A TEXTBOOK

of

HISTOLOGY

By

ALEXANDER A. MAXIMOW

Late Professor of Anatomy, University of Chicago

and

WILLIAM BLOOM

Associate Professor of Anatomy, University of Chicago

SECOND EDITION, COMPLETELY REVISED
WITH 530 ILLUSTRATIONS
SOME IN COLORS

PHILADELPHIA AND LONDON

W. B. SAUNDERS COMPANY

1934

MADE IN U. S. A.

PRESS OF
W. B. SAUNDERS COMPANY
PHILADELPHIA

PREFACE TO THE SECOND EDITION

As the first edition of this book was found by many teachers to be too large for beginning students of medicine, I have recast it completely, placing the basic facts and concepts in large type and many of the details in small type. I have added more summaries, supplemented in small type by the conflicting evidence on which they were based, and have tried to include most of the significant recent findings in histology and histophysiology.

I am deeply indebted to Professor C. Judson Herrick, who has again been kind enough to assume responsibility for the section on the Nervous Tissue. For the present revision he has completely rewritten this part of the book and produced a new formulation of the theme.

Others of my colleagues have given generously of their time in helping me with this revision. Professor G. W. Bartelmez has rewritten the discussion of the physiology of the female genital system. Professor S. Poljak has revised the description of the retina and included therein some of his recent findings on the primate retina. Professor W. H. Taliaferro has helped revise the histophysiologic remarks on the spleen. As in the first edition, I am indebted to Professor R. R. Bensley for many helpful suggestions. I wish also to thank Doctor I. Gersh for aid in the preparation of the manuscript, and Miss A. Nixon for twelve of the 49 new figures.

In response to many requests, I have included references at the end of each chapter. As it is impossible in a textbook to give the major references to all controversial points, I have tried to include articles with extensive bibliographies and, in nearly every case, at least one important historical reference. For by referring only to current works—often on minor points—the student is apt to overlook the great accomplishments of previous generations which have passed into anonymity.

I wish to express my appreciation of the criticisms and suggestions which have come to me from many teachers of histology, and I hope they will continue to be as critically helpful.

WILLIAM BLOOM.

CHICAGO, ILLINOIS,
July, 1934.

PREFACE

At the time of his death in December, 1928, Professor Maximow was writing a Text-book of Histology. This was to be based as far as possible, both as to text and figures, on human material, and the functional aspects of the structures described were to be emphasized. For this work he had collected much new material and had made many new illustrations. He had completed the sections on the male and female generative organs, the urinary tract, the organs of special sense, and epithelium. In rough manuscript he left the sections on the blood and connective tissue, the gastro-intestinal tract, the blood vascular and lymphatic systems, the spleen, the integument, and the mammary gland.

Professor Maximow's colleagues in the Department of Anatomy felt very keenly the desirability of seeing the book completed, and at the suggestion of Professor Bensley I undertook the task.

As placentation and general embryology are treated so thoroughly in text-books of embryology and obstetrics, Professor Maximow decided to omit descriptions of these subjects, although he included descriptions of the histogenesis of tissues and organs where they aid in understanding the structure of the mature tissue or organ. He omitted any detailed discussion of histologic technic in view of the several excellent manuals now in existence. He had originally written extensive sections on the comparative histology of each tissue and organ, but as the manuscript was becoming much larger than he had anticipated, he made drastic cuts in these sections wherever possible, and even eliminated them completely in several instances.

None of the chapters on the Nervous Tissue were written by Professor Maximow in their present form. His papers included some notes and drawings which were helpful in a general way as indicative of the line of treatment contemplated. There was also available the Russian text of 1918 in which the nervous tissues are treated very fully. A complete translation of these Russian chapters and the notes and drawings were placed in the hands of Professor Maximow's colleague, Professor C. Judson Herrick, and these served as the basis upon which the present text was written. In reorganizing this material and bringing it up to date, the attempt was made to conform with Professor Maximow's method of treatment as far as practicable; but the twelve years since the Russian text was published have been very fruitful in this field and much of the discussion which was apposite at that time is now out of date. The section dealing with the physiology of the nerve fibers and part of that on the synapse have been taken from a more complete treatment of the correlation of structure and function of nervous tissues by Professor R. W. Gerard. These chapters, accordingly, are to be regarded not as a posthumous publication, but as an entirely new formulation of the theme, the responsibility for which rests chiefly with Professor Herrick.

I am indebted to Dr. N. Hoerr for writing the description of the suprarenal bodies.

I have written the sections on the biliary and respiratory systems, the pancreas, the endocrine glands (with the exception of the suprarenals) and the intro-

ductory chapter. In all of these sections I have conformed, in general, with Professor Maximow's ideas on these subjects. In addition, I have thoroughly revised the sections on cartilage, bone and muscle, which were based on translations of parts of his Principles of Histology (Russian), and his rough manuscript on the blood vascular and lymphatic systems, the spleen, integument, mammary gland, gastro-intestinal tract, the blood, connective tissue, and the blood-forming and destroying tissues.

All of the illustrations with the exception of those by Professor Maximow are indicated by initials or by acknowledgment in the accompanying legend. I have included a few "key" references; a complete bibliography would be beyond the scope of the present volume and would increase, perhaps unnecessarily, the size of the book.

Throughout the work of editing and completing this book I have profited greatly by frequent consultations with Professor Bensley. I wish to express to him my appreciation of the many valuable suggestions he has given me and in particular for his critical reading of the text of the introduction, pancreas, thyroid, and pituitary. I am further indebted to him for several unpublished figures for reproduction here; these are acknowledged in the appropriate legends.

I am indebted to Dr. R. McKinney for his help in copying certain of the figures and in preparation of the manuscript, and to Mr. H. A. Harris for aid in reading the proof.

Various portions of the text have benefited as a result of the critical reading by Professors P. Bailey, G. W. Bartelmez, R. W. Gerard, B. Halpert, B. C. H. Harvey, P. Kyes, P. C. Kronfeld, and C. H. Swift of the University of Chicago, and Professor B. Orban of the Chicago Dental College. I am indebted to Professors P. Bailey, G. W. Bartelmez, W. Becker, B. Halpert, W. H. Lewis, W. S. Miller, and B. Orban for their kindness in extending to me original figures for reproduction here.

While this book was in press it was suggested that several of the newer staining methods which are referred to in the text should be detailed in the book. These methods are to be found in the technicological manuals listed at the end of the first chapter—especially in that of Romeis—and in the new Handbook of Microscopical Technic edited by McClung (1929, New York). An account of the celloidin embedding and sectioning methods, which are routine in this laboratory, is to be found in the article by Maximow in the Zeit. f. wiss. Mikroskopie, 1909, volume 26, page 177.

Much of Professor Maximow's manuscript was left in Russian. For their careful translations of this and of portions of his Principles of Histology (in Russian) I am indebted to Doctors G. Hassin, O. T. Hess, and E. Piette.

I wish to express my appreciation to the W. B. Saunders Company for their generosity in providing for the splendid reproduction of the illustrations.

In the course of completing the unfinished work of another man it is almost inevitable that errors and discrepancies should enter the manuscript. For these I ask the indulgence of my colleagues in the science; I shall be very grateful to have any mistakes pointed out to me.

WILLIAM BLOOM.

CHICAGO, ILLINOIS.

CONTENTS

CHAPTER XVII

CHAPTER XVIII

CHAPTER XIX

CHAPTER XX

CHAPTER XXI

CHAPTER XXVII

CHAPTER XXVIII

CHAPTER XXIX

CHAPTER XXX

CHAPTER XXXI

TEXTBOOK OF HISTOLOGY

CHAPTER I

INTRODUCTION

HISTOLOGY deals with the minute structures of plant and animal bodies and the morphologic evidence of their functions.

The simple animals consist of but a single cell; in the multicellular animals, groups of more or less similar cells are combined with varying amounts of intercellular substance to form *tissues*. In the more complex animals the tissues are present as such and are also combined in various ways to form different *organs*. *General histology* is the science of the tissues, while *special histology* or *microscopic anatomy* deals with the minute structure of the organs.

This chapter consists of a brief, almost definition-like consideration of the cell to afford a working basis for the descriptions of the tissues and organs. No attempt will be made here to consider all of the manifold variations in the primary cellular constituents.[1] Many of these are characteristic only of the lower forms, but those of the mammalian organism, and in particular of man, will receive more detailed treatment in the descriptions of the particular tissues and organs in which they occur.

For the analysis of the structure of the embryonic and adult mammal, the cell is a convenient living unit, although it is possible that smaller units of life may exist. Relatively simple organisms, such as bacteria which lack some of the characteristics of a true cell (for their structure cannot be divided into the characteristic nucleus and cytoplasm) can carry on all of the vital functions. Moreover, the filtrable viruses are probably a form of living matter so small that it cannot be seen, and yet which can be cultured, made to produce diseases, and which is known to multiply.

METHODS OF STUDY

Direct Observation of Living Cells.—Cells, tissues, and organs may be studied in both the living and the dead conditions. The unicellular organisms and, occasionally, free cells from a complex animal may be studied while living directly under the microscope. From such a study it appears that the animal cell is usually composed of two main constituents: the *cell body*, or the *cytoplasm*, and the *nucleus*. Free cells are of roughly spherical form and colorless, so that structures within them can be seen very indistinctly because their indices of refraction differ but slightly from those of their neighbors. Living cells may be seen in some cases to possess the ability to move; in some instances to ingest foreign material and, occasionally, to divide.

In a few isolated conditions portions of a higher organism may be so thin that there are no technical difficulties which prevent placing this thin membrane of living tissue, while still connected with the animal, under the microscope. Examples of this are the tongue and web of a frog, the web in the wing of a bat, etc.

Recent advances have made it possible in a few instances to study thin portions of relatively thick organs, such as the liver and kidney in both amphibians

and mammals, directly under the microscope.[2] However, the technical difficulties have prevented the application of this method to all tissues and organs.

A method has recently been devised for placing an observation chamber in the ear of a rabbit. This permits long-continued study of a particular bit of tissue in the living animal. It has given very interesting observations and promises many more.[3]

Bits of any tissue may be removed from the animal, teased into small particles, and studied directly. Such particles of tissue, even when protected from desiccation, die after a relatively short period of time because of the lack of a mechanism by which they can be nourished, oxygenated, and freed from waste products.

The method of *tissue culture* consists of the transfer of small bits of tissue with absolutely aseptic precautions (that is, in the complete absence of bacteria and molds) to a medium which contains a nutritive phase and a solid phase for the mechanical support of the cells (*explantation*). In tissue cultures the growth, multiplication and, in some cases, the differentiation of cells into other cell types have been observed directly under the microscope.[4]

Methods have also been devised by which small portions of a cell may be removed, the physical make-up of the cytoplasmic constituents may be investigated directly, and various solutions or reagents may be injected directly into the cell. This is called *microdissection*. In a relatively few years it has yielded important facts, in spite of the drawback that the cell frequently changes its characteristics after microsurgical intervention.[5]

Two staining methods have been applied successfully to living animals or surviving tissues. In *vital staining*, the dyestuff is introduced into the living organism and, depending on the constitution of the dye, certain parts of the organism will accumulate this material. As examples of this procedure may be mentioned the staining of the macrophages (see Fig. 6, *5*, p. 89), the liver epithelium (p. 417), and portions of the kidney (p. 473) after the intravenous injection of lithium carmine, and the filling of the bile capillaries (p. 422) after the intravenous injection of sodium sulphindigotate.[6] This method, although limited in its applications, has contributed toward the solution of certain problems connected with the morphology and function of particular cells and tissues. *Supravital staining* consists in the addition of a dyestuff to surviving tissues. Its most prominent accomplishment is the staining of mitochondria in living cells with Janus green B (Fig. 4) and the staining of nerve fibers and cells with methylene blue (p. 186).[7]

From these examples it is apparent that progressive advances in the study of living cells and tissues depend on the discovery of methods for the continuation of the life of the cells in complex tissues after removal from the body, and of methods which by either a physical or chemical means will enable us to distinguish various cytological constituents within the more or less optically homogeneous body of the living cell. Unfortunately, most of these methods are cumbersome and require years of experience to insure reliability in observation and conclusion.

Study of Dead Cells.—The study of the living cells lacks the factor of permanency of record, except in those instances where this has been accomplished by photographic methods. This difficulty, and that of distinguishing the different parts of the cell in the living condition, have been overcome to some extent by the study of cells and tissues which have been killed, that is, "fixed," and then stained in various ways. A study of both living and fixed cells is necessary for knowing the structure and function of particular cells and tissues.

The great mass of work done today in both normal and pathologic histology depends on the fixation of the tissues and their subsequent staining in an elective manner. All of the fixatives in use precipitate the proteins; many of them leave

the lipins unaffected, but most of them remove the carbohydrates and many of the salts. Accordingly, to study all of these constituents of a cell, various fixation methods must be used.

The next step in the preparation of fixed tissues for study consists in slicing them into very thin layers. This is usually accomplished by freezing a bit of tissue, after which it can be sectioned in a special instrument, or by infiltrating it with a solution of gelatin, paraffin, or celloidin which is later solidified so that the tissue and the embedding matrix may be sectioned together. The use of both paraffin and celloidin requires that the tissue shall be dehydrated in alcohol, which removes most of the lipins. The use of paraffin permits the tissues to be sectioned relatively rapidly and in very thin slices. Celloidin, on the other hand, disturbs the arrangement of the cells less and causes less shrinkage than does the paraffin method.

These thin slices may be stained to demonstrate the various parts of the cell and the intercellular substance. The most usual staining method—hematoxylin and eosin—stains the nucleus blue and the cytoplasm pink. Unless otherwise noted, the figures in this book are after Zenker-formol fixation and "H and E" staining. Special staining methods are necessary to demonstrate certain cellular constituents which are present in the dead cell body but are not made visible by hematoxylin and eosin. A host of such staining methods has been devised; a few are indispensable but most of them are of questionable value.[8]

By the various fixation and staining methods, many structures have been described within the cell; these are artificial to the extent that the structures in fixed material are not the same as the structures in the living cell. However, with constant fixation and staining methods, there is a constant factor of artificiality in this method of preparation. With refinements in the methods of studying living cells, evidence is being found for the existence in the living cell of some of the structures which have been described on the basis of fixed and stained preparations. Because direct *in vivo* observation has failed to discern a particular structure in a cell does not mean that the structure does not exist; it may mean that its index of refraction or its physical constitution is identical with that of the surrounding, contiguous structures. It may be pointed out, moreover, that the biochemist also analyzes dead material, since the first steps in the chemical analysis of a cell result in its death.

The method of fixation devised by Altmann in 1890[9] has been revived recently. In this technic tissues rapidly removed from the body are promptly frozen in liquid air and dehydrated in a low vacuum at $-$ 20° C. After the water is removed from the frozen tissues, they are embedded directly in paraffin and sectioned as usual. In this way, tissues are made available for chemical study almost unaltered. The movement of crystalloids and some organic substances that takes place during the application of the usual fixatives is avoided. Also, the protein elements are altered less by this freezing-drying technic than by the usual fixatives. It is now possible to make a close approximation of the actual distribution of substances in certain types of cells and to determine the nature of some cytological elements (see Figs. 9, 10). This method makes possible the beginning of a study of the chemistry of the cell.

The method of micro-incineration for the demonstration of the inorganic constituents of the cell promises to yield much information.[10]

STRUCTURE OF THE CELL

Protoplasm.—Nearly all cells consist of a nucleus surrounded by cytoplasm (Fig. 1). Although the nucleus and cytoplasm have somewhat different chemical compositions, the underlying structure of both is the same "protoplasm."

The exact constitution of protoplasm is unknown. The older writers, whose work was based mainly on the appearance of protoplasm in fixed (that is, coagulated) material, held many theories as to the structure of this substance, the most important of these being the reticular, the fibrillar, the granular, and the alveolar theories. Various authors sought in these structures analyses of the cell into smaller living constituents. It has been shown, however, that the apparent composition of protoplasm of threads or granules or bubbles is due primarily to the coagulation of proteins by different agents. It is now believed that protoplasm consists of an aqueous colloidal solution of proteins, lipins, carbohydrates, and inorganic salts, which are chemically and physically combined in many ways, and which change from time to time in the same and different cells. Moreover, the consistency of the protoplasm varies from time to time in the same cell and undergoes reversible gelation during life. As the differences between living protoplasm and its constituents are unknown, it must be concluded that they are integrated in some manner which is beyond the scope of our present analytical methods.

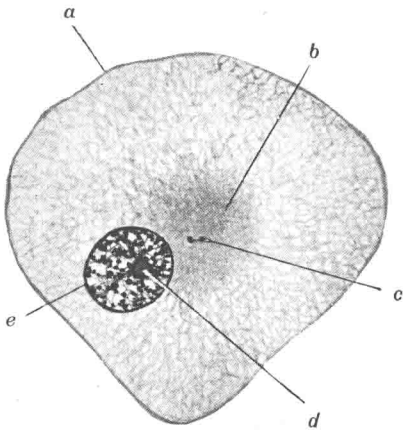

Fig. 1.—Interstitial cell from the ovary of a rabbit: *a*, Cell membrane; *b*, attraction sphere; *c*, centrioles (diplosome); *d*, nucleolus; *e*, nuclear membrane. Iron-hematoxylin stain. 1300 ×.

Cell Membrane.—The outer limit of the cell, *cell membrane* (Fig. 1), is supposed to be a condensation of the protoplasm of the cell body. In most cases, this membrane is difficult to delimit for morphological purposes, and yet its existence cannot be doubted. Some hold that the cell membrane in animals contains much lipoid material. In any event, the cell membrane in many respects functions as a semipermeable membrane through which osmotic interchanges are taking place more or less continuously. By microdissection it has been determined that the cell membrane is somewhat resistant and slightly elastic and that when it is destroyed at one point on a cell, a new membrane is soon formed from the cytoplasm.

The liquid or semiliquid nature of protoplasm becomes evident when a single cell is immersed in an indifferent liquid medium for under these conditions, in the absence of preventing factors, the cell body tends to assume a globular shape.

Between the nucleus and the cytoplasm is another membrane, called the *nuclear membrane* (Fig. 1). By microdissection it has been determined that the nuclear membrane is quite tough and slightly elastic, and that when it is punctured the nuclear content may run out, although nuclei usually "set" as a very viscous gel when injured. It has been assumed that the nuclear membrane is of much the same nature as the interphase between two different colloidal systems and that it, too, is subject to osmotic interchanges. In fixed preparations this membrane stands out as a very sharply isolated structure which stains deeply with certain dyes—as hematoxylin.

The Nucleus.—The nucleus of the cell is usually a globular or ovoid structure. It is slightly more dense in the living cell than the surrounding protoplasm, from which it is sharply delimited by the nuclear membrane. As seen in the living cell, the nucleus contains irregular wavy lines and clumps which are slightly grayer than the rest of the nucleus. Often a distinct body, the nucleolus (Fig. 1, *d*), can