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OUTLINES OF HISTOLOGY

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KAROLINUM

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Published by Charles University
Karolinum Press
as a teaching text for the Faculty of Medicine in Pilsen
Typesed by DTP Karolinum Press
Second, revised edition

ISBN 978-80-246-3743-3
ISBN 978-80-246-3758-7 (online : pdf)

Charles University
Karolinum Press 2017

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ebooks@karolinum.cz

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PREFACE

Histology is a science of the tissues which are formed by conglomeration of cells and extracellular matrix. We are always interested in understanding the origin, microscopic structure and function of these tissues.

Contemporary general histology deals – in addition to the description of the fundamental unit of the tissue, the cell – with four kinds of basic tissues, presented in this textbook. These tissues participate in construction of various organs and organ systems.

This textbook outlines the courses in general histology, given to the international students of general and dental medicine in the first year of their pregraduate studies at the Charles University, Faculty of Medicine in Pilsen. The first edition was prepared in 1994 and revised in 2004 by Prof. Dr. Jaroslav Slípka, DSc (1926–2013), who was an enthusiastic and inspiring researcher and teacher at the Department of Histology and Embryology. The second edition was updated in 2017 to reflect some of the advances in teaching of histology. Nevertheless, the illustrations and the concise concept of the book designed originally by prof. Slípka were kept. We recommend using this textbook for revising and summarizing the essential knowledge. For full color textbooks and atlases that are necessary for understanding the histological slides, see the literature recommended at the end.

We wish all our students might enjoy the insight into the universe of cells and tissues the human body is made of. Welcome to the world of Histology!

Zbyněk Tonar
Pilsen, 2017

PART I: THE CELL

The cell is a basic integrated entity of all living organisms. It is a fundamental morphologic and physiologic unit, capable of multiplication, metabolism, growth, excitability and other specialized functions. The microscopic analysis of the fine structure and function of cells is referred to as *cytology*.

There are two different structural types of cells:

Prokaryotic cells with no nuclear membrane and no membranous organelles like in bacteria.

Eukaryotic cells with a nuclear membrane and various membranous organelles. These cells can form assemblies, classified into four basic tissues in multicellular animals *(Metazoa)*. The science of the morphologic and functional features of cells and tissues constitutes histology, the topic of this textbook.

Shapes and dimensions of cells: Although the primary form of cells is rounded or spherical, during development of tissues cells become, depending on their function, squamous, cuboidal, columnar, pyramidal, spindle

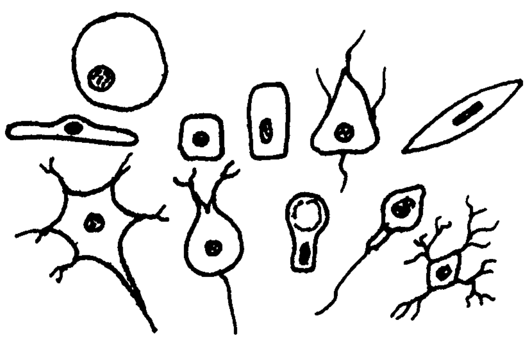

Fig. 1 Shapes of cells

shaped, star shaped, goblet shaped etc. The shape of cells is organized by an internal scaffolding of proteins known as the cytoskeleton. Those cells which have remained free, e.g. blood cells, retain their spherical form. Most of the cells of the human body range from 4–30 micrometers in diameter; the largest are the oocytes (150 µm in human). The red blood cell, which ranges around 7.5 µm in diameter, can be used as a rough measure of the size of the tissue cells seen in the same field.

Composition of cells: The cell is formed by *protoplasm* which is composed of *cytoplasm* (or *cytosol*), the fluid matrix of the cell, and *nucleoplasm*, the matrix of the nucleus. Cytoplasm is composed of a colloid solution, contained by a cell (or plasma) membrane – *plasmalemma*. The cytoplasm contains many smaller elements – subcellular structures – called *organelles* which provide the framework for cellular activities. It contains also many of the essential enzymes and metabolites. In the nucleoplasm is the genetic material in the form of chromosomes. Chemical composition of cells: in addition to water and inorganic substances, cells contain four main classes of organic constituents: proteins, carbohydrates, fats (lipids) and

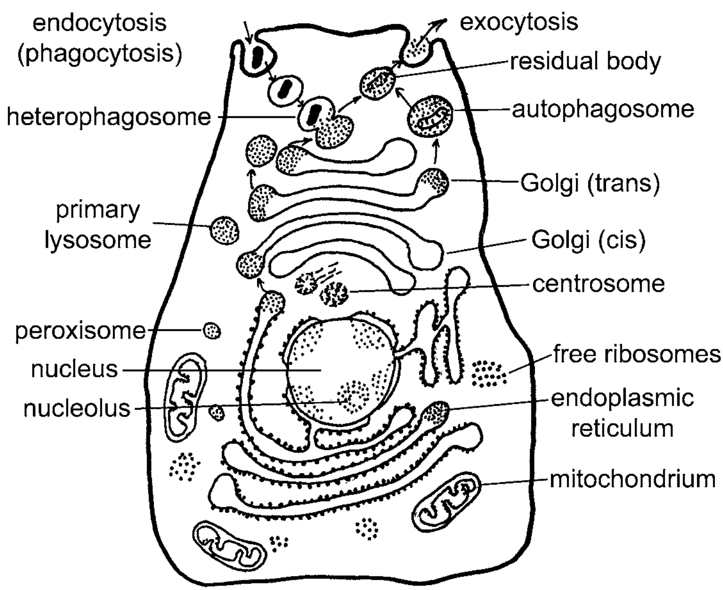

Fig. 2 The cell

nucleic acids. The pH of the cytoplasm ranges between 7.0–7.4. However, in most histological staining methods, the cytoplasm of most cells appears as slightly acidophilic (e.g., stained pink to reddish by an acidic dye named eosin using the routine hematoxylin-eosin staining).

Cell membranes

The term comprises not only the outer membrane surrounding each cell, i.e. **plasmalemma**, but also the membranes surrounding cellular organelles. The basic structure consists of a **lipid bilayer** containing specialized proteins in association with surface carbohydrates.

The membrane *lipids* are of three types: *phospholipids*, *cholesterol* and *glycolipids*. The phospholipids are organized into a double layer of molecules, in which each molecule has an outer hydrophilic head and an inner hydrophobic chain. Cholesterol is inserted into the phospholipid bilayer and is present in about the same amounts as are phospholipids, and is responsible for the mechanical stability of the otherwise fluid membrane. Glycolipids with their associated sugars are exposed to the extracellular surface and are involved together with glycoproteins in intercellular communication as mediators of cellular interactions like adhesion and recognition.

Membrane protein molecules can be classified according to their spatial relations to the membrane: *Integral (intrinsic) membrane proteins* of-

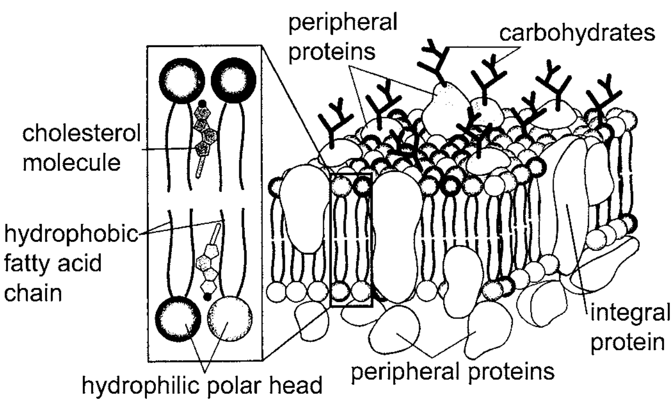

Fig. 3 Cell membrane

ten span the whole lipid bilayer from one surface to another, and form a transmembrane channel for passing the ions through the membrane. Some integral membrane proteins are confined to the inner or outer part of the membrane only. The *peripheral (extrinsic) membrane proteins* are not fully embedded within the lipid bilayer and are more loosely attached to a membrane surface.

Some membrane proteins are receptors, which allow cells to respond to external signals when binding a variety of *signaling molecules* (or *ligands*). Binding of signaling molecules (released by a signaling cell) to their receptors activates in the target cell an intracellular *second messenger* system, initiating a cascade of reactions that result in the required response. For example, a hormone (the first messenger) activates through a receptor a transmembrane protein – *adenylate cyclase*, which in cytoplasmic region catalysates the transformation of ATP to *cyclic adenosine monophosphate* (*cAMP*), i.e. the second messenger.

Numerous membrane proteins bear polysaccharide chains and represent the *glycoprotein molecules*. The membrane carbohydrates cover the extracellular surface of the cell membrane like a sugar coating – the *glycocalyx*. The polysaccharide chains confer a certain surface specificity on every type

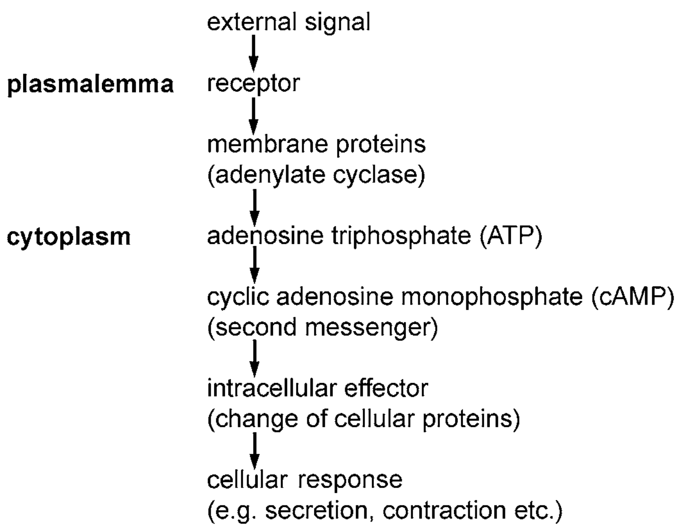

Fig. 4 Cellular processing of external signals

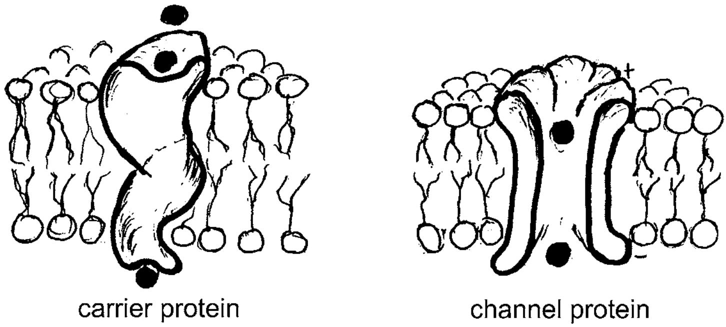

Fig. 5 Membrane transport

of cell. The glycocalyx is directly involved in the recognition and adhesion of different cell types, particularly during morphogenesis. The carbohydrate chains can be demonstrated by staining with lectins (proteins extracted mostly from some plants).

The role of the cell membrane lies not only in preserving the integrity of the cell, but also in cell-cell recognition and selective transport of molecules. Whereas the cell membrane is impermeable to most large molecules, it is permeable to some smaller molecules and ions, and so important for bringing needed material into the cell and releasing waste products. The membrane is equipped with *active transport mechanisms* to transfer various substances (e.g., glucose, amino acids) in the required direction. Small molecules are bound to an integral carrier protein which undergoes series of conformational (shape) changes to release the molecule on the cytoplasmic side. Some ions can be transported according to the ion gradient through the plasmalemma by ion selective channel proteins via a mechanism called *facilitated diffusion*. Another example is a *sodium-potassium pump* which utilizes energy from mitochondria to release the sodium ions from the cell and to pump potassium into the cell (see, e.g., nerve tissue).

The cell can also ingest macromolecules from the extracellular space by invagination of the cell surface, termed **endocytosis**. The invaginated cell membrane encloses the incorporated material for further processing in an *endocytotic vesicle (endosome)*. In the case of very small molecules, we specify the endocytotic process as *pinocytosis (i.e. cell drinking)* with the formation of *pinocytotic vesicles*. For ingestion of large particles (e.g. bacteria) the term *phagocytosis (cell eating)* is used. In such cases the cell