MODERN PHYSIOLOGY

THE CHEMICAL AND STRUCTURAL BASIS OF FUNCTION

FLEUR L. STRAND

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Chapter on
MUSCLE AND BONE
AS A FUNCTIONAL UNIT
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foreword

Dr. Strand departs from the time-honored custom of discussing anatomy and physiology as they relate to separate organ systems. More profitably, she weaves, in a logical and skillful manner, the basic concepts of modern biology and their chemical and physical derivations into broad patterns of integrated structure and function. Comprehensive treatment is given here to the mechanisms involved in the regulation of the metabolism of water, minerals, and organic substances and how these processes contribute to maintaining the constancy of the internal environment. The central theme of homeostasis is continued with descriptions of the adaptation of the organism to its surroundings in terms of the protective role of the nervous system and sense organs. The last section provides a concise and practical discussion of the coordination mechanisms underlying the endocrine and genetic regulation of reproduction and development.

The text places commendable emphasis on molecular phenomena as they apply to biological systems. Yet a minimum of complicated terminology and expression is used. This will prove of assistance to students who are virtually untrained in related sciences, enabling them to assimilate the concepts presented and to apply them, with gain, to the basic understanding of the living body.

ALBERT S. GORDON

organs of the individual. Despite the emphasis on the molecular and cellular level, it is of vital importance that the student be aware that these mechanisms are only partly explained, and that the physiologist may use them now as tools with which to unravel the complexities of the living organism.

Most of the drawings are new, clearly and artistically done by Parker Panttila. They are an integral part of the text, and the author has worked closely with the artist so that the emphasis on the correlation of structure and function is repeated in his illustrations. Wherever possible, both these aspects are incorporated in one diagram, and this concept is extended and reinforced by the clarity of the outstanding electron micrographs. I am greatly indebted to Dr. Johannes A. G. Rhodin for his kindness in permitting the reproduction of so many of the photographs from his *Atlas of Ultrastructure*.

I would like to use this opportunity to express my great appreciation to Dr. Albert S. Gordon, at New York University, for his unfailing encouragement from my early days as a graduate student through the writing of this book. His logical and deceptively simple presentation of complex material sets a standard of teaching that is hard to emulate but acts as a lodestar.

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contents

PART III ADAPTATION TO THE EXTERNAL ENVIRONMENT

PART IV REPRODUCTION

PART I
the cell

1

the living cell

Functional structure of the cell
- Tissue culture and the embryonic cell
- Cell membrane
- Cytoplasmic inclusions
  - Mitochondria
  - Ribosomes
  - Golgi complex
  - Granules
  - Vacuoles
- Nucleus
  - Nucleoplasm and chromosomes
  - Molecular nature of the gene
    - Transmission of instructions from gene to cell

Duplication and specialization of cells
- Mitosis
  - Preparation for mitosis
  - The four phases of mitosis
- Organization of cells into tissues and organs
  - The germ layers
  - In the embryo
  - Outside the embryo
- Differentiation and specialization

Tissues
- Epithelial tissue—protective, lining, secretory (ectoderm or endoderm)
- Muscle tissue—specialized contractility (mesoderm)

Skeletal muscle
Smooth muscle
Cardiac muscle
Nerve tissue—conducting (ectoderm)
Connective tissue—supporting, connecting, transporting (mesoderm)
From molecule to gene, from gene to cell, from cell to tissue, organ, and man

Since the earliest description of the unit of living matter as a "cell" or cavity circumscribed by a wall, like the cells of a honeycomb, much biological endeavor has been directed toward determining the nature of this unit and the factors controlling its growth and behavior. One of the most important discoveries was that the "cavity" is no empty space; on the contrary, it is filled with the stuff of life—*protoplasm*. The circumscribing wall is also of vital importance because in animal cells it consists of an invisible, living membrane, the *cell membrane,* that controls the rate and type of substance getting into and leaving the cell. In plant cells the cell membrane is covered by a thicker, protective coat which is the microscopically visible *wall.* Animal cells do not have a cell wall, and the delicate plasma membrane is protected only by a thin layer of cementing material that binds neighboring cells together. Some eggs are protected by a layer of jelly or even by a shell, but these may be regarded as specializations.

Protoplasm is an unbelievably complex structure, the physical and chemical constituents of which can be analyzed, but the intricacies of its organization cannot be duplicated yet in a laboratory. This indicates that the properties of life that are so singularly confined to protoplasm are intimately bound to the particular organization of its molecular structure, rather than to the mere presence of the various molecules. One of the most fascinating discoveries of modern biology is that the basic processes of protoplasm are found throughout the plant and animal kingdoms. The differences in the molecular organization of the chromosomes, which control the inheritance and functioning of the cell, result in the evolution of the infinite number of variations, found not only between widely different animal groups but even between individuals of the same species. This is true whether the cell exists independently, a complete entity in itself, as in many unicellular forms such as the ameba, or whether it forms one of the countless millions of cells in a multicellular organism, such as man.

The chromosomes in most forms are found within a specialized body inside the cell, the *nucleus.* If the nucleus is removed, or if the chromosomes are damaged or destroyed, the entire cell disintegrates and dies. Thus the life of the cell depends on the functional integration of the nucleus and the *cytoplasm* surrounding it, and this has been shown to be dependent on the organization of chemical reactions in the cell in response to the specific molecular arrangement within the chromosomes. It can be immediately appreciated that the distribution of this controlling material, the chromosomes, to new cells formed is of vital importance to ensure the continuation of the same type of molecular and structural organization of the daughter cells as was characteristic of the mother cell.

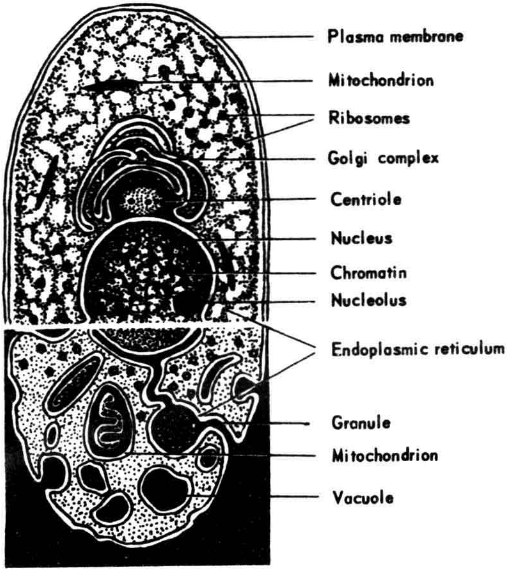

Figure 1–1. Diagram of a typical cell. *The upper portion indicates its structure as seen under the light microscope. The lower portion represents the structure as magnified by the electron microscope.* (*Not proportional.*)

FUNCTIONAL STRUCTURE OF THE CELL

The cell that can be best described in general terms is probably the embryonic cell, because it has not yet become specialized, or differentiated, and its general structure is fairly representative of the basic plan of all animal cells (see Fig. 1–1). The embryonic cell divides much more rapidly than adult cells do and also possesses the remarkable potentiality for developing into almost any other kind of cell, such as those of muscle, nerve, or blood.

Tissue Culture and the Embryonic Cell

The embryonic cell as it lives, grows, and specializes, can be studied by an ingenious technique called *tissue culture.* By providing living cells, usually taken from very young frog, chick, or rabbit embryos, with the correct aqueous environment in which the necessary nutrients are dissolved, with the right temperature for that particular type of cell, and by carefully excluding bacterial infection and removing metabolic wastes, a group of healthy cells can be studied in detail outside the organism. Experimentation with living cells outside the body is designated as being *in vitro* (in glass) as opposed to studies on cells and functions within the body, or *in vivo* (in life).

The cells of the tissue culture are seen to vary considerably in shape, from round to oval, and fine protoplasmic projections often increase this irregularity considerably. These projections probably serve as points of attachment to the surface on which the cell grows. Cells move by an alternate flowing and stiffening of the protoplasm, similar to the way in which an ameba moves, but the protoplasm is always contained within a flexible membrane. This is the invisible, yet experimentally demonstrable cell membrane.

Cell Membrane

The cell membrane is highly selective in the type of substance it permits to enter or leave the cell, and this selectivity in turn is dependent on its intricate molecular structure. The membrane is made up of exceedingly thin layers of interwoven protein and lipid molecules (see Chap. 4 and 8 for a discussion of these molecules). This structure is interspersed by many holes or pores.

Many factors determine which substances can pass through the cell membrane:

1. Small molecules squeeze through the pores of the membrane.
2. Fat-soluble particles dissolve in the lipid portion of the membrane.
3. Water-soluble substances have difficulty penetrating unless they are small enough to get through the pores. The individual differences in the ease with which substances do get into the cell suggest that certain areas of the membrane might be specifically permeable to some chemical structures but not others.
4. Particles that are not charged electrically penetrate the membrane more readily than charged ones do, because a positive charge on the outside of the membrane repels similarly charged ions. Negatively charged particles are hampered by electrostatic attraction and, although they do get through the membrane, in general, uncharged particles penetrate more readily.
5. Some large particles are actually engulfed by the plasma membrane, which forms small invaginations around them. These captured par-

ticles, surrounded by the layer of plasma membrane (which probably is digested away by intracellular enzymes), sink into the cytoplasm, having evaded the problem of pentration through the membrane. This phenomenon is called *pinocytosis* (see Fig. 5–6).

If the structure of the plasma membrane is destroyed (fat solvents, like chloroform, dissolve the lipid of the membrane), substances can enter or leave the cell so freely that the delicately balanced composition of the protoplasm is deranged, and rapid death of the cell ensues.

Within the surrounding membrane is the remaining protoplasm, consisting of the *nucleus* and the *cytoplasm.* The viscosity of the cytoplasm changes constantly as it flows through the cell, moving with it the many small structures and inclusions it contains. The nucleus also moves within the cytoplasm, to the site of greatest metabolic activity. With the enormous magnification afforded by the electron microscope, the presence of a very fine reticulum or network, the *endoplasmic reticulum,* has been demonstrated within the cytoplasm (see Figs. 1–1 and 1–2). This reticulum is made up of exceedingly delicate membranes that appear to be continuous with the other cytoplasmic structures, thus giving a very definite organization to the relationship of these structures to each other and to the cell as a unit.

Cytoplasmic Inclusions

(1) Mitochondria, (2) ribosomes, (3) Golgi complex, (4) granules, (5) vacuoles, (6) structures associated with cell division (not always present in the nondividing cell).

Mitochondria (Fig. 1–3)

These are small, numerous, rod-shaped or spherical bodies that have been shown to have an intricate internal structure. They consist of membranes and tubules, the most important function of which is probably to provide large surface areas for the many enzymes that are concentrated on or in the mitochondria. The enzymes are essential for most of the chemical reactions that occur within the cell (see Chap. 4), and the innumerable reactions are separated to a certain extent by the complex surfaces afforded by the mitochondria. Because these chemical transformations make available the energy from absorbed foodstuffs, the mitochondria are often referred to as the "powerhouses" of the cell. Cells that are particularly active have many more mitochondria than less active cells.

Ribosomes

These are still smaller particles than mitochondria which are attached to the reticulum of the cytoplasm (see Fig. 1–2). They are solid bodies

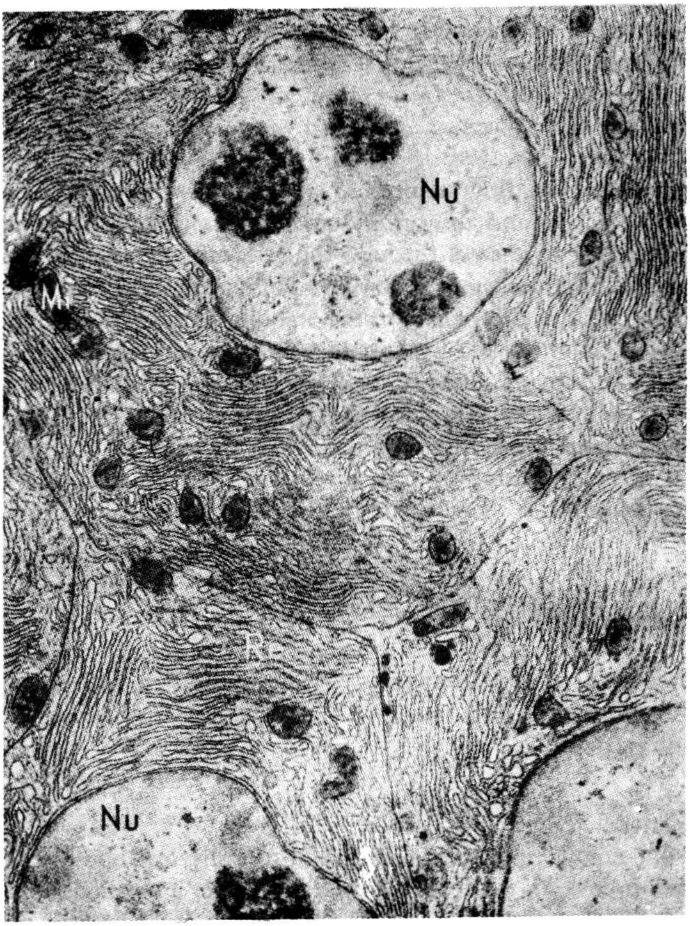

Figure 1–2. Endoplasmic reticulum (Re). (Nu) *Nucleus,* (Mi) *mitochondria. Magnification 7600* ×. (*From J. Rhodin:* An Atlas of Ultrastructure. *W. B. Saunders, Philadelphia, 1963.*)

composed of ribonucleic acid (RNA) in combination with protein. Only very recently has their extremely important role in the life of the cell been elucidated. The ribosomes are the *protein factories* of the cell, obtaining their instructions from the molecular organization of the chromosomes and the necessary energy for protein synthesis from the reactions occurring in the mitochondria. (See Chap. 4 for more details on the synthesis of protein.)