STRUCTURE OF THE CELL

The cell is the smallest standard unit of the organisms.

- nucleus
- vital functions (growth, metabolism, irritability, movement,reproduction)
- independent existence in certain conditions (cultivation *in vitro*)

Cell shape (various):

- *spherical (leukocytes), oval (plasma cells), biconcave disc (normal erythrocytes), cubic, columnar, polyhedral (epithelial cells), pyramidal (some neurons), spindle or elongated (muscle cells), stellate (some supporting cells in nerve tissue), etc.*

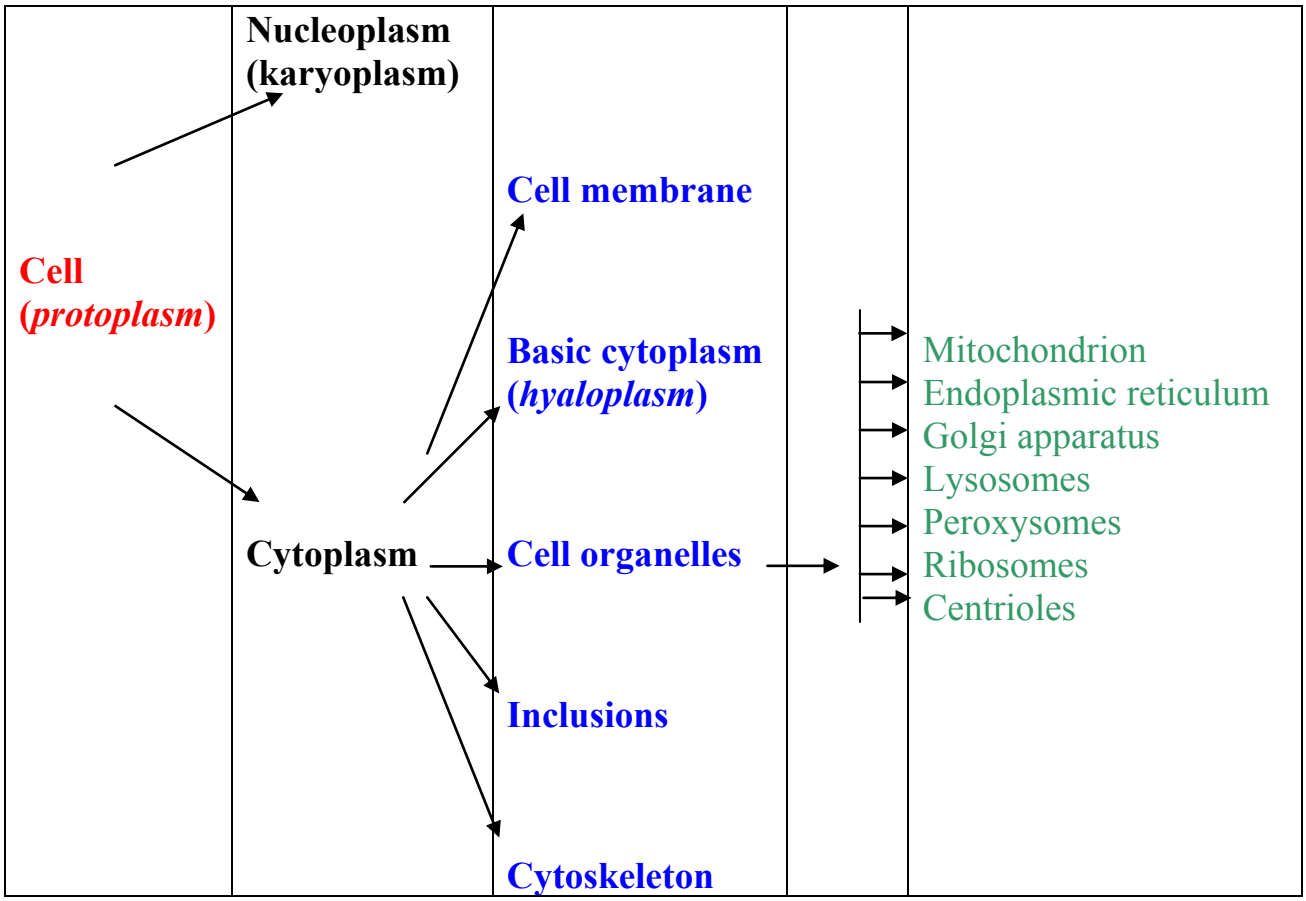
Cell size (on average 10 – 30 μm):

- *2 – 4 μm blood plattelets*
  5 μm – the smallest neurons in cerebellum
  55 μm – length of spermatozoon
  120 μm – oocyte, the largest neurons in brain cortex and spindle cord
  several cm – length of skeletal muscle cells

Lifespan of the cell (hours – years):

- *6 – 7 hours – neutrophils (type of white blood cells)*
  7 – 14 days – eosinophils (-,,-)
  120 days – erythrocytes
  1 – 2 years – liver cells (hepatocytes)
  from birth to death of organism – neurons

Cell components:



Nucleus

- *1 or 2 (rarely more)*
- *diameter: 4 – 10 µm*
- *shape – spherical, oval, lobated, segmented*
- *contains **chromosomes** with DNA and proteins (genetic informations), chromosomes are visible only during cell division (mitosis, meiosis); during interphase (= period between cell divisions) chromosomes are decondensed and form fine, granular **chromatin***

NUCLEAR COMPONENTS:

- *chromatin (decondensed chromosomes)*
- *nucleolus*
- *nuclear envelope – inner + outer membrane*
- *nuclear skeleton*

Nuclear envelope

The nucleus is enveloped by a pair of membranes (inner + outer) enclosing a **perinuclear space** that is continuous with that of the endoplasmic reticulum and ribosomes can be attached to the external surface of outer membrane. The inner membrane is stabilized by a meshwork of intermediate filament proteins called **lamins**.

The nuclear envelope is perforated by thousands of **nuclear pores** that control the passage of molecules in and out of the nucleus. Each is constructed from a number different proteins called **nucleoporins**.

The entire assembly forms an aqueous channel connecting the cytosol with the interior of the nucleus (nucleoplasm). When materials are to be transported through the pore, it opens up to form a channel some 25 nm wide - large enough to get such large assemblies as ribosomal subunits through.

Import into the nucleus

All proteins are synthesized in the cytosol and those needed by the nucleus must be imported into it through the pores.

They include:

- all the **histones** needed to make the nucleosomes
- all the **ribosomal proteins** needed for the assembly of ribosomes
- all the **transcription factors** (e.g., the steroid receptors) needed to turn genes on (and off)
- all the **splicing factors** needed to process pre-mRNA into mature mRNA molecules; that is, to cut out intron regions and splice the exon regions.

Export from the nucleus

Molecules and macromolecular assemblies exported from the nucleus include:

- the **ribosomal subunits** containing both rRNA and proteins
- **messenger RNA** (mRNA) molecules (accompanied by proteins)
- **transfer RNA** (tRNA) molecules (also accompanied by proteins)
- **transcription factors** that are returned to the cytosol to await reuse

Both the RNA and protein molecules contain characteristic **nuclear export signals** needed to ensure their association with the right carrier molecules to take them out to the cytosol.

Chromatin

Chromosomes during interphase are more or less decondensed and in this form are called **chromatin**:

- **euchromatin** – light in EM, completely decondensed chromosomes, intensly active RNA synthesis
- **heterochromatin** – dark in EM, partly decondensed chromosomes, inactive, according to localization in nucleus 3 types of heterochromosomes are recognised: **marginal heterochromatin** (attached to inner membrane), **perinucleolar heterochromatin** (around nucleolus), **karyosomes** (within euchromatin)

[Chromosomes]

Each chromosome consists of a single molecule of DNA complexed with an equal mass of proteins. Length of human chromosomes is 2 – 10 μm,

	- Chromosome contains 2 chromatids - Short arm (p-arm), long arm (q-arm) - Primary constriction (centromere) with kinetochore - Diploid set of chromosome in nucleus of somatic cells: 46 (2n) = 23 pairs haploid set in gametes: 23 (1n)

Nucleolus

- 1 – 2 – more nucleoli in nucleus during the period between cell divisions (interphase)
- 1 – 3 μm ∅
- is not separated by any membrane
- contant: RNA, DNA, proteins
- structure in EM: pars fibrosa (with fibrilar form of RNA), pars granulosa (with granular form of RNA), fibrilar center(s) with DNA

- types of nucleoli: reticular, ring-shaped, compact
- function: synthesis of preribosomal RNA which is connected with proteins forming together ribosomal subunits, these are transported into the cytoplasm through pores in nuclear envelope.

Nuclear skeleton

- *network of fibers and trabecules composed of structural proteins*

CELL ORGANELES

Mitrochondrion

- spherical or oval or elongated bodies
- 0.5 μm ∅, length of elongated mitochondria 1-10 μm
- volume density of mitochondria in the cytoplasm depends on the metabolic activity of the cell

function: oxydative phosphorylation (transformation of energy of chemical compound into energy of macroergic bounds (ATP - the universal energy currency of the cell).

Structure of mitochondrion:

- outer mitochondrial membrane – smooth; with transporting channels
- inner mitochondrial membrane – forms flattened (rarely tubular) invaginations into the inner matrix called cristae with stalked particles (these are ATP synthase enzyme molecules, which produce ATP)
- intermembrane space between the membranes contains enzymes that use ATP to phosphorylate other nucleotides and that catalyze other reactions
- mitochondrial matrix – finely granulated, contains enzymes of Krebs' cycle (citric acid cycle), ADP, ATP, DNA, RNA, ribosomes, proteins
- mitochondrial ribosomes and granules with ions (Ca mainly) were detected here
- mitochondria are partly autonomous (semiautonomous) structures: they contain DNA and their own ribosomes and produce own proteins
- they are able divide themselves (replication)

Ribosomes

- small particles (below recognizing ability of LM)
- in EM they appear as granules sized 20 – 25 nm
- chemical composition: several types of RNA with associated proteins (cells containing large amount of ribosomes show basophilia of cytoplasm because ribosomes are acid structures in the cell)

Forms of ribosomes:

- free ribosomes
- polysomes
- connected with membranes of endoplasmic reticulum by ribophorin receptors (rough endoplasmic reticulum)

	Polysomes –complexes of ribosomes connected together by fiber of mRNA

Function of ribosomes:

- synthesis of proteins (polypeptides) for "export" (are released externally from cell cytoplasm) by rough endoplasmic reticulum
- synthesis of proteins used by cell by free ribosomes and polysomes (stem cells need proteins to grow intensly – examples: "young" cells involved in embryogenesis, "young" blood cells – precursors of mature blood cells)

Endoplasmic reticulum

- 2 forms: rough (granular) – **GER**, and smooth (agranular) – **AER**

GER:

- 3D system of communicating flattened cisternae with membrane covered with ribosomes
- binding of ribosomes to GER is reversible, they can be released from membrane.
- function of GER – protein synthesis for export. GER is the site of translation and folding of and transport of proteins that are to become part of the cell membrane (e.g., transmembrane receptors and other integral membrane proteins) as well as proteins that are to be secreted or "exocytosed" from the secretory cell (e.g., digestive enzymes).

AER:

- 3D system of communicating short tubules and small vesicles with smooth membrane without ribosomes
- Function of AER – numerous:
  - participatin in detoxicating processes in the cells (liver and some kidney cells)
  - participation in steroid hormones production
  - participation in glycogen metabolism (liver cells)
  - reservoir of Ca ions (sarcoplasmic reticulum in muscle cells)
  - etc.

Golgi apparatus

- usually near the nucleus; several GA in some region of cytoplasm = Golgi field
- 3 components:
  - paralell flat **cisternae** (3 – 10) – they are curved like horse-shoe and polarized: **cis–face** (forming face) and **trans–face** (maturing face) are distinguished
  - small **vesicles** (numerous)
  - large **vacuoles** (several)

Function of GA:

- GER + GA cooperate and represent together functionally connected system of 3D network of cisternae, vesicles and vacuoles with metabolic, proteosynthetic and secretory functions:

1) **ribosomes** on GER – produce polypeptides and release them into cisternae of GER
2) contant of **GER** cisternae is transported through them and small transporting vesicles with proteins are detached
3) transporting vesicles migrate to cis–cisterna of **GA** and fuse together, protein is released into GA, pass through all cisternae into GA trans–cisterna; proteins are processed in GA (finalization of product into hormones, enzymes and other substances)
4) **vesicles** and **vacuoles** with final product are detached from trans–cisterna; their contant is condensed and vacuoles are transformed into secretory granules, lysosomes, smooth and coated vesicles for exocytosis

Lysosomes and endosomes

- **endosomes** – vesicles (20 – 150 nm ∅) which enter the cell (*via pinocytosis*) and either they fuse with lysosomes, or they are transported throughout the cells to be released from them (transcytosis)
- **lysosomes** – heterogenous group of spherical bodies (0.05 -0.5 μm ∅) containing hydrolytic enzymes
  - **primary lysosomes** – small vesicles with intact enzyme contant
  - **secondary lysosomes** – after fusion with material for digestion; according to origin of this material they are divided into **fagosomes** (extracellular origin) and **autophagic vacuoles** (intracellular origin)
  - **residual bodies** – inactive lysosomes with indigestible material (rest)

Peroxisomes
(microbodies)

- spherical vesicles
- ∅ 0.5 μm
- surrounded by single membrane
- nucleoid

- enzymes: uricase, oxidase (oxidation of long and very long chain fatty acids) , catalase (splits H_2O_2 - detoxication)
- in nearly all eukaryotic cells, mainly in liver cells (hepatocytes) and in epithelial cells of proximal tubule of kidney
- function: participation in anabolic (bile acid, cholesterol or phospholipids synthesis) and catabolic processes

Centriole

- oval body
- ∅ 0.2 μm and 0.2 – 0.5 μm in the length
- 9 triplets of microtubules
- paired organelle: one centriol is organized at right angle to the other
- in centrosome = centrosphere (region of cytoplasm near the nucleus)

Function:
after duplication or multiplication
- centrioles organize the microtubules of **mitotic spindle** apparatus at the beginning of mitosis

- are also needed to make cilia (ciliogenesis) and flagella – these project from cell surface and centriols as **basal bodies** of cilia or flagella are present in the cytoplasm bellow them.

Inclusions

- are cytoplasmic structures of transitional character arrising by accumulution of unsoluble metabolits of storing materials or they are of exogenous origin and enter the cell via phagocytosis.

Secretory granules

- membranous vesicles with protein or glycoprotein contant in glandular cells
- they are released from the cell

Reserve materials:
Glycogen

- **β** – granules (sized 20 nm) or **α** – granules (clusters of **β** – granules, sized 500 nm)

Lipid droplets

- non-membranous, round particles (∅ 100 nm – 10 μm)

Kristals

Pigments:
colored inclusions are divieded into
- autogenous – synthetized from precursors inside of cell and having specific function (**melanin**)
- hematogenous – arrise by break-down of hemoglobin (**hemosiderin**, **biliverdin** → **bilirubin**)
- exogenous – from extracellular medium (carotens, dust particles, arteficial dyes – tattoo)

Cell surfaces

- free
- lateral (surface attached to the neighbouring cell)
- basal (turned to the acellular structure – basal lamina)

Cell surface	special structures
Free	microvilli, sterocilia, kinocilia , flagella, pseudopodia, endocytosis, exocytosis
Lateral	Intercellular junctions (connections): zonula occludens, zonula adherens, desmosome, gap junction (nexus)
Basal	hemidesmosome, basal labyrinth

FREE SURFACE DERIVATIVES

Microvilli

- irregular cytoplasmic processes 1 – 6 μm long and 0.1 μm in ∅
- cell membrane + cytoplasm + actin filaments

- densly arranged regular microvilli = brush border (intestine epithelium)
- densly arranged long and branched microvilli = striated border (epithelia in kidney tubules
- function: increased surface of usually epithelial cells (resorption)

brush border *striated border*

Stereocilia

- like microvilli but longer (immobile cilia)
- present on apexes of the epithelial cells of epididymis tubules and on some sensory cells

Kinocilia

- oscillating cilia, to 10 μm long and 0.25 μm in ∅
- cell membrane + cytoplasm + axoneme = 9 doublets of microtubules + 1 pair of single microtubules

Cilium – 9 doublets + 1

Basal body = centriol – 9 triplets
(kinetic center of cilium)

Function: movement of fluid or mucus in tubular organs (reproductive ducts, respiratory passages)

Flagellum

- similar to kinocilia, but longer. Only spermatozoa are the cells with flagellum in human organism. Flagellum function – locomotion for spermatozoon.

Pseudopodia

- transitory derivatives of the cell surface. Pseudopodia function – locomotion for the cell

Endocytosis and exocytosis

- cell membrane plays an important role in macromolecules transport into the cell (**endocytosis**) and from the cell (**exocytosis**)
- internalization of substances is realized via **phagocytosis** (phagocytic vacuoles with solid particles) or **pinocytosis** (pinocytic vesicles with fluid content)

LATERAL SURFACE DERIVATIVES – INTERCELLULAR JUNCTIONS

Occlusive junction	tigh junction (zonula occludens)	
Adhesive junctions	belt desmosome (zonula adherens), spot desmosome (macula adherens), hemidesmosome – on basal surface	
Communicating junction	nexus (gap junction)	

Zonula occludens – tigh junction

- forms a belt arround the cell and is usualy situated near the apex of epithelial cell. Membranes of neighbouring cells fuse together in regular points. Function – to pack an intercellular slit.

Zonula adherens

- belt desmosome, usually bellow tigh junction. Intercellular slit is narrow (15 – 20 nm) and is filled with protein substance. Cytoplasmic plaques are attached to inner surfaces of cell membranes and actin microfilaments insert into these plaques.

Macula adherens

- spot desmosome, discoid shape (0.3 – 0.5 μm ∅), cytokeratin filaments (tono-filaments) insert into cytoplasmic plaques. Intercellular space is 25 – 45 nm wide. Density of desmosomes between adjacent cells depends on intensity of adhesion. This structure gives strength to cellular tissues (mainly epithelium, muscles).

Gap junction

- nexus, irregular shape of various size (several nm – several μm), corresponding channels are present in both cell membranes. The wall of channels is formed by 6 integral proteins – connexins. Intercellular space is narrow (2 nm)
  Size and density of nexuses depends on intensity of intercellular communication. Small molecules and electrical signals in one cell can pass through the gap junctions to adjacent cells.

BASAL SURFACE DERIVATIVES

Hemidesmosome

- a half of spot desmosome; junction between basal side of cell membrane and non-cellular lamina basalis.

Cytoskeleton

Cells contain elaborate arrays of protein fibers that serve such functions as:

- establishing cell shape
- providing mechanical strength
- locomotion
- chromosome separation during cell division
- intracellular transport of organelles

The cytoskeleton is made up of three kinds of protein filaments:

- **microtubules**

- **microfilaments**
- **intermediate filaments**

Microtubules

- are straight, hollow cylinders
- have a diameter of about 25 nm
- are variable in length but can grow 1000 times as long as they are thick (grow at each end by the polymerization of tubulin dimers and shrink at at each end by the release of tubulin dimers (depolymerization)
- are built by the assembly of dimers of **alpha and beta tubulin**.

Microtubules participate in a wide variety of cell activities. Most involve motion. The motion is provided by protein "motors" that use the energy of ATP to move along the microtubule.

Microtubule motors
(there are two major groups of microtubule motors)

- **kinesins** (most of these move toward the plus end of the microtubules) and
- **dyneins** (which move toward the minus end).

Microfilaments

Monomers of the protein **actin** polymerize to form long, thin fibers. These are about 8 nm in diameter and, being the thinnest of the cytoskeletal filaments, are also called **microfilaments**. (In skeletal muscle fibers they are called „thin“ filaments, while „thick“ filaments are composed of protein **myosin**). Some functions of actin filaments:

- form a band just beneath the plasma membrane that
  - provides mechanical strength to the cell
  - links transmembrane proteins (e.g., cell surface receptors) to cytoplasmic proteins
  - anchors the centrosomes at opposite poles of the cell during mitosis
  - pinches dividing animal cells apart during cytokinesis
- generate cytoplasmic streaming in some cells
- generate locomotion in cells such as white blood cells and the amoeba
- interact with myosin filaments in skeletal muscle fibers to provide the force of muscular contraction

Intermediate filaments

These cytoplasmic fibers average 10 nm in diameter (and thus are "intermediate" in size between actin filaments (8 nm) and microtubules (25 nm)

There are several types of intermediate filament, each constructed from one or more proteins characteristic of it.

Type of filament	Cells where they are found
cytokeratins	epithelial cells, and also form hair and nails
vimentin	cells of mesenchymal origin – smooth muslce cells, some endothelial and connective tissue cells
desmin	muscle cells
neurofilaments	strenthen the long axons of neurons
glial fibrilary acid protein	supporting neuroglial cells in nerve system

Despite their chemical diversity, intermediate filaments play similar roles in the cell: providing a supporting framework within the cell.

Detection of type of intermediate filaments in tumor cells is used for estimation of tumor origin.