# MUSCLE CONTRACTION

Its Regulatory Mechanisms

Edited by S. EBASHI, K. MARUYAMA, and M. ENDO



JAPAN SCIENTIFIC SOCIETIES PRESS, Tokyo SPRINGER-VERLAG, Berlin Heidelberg New York

# MUSCLE CONTRACTION

Its Regulatory Mechanisms

Edited by SETSURO EBASHI, KOSCAK MARUYAMA, and MAKOTO ENDO

JAPAN SCIENTIFIC SOCIETIES PRESS, Tokyo SPRINGER-VERLAG, Berlin Heidelberg New York

1980



#### © JAPAN SCIENTIFIC SOCIETIES PRESS, 1980

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.

JSSP No. 02392-1104

ISBN 3-540-10411-9 Springer-Verlag Berlin Heidelberg New York ISBN 0-387-10411-9 Springer-Verlag New York Heidelberg Berlin

Sole distribution rights outside Japan granted to Springer-Verlag Berlin Heidelberg New York

Published jointly by
Japan Scientific Societies Press Tokyo
and
Springer-Verlag Berlin Heidelberg New York

#### MUSCLE CONTRACTION

Its Regulatory Mechanisms

Proceedings of the Oji Seminar, Symposium on Regulatory Mechanisms of Muscle Contraction (Kumagai-Natori Symposium), held on October 28-30, 1979, sponsored by Japan Society for Promotion of Science and Fujihara Foundation of Science.

此为试读,需要完整PDF请访问: www.ertongbook.com

## Contributors

Adelstein, R. S.

Aksoy, M. O.	Department of Physiology, University of Virginia School of Medicine, Charlottesville, Virginia 22901,
	U.S.A.
Amemiya, Y.	Engineering Research Institute, Faculty of Engineering,
	University of Tokyo, Tokyo 113, Japan
Anderson, K.	Department of Molecular, Cellular, and Develop-
	mental Biology, University of Colorado, Boulder
	Colorado 80302, U.S.A.
Arai, K.	Department of Food Science, Faculty of Fisheries,
	Hokkaido University, Hakodate 040, Japan
Arata, T.	Department of Biology, Faculty of Science, Osaka
	University, Toyonaka 560, Japan
Birnbaum, R. J.	Department of Physiology, Boston University School of
	Medicine, Boston, Massachusetts 02118, U.S.A.
Botts, J.	Cardiovascular Research Institute, University of Cali-
	fornia, San Francisco, California 94143, U.S.A.
Chandler, W. K.	Department of Physiology, Yale University School of
	Medicine, New Haven, Connecticut 06510, U.S.A.
Conti, M. A.	Section on Molecular Cardiology, Cardiology Branch,
	National Heart, Lung, and Blood Institute, Bethesda,
	Maryland 20205, U.S.A.
Couch, J.	Medical Research Council Cell Biophysics Unit, King's
	College, London W.C. 2, U.K.

NIH, Bethesda, Maryland 20014, U.S.A.

X	
Ebashi, S.	Department of Pharmacology, Faculty of Medicine, University of Tokyo, Tokyo 113, Japan
Endo, M.	Department of Pharmacology, Tohoku University School of Medicine, Sendai 980, Japan
Endoh, M.	Department of Pharmacology, Tohoku University School of Medicine, Sendai 980, Japan
Fujime, S.	Mitsubishi-Kasei Institute of Life Sciences, Tokyo 194, Japan
Gergely, J.	Department of Muscle Research, Boston Biomedical Research Institute, Boston, Massachusetts 02114, U.S.A.
Gonzalez-Serratos, H.	Department of Biophysics, School of Medicine, University of Maryland, Maryland, U.S.A.
Hartshorne, D. J.	Department of Nutrition and Food Science, University of Arizona, College of Agriculture, Tucson, Arizona 85721, U.S.A.
Hashizume, H.	Engineering Research Institute, Faculty of Engineering, University of Tokyo, Tokyo 113, Japan
Head, J. H.	Department of Physiology, Boston University School of Medicine, Boston, Massachusetts 02118, U.S.A.
Hirabayashi, T.	Institute of Biological Science, University of Tsukuba, Niihari, Ibaraki 300-31, Japan
Huxley, A. F.	Department of Physiology, University College London, WC1E 6BT, U.K.
Huxley, H. E.	MRC Laboratory of Molecular Biology, University Medical School, Cambridge, CB2 2QH, U.K.
Kaminer, B.	Department of Physiology, Boston University School of Medicine, Boston, Massachusetts 02118, U.S.A.
Katayama, E.	Department of Pharmacology, Faculty of Medicine, University of Tokyo, Tokyo 113, Japan
Kitazawa, T.	The Pennsylvania Muscle Institute, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104, U.S.A.
Konno, K.	Department of Food Science, Faculty of Fisheries, Hokkaido University, Hakodate 040, Japan
Kumagai, H.	Faculty of Medicine, University of Tokyo, Tokyo 113, Japan
Kuroda, M.	Institute of Basic Medical Sciences, University of Tsukuba, Niihari, Ibaraki 300-31, Japan
Leavis, P. C.	Department of Muscle Research, Boston Biomedical Research Institute, Boston, Massachusetts 02114, U.S.A.

CH	180	TERES	T	DIT	TO	DC

Department of Biology, Faculty of Science, Chiba Maruyama, K. University, Chiba 260, Japan Institute of Basic Medical Sciences, University of Masaki, T. Tsukuba, Niihari, Ibaraki 300-31, Japan Department of Pharmacology, Tohoku University Matsubara, I. School of Medicine, Sendai 980, Japan The Laboratory for Contractile Proteins, The Tokyo Matsuda, R. Metropolitan Institute of Medical Science, Tokyo 113, Japan Department of Chemistry, Faculty of Science and Matsumoto, J. J. Technology, Sophia University, Tokyo 102, Japan The Pennsylvania Muscle Institute, Department of McClellan, G. Physiology and Pathology, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104, U.S.A. Mikawa, T. Department of Pharmacology, Faculty of Medicine, University of Tokyo, Tokyo 113, Japan Morales, M. F. Cardiovascular Research Institute, University of California Medical Center, San Francisco, California 94143, U.S.A. Medical Research Council Cell Biophysics Unit, King's Morris, E. P. College, London W.C. 2, U.K. Department of Biochemistry, University of Pennsyl-Murray, J. M. vania School of Medicine, Philadelphia, Pennsylvania 19104, U.S.A. Jikei University, Tokyo 105, Japan Natori, R. Department of Pharmacology, Faculty of Medicine, Nonomura, Y. University of Tokyo, Tokyo 113, Japan Obinata, T. Department of Biology, Faculty of Science, Chiba University, Chiba 260, Japan O'Brien, E. J. Medical Research Council Cell Biophysics Unit, King's College, London W.C. 2, U.K. Ohara, O. Institute for Chemical Research, Kyoto University, Uji 611, Japan Ohashi, K. Department of Biology, Faculty of Science, Chiba University, Chiba 260, Japan Ohtsuki, I. Department of Pharmacology, Faculty of Medicine, Kyushu University, Fukuoka 812, Japan Ooi, T. Institute for Chemical Research, Kyoto University, Uji 611, Japan Oosawa, F. Department of Biophysical Engineering, Osaka University, Toyonaka 560, Japan

Pato, M. D.	Section on Molecular Cardiology, Cardiology Branch, National Heart, Lung, and Blood Institute, Bethesda, Maryland 20205, U.S.A.
Perry, S. V.	Department of Biochemistry, University of Birmingham, Birmingham, B15 2TT, U.K.
Podolsky, R. J.	Laboratory of Physical Biology, National Institute of Arthritis, Metabolism, and Digestive Diseases, NIH, Bethesda, Maryland 20205, U.S.A.
Porter, K. R.	Department of Molecular, Cellular and Developmental Biology, University of Colorado, Boulder, Colorado 80302, U.S.A.
Sakai, T.	Department of Physiology, Jikei University School of Medicine, Tokyo 105, Japan
Seymour, J.	Medical Research Council Cell Biophysics Unit, King's College, London W.C. 2, U.K.
Shuman, H.	The Pennsylvania Muscle Institute, Department of Physiology and Pathology, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104, U.S.A.
Siemankowski, R. F.	Department of Nutrition and Food Science, Muscle Biology Group, University of Arizona, Tucson, Arizona 85721, U.S.A.
Somlyo, A. P.	The Pennsylvania Muscle Institute, Department of Physiology and Pathology, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104, U.S.A.
Somlyo, A. V.	The Pennsylvania Muscle Institute, Department of Physiology and Pathology, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104, U.S.A.
Sugi, H.	Department of Physiology, School of Medicine, Teikyo University, Tokyo 173, Japan
Szent-Györgyi, A. G.	Department of Biology, Brandeis University, Waltham, Massachusetts 02154, U.S.A.
Takahashi, S.	Institute for Chemical Research, Kyoto University, Uji 611, Japan
Tameyasu, T.	Department of Physiology, School of Medicine, Teikyo University, Tokyo 173, Japan
Tanaka, H.	Department of Physiology, School of Medicine, Teikyo University, Tokyo 173, Japan
Tawada, K.	Laboratory of Physical Biology, National Institute of

00112111001	
	Arthritis, Metabolism, and Digestive Diseases, NIH, Bethesda, Maryland 20205, U.S.A.
Tonomura, Y.	Department of Biology, Faculty of Science, Osaka University, Toyonaka 560, Japan
Tsuchiya, T.	Department of Chemistry, Faculty of Science and Technology, Sophia University, Tokyo 102, Japan
Umazume, Y.	Department of Physiology, Jikei University School of Medicine, Tokyo 105, Japan
Wakabayashi, T.	Department of Physics, Faculty of Science, University of Tokyo, Tokyo 113, Japan
Watanabe, S.	Department of Chemistry, Faculty of Science, Tokyo Institute of Technology, Tokyo 152, Japan
Weber, A.	Department of Biochemistry, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104, U.S.A.
Wegner, A.	Department of Biochemistry, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104, U.S.A.
Yagi, N.	Department of Pharmacology, Tohoku University School of Medicine, Sendai 980, Japan
Yagi, S.	Department of Pharmacology, Tohoku University School of Medicine, Sendai 980, Japan
Yamada, K.	Department of Physiology, Medical College of Oita, Oita 879-56, Japan
Yamashita, T.	Laboratory of Physiological Chemistry, Juntendo University School of Medicine, Tokyo 113, Japan
Yanagida, T.	Department of Biophysical Engineering, Osaka University, Toyonaka 560, Japan
Yoshino, S.	Department of Physics, Nagoya University, Nagoya 464, Japan
Yoshioka, T.	Department of Physiology, Tokai University School of Medicine, Isehara 259-11, Japan

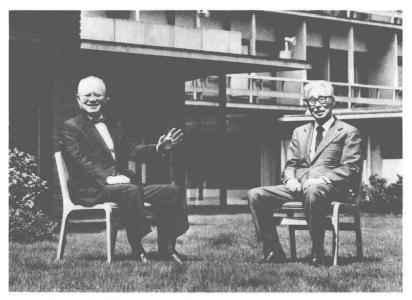
#### Preface

One of the aims of this Symposium was to celebrate the seventy-fifth birthday of Prof. Hiroshi Kumagai and the twenty-fifth anniversary of the discovery of 'skinned fibers' by Prof. Reiji Natori. This did not mean that the meeting would be only a ceremonial one, placing rather minor emphasis on scientific aspects. On the contrary, it was a result of the desire of Japanese muscle scientists to pursue the mechanism of muscle contraction, which has been inseparably linked with their admiration for the unparallelled contribution to muscle science of Profs. Kumagai and Natori.

We take the liberty of quoting a part of the 'Introduction' of a book dedicated to Prof. Kumagai (*Molecular Biology of Muscular Contraction*, Igaku Shoin, Tokyo, and Elsevier, Amsterdam, 1965):

"..., even this somewhat encouraging event did not change his deep feeling that the best days of his career as a research scientist were over and that the best he could do then would be to bring up the younger generation to be full-fledged scientists on an international level. Since then he has performed his chosen task faithfully and enthusiatically, often at the expense of his private life."

The latter half of the 1940's was a most difficult time for Japanese scientists. However, this could not depress Prof. Natori, but stimulated him to create a new thing, 'Natori's fibers' or skinned fibers. His ardor for muscle



Professors H. Kumagai and R. Natori in front of the International House of Japan, Tokyo, where the 1957 Muscle Conference was held. June 28, 1980

science further compelled him to organize periodical muscle physiology meetings, 'Kin-seiri no Tsudoi', every two or three months, where young people could find a place to report their findings.

It was very timely that in 1955 Prof. Kumagai as the chairman of the research group on 'Chemistry of Muscular Contraction' invited Prof. Natori to join his group as a chief member. Thus links between muscle physiology and biochemistry began to bud in Japan, too.

We wish to quote again the above book:

"He (Prof. Kumagai) moved further in organizing the 'Conference on the chemistry of muscular contraction', Tokyo, in 1957. To this conference, he invited many scientists to come from abroad. At that time, Japan was still experiencing difficult economic situation, and no financial support to the conference could be obtained from official sources. Nevertheless, the meeting was held, largely through his personal efforts. There were some difficulties in communication, but the conference was a

PREFACE XVIII

great gain for the Japanese scientists, first because they could estimate their own level of achievement in the world, and second, because they made many friends from abroad."

It was our great pleasure to have Profs. M. F. Morales and J. Gergely, who played main roles in that Conference, in attendance at this Symposium. We were particularly delighted to welcome Prof. T. C. Tsao from Shanghai, who tried hard to attend the 1957 Conference but without success owing to unavoidable circumstances.

Our original plan was to have this Symposium in the same place where the 1957 Conference was held (see the photograph above) to refresh the nice memories of twenty-two years ago. However, Tokyo has changed very much in a direction unfavorable for such a meeting. So the meeting was held in a hotel near Mt. Fuji, where participants could enjoy the beautiful scenery and the courtesy of the hotel.

Taking this opportunity, we wish to express our cordial thanks to all participants, especially those from abroad. We are particularly indebted to Sir Andrew Huxley for his historical survey of the studies on regulatory mechanisms of muscle contraction, which has exempted us from explaining the scientific reason why we planned this Symposium.

We are very grateful to the officials of The Japan Society for the Promotion of Science and the Fujiwara Foundation of Science for their extending us cordial assistance in organizing this Symposium, especially to Mr. Y. Ichikawa, the director of the Fujiwara Foundation, for his sincere encouragement. Our thanks are also due to our colleagues, especially Dr. Y. Nonomura, for their efforts behind the curtain in managing the Symposium.

July 1980

S. Ebashi K. Maruyama M. Endo My dear Dr. Ebashi:

You have made me very happy with your letter—a new expression of an old friendship. You have also deeply honored me by the generous invitation to the Kumagai-Natori Symposium on Regulatory Mechanisms of Muscle Contraction. It would have been a very great pleasure for me to attend the meeting and meet old friends. It would have given me a special pleasure to convey personally the expression of my admiration for Professor Kumagai, the father to Japanese muscle scientists, for the wonderful research he has conducted all his life, and the equally wonderful example and teaching which he has given to the younger Japanese generation devoted to science. During my long research I could never separate ethics, morals, goodwill and the search of new truth which formed one unit in Dr. Kumagai's life. I also would have loved to express personally my admiration for the wonderful scientific achievements of Professor R. Natori, inventor of the fiber carrying his name. To both of them I wanted to express also my best wishes for their further work, long life, health and happiness.

Very unfortunately my advanced age and many obligations prevent me from partaking in the Sypmosium in commemoration of Professor Kumagai's 75th anniversary, and the 25th anniversary of the publication of the skinned fiber which opened an entirely new road for research.

I could not have been a useful member, having left muscle research long ago, but I would have been proud of seeing the splendid research going on. If one had even a small part in planting a tree, one is always proud and glad to see that the tree grows and blossoms, even if one can do nothing for it any more.

With the warmest regards and the best wishes to all of you.

Yours,

Albert Szent-Györgyi

aunos frent gricer

### Contents

Contributors Preface	vv
Special Lecture	
The Variety of Muscle Activating Systems	3 19
Cross-bridge Movement	
The Movement of Myosin Cross-bridges during Contraction	33
Kinetic Properties of the Cross-bridges in Frog Skeletal Muscle as Studied by Time-resolved X-ray Diffraction	45
Y. Amemiya, H. Hashizume, T. Tameyasu, and H. Tanaka S A Rate-limiting Step in Muscle Contraction	53
	5 <i>5</i>

The Role of the Sulfhydryl Group of L-Meromyosin in the Actin-Myosin Interaction	Relationship of Cross-bridge Movement to ATP Splitting in Grycerol-treated Muscle Fibers	99
Dynamic Aspects of Thin Filament  Structure and Activity of the Thin Filament  E. J. O'Brien, E. P. Morris, J. Seymour, and J. Couch 147  Dynamics of Actin Filament  F. Oosawa 165  The Angles of Cross-bridges Bound to Nucleotide at Various Concentrations of Mg-(\varepsilon)-ATP  Trapagida 173  Dynamic Aspects of Muscle Thin Filaments  S. Yoshino and S. Fujime 181  Troponin-linked Regulation  The Structure of Troponin-C and Thin Filament Regulation in Striated Muscle  Structure and Function Relationships in Troponin and Calmodulin Regulatory Systems  S. V. Perry 207  Tropomyosin and the Various States of the Regulated Actin Filament  J. M. Murray, A. Weber, and A. Wegner 221  Functional Organization of the Troponin-Tropomyosin System  J. Ohtsuki 237  Interactions among Thin Filament Proteins  L. Katayama 251  A Study on Troponin-T and Troponin-C Interaction by Crosslinking Reagents  O. Ohara, S. Takahashi, and T. Ooi 259  Thermodynamics of the Interaction of Calcium with the Regulatory Protein System Relating to the Heat Production of Muscle  K. Yamada 267  Differentiation of Troponin in Developing Chicken Skeletal Muscle	Commentary on Certain Problems in the Use of Molecular Probes	115
Structure and Activity of the Thin Filament  E. J. O'Brien, E. P. Morris, J. Seymour, and J. Couch 147  Dynamics of Actin Filament F. Oosawa 165  The Angles of Cross-bridges Bound to Nucleotide at Various Concentrations of Mg-(\varepsilon)-ATP T. Yanagida 173  Dynamic Aspects of Muscle Thin Filaments		133
Dynamics of Actin Filament	Dynamic Aspects of Thin Filaments	
Dynamics of Actin Filament		
The Angles of Cross-bridges Bound to Nucleotide at Various Concentrations of Mg-(\varepsilon)-ATP		
Dynamic Aspects of Muscle Thin Filaments  S. Yoshino and S. Fujime 181  Troponin-linked Regulation  The Structure of Troponin-C and Thin Filament Regulation in Striated Muscle  J. Gergely and P. C. Leavis 191  Structure and Function Relationships in Troponin and Calmodulin Regulatory Systems  S. V. Perry 207  Tropomyosin and the Various States of the Regulated Actin Filament  J. M. Murray, A. Weber, and A. Wegner 221  Functional Organization of the Troponin-Tropomyosin System  J. Ohtsuki 237  Interactions among Thin Filament Proteins  J. E. Katayama 251  A Study on Troponin-T and Troponin-C Interaction by Crosslinking Reagents  O. Ohara, S. Takahashi, and T. Ooi 259  Thermodynamics of the Interaction of Calcium with the Regulatory Protein System Relating to the Heat Production of Muscle  K. Yamada 267  Differentiation of Troponin in Developing Chicken Skeletal Muscle	The Angles of Cross-bridges Bound to Nucleotide at Various Con-	
Troponin-linked Regulation  The Structure of Troponin-C and Thin Filament Regulation in Striated Muscle		173
The Structure of Troponin-C and Thin Filament Regulation in Striated Muscle		181
Striated Muscle		
	Troponin-linked Regulation	
	The Structure of Troponin-C and Thin Filament Regulation in Striated Muscle	191 207 221 237 251 259

CONTENTS

Regulatory Mechanisms in Smooth Muscle
Ca Regulation in Smooth Muscle and Phosphorylation: Some Properties of the Myosin Light Chain Kinase
Regulation of Smooth Muscle Myosin Kinase Activity by Phosphorylation and Dephosphorylation
Myosin-linked Regulation in Chicken Gizzard Muscle and in Clam
Foot Muscle
Leiotonin, Regulatory Protein of Smooth Muscle Y. Nonomura 329 "Freezing" of Activated and Depressed Thin Filaments of Skeletal
and Smooth Muscles
J. H. Head, R. J. Birnbaum, and B. Kaminer 359
Myosin-linked Regulation
Role of Regulatory Light Chains in Myosin-linked Regulation
Myosin-linked Calcium Regulation in Squid Muscle
Excitation-Contraction Coupling
Voltage Dependence of Calcium Release in Vertebrate Skeletal Muscle Fibers
The Sarcoplasmic Reticulum and Its Composition in Resting and in Contracting Muscle
A. V. Somlyo, H. Gonzalez-Serratos, H. Shuman, and G. McClellan 421
On the Controlling Factors for Activation of Rapid Cooling Contracture
Different Features of Responses of the Sarcoplasmic Reticulum in Cardiac and Smooth Muscles
Contractile Activation and Calcium Movement in Mammalian Cardiac