Course «Medical biology»

Learning outcomes

1. CELL BIOLOGY AND MEDICINE.

L - Cell structure and function. Prokaryotes *vs.* Eukaryotes. Cell chemistry. Macromolecules.

1. Explain the main differences between prokaryotic and eukaryotic cells
2. Identify and describe the structures that are typically found in prokaryotic cells
3. Name groups of prokaryotes
4. Identify and describe the structures that are typically found in eukaryotic cells
5. Describe the origin of eukaryotic cells
6. Identify the differences between plant and animal cells
7. Name main tissue systems in plants and animals and describe their function
8. Describe the evolution of metabolism
9. Describe the development of multicellular organisms
10. Explain the structure of monosaccharides, their linear and ring forms and describe the difference between alpha and beta forms of the ring structure of monosaccharides
11. Explain how oligosaccharides and polysaccharides are formed from monosaccharides, explain their function in the cells, name the bonds between monosaccharides
12. Explain the structure of triglycerides, phospholipids, and steroids, and explain their functions in cells
13. Name four categories of amino acids, explain the difference between the primary, secondary, tertiary and quaternary structure of a protein, name the bonds between amino acids in proteins and explain their function in the cell
14. Identify and explain the structure of DNA and RNA, name the bonds between nucleotides and explain the function of DNA and RNA molecules in the cell

S - Cell research methods.

1. Name and explain methods in light microscopy
2. Explain the differences between light and electron microscopy
3. Describe and explain the subcellular fractionation method
4. Describe and explain cell culture methods

P - Microscopy. Visual field size. Sample preparation

1. Explain how microscopy techniques can be used in the detailed study of prokaryotic and eukaryotic cells
2. Explain how to measure the visual field diameter and how to calculate the real size of the visual field
3. Perceive and recognize the nucleus, cytoplasm and cell membrane of eukaryotic cells

2. NUCLEIC ACIDS - DNA.

L - Deoxyribonucleic acid - DNA.

1. Identify and describe major components of nucleic acids
2. Describe the three-dimensional structure of the DNA helix
3. Define genetic terms: gene, allele, chromosome, genotype, phenotype, mutation, nucleoside, nucleotide
4. Describe main experiments that defined the role of DNA as the genetic material
5. Describe the experiment that demonstrated semiconservative replication of DNA

S - DNA structure and replication

1. Identify all DNA polymerases in prokaryotes and eukaryotes and describe their role in the replication and the fidelity of replication
2. Identify all the enzymes and accessory proteins that take part in the replication process of DNA and describe thoroughly DNA replication process
3. Define main terms related to replication: Okazaki fragments, leading strand, lagging strand, replication fork, origin of replication
4. Describe the process of maintaining the ends of chromosomes by the enzyme telomerase

P - DNA isolation (M)

1. Describe the process of DNA isolation from blood
2. Perform the process of DNA isolation from blood under the supervision

3. NUCLEIC ACIDS - RNA.

L – Ribonucleic acid – RNA. Transcription.

1. Describe the structure of the RNA molecule
2. Name all types of RNA in the cell and describe their function
3. Describe the process of transcription and define the enzyme RNA polymerase
4. Explain the structure of RNA-polymerase in prokaryotes
5. Define the promotor and describe its role and structure
6. Describe the transcription termination in prokaryotes
7. Describe the *lac* operon and negative and positive control of transcription
8. Define the genetic code
9. Describe the experiment that demonstrated genetic evidence for a triplet code and the experiment that enabled deciphering the genetic code
10. Describe the RNA viruses and reverse transcription

S - Molecular mechanisms of transcription in eukaryotes.

1. Identify and describe the function of eukaryotic RNA-polymerases and general transcription factors in the process of RNA transcription
2. Identify and describe the function of *cis*-acting regulatory sequences
3. Describe the structure and function of transcription activators and repressors

4. Describe the process of transcriptional elongation
5. Describe the relationship of chromatin structure and transcription process
6. Describe the role of noncoding RNA molecules and DNA methylation in the regulation of transcription
7. Describe the processing of ribosomal and transfer RNAs

P - Methods of DNA analysis. DNA electrophoresis. (M).

1. Describe the process of DNA electrophoresis
2. Exercise the deposition of DNA samples on electrophoretic gel under the supervision and monitoring the process of electrophoresis

4. THE NUCLEUS.

L - The nucleus (structure and organisation)

1. Define and explain the structure and function of the nuclear envelope
2. Define and explain the structure and function of the nuclear lamina
3. Define and explain the structure and function of the nuclear pore complex
4. Explain selective transport of proteins to and from the nucleus
5. Define terms: nuclear localization signal, nuclear transport receptor, importin, Ran protein, nuclear export signal, exportin and explain their function
6. Define euchromatin, heterochromatin, and types of heterochromatin
7. Define sub-compartments within the nucleus and explain their function
8. Define and explain nucleolus and nucleolar organizing region
9. Define and explain the transcription and processing of rRNA
10. Define the role of snoRNA

S – mRNA processing. Nuclear transport. Nucleolus.

1. Describe the process and explain the importance of the mRNA processing in eukaryotes
2. Describe the structure of the nuclear envelope
3. Describe the nuclear pore complex
4. Define and describe selective transport of proteins to and from the nucleus
5. Describe the regulation of the transport
6. Describe the transport of RNAs
7. Define the nucleolus and describe its structure
8. Describe the transcription and processing of rRNA

P – Nucleus in prokaryotes and eukaryotes. Cell size measurement.

1. Perceive and recognize prokaryotic cells – different types of bacteria
2. Perceive and recognize epithelial cells (human tongue squamous cells)
3. Monitor the experiment of fractionation and centrifugation of the animal cells

5. DNA - RNA - PROTEINS.

L - From DNA to proteins. Genetic code. Translation.

1. Describe the structure and function of transfer RNAs
2. Define the main terms related to translation: aminoacyl tRNA synthesis, genetic code, wobble base pair, Shine-Delgarno sequence, monocistronic mRNA, polycistronic mRNA, initiation factors, elongation factors, release factors, RNA interference polysome
3. Describe the structure and function of prokaryotic and eukaryotic ribosomes
4. Describe the process of initiation, elongation, and termination of translation
5. Identify all mechanisms of translational regulation with special attention on regulation by microRNAs

S - Chromosome structure.

1. Define the terms: chromatin, histone, nucleosome, nucleosome core particle, chromatosome, euchromatin, heterochromatin, and types of heterochromatin.
2. Explain the principles of chromatin condensation when cells enter mitosis
3. Define chromosome types, define chromosome types in humans
4. Define the structure of centromeres and kinetochore
5. Explain epigenetic inheritance of centromeres
6. Define and explain the structure and function of telomeres and telomerase
7. Define Drosophila melanogaster polytene chromosomes and amphibian oocyte chromosomes “lampbrush chromosomes”

P - Chromosomes and sex chromatin. (M).

1. Perceive and recognize Drosophila melanogaster polytene chromosomes
2. Perceive and recognize amphibian oocyte chromosomes
3. Perceive and recognize human leukocyte chromosomes
4. Prepare the specimen of human buccal interphase cells and recognize sex chromatin

6. MEMBRANE – STRUCTURE AND TRANSPORT.

L – Cell membrane structure. Human erythrocyte membrane.

1. Explain the function and describe the structure of the cell membrane
2. Identify all types of phospholipids
3. Describe phospholipid bilayer and lipid component of the cell membrane
4. Identify types of proteins in the cell membrane and describe their function
5. Describe the erythrocyte membrane
6. Describe the components of the extracellular matrix and explain their functions

S - Plasma membrane transport principles.

1. Identify all types of molecular transport through the cell membrane
2. Define the main terms related to molecular transport: passive diffusion, facilitated diffusion, carrier proteins, channel proteins, ion channels, membrane potential, action potential, neurotransmitter, active transport, Na^+/K^+ pump, uniport, antiport, symport, endocytosis, phagocytosis, pinocytosis, clathrin-coated vesicle, calveolae

3. Describe the transport of molecules by passive and facilitated diffusion
4. Describe changes of membrane potential during the nerve impulse (action potential) and describe signalling by neurotransmitter release at a synapse
5. Define the active transport driven by ATP hydrolysis and describe this process on Na^+/K^+ pump example
6. Define the active transport driven by ion gradients and describe this process on glucose symport with Na^+ during the glucose transport through the intestinal epithelium
7. Describe the process of phagocytosis and receptor-mediated endocytosis (pinocytosis) on LDL transport example
8. Describe the protein trafficking in endocytosis (sorting and recycling)

P - Human erythrocyte membrane isolation and biochemical analysis (M).

1. Perceive and recognise human erythrocytes in the physiological solution on the wet-mount sample slide
2. Perceive and recognise erythrocyte membranes („white ghosts“) on the wet-mount sample slide
3. Monitor the experiment of lipid and protein extraction from the human erythrocyte membrane
4. Perceive and recognise human hemoglobin crystals in the prepared sample slide

7. BIOENERGENTICS. PROTEIN SORTING AND TRANSPORT I.

L – Mitochondria, Chloroplasts, and Peroxisomes.

1. Define and explain the organization and function of mitochondria
2. Define the genetic system of mitochondria
3. Explain how mitochondria evolved from bacteria
4. Explain protein import and mitochondria assembly
5. Explain the mechanism of oxidative phosphorylation and electron transport chain
6. Define chemiosmotic coupling
7. Explain electrochemical gradient in the process of ATP synthesis and define the role of ATP synthase
8. Define and explain the structure and function of chloroplasts
9. Explain the chloroplast genome
10. Explain the import and sorting of chloroplast proteins
11. Define and explain the development of chloroplasts and other plastids
12. Explain photosynthesis and electron flow through photosystems I and II – non-cyclic electron flow
13. Explain cyclic electron flow
14. Explain ATP synthesis in chloroplasts
15. Explain the structure, function, and assembly of peroxisomes

S – Endoplasmic reticulum.

1. Describe the structure of the endoplasmic reticulum
2. Explain the difference in structure and function between the rough and smooth ER
3. Describe and explain the secretory pathway, protein sorting, cotranslational and posttranslational translocation of proteins into the ER

4. Describe the insertion of proteins into the ER membrane
5. Describe the smooth ER and explain its function
6. Describe the vesicular transport from the ER to the Golgi

P – Membrane - transport. Mitochondria (M).

1. Perceive and recognize human erythrocytes in hypo-, iso- and hypertonic solution of NaCl
2. Perceive and recognize cells of the onion epidermis and monitor plasmolysis and deplasmolysis in these cells
3. Perceive and recognize mitochondria in the rat liver cells

8. CYTOSKELETON AND CELL MOVEMENT. PROTEIN SORTING AND TRANSPORT II.

L - Cytoskeleton and cell movement.

1. Describe and explain the structure, organization, assembly, and disassembly of actin filaments
2. Explain the association of actin filaments with the plasma membrane – focal adhesion and adherents junction
3. Explain the role of actin filaments in the protrusion of cell surface – microvillus, structures extended from the leading edge of a moving cell involved in cell locomotion and phagocytosis.
4. Describe the structure of muscle fibers and the principle of muscle contraction and relaxation
5. Describe the contractile assemblies of actin and myosin in nonmuscle cells.
6. Describe the structure and function of myosin 1
7. Describe the formation of protrusions and cell movement
8. Define intermediate filament proteins and explain the assembly of intermediate filaments
9. Explain the structure and function of desmosome and hemidesmosome
10. Explain the structure and dynamic organization of microtubules
11. Define the structure of centrosome, centriole and the role of pericentriolar material
12. Explain the organization of microtubules within nerve cell axons and dendrites
13. Explain the function of microtubule motor proteins and their role in cargo transport and intracellular organization
14. Describe the structure of cilia and flagella
15. Explain the reorganization of microtubule during mitosis

S - Golgi apparatus and lysosomes.

1. Explain the organization of the Golgi apparatus
2. Explain protein glycosylation in the Golgi, lipid and polysaccharide metabolism in the Golgi and protein sorting and export from the Golgi
3. Explain cargo selection, coat proteins, and vesicle budding
4. Define the structure and function of lysosomes
5. Explain the principles of regulation of acidic internal pH of lysosomes and activation of acid hydrolase
6. Describe endocytosis and lysosome formation
7. Describe phagocytosis and autophagy

P – Muscle cells (M)

1. Perceive and recognize skeletal muscle pattern of cross-striation
2. Perceive and recognize smooth muscle cell and position of the nucleus in the cell
3. Perceive and recognize cardiac muscle

9. CELL SIGNALING. FERTILIZATION.

L - Intracellular signal transduction. Apoptosis.

1. Name the cell signaling models
2. Describe the function of steroid hormones and their nuclear receptor superfamily
3. Define the function of nitric oxide and carbon monoxide as paracrine signaling molecules
4. Define the principles of neurotransmitter signaling
5. Identify peptide hormones and growth factors as signaling molecules
6. Name and define cell surface receptors and their function – G-protein coupled receptor, receptor protein-tyrosine kinase, etc.
7. Name pathways of intracellular signal transduction
8. Describe the cAMP pathway, cyclic GMP and phospholipids, and Ca^{++} pathways
9. Define and explain programmed cell death
10. Describe caspase activation in the mitochondrial and non-mitochondrial pathways of apoptosis

S – Meiosis, fertilization, and early embryonic development. Stem cells.

1. Identify and describe all phases of meiosis I and meiosis II
2. Define main terms related to meiosis and fertilization: leptotene, zygotene, pachytene, diplotene, diakinesis, synaptonemal complex, recombination, chiasmata, cytostatic factor, acrosome reaction, cortical reaction, male and female pronuclei, oogenesis, spermatogenesis
3. Describe the oocyte regulation during female life
4. Describe the acrosome and cortical reaction during fertilization
5. Identify all types of differentiated cells capable of proliferation in adult tissues
6. Define terms: stem cell, embryonic stem cell, therapeutic cloning, pluripotency, cloning, induced pluripotent stem cell
7. Identify different types of stem cells and describe the medical application of adult stem cells

8. Describe the medical application of embryonic stem cells and pluripotent stem cells and describe therapeutic cloning
9. Describe the process of cloning by somatic cell nuclear transfer
10. Evaluate the ethical aspect of the medical application of embryonic stem cells

P - Gametogenesis, fertilization, and early development (M).

1. Perceive and recognize rat ovaries with follicles in different phases of maturation
2. Perceive and recognize rat testis
3. Perceive and recognize rat epididymis
4. Perceive and recognize fertilized eggs and early developmental stages of sea urchin

10. CELL CYCLE. CANCER. CANCER MOLECULAR GENETICS.

L – Cell cycle.

1. Identify and describe the phases of the cell cycle
2. Describe the regulation of the cell cycle by cell growth factors and extracellular signals
3. Identify cell cycle checkpoints and describe their main features
4. Define protein kinases and describe the experiments of the identification of maturation promoting factor (MPF)
5. Describe the regulation of the cell cycle by cyclins and cyclin-dependent kinases
6. Describe the function of p53 and Rb proteins
7. Identify and describe the phases of mitosis
8. Describe the function of Cdk1/cyclin B complex in mitosis and events that this process induces

S - Basics of molecular and cancer biology.

1. Describe the development of cancer
2. Define types of cancer and their causes
3. Explain the properties of cancer cells
4. Name tumor viruses and tumors they cause
5. Explain retroviral oncogenes and their function in human cancer, name some of them
6. Explain the function of proto-oncogenes in human cells, explain their conversion in oncogenes in human cancer
7. Explain the activation of c-myc oncogenes in Burkitt's lymphomas and abl-oncogene in chronic myeloid leukaemia
8. Explain the function of tumor suppressor gene in human cells and loss of their function in human cancer
9. Explain the function of p53 and Rb genes

P - Embryonic and fetal developmental stages in rats. Tumors: teratoma and teratocarcinoma. (M).

1. Perceive and recognize a rat embryo: 9 days old, its orientation and main parts
2. Perceive and recognize a rat fetus: 20 days old and identify at least three types of differentiated tissues
3. Perceive and recognize a rat fetus and placenta in formalin

4. Perceive and recognize rat experimental teratoma and types of differentiated tissues
5. Perceive and recognize human teratocarcinoma and undifferentiated cells

11. MEDICAL GENETICS BASICS.

L - Classical and molecular genetics. Basic principles of medical genetics.

1. Define terms of classical genetics with a focus on genealogical analysis
2. Define molecular genetics
3. Identify key events in molecular genetics history: discovery of the tridimensional structure of DNA, sequencing of the human genome, genome-wide studies, comparative genetics
4. Identify main types of genetic research with a focus on genome-wide association studies
5. Recognize the potential of genetic studies and translation of their results in clinical practice

S – Monohybrid inheritance. Autosomal recessive and dominant disorders in humans. Multiple alleles.

1. Define monohybrid cross and describe the following terms: genotype, phenotype, allele, locus, dominant and recessive trait
2. Explain Mendel's laws of inheritance
3. Explain incomplete dominance and codominance
4. Define test cross
5. Define multiple alleles

P – Cell cycle. Interphase and mitosis. Mitotic index (M).

1. Perceive and recognize the phases of mitosis in plant cells (onion root tips)
2. Perceive and recognize cell divisions of yeast cells (closed mitosis)
3. Perceive and recognize the phases of mitosis in rat follicular ovarian cells
4. Perceive and recognize the phases of mitosis in cervical cancer cells (HeLa cells)

12. X-LINKED INHERITANCE. LINKED GENES.

L - X-linked inheritance and inheritance of sex. Monogenic disorders. Linked genes and gene recombination.

1. Define sex determination in humans
2. Describe the main characteristics of sex chromosomes (chromosome X and Y)
3. Describe the process of X chromosome inactivation
4. Describe the process of testis and ovaries differentiation during embryonic development
5. Identify sex-linked diseases and describe the main characteristics of X-linked recessive diseases, X-linked dominant diseases, and Y-linked diseases
6. Describe X-linked recessive inheritance on colour blindness example

S – Dihybrid inheritance. Independent assortment. Problem-solving.

1. Define and describe the dihybrid cross
2. Explain the independent assortment
3. Master the process of solving genetic problems (inheritance of recessive, dominant and sex-linked traits)

V - PTC-test (**P**henyl **T**hio **C**arbamide). Problem-solving. (M)

1. Perform the experiment of PTC testing
2. Master the process of solving genetic problems

13. RECOMBINANT DNA

L – Gene therapy

1. Describe the basics of recombinant DNA
2. Describe the meaning of genetic therapy, its utility in correcting/curing the disease and identify major requirements for successful gene therapy
3. Describe *in vivo* and *ex vivo* gene therapy and explain the difference
4. Identify types of vectors used for gene therapy and explain characteristics important for their efficiency
5. Recognize and explain the risks of gene therapy

S - DNA, RNA, and protein analysis methods. Case report (mushroom poisoning).

1. Describe the occurrence, types, and incidence of SNPs in the genome
2. Explain the role and the mode of function of restriction endonucleases
3. Explain the PCR reaction and roles of all PCR reaction components
4. Explain the RFLP method, electrophoresis and describe the genotyping results
5. Explain the DNA sequencing and the role of dideoxynucleotides
6. Explain nucleic acid hybridization methods: Southern blotting, Northern blotting, DNA microarrays, hybridization in situ, FISH
7. Explain Western blotting and immunoprecipitation methods

P - DNA: PCR (**P**olymerase **C**hain **R**eaction) (M).

1. Explain the PCR method
2. Perform the PCR method under the supervision

14. MUTATIONS.

L –Gene and chromosomal aberrations

1. Enumerate and describe all types of numeric and structural chromosome aberrations
2. Define terms related to chromosome aberrations and human health: mosaicism, genetic disorder, diploidy, polyploidy, aneuploidy, nondisjunction, deletion, ring chromosome, duplication, inversion, isochromosome, translocation
3. Describe the process of chromosomal nondisjunction during diploid gametes genesis
4. Provide the examples of diseases caused by aneuploidy
5. Describe the influence of chromosomal aberrations on pregnancy outcome

S - Mutations and human health.

1. Describe clinical characteristics of chromosomal disorders: Down syndrome, Edwards syndrome, Patau syndrome, Turner syndrome, Klinefelter syndrome, 47, XYY syndrome, Cris du chat syndrome, Wolf-Hirschhorn syndrome
2. Differentiate types of gene mutations
3. Describe the process of point mutation occurrence due to the mismatch base incorporation during replication
4. Describe the effect of a mutation on protein development in case of: missense mutation, nonsense mutation, frameshift mutation, and silent mutation

P - DNA: RFLP (Restriction Fragment Length Polymorphism). Problem-solving (M).

1. Describe the RFLP method for sample genotyping
2. Perform the RFLP method under the supervision and determine genotypes of the samples
3. Master solving problems in monohybrid, dihybrid, and sex-linked inheritance

15. DNA REPAIR. CLINICAL CYTOGENETICS.

L- DNA repair mechanisms. Polygenic disease in humans.

1. Identify common types of DNA damage and mechanisms of its repair
2. Identify and define major types of genetic diseases (chromosomal aberrations, monogenic, polygenic)
3. Explain the difference between qualitative and quantitative traits
4. Describe the term ‘polygenic disease’ and name a few examples
5. Explain the difference between a mutation and a polymorphism
6. Identify and explain different types of research studies of complex diseases

S - Karyotype. Chromosome *banding* methods. Human genome. Case report (diabetes).

1. Identify and explain a phase of the cell cycle when chromosomes are best suited for the analysis
2. Describe the chromatin structure and its condensation to a metaphase chromosome
3. Describe the Moorhed method in cytogenetic

4. Describe chromosome banding and define G and R bands
5. Name main abbreviations in the ISCN nomenclature
6. Define the types of chromosomes
7. Describe the FISH method and types of probes that can be used, define multicolor FISH

P - Human karyotype and metaphase plate formation from leucocytes (M).

1. Perform Moorhed method in the preparation of human karyotype from leucocytes under supervision
2. Perceive and recognize metaphase plate formation

16. GENE THERAPY. GENOM ORGANISATION

L – Recombinant DNA technology, application in medicine.

1. Define restriction endonucleases, name some of them, explain their role in bacterial cells and their application in medicine
2. Explain the generation of recombinant DNA molecules
3. Define the role of vectors and types of vectors used in recombinant DNA technology
4. Explain gene transfer in plants and animals (transgenic mice, chimeric mice)
5. Explain the approaches of introducing mutations into cellular genes
6. Explain the approaches of interfering with cellular gene expression

S – The organization and sequences of cellular genomes.

1. Describe the structure of the eukaryotic genome
2. Explain the structure and characteristics of repetitive DNA sequences
3. Identify all types of repetitive DNA sequences

P – PubMed and genome databases

1. Master the process of working with PubMed and genomic databases

17. MOLECULAR BIOLOGY IN MEDICINE.

L – Gene cloning. Genetically modified organisms.

1. Define the terms totipotency and pluripotency
2. Describe the first attempts of cloning amphibians and their success
3. Describe the methods of mammalian cloning before cloning Dolly, the sheep
4. Describe the possible consequences of cloning
5. Define methods of artificial gene transfer from cell to cell
6. Define methods of artificial cloning of whole organisms (plants)
7. Define GMO
8. Describe methods of obtaining GMOs and name some examples
9. Define the dangers of cloning

S – Prenatal diagnostics. Case report (Ion channels).

1. Define the needs for prenatal diagnosis
2. Name prenatal diagnostic methods and briefly describe each of them
3. Name diagnostic interventions in the fetus
4. Define the consequences of prenatal diagnosis