CELL STRUCTURE

AN INTRODUCTION TO BIOMEDICAL ELECTRON MICROSCOPY

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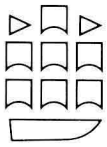
THIRD EDITION



CHURCHILL LIVINGSTONE
EDINBURGH LONDON MELBOURNE AND NEW YORK 1982

CHURCHILL LIVINGSTONE
Medical Division of Longman Group Limited

Distributed in the United States of America by
Churchill Livingstone Inc., 1560 Broadway, New York,
N.Y. 10036, and by associated companies, branches and
representatives throughout the world.

First Edition 1968
Second Edition 1971
Third Edition 1982

ISBN 0 443 02324 7

British Library Cataloguing in Publication Data
Carr, Katharine E.
Cell structure – 3rd ed.
1. Cells 2. Electron microscopy
I. Title II. Toner, Peter G.
574.87′028 QH585

Library of Congress Catalog Card No. 81–67939

Printed in Great Britain by
William Clowes (Beccles) Limited, Beccles and London.

CELL STRUCTURE

For Ian and Helen

Preface to the Third Edition

During the last 10 years, the electron microscope has become increasingly employed in almost every corner of the biomedical field, while the range and availability of ultrastructural technology has greatly expanded. *Cell Structure* has evolved into its third edition under these continuing environmental pressures.

The most significant expansion in the use of electron microscopy has been its increasing integration into human medicine, through the pathology laboratory. The insights into cell structure and function provided by the basic scientist can now help to solve clinical problems. Conversely, the wealth of clinical material now readily available from wards and operating theatres can help to broaden the horizons of research and give new relevance to the work of the ultrastructurally orientated basic scientist. A new chapter has been added to explore this area in greater detail, explaining in simple terms the practical relevance of ultrastructural knowledge to the medical laboratory specialist. Human material has been used for over half of the illustrations of this third edition.

The image of electron microscopy has also been changed, both literally and figuratively, by new technology. The biggest single change has been the integration of scanning systems, particularly surface scanning, into biological and clinical research. This has particularly influenced the teaching of structural concepts, helping students to break free from the limitations of two dimensions. Other recent technical advances include the growing importance of X-ray microanalysis in association with electron columns, and the continuing development of high voltage electron microscopy. Specimen preparation has also advanced, with freeze etching and cytochemical methods playing an increasing part in research. Techniques such as these have encouraged a more functional approach to the ultrastructural study of tissues and cells. An attempt has been made in this book to give recognition to these many developments, without losing sight of the continuing central role of conventional transmission electron microscopy.

We recognise that this book is now likely to be more used by undergraduates and postgraduates in biological sciences, and by medical specialists in training, than by the medical undergraduates who provided us with the stimulus to write the first edition. As a result, this edition has become larger than its predecessors, while continuing to follow the general pattern of the previous editions. The text has been almost entirely re-written, with the addition of new topics where appropriate to the overall aim. The space devoted to electron micrographs has almost doubled, allowing the illustration of a wider range of topics and techniques. Most of the micrographs are new. The line drawings, favourably received in previous editions, have been largely redrawn and have been added to. The reading list has been expanded and updated. Despite its increased size we hope that this edition will prove a concise and useful source of basic ultrastructural information for anyone exploring the ultrastructural world for the first time, at whatever level of specialisation.

We are grateful to many of our colleagues for their generosity in allowing us to use their micrographs and for other assistance. Particular thanks are due to H. S. Johnston, G. Bullock, C. Skerrow, I. A. R. More, A. A. M. Gibson, A. L. C. McLay and A. Jack. Dr R. V. Kristć has kindly given us permission to use four of his superb line

drawings. We are indebted to Mrs M. Johnston for her creative skill with the other drawings.

We would like to thank our technical colleagues for their unstinting support over many years, particularly J. D. Anderson, J. Ito, C. Watt and D. McSeveney, along with the staff of the EM Units of the Royal Infirmary and Western Infirmary Departments of Pathology and of the Department of Anatomy. Thanks are also due to the past and present members of the clerical staff for their efforts with the various drafts of the manuscript. The help of Mrs Peedle, Mrs Main and Mrs Thomson is particularly appreciated. Finally we are grateful to Professor R. J. Scothorne and Professor R. B. Goudie for the use of the facilities of their respective Departments.

K.E.C.
Glasgow, 1982 P.G.T.

Preface to the First Edition

This book is intended as a simple introduction to biological electron microscopy. In it we have set out to do three things: firstly, to present the fine structure of the cell and a number of the more interesting specialisations of cell structure; secondly to provide enough technical information to satisfy the first questions of the more interested student and to indicate to him the potential uses and limitations of electron microscopy; finally to help the beginner to approach the examination and interpretation of an unknown micrograph in a systematic way.

We have not attempted to compile a comprehensive reference work on fine structure since texts of this type are already available. Nor have we tried to present a manual of technique but instead have limited this section to give background information upon which an interested student might subsequently build. We have assumed that the study of fine structure will form part of a more general biological training and our limited treatment of functional aspects is not intended to take the place of the detailed study of biochemistry.

We have become convinced of the need for a book of this kind from our contact with students at the early stages of their medical studies and also from our experience of the needs and interests of students attending extramural classes on biological electron microscopy at Glasgow University. We believe that a working knowledge of fine structure may soon be as important to the biologist as a knowledge of histology and that a systematic introduction to the subject is best provided in the present form, rather than as supplements in a larger text of anatomy or histology. We hope that the book will prove of interest not only to the medical and biology students at whom it is primarily aimed, but also to those now past their student days who have not been exposed to any formal teaching of the elements of fine structure. We would like to feel that this book might help any, who for this reason regard fine structure with misgivings, to feel more at ease when confronted with the increasing numbers of electron micrographs appearing in the pages of the scientific press.

We are indebted to Professor G. M. Wyburn for the use of the facilities of the Department of Anatomy and for his advice and helpful criticism, not only during the preparation of this book, but on many occasions in the past. The electron micrographs with which the book is illustrated were taken by us using the Philips E.M. 200 electron microscope of the Department of Anatomy at Glasgow University. Miss Jean Hastie and Miss Pauline Semple assisted in collecting and processing the tissues and in preliminary screening. Miss Margaret Hughes gave invaluable photographic support and prepared all of the final prints. Miss Jane Young of the Department of Anatomy and Mr D. Lang of E. & S. Livingstone produced the line drawings with skill and care. We are most grateful for the assistance provided in these different ways, without which our own work would have been immeasureably increased. We would also like to thank the staff of E. & S. Livingstone for their co-operation and assistance at all stages in the production of the book and we are most grateful to Mr F. Dubrey of Scottish Studios for the care he has taken with the reproductions of our electron micrographs.

A number of our friends and colleagues have given us their help and criticism. We are particularly grateful to Dr J. P. Arbuthnott and to Dr I. A.

Carr, and we would like also to thank Drs R. B. Goudie, W. A. Harland, E. Arbuthnott, D. Graham, K. C. Calman, J. S. Dunn, A. R. Henderson, A. M. MacKay, R. F. Macadam, Mr A. Martin, Miss J. Rentoul, and Mr R. Young for their comments at different stages. Professor J. R. Anderson, Western Infirmary Department of Pathology, Glasgow University, has kindly given his encouragement and interest. We accept all responsibility for the remaining shortcomings in the text and for inadequacies in the micrographs, but we hope that they will not prevent the book from being of use to those with an interest in cell structure.

P.G.T.

Glasgow, June 1968 K.E.C.

Contents

Section I

THE CELL AND ITS COMPONENTS

The purpose of this section is to introduce the reader to the place of the electron microscope in the study of cellular structure and to present, in a compact form, the fundamentals of the structural organisation of the subcellular components. Where possible, simple functional considerations are introduced, without an attempt being made to trespass on the territory of the cellular biochemist or the molecular biologist.

1

The study of biological structure

1.1 MORPHOLOGICAL SCIENCE

The study of structure is an essential basis of biology. Structural studies, however, can be pursued by different techniques, each suited to a particular level of detail. In the past, the texture of different tissues could be revealed by simple visual examination and dissection, but the introduction of the light microscope suddenly extended the horizons of the early anatomists beyond the range of the unaided eye. This forced a radical revision of previous concepts of scale and dimension: the obstetrician's fingerbreadth and the inch gave way to the millimetre and the micron.

Since then, the light microscope has been a mainstay of biological research and medical practice. Magnifications of up to 2000 times show details far beyond the reach of unaided vision, but with one important limitation. No matter how good the microscope and the specimen may be, the detail it can display is limited to half the wave-length of the illuminating beam. This limitation lies in the physical nature of light itself. For this reason two particles less than 0.2 μm apart in the specimen will not be distinguished, or resolved, as separate images but will appear to fuse into a single blob. Such details are said to be beyond the *limit of resolution* of the light microscope.

Despite this limitation, the foundations of cellular biology have been laid by light microscopy. From it came the theory of the cell as the unit of life, the description of the nucleus and cytoplasm and the identification of the elementary subcellular components, such as the mitochondria and the Golgi apparatus.

At the same time, scientists in other disciplines had been pursuing the study of structure with other techniques. X-ray diffraction, first introduced by physical chemists, provided new insights into the three dimensional structure of complex macromolecules, such as DNA, myoglobin and lysozyme. Aided by modern computer expertise, it is now a routine tool in structural biochemistry. Structure and function at the molecular and atomic level have become the province of the biochemist, the biophysicist, the molecular biologist and the physical chemist.

1.2 THE TECHNIQUE OF ELECTRON MICROSCOPY

The *electron microscope* provided the missing link between the details of tissue organisation as seen by the light microscope and the details of molecular architecture as revealed by the new biochemical and biophysical techniques. By using electrons instead of light, restrictions on resolution could be removed. The wave-length of the electron beam in the operating conditions of the electron microscope is many times smaller than the wave-length of visible light. The difference in scale is so great that a new range of units of measurement has become common currency in biology. In the now standard international system of units of measurement (SI units) the electron microscopist thinks in terms of nanometres (nm), each one representing one thousandth of a micron. It is this unit which is used in the following chapters to describe the dimensions of many subcellular components. An old unit still popular with the electron microscopist is the Ångstrom Unit (Å) originally used as the unit of wave-length in optical spectroscopy. The Ångstrom unit represents one ten-thousandth part of a micron. Hence one nanometre (nm) is equal