

Ultrastructure of Skeletal Tissues

Bone and Cartilage in Health and Disease

ELECTRON MICROSCOPY IN BIOLOGY AND MEDICINE

Current Topics in Ultrastructural Research

SERIES EDITOR: P.M. MOTTA

Already published in this series

- Vol. 1 Motta, P.M. (ed.): Ultrastructure of Endocrine Cells and Tissues.
ISBN: 0-89838-568-7.
- Vol. 2 Van Blerkom, J. and Motta, P.M. (eds.): Ultrastructure of Reproduction: Gametogenesis,
Fertilization, and Embryogenesis. ISBN: 0-89838-572-5.
- Vol. 3 Ruggeri, A. and Motta, P.M. (eds.): Ultrastructure of the Connective Tissue Matrix.
ISBN: 0-89838-600-4.
- Vol. 4 Motta, P.M., Fujita, A. (eds.): Ultrastructure of the Digestive Tract. ISBN: 0-89838-893-7.
- Vol. 5 Van Blerkom, J. and Motta, P.M. (eds.): Ultrastructure of Human Gametogenesis and Early
Embryogenesis. ISBN: 0-89838-383-8.
- Vol. 6 Riva, A. and Motta, P.M. (eds.): Ultrastructure of the Extraparietal Glands of the Digestive
Tract. ISBN: 0-7923-0303-2.

Series Editor

P.M. MOTTA, Department of Anatomy, Faculty of Medicine, University "La Sapienza" of Rome, Viale
R. Elena 289, 00161 Rome, Italy

Advisory Scientific Committee

D.J. ALLEN (Toledo, Ohio, USA) / A. AMSTERDAM (Rehovot, Israel) / P.M. ANDREWS
(Washington, DC, USA) / L. BJERSING (Umea, Sweden) / I. BUCKLEY (Canberra, Australia) / F.
CARAMIA (Rome, Italy) / A. COIMBRA (Porto, Portugal) / I. DICULESCU (Bucharest, Romania) /
L.J.A. DIDIO (Toledo, Ohio, USA) / M. DVORAK (Brno, Czechoslovakia) / H.D. FAHIMI
(Heidelberg, FRG) / H.V. FERNANDEZ-MORAN (Chicago, Ill., USA) / H. FUJITA (Osaka, Japan) /
T. FUJITA (Niigata, Japan) / E. KLIKA (Prague, Czechoslovakia) / L.C.U. JUNQUEIRA (São Paulo,
Brazil) / R.G. KESSEL (Iowa City, Iowa, USA) / F.N. LOW (New Orleans, Louisiana, USA) / B.L.
MUNGER (Hersey, Pa., USA) / T. MURAKAMI (Okayama, Japan) / O. NILSSON (Uppsala,
Sweden) / A. OKSCHE (Giessen, Federal Republic of Germany) / K.R. PORTER (Boulder, Colo.,
USA) / J.A.G. RHODIN (Tampa, Fla., USA) / K. SMETANA (Prague, Czechoslovakia) / K.
TANAKA (Yonago, Japan) / K. TANIKAWA (Kurume, Japan) / I. TÖRÖ (Budapest, Hungary) / J.
VAN BLERKOM (Boulder, Colo., USA)

Ultrastructure of Skeletal Tissues

Bone and Cartilage in Health and Disease

edited by

E. Bonucci, M.D.

*Department of Human Biopathology, Faculty of Medicine
University "La Sapienza" of Rome, Italy*

and

P.M. Motta, M.D., Ph.D.

*Department of Anatomy, Faculty of Medicine
University "La Sapienza" of Rome, Italy*



Kluwer Academic Publishers

Boston/Dordrecht/London

Distributors

for North America: Kluwer Academic Publishers 101 Philip Drive, Assinippi Park, Norwell, Massachusetts 02061 USA
for all other countries: Kluwer Academic Publishers Group, Distribution Centre, Post Office Box 322 3300 AH Dordrecht, THE NETHERLANDS

Library of Congress Cataloging-in-Publication Data

Ultrastructure of skeletal tissue / edited by E. Bonucci and P.M. Motta.

p. cm. — (Electron microscopy in biology and medicine)

Includes bibliographies and index.

ISBN 0-7923-0373-3

1. Bones—Ultrastructure. 2. Cartilage—Ultrastructure.

I. Bonucci, E. II. Motta, Pietro M. III. Series.

[DNLM: 1. Bone and Bones—Ultrastructure. 2. Cartilage-ultrastructure. W1 EL33E / WE 200 U47]

QM569.U48 1990

611'.0184—dc20

DNLM/DLC

for Library of Congress

89-15435

CIP

Copyright 1990 by Kluwer Academic Publishers

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher, Kluwer Academic Publishers, 101 Philip Drive, Assinippi Park, Norwell, Massachusetts 02061.

PRINTED IN THE UNITED STATES OF AMERICA.

Contents

Preface <i>by the editors</i>	vii
Contributing authors	ix
1. The ultrastructure of calcified tissues: Methods and technical problems <i>by</i> A.L. Arsenault ...	1
2. The original contributions of the scanning electron microscope to the knowledge of bone structure <i>by</i> G. Marotti	19
3. Collagen mineralization: Aspects of the structural relationship between collagen and the apatitic crystallites <i>by</i> H.J. Höhling, R.H. Barckhaus, E.-R. Krefting, J. Althoff & P. Quint	41
4. Ultrastructural immunohistochemistry of noncollagenous proteins in calcified tissues <i>by</i> P. Bianco	63
5. Ultrastructure of cartilage <i>by</i> E.B. Hunziker & W. Herrmann	79
6. Ultrastructural cytochemistry of cartilage proteoglycans and their relation to the calcification process <i>by</i> M. Takagi	111
7. Ultrastructural localization of calcium in normal and pathologic cartilage <i>by</i> D. Lewinson & M. Silbermann	129
8. Glucocorticoid effects on the ultrastructure of epiphyseal cartilage <i>by</i> L.C. Dearden	153
9. Ultrastructural aspects of osteochondrodysplasias <i>by</i> E. Ippolito, J.A. Maynard, A. Pedrini-Mille & V. Pedrini	173
10. The ultrastructure of the cartilaginous tumors <i>by</i> F.J. Martinez-Tello & M.A. Martinez-Gonzales	189
11. The electron microscopic structure of the osteoblast <i>by</i> J.P. Scherft & C.G. Groot	209
12. The ultrastructure of the osteocyte <i>by</i> E. Bonucci	223
13. Ultrastructural biology and pathology of the osteoclast <i>by</i> S.C. Marks Jr. & S.N. Popoff	239

14. The ultrastructural effects of parathyroid hormone, calcitonin and vitamin D on bone <i>by</i> S.E. Weisbrode & C.C. Capen	253
15. The ultrastructure of bone tumors <i>by</i> G.C. Steiner	271
Index	293

Preface

The calcified tissues have fundamental functions in the biology of organisms, not only because their strength, solidity, and elasticity permit movement and mechanical activities, and protect soft tissues against traumatic forces, but also on account of their role in mineral homeostasis. For this reason, extensive investigation in the last 30 years has provided much to explain the complex chemical and physical processes occurring in cells and matrices composing the skeleton, and their alterations in pathological conditions.

The use of ultrastructural methods such as immunocytochemistry, scanning and transmission electron microscopy, cytoautoradiography, freeze/fracture etching, high voltage, etc. has proven to be of great value when applied to cells and matrix components of bone and cartilage, in spite of the technical difficulties due to the hardness of these tissues. However, available information on this subject is disseminated in a variety of scientific and medical articles. This volume is an attempt to collect together the most significant data on the ultrastructure of cartilage and bone in normalcy and pathology. Obviously, it cannot be a complete report of all these data, its principal aim being that of: a) giving a comprehensive statement of the results concerning the basic structures common to these tissues, especially collagen fibrils, noncollagenous proteins, and proteoglycans, and their relationships with the mineral substance (for which another volume of this series can also be consulted; see Ruggeri A., Motta P.M. (eds.): *Ultrastructure of the Connective Tissue Matrix*, 1984); b) providing a cohesive collection of the data concerning cell and matrix ultrastructure of normal cartilage and bone; c) gathering the electron microscopic findings concerning some principal aspects of cartilage and bone physiopathology, especially the effects of hormones on the ultrastructure of these tissues, and its changes in osteochondrodysplasias and tumors.

Obviously, this volume reports not only the well-established and accepted findings, but also those that are still debated, one of the objectives of the editors being that of bringing controversial questions into evidence. Consequently, different points of view can be found in different chapters. No attempts have been made to smooth matters, because it is hoped that the knowledge of gaps and debated topics can stimulate new ideas and research projects.

The editors express their sincere thanks to the authors of the chapters of this volume, not only for their invaluable contributions, but also for the prompt delivery of the manuscripts, which allowed us to issue this volume within the established time limits.

E. Bonucci and P.M. Motta

Contributing authors

Jörg Althoff, Institut für Medizinische Physik der Universität Münster, Hüfferstrasse 68, D-4400 Münster, FRG

A. Larry Asenault, Electron Microscopic Facility, Faculty of Health Sciences, McMaster University, 1200 Main Street West, Hamilton, Ontario L8N 3Z5, Canada

Rudolf H. Barckhaus, Institut für Medizinische Physik der Universität Münster, Hüfferstrasse 68, D-4400 Münster, FRG

Paolo Bianco, Dipartimento di Biopatologia Umana, Sezione di Anatomia Patologica, Università di Roma, Viale Regina Elena 324, 00161 Roma, Italy

Ermanno Bonucci, Dipartimento di Biopatologia Umana, Sezione di Anatomia Patologica, Università di Roma, Viale Regina Elena 324, 00161 Roma, Italy

Charles C. Capen, Department of Veterinary Pathobiology, The Ohio State University, Columbus, OH, USA

Lyle C. Dearden, Department of Anatomy and Neurobiology, College of Medicine, University of California, Irvine, CA 92717, USA

Cornelis G. Groot, Laboratory of Cell Biology and Histology, Faculty of Medicine, University of Leiden, Rijnsburgerweg 10, 2333AA Leiden, The Netherlands

Wolfgang Herrmann, Universität Bern, Anatomisches Institut, Abteilung für Systematische Anatomie, CH-3000 Bern 9, Postfach 139, Buhlstrasse 26, Switzerland

Hans J. Höhling, Institut für Medizinische Physik der Universität Münster, Hüfferstrasse 68, D-4400 Münster, FRG

Ernst B. Hunziker, M.E. Muller Institute for Biomechanics, University of Bern, Murtenstrasse 35, 3008 Bern, Switzerland

Ernesto Ippolito, Istituto di Clinica Ortopedica dell'Università di Reggio Calabria, Reggio Calabria 89100, Italy

Ernst-R. Krefting, Institut für Medizinische Physik der Universität Münster, Hüfferstrasse 68, D-4400 Münster, FRG

Dina Lewinson, Laboratory for Musculoskeletal Research, Rappaport Family Institute for Research in the Medical Sciences and Faculty of Medicine, Technion-Israel Institute of Technology, Haifa 31096, Israel

Sandy C. Marks, Jr., Department of Cell Biology, University of Massachusetts Medical School, 55 Lake Avenue North, Worcester, MA 01655, USA

Gastone Marotti, Istituto di Anatomia Umana Normale, Università di Modena, Policlinico, Via del Pozzo 71, 41100 Modena, Italy

Miguel A. Martinez-Gonzales, Hospital "I de Octubre" del Instituto Nacional de la Salud y Universidad Complutense de Madrid, Departamento de Anatomía Patológica, Carretera de Andalucía Km 5,400, 28041 Madrid, Spain

Francisco J. Martinez-Tello, Hospital "I de Octubre" del Instituto Nacional de la Salud y Universidad Complutense de Madrid, Departamento de Anatomía Patológica, Carretera de Andalucía Km 5,400, 28041 Madrid, Spain

Jerry A. Maynard, Division of Physical Education, Department of Exercise Science, The University of Iowa, Iowa City, IA 52242, USA

Vittorio Pedrini, Division of Physical Education, Department of Exercise Science, The University of Iowa, Iowa City, IA 52242, USA

Angiola Pedrini-Mille, Division of Physical Education, Department of Exercise Science, The University of Iowa, Iowa City, IA 52242, USA

Steven N. Popoff, Department of Anatomy, University of Massachusetts Medical School, 55 Lake Avenue North, Worcester, MA 01655, USA

Peter Quint, Institut für Medizinische Physik der Universität Münster, Hufferstrasse 68, D-4400 Münster, FRG

Johannes P. Scherft, Laboratory of Cell Biology and Histology, Faculty of Medicine, University of Leiden, Rijnsburgerweg 10, 2333AA Leiden, The Netherlands

Michael Silbermann, Laboratory for Musculoskeletal Research, Rappaport Family Institute for Research in the Medical Sciences and Faculty of Medicine, Technion-Israel Institute of Technology, Haifa 31096, Israel

German C. Steiner, Department of Pathology and Laboratory Medicine, Hospital for Joint Diseases, Orthopaedic Institute, 301 East 17th St., New York, NY 10003, USA

Minoru Takagi, Department of Anatomy, Nihon University School of Dentistry, 1-8-13 Kanda-Surugadai, Chiyoda-ku, Tokyo 101, Japan

Steven E. Weisbrode, Department of Veterinary Pathobiology, The Ohio State University, Columbus, OH, 43210 USA

Ultrastructure of Skeletal Tissues

Bone and Cartilage in Health and Disease