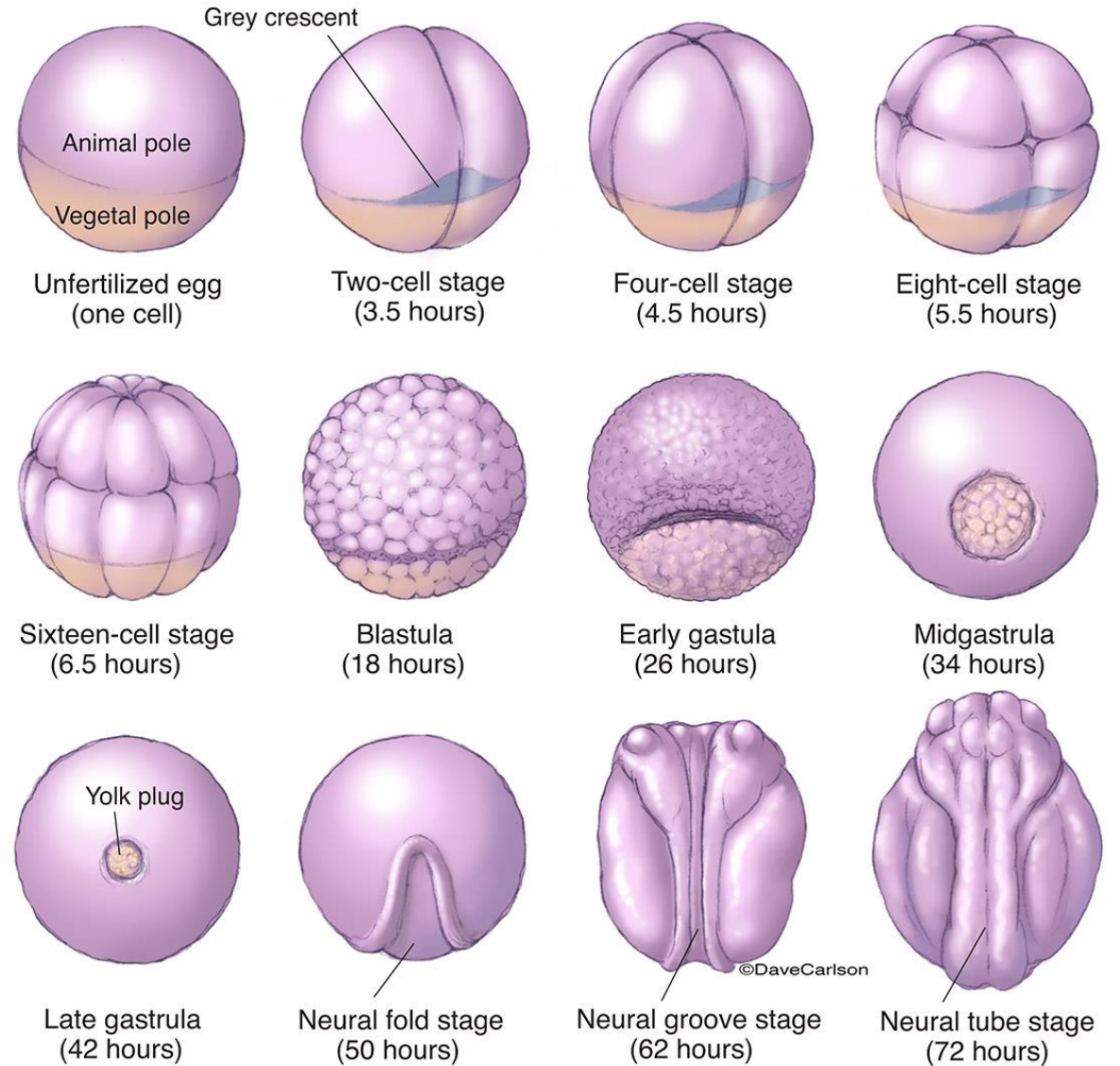
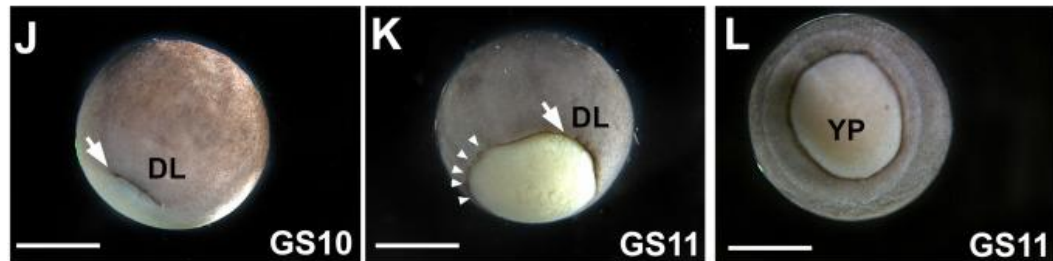
Some other internal changes are also taking place along with those morphogenetic movements. As the archenteron is enlarging, the yolky megameres are pushed out towards the blastopore. This structure is called as **yolk plug**.



Cleavage



Gastrulation

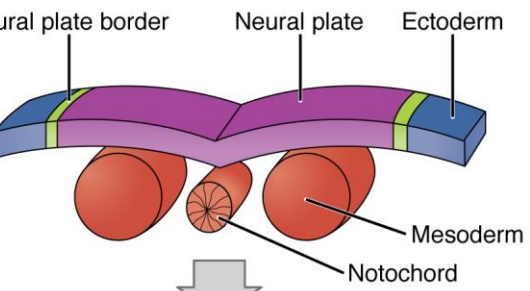


Neurulation

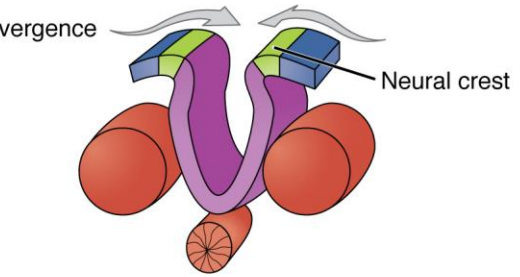
Neurulation in vertebrates results in the formation of the neural tube, which gives rise to both the spinal cord and the brain. **Neural crest cells** are also created during neurulation. Neural crest cells migrate away from the **neural tube** and give rise to a variety of cell types, including pigment cells and neurons.

Neurulation begins with the formation of a **neural plate**, a thickening of the ectoderm caused when cuboidal epithelial cells become columnar. The notochord is necessary in order to induce neural plate formation. Changes in cell shape and cell adhesion cause the edges of the plate to fold and rise, meeting in the midline to form a tube. The cells at the tips of the **neural folds** come to lie between the neural tube and the overlying epidermis. These cells become the neural crest cells. Both epidermis and neural plate are capable of giving rise to neural crest cells.

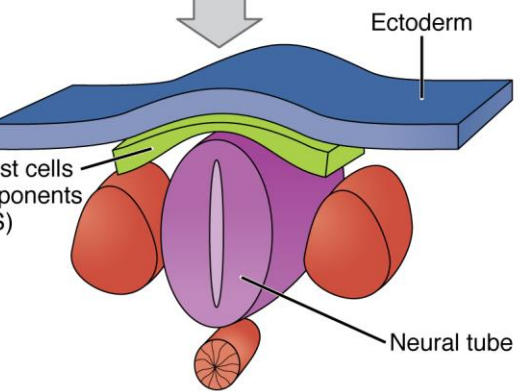
During neurulation, **somites** form in pairs flanking the neural tube. Somites are blocks of cells that form a segmental pattern in the vertebrate embryo. Somites produce cells that become vertebrae, ribs, muscles, and skin. The region where neural tube closure begins varies between different classes of vertebrates. In amphibians such as *Xenopus*, the neural tube closes almost simultaneously along its entire length.



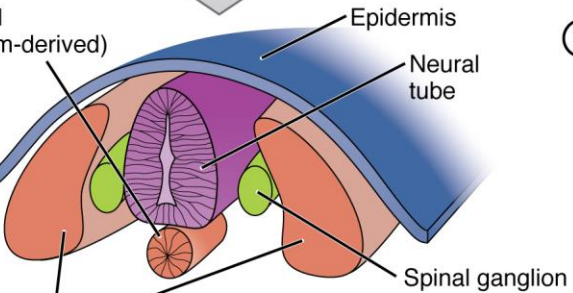
① Neuroectodermal tissues differentiate from the ectoderm and thicken into the neural plate. The neural plate border separates the ectoderm from the neural plate.



② The neural plate bends dorsally, with the two ends eventually joining at the neural plate borders, which are now referred to as the neural crest.

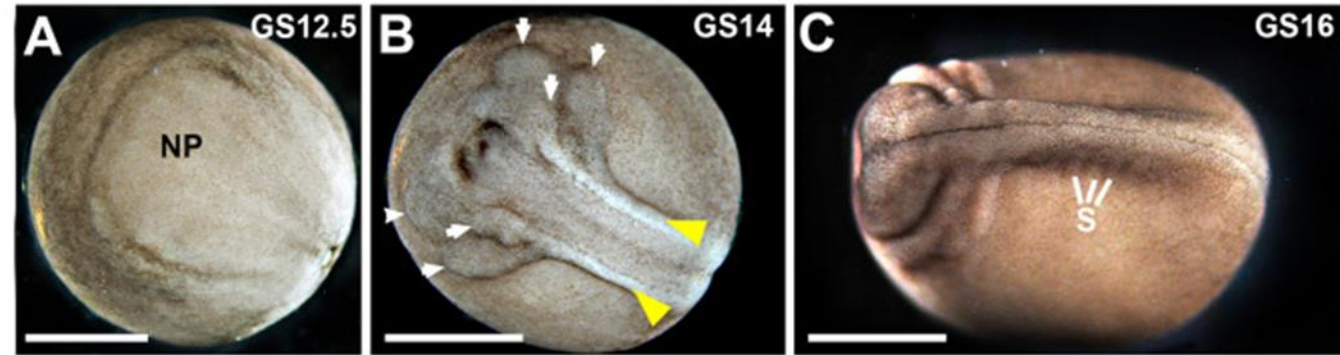


③ The closure of the neural tube disconnects the neural crest from the epidermis. Neural crest cells differentiate to form most of the peripheral nervous system.

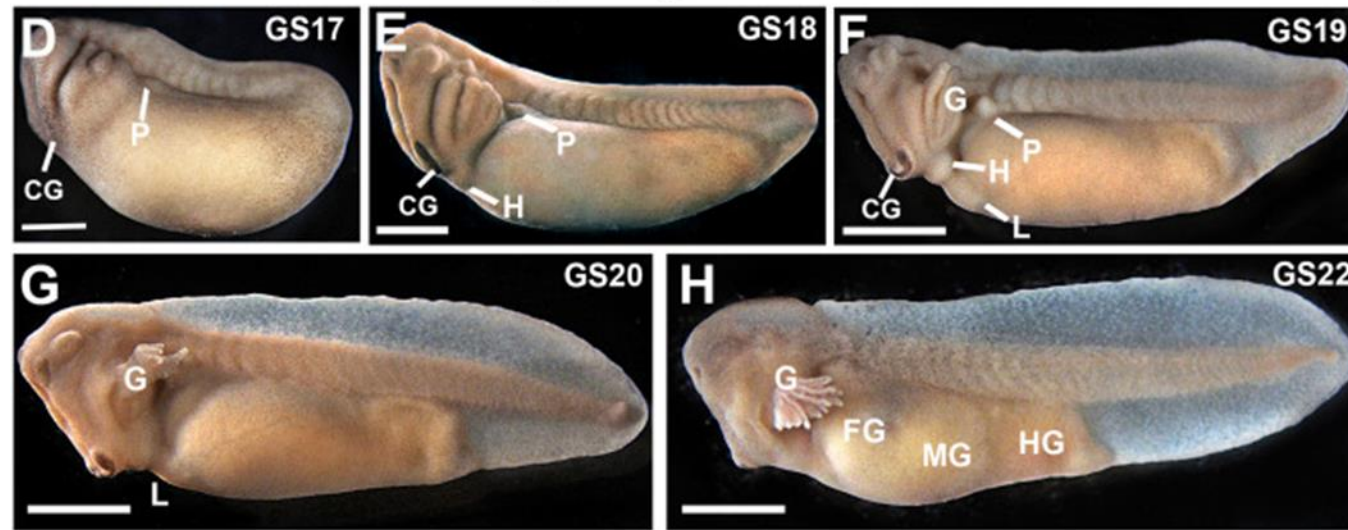


④ The notochord degenerates and only persists as the nucleus pulposus of the intervertebral discs. Other mesoderm cells differentiate into the somites, the precursors of the axial skeleton and skeletal muscle.

Neurulation



Organogenesis



Organogenesis

The primary organ rudiments from ectoderm, mesoderm and endoderm get well established during the processes of gastrulation and neurulation. In the next stage the primary organ rudiments subdivide into secondary organ rudiments. These rudiments get differentiated into various organs and organ systems.

- **Development of ectodermal organs**

The neurula of frog has three kinds of ectodermal tissues namely, epidermal ectoderm, neural ectoderm and neural crest cells.

Epidermal ectoderm

The epidermal derivatives are the skin, olfactory sense organs, ear, lateral line sense organs, median fins, external gills and lining of mouth and anus.

Neural ectoderm

This layer of cells form the central nervous system and peripheral nervous systems.

- **Development of mesodermal organs**

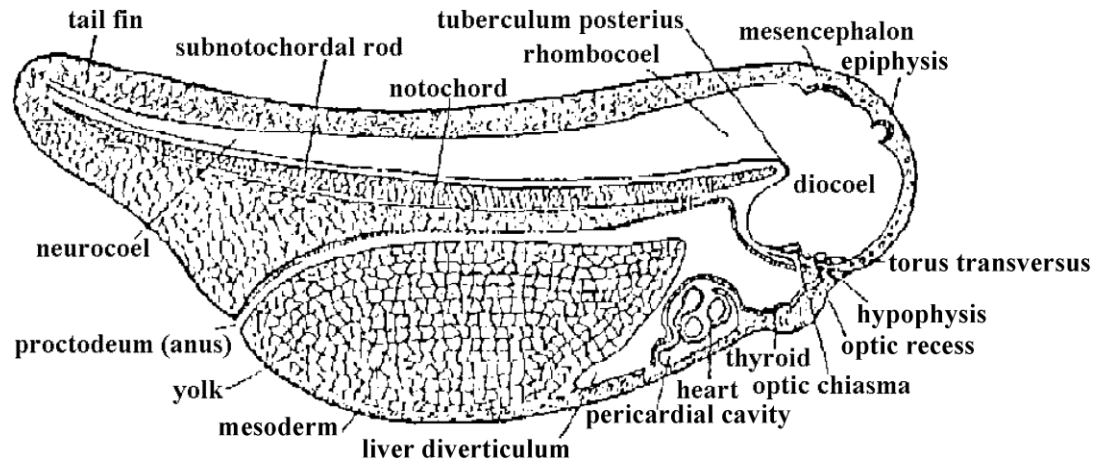
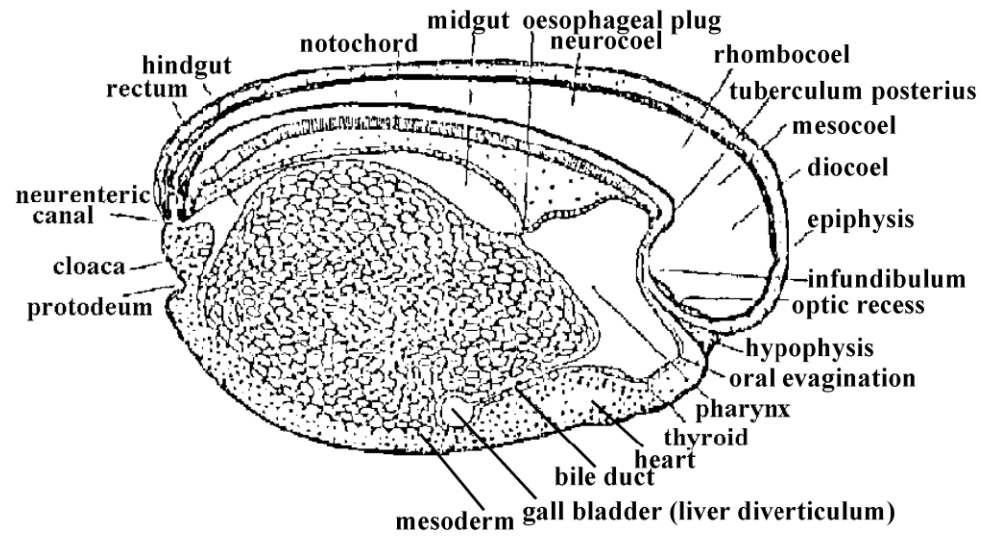
The mesodermal derivatives are the limbs, endoskeleton, heart, blood vessels, kidney, coelom and reproductive organs.

- **Development of endodermal organs**

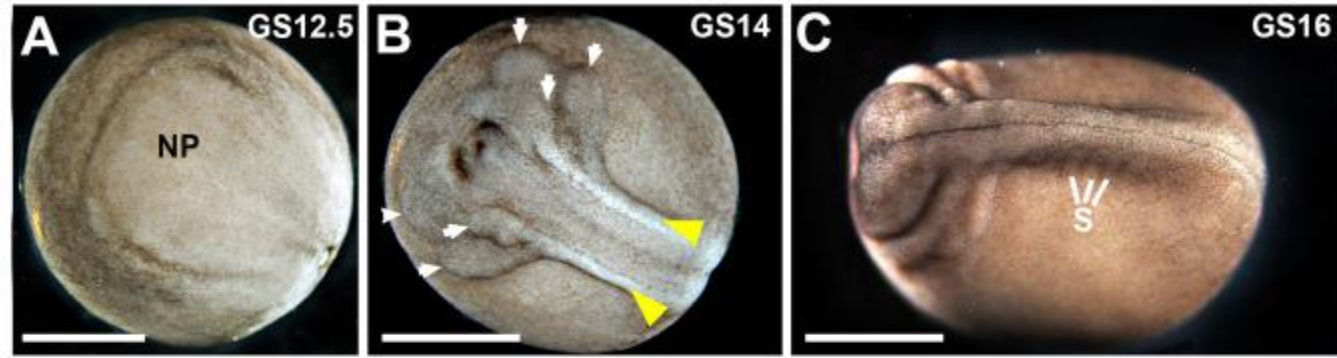
The predominant endodermal organs are the organs of the alimentary canal, lungs, pancreas and urinary bladder.

- **Development of heart**

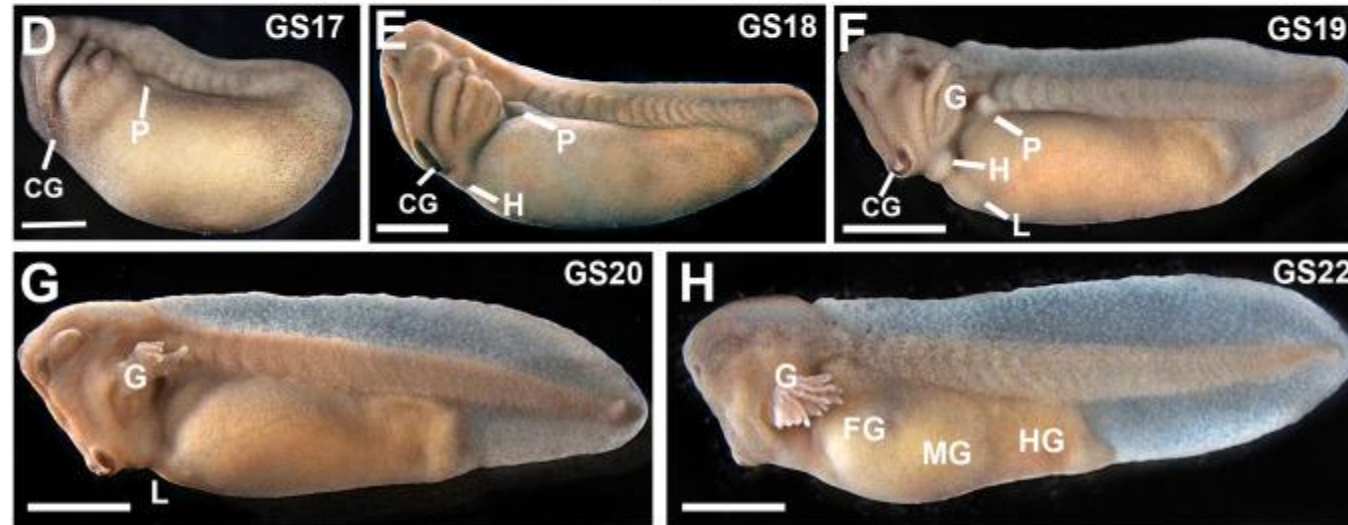
The heart is a mesodermal derivative. It develops on the ventral side of pharynx. It is formed from the lateral plate mesoderm. Initially the heart is formed as a straight tube. Later it gets folded to form the chambered heart.



Neurulation



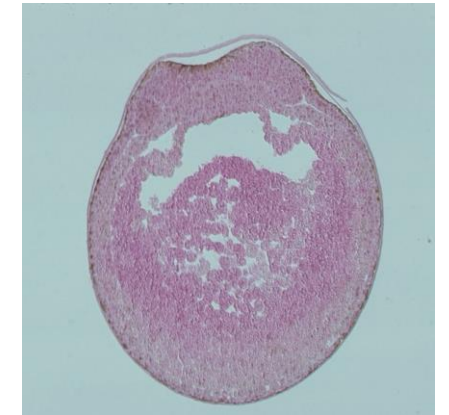
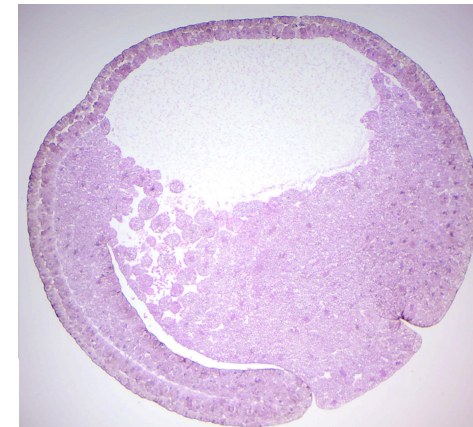
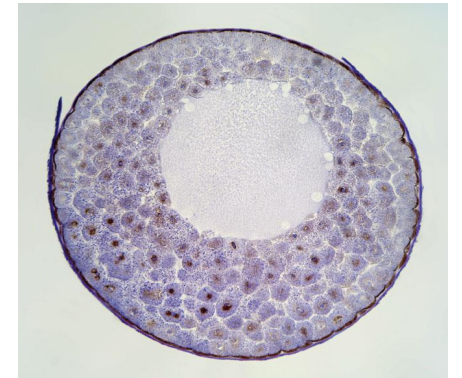
Organogenesis



Classwork

You have to draw pictures from the following micrographs:

1. **Frog cleavage (stage of eight cells)**
2. **Frog blastulation**
3. **Frog gastrulation (stage of yolk plug)**
4. **Frog neurula (stage of neural groove)**
5. **Frog neurula (stage of neural tube)**





What should be marked:

- 1) Macromeres
- 2) Micromeres
- 3) Vitelline membrane
- 4) Animal pole
- 5) Vegetal pole

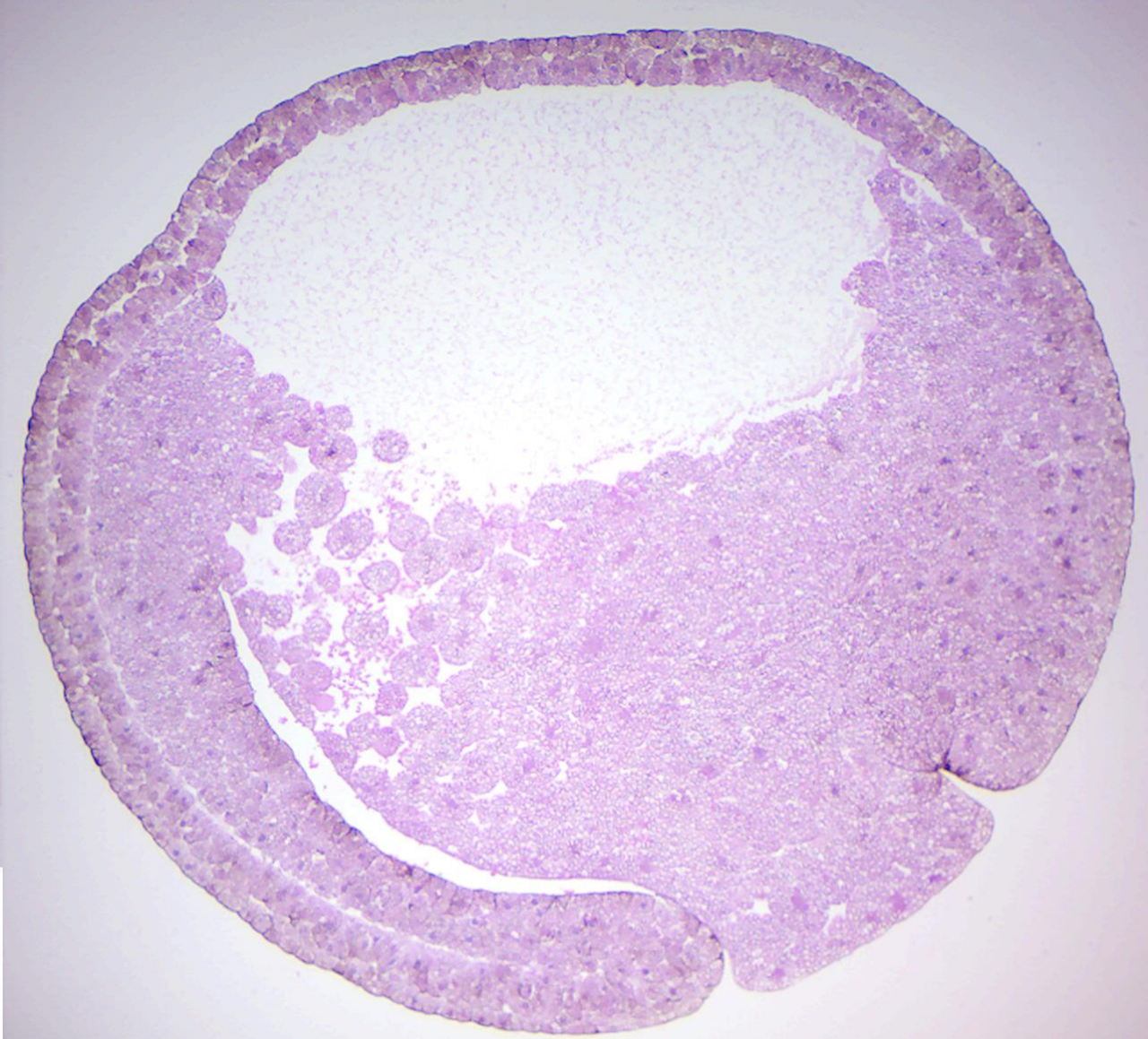
Picture 1: Frog cleavage (stage of eight cells)



Picture 2: Frog blastulation

What should be marked:

- 1) Macromeres
- 2) Micromeres
- 3) Blastocoel
- 4) Vitelline membrane
- 5) Animal pole
- 6) Vegetal pole



What should be marked:

- 1) Blastocoel
- 2) Ventral lip of blastopore
- 3) Dorsal lip of blastopore
- 4) Archenteron
- 5) Yolk plug
- 6) Animal pole
- 7) Vegetal pole

Picture 3: Frog gastrulation (stage of yolk plug)



What should be marked:

- 1) Neural groove
- 2) Neural fold
- 3) Notochord
- 4) Somite mesoderm
- 5) Mesoderm
- 6) Ectoderm
- 7) Endoderm
- 8) Gut

Picture 1: Frog neurula (stage of neural groove)



What should be marked:

- 1) Neural tube
- 2) Neurocoel
- 3) Notochord
- 4) Somite mesoderm
- 5) Mesoderm
- 6) Ectoderm
- 7) Endoderm
- 8) Gut

Picture 2: Frog neurula (stage of neural tube)

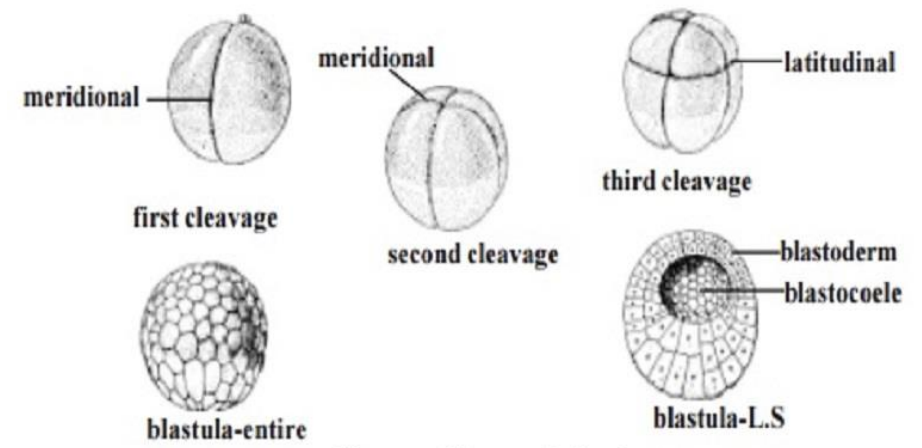
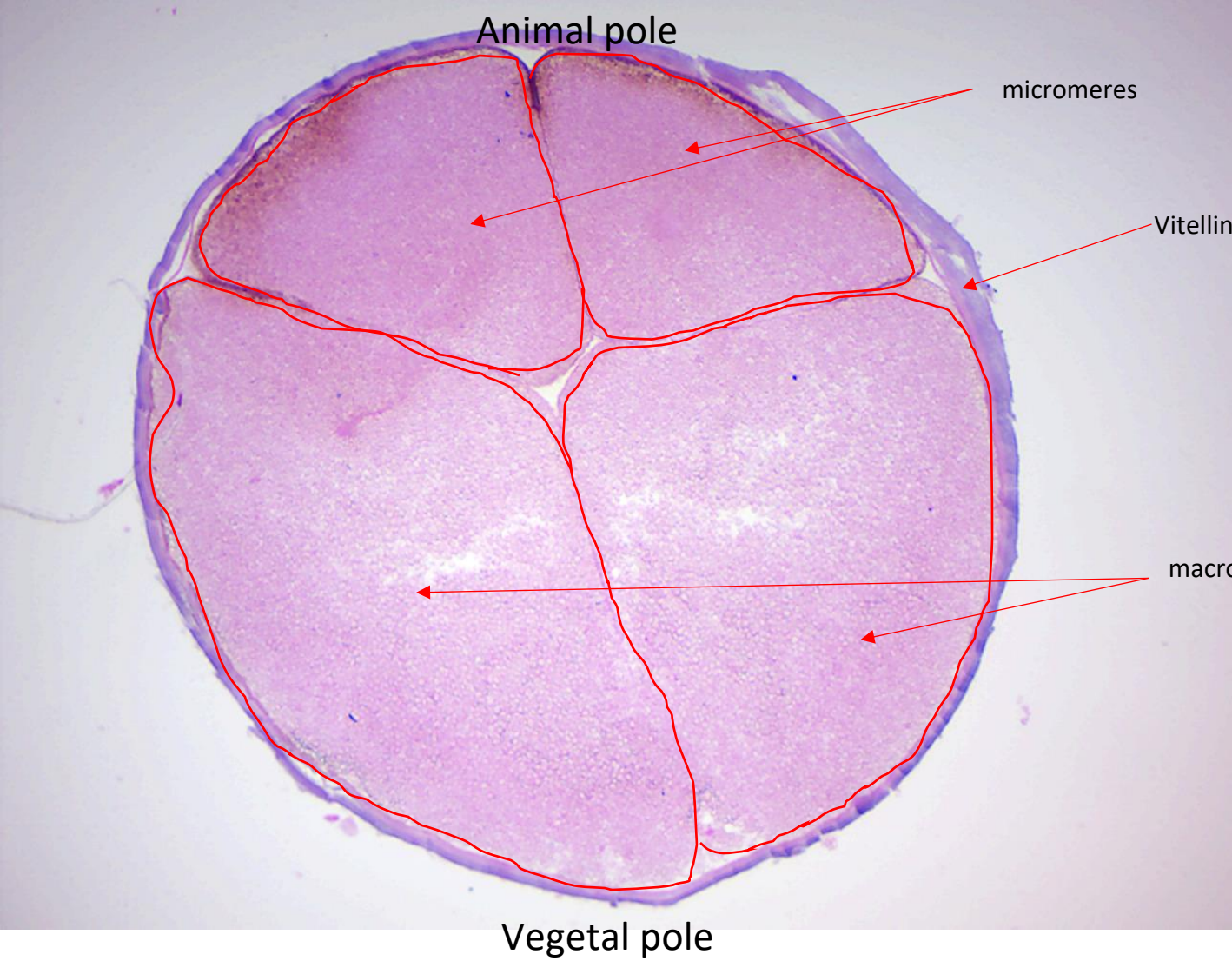
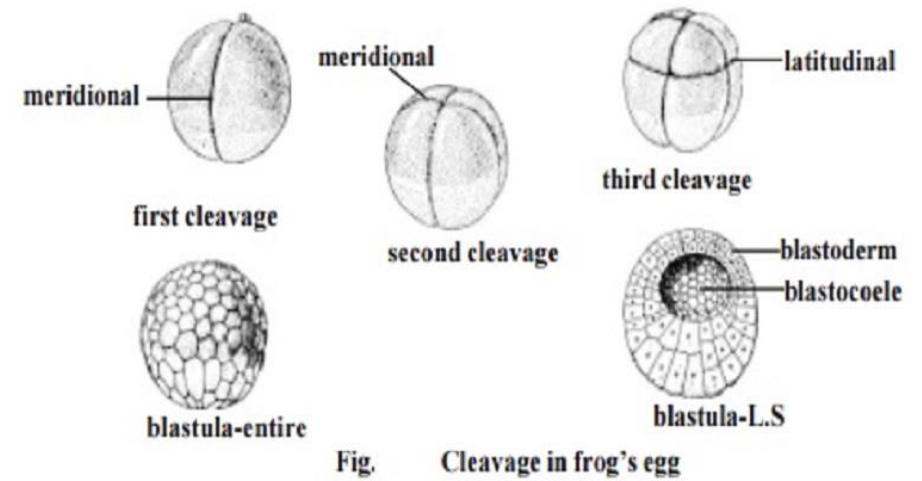
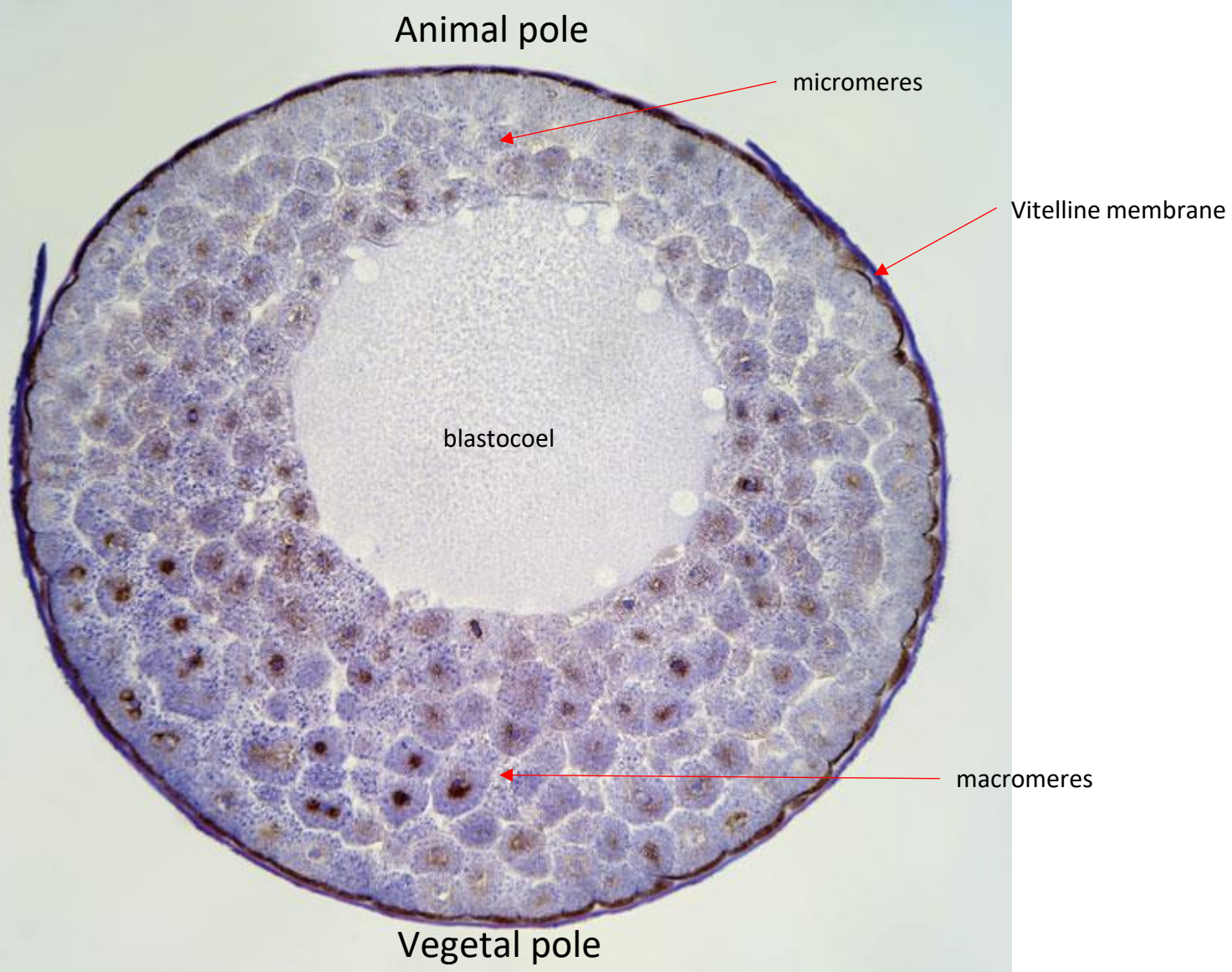


Fig. Cleavage in frog's egg



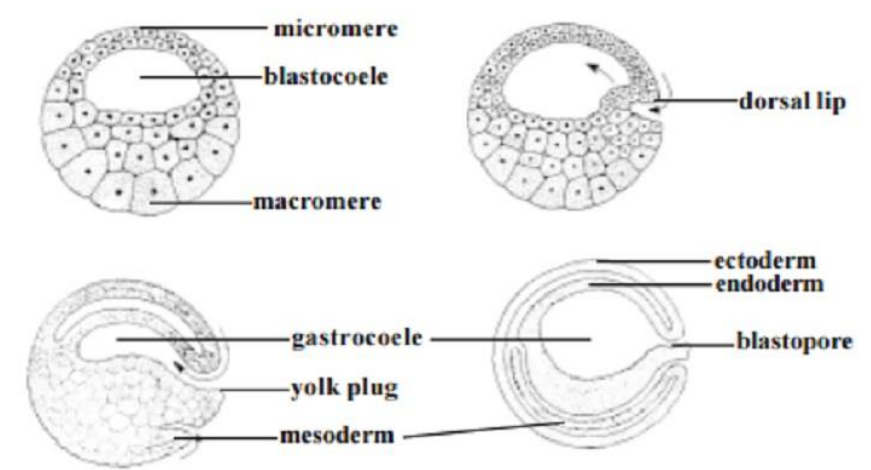
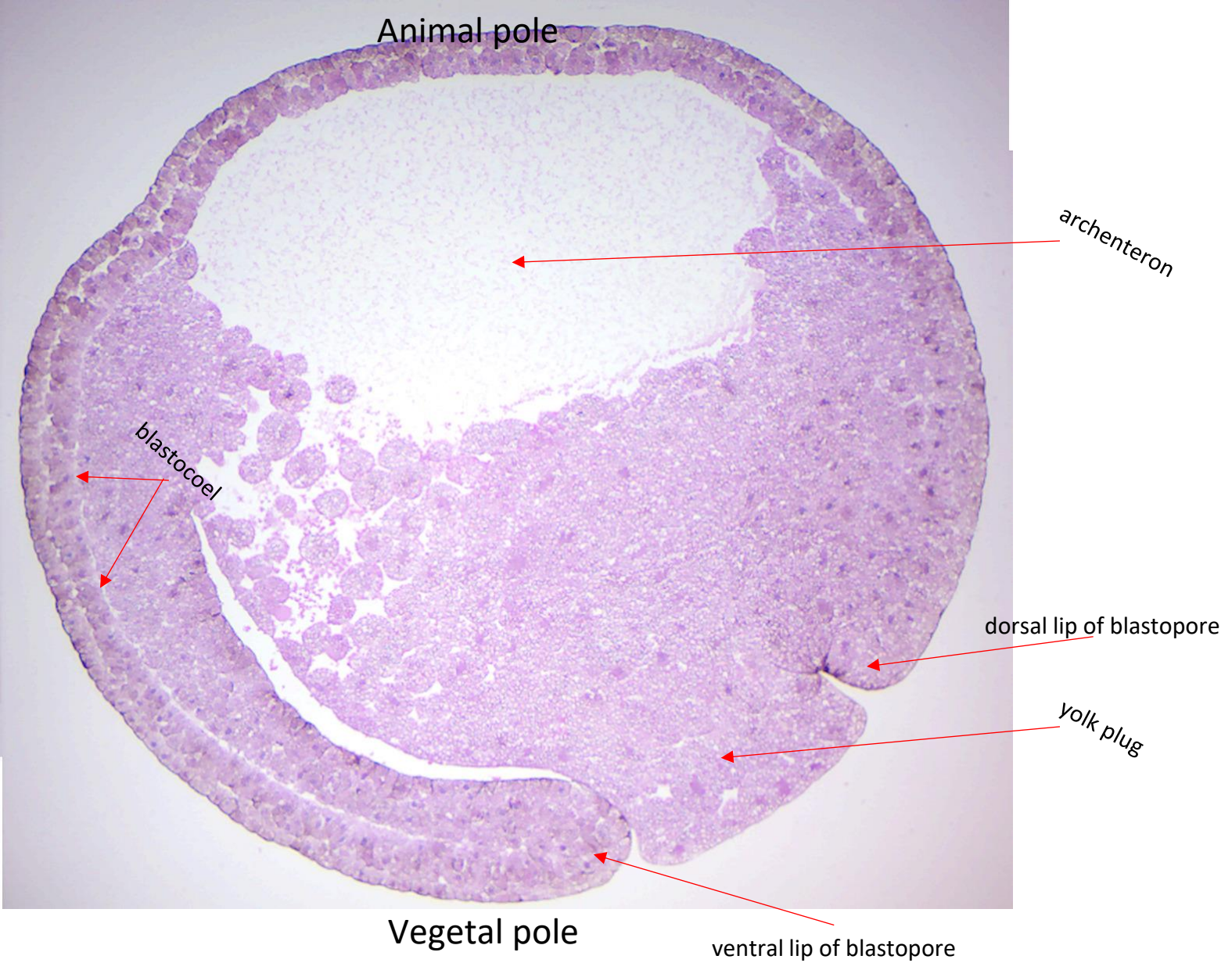


Fig. Gastrulation of Frog

