

CONTRIBUTORS

J. R. BENDALL

G. H. BOURNE

R. COUTEAUX

ARPAD I. CSAPO

E. J. FIELD

HARRY A. FOZZARD

CLARA FRANZINI-ARMSTRONG

R. P. GOULD

P. HUDGSON

SOHAN L. MANOCHA

ZBIGNIEW OLKOWSKI

ERNEST PAGE

E. VIVIER

THE STRUCTURE AND FUNCTION OF MUSCLE

Second Edition

VOLUME II

Structure Part 2

Edited by

Geoffrey H. Bourne

*Yerkes Primate Research Center
Emory University
Atlanta, Georgia*



ACADEMIC PRESS 1973 New York and London

A Subsidiary of Harcourt Brace Jovanovich, Publishers

**COPYRIGHT © 1973, BY ACADEMIC PRESS, INC.
ALL RIGHTS RESERVED.**

**NO PART OF THIS PUBLICATION MAY BE REPRODUCED OR
TRANSMITTED IN ANY FORM OR BY ANY MEANS, ELECTRONIC
OR MECHANICAL, INCLUDING PHOTOCOPY, RECORDING, OR ANY
INFORMATION STORAGE AND RETRIEVAL SYSTEM, WITHOUT
PERMISSION IN WRITING FROM THE PUBLISHER.**

**ACADEMIC PRESS, INC.
111 Fifth Avenue, New York, New York 10003**

United Kingdom Edition published by
**ACADEMIC PRESS, INC. (LONDON) LTD.
24/28 Oval Road, London NW1**

LIBRARY OF CONGRESS CATALOG CARD NUMBER: 72-154373

PRINTED IN THE UNITED STATES OF AMERICA

LIST OF CONTRIBUTORS

Numbers in parentheses indicate the pages on which the authors' contributions begin.

- J. R. BENDALL, *Agricultural Research Center Meat Research Institute, Langford Bristol, England* (243)
- G. H. BOURNE, *Yerkes Primate Research Center, Emory University, Atlanta, Georgia* (483)
- R. COUTEAUX, *Faculté des Sciences, Université de Paris, Paris, France* (483)
- ARPAD I. CSAPO, *Department of Obstetrics and Gynecology, Washington University School of Medicine, St. Louis, Missouri* (1)
- E. J. FIELD, *Medical Research Council Demyelinating Diseases Unit, Newcastle General Hospital, Newcastle upon Tyne, England* (311)
- HARRY A. FOZZARD, *Department of Medicine and Physiology, Pritzker School of Medicine, The University of Chicago, Chicago, Illinois* (91)
- CLARA FRANZINI-ARMSTRONG, *Department of Physiology, University of Rochester, School of Medicine and Dentistry, Rochester, New York* (531)
- R. P. GOULD, *Department of Anatomy, The Middlesex Hospital, Medical School, London, England* (185)
- P. HUDGSON, *The Muscular Dystrophy Research Laboratories and the Medical Research Council Demyelinating Diseases Research Unit, Newcastle General Hospital, Newcastle upon Tyne, England* (311)
- SOHAN L. MANOCHA, *Yerkes Primate Research Center, Emory University, Atlanta, Georgia* (365)
- ZBIGNIEW OLKOWSKI, *Department of Radiation Therapy, Winship Clinic, Emory University Medical School, Atlanta, Georgia* (365)
- ERNEST PAGE, *Department of Medicine and Physiology, The University of Chicago, Chicago, Illinois* (91)
- E. VIVIER, *Department of Animal Biology, Science Faculty, Lille, and Laboratory of Electron Microscopy, Pasteur Institute, Paris, France* (159)

PREFACE

In the years that have elapsed since the first edition of this work was published in 1960, studies on muscle have advanced to such a degree that a second edition has long been overdue. Although the original three volumes have grown to four, we have covered only a fraction of the new developments that have taken place since that time. It is not surprising that these advances have not been uniform, and in this new edition not only have earlier chapters been updated but also areas in which there was only limited knowledge before have been added. Examples are the development of our knowledge of crustacean muscle (172 of 213 references in the reference list for this chapter are dated since the first edition appeared) and arthropod muscle (205 of 233 references are dated since the last edition). Obliquely striated muscle, described in 1869, had to wait until the electron microscope was focused on it in the 1960's before it began to yield the secrets of its structure, and 33 of 43 references dated after 1960 in this chapter show that the findings described are the result of recent research. There has also been a great increase in knowledge in some areas in which considerable advances had been made by the time the first edition appeared. As an example, in Dr. Hugh Huxley's chapter on "Molecular Basis of Contraction in Cross-Striated Muscles," 76 of his 126 references are dated after 1960.

The first volume of this new edition deals primarily with structure and considers muscles from the macroscopic, embryonic, histological, and molecular points of view. The other volumes deal with further aspects of structure, with the physiology and biochemistry of muscle, and with some aspects of muscle disease.

We have been fortunate in that many of our original authors agreed to revise their chapters from the first edition, and it has also been our good fortune to find other distinguished authors to write the new chapters included in this second edition.

To all authors I must express my indebtedness for their hard work and patience, and to the staff of Academic Press I can only renew my confidence in their handling of this publication.

Geoffrey H. Bourne

PREFACE

TO THE FIRST EDITION

Muscle is unique among tissues in demonstrating to the eye even of the lay person the convertibility of chemical into kinetic energy.

The precise manner in which this is done is a problem, the solution of which has been pursued for many years by workers in many different disciplines; yet only in the last 15 or 20 years have the critical findings been obtained which have enabled us to build up some sort of general picture of the way in which this transformation of energy may take place. In some cases the studies which produced such rich results were carried out directly on muscle tissue. In others, collateral studies on other tissues were shown to have direct application to the study of muscular contraction.

Prior to 1930 our knowledge of muscle was largely restricted to the macroscopical appearance and distribution of various muscles in different animals, to their microscopical structure, to the classic studies of the electro- and other physiologists and to some basic chemical and biochemical properties. Some of the latter studies go back a number of years and might perhaps be considered to have started with the classic researches of Fletcher and Hopkins in 1907, who demonstrated the accumulation of lactic acid in contracting frog muscle. This led very shortly afterward to the demonstration by Meyerhof that the lactic acid so formed is derived from glycogen under anaerobic conditions. The lactic acid formed is quantitatively related to the glycogen hydrolyzed. However, it took until nearly 1930 before it was established that the energy required for the contraction of a muscle was derived from the transformation of glycogen to lactic acid.

This was followed by the isolation of creatine phosphate and its establishment as an energy source of contraction. The isolation of ADP and ATP and their relation with creatine phosphate as expressed in the Lohmann reaction were studies carried out in the thirties. What might be described as a spectacular claim was made by Engelhart and Lubimova,

who in the 1940's said that the myosin of the muscle fiber had ATPase activity. The identification of actin and the relationship of actin and myosin to muscular contraction and the advent of the electron microscope and its application with other physical techniques to the study of the general morphology and ultrastructure of the muscle fibers were events in the 1940's which greatly developed our knowledge of this complex and most mobile of tissues.

In the 1950's the technique of differential centrifugation extended the knowledge obtained during previous years of observation by muscle cytologists and electron microscopists to show the differential localization of metabolic activity in the muscle fiber. The Krebs cycle and the rest of the complex of aerobic metabolism was shown to be present in the sarcosomes—the muscle mitochondria.

This is only a minute fraction of the story of muscle in the last 50 years. Many types of disciplines have contributed to it. The secret of the muscle fiber has been probed by biochemists, physiologists, histologists and cytologists, electron microscopists and biophysicists, pathologists, and clinicians. Pharmacologists have insulted skeletal, heart, and smooth muscle with a variety of drugs, *in vitro*, *in vivo*, and *in extenso*; nutritionists have peered at the muscle fiber after vitamin and other nutritional deficiencies; endocrinologists have cycled the metabolic process through hormonal glasses. Even the humble histochemist has had the temerity to apply his techniques to the muscle fiber and describe results which were interesting but not as yet very illuminating—but who knows where knowledge will lead. Such a ferment of interest (a statement probably felicitously applied to muscle) in this unique tissue has produced thousands of papers and many distinguished workers, many of whom we are honored to have as authors in this compendium.

Originally we thought, the publishers and I, to have *a book* on muscle which would contain a fairly comprehensive account of various aspects of modern research. As we began to consider the subjects to be treated it became obvious that two volumes would be required. This rapidly grew to three volumes, and even so we have dealt lightly or not at all with many important aspects of muscle research. Nevertheless, we feel that we have brought together a considerable wealth of material which was hitherto available only in widely scattered publications. As with all treatises of this type, there is some overlap, and it is perhaps unnecessary to mention that to a certain extent this is desirable. It is, however, necessary to point out that most of the overlap was planned, and that which was not planned was thought to be worthwhile and was thus not deleted.

We believe that a comprehensive work of this nature will find favor with all those who work with muscle, whatever their disciplines, and

that although the division of subject matter is such that various categories of workers may need only to buy the volume which is especially apposite to their specialty, they will nevertheless feel a need to have the other volumes as well.

The Editor wishes to express his special appreciation of the willing collaboration of the international group of distinguished persons who made this treatise possible. To them and to the publishers his heartfelt thanks are due for their help, their patience, and their understanding.

Emory University, Atlanta, Georgia
October 1, 1959

GEOFFREY H. BOURNE