Calcium Phosphates in Oral Biology and Medicine

Monographs in Oral Science

Vol. 15

Editor
Howard M. Myers, San Francisco, Calif.

KARGER

Basel • München • Paris • London • New York • New Delhi • Bangkok • Singapore • Tokyo • Sydney

Calcium Phosphates in Oral Biology and Medicine

Racquel Zapanta LeGeros
New York University College of Dentistry, New York, N.Y.

108 figures and 21 tables, 1991

KARGER

Basel • München • Paris • London • New York • New Delhi • Bangkok • Singapore • Tokyo • Sydney

About the Author

Raquel Zapanta LeGeros was born in Manila, Philippines; received her BS from Adamson University (Manila) and her MS and PhD in chemistry from New York University. She is presently a professor in the Department of Dental Material Science as well as the Director of the Office of Research Program Coordination and Development at the New York University College of Dentistry, and a member of the National Advisory Council for the National Institute of Dental Research. She has served as a member of the Oral Biology and Medicine Study Section, National Institutes of Health (NIH); and as chairman of the Gordon Research Conference on Calcium Phosphates. Her research areas funded by NIH and industry, include: characterization of the mineral phase of calcified tissues and of commercial bone graft biomaterials; pioneering studies on substitutions of carbonate, magnesium, etc in apatites and on the formation and stability of calcium phosphates (relating to denta caries and calculus) in vitro; development of calcium phosphate-based bone substitute and coating materials for implants; and investigations on the physico-chemical events at the bone-biomaterial interfaces. She has published
more than 80 articles and 120 abstracts on these subjects.

Library of Congress Cataloging-in-Publication Data
LeGeros, Racquel Zapanta.
Calcium phosphates in oral biology and medicine / Racquel Zapanta LeGeros.
p. cm. - (Monographs in oral science: vol. 15)
Includes bibliographical references.
Includes index.
1. Dental materials. 2. Calcium phosphate. 3. Teeth - Composition. I. Title. II. Series.
[DNLM: 1. Calcium Phosphates - chemical synthesis. 2. Dental Materials.]
ISBN 3-8055-5236-X

Bibliographic Indices
This publication is listed in bibliographic services, including Current Contents® and Index Medicus.

All rights reserved.
No part of this publication may be translated into other languages, reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording, microcopying, or by any information storage and retrieval system, without permission in writing from the publisher.

© Copyright 1991 by S. Karger AG, P.O. Box, CH-4009, Basel (Switzerland)
Printed on acid-free paper.
ISBN 3-8055-5236-X

Contents

Preface VII
Acknowledgements IX

1. Introduction - Scope 1

2. Biologically Relevant Calcium Phosphates:
Preparation and Characterization 4

2.1. Introduction 4
2.2. Calcium Phosphate Reagents 5
2.3. Preparation of Biologically Relevant Calcium Phosphates 8
2.4. Characterization of Calcium Phosphates 24
2.5. Crystal Properties of Biologically Relevant Calcium Phosphates 38
2.6. Summary 44
3. Formation of Calcium Phosphates in vitro 46

3.1. Introduction 46
3.2. Thermodynamic Considerations 46
3.3. In vitro Formation of Calcium Phosphates in Saliva 49
3.4. In vitro Formation of Calcium Phosphates in Synthetic Solutions 52
3.5. In vitro Formation of Calcium Phosphates in Other Systems 62
3.6. Summary 66

4. Transformations of Calcium Phosphates in vitro 68

4.1. Introduction 68
4.2. Amorphous Calcium Phosphates 68
4.3. Dicalcium Phosphate Dihydrate, Brushite, CaHPO4-2H2O 71
4.4. Dicalcium Phosphate Anhydrous, Monetite, CaHPO4 72
4.5. Octacalcium Phosphate, Ca8H2(PO3)6-5H2O 73
4.6. Tricalcium Phosphate, Whitlockite, Ca3(PO4)2 79
4.7. Apatitic Calcium Phosphates 80
4.8. Transformations of Other Calcium Compounds 81
4.9. Summary 81

5. Formation and Stability of Synthetic Apatites: Effect of Some Elements 82

5.1. Introduction 82
5.2. Effect of Fluoride 83
5.3. Effect of Carbonate: Type A and Type B Substitutions in the Apatite 89
5.4. Effect of Chloride 95
5.5. Effect of HPO2-4 95
5.6. Effect of Magnesium 97
5.7. Effect of Strontium 99
5.8. Effect of Other Cations 99
5.9. Effect of Other Anionic Substituents 104
5.10. Synergistic and Antagonistic Effects of Substituents in the Apatite 104
5.11. Summary and Biological Implications 107

6. Calcium Phosphates in Enamel, Dentin and Bone 108

6.1. Introduction 108
Studies of synthetic and biological calcium phosphates are important for an improved understanding of dental calculus, dental caries, and of the biological fate of calcium phosphate biomaterials used as bone grafts. Calcium phosphates (Ca-P) of biological significance are: amorphous calcium phosphate (ACP); brushite or dicalcium phosphate dihydrate (DCPD); monetite or dicalcium phosphate anhydrous (DCPA); octacalcium phosphate (OCP); whitlockite or tricalcium phosphate (-TCP); calcium pyrophosphate dihydrate (CPPD), and apatite (AP). Several Ca-P phases coexist in the mineral phases of pathological calcifications (e.g., dental and urinary calculi, soft-tissue calcifications, etc.) while principally one Ca-P, apatite, is usually associated with those of normal calcifications (enamel, dentin, cementum, bone). This monograph describes simple methods
of preparing synthetic calcium phosphates and points out some of the factors and conditions which favor or inhibit their formation in order to provide insights into the formation and stability of Ca-P in biological systems.

As early as 1926, using X-ray diffraction and chemical analyses, the mineral phases of enamel, dentin and bone have been identified as a calcium phosphate with an apatite structure, idealized as Ca10(PO4)6(OH)2, HA. However, the nonstoichiometry and the association of several minor and trace elements with biological apatites cause continued scientific inquiry and varied points of view. Some of the issues are: Does the mineral phases of enamel, dentin and bone consist only of apatite or apatite mixed with nonapatitic phase? What is the role of carbonate and fluoride on the formation and stability of dental apatite relating to caries? What is the role and distribution of magnesium in the organic/inorganic phase, in the apatitic/nonapatitic phase? What is the mechanism for the cariostatic effect of F and cariogenic/cariostatic effects of other elements (e.g., strontium, zinc)? What is the appropriate in vitro model for biological apatite-carbonate apatite? HA? Many competent researchers are diligently seeking answers to these and other important questions.

Preface VIII

Calcium phosphate biomaterials, principally HA, now find wide clinical applications for repair of bony defects, bone augmentation, and coatings for metal implants. This monograph presents studies showing properties of commercial Ca-P biomaterials and studies on the in vitro and in vivo transformations of the Ca-P biomaterials. This monograph attempts to show that results of studies of in vitro systems may, with great care, be extrapolated to answer to questions about in vivo systems relating to calcium phosphates in biological systems. Much of the author’s published and unpublished research findings cited in this monograph were made possible through the support of the National Institute of Dental Research, National Institutes of Health.

Racquel Zapanta LeGeros, PhD

Acknowledgements

I gratefully acknowledge the considerable patience, understanding, physical and moral support of my family - my husband and colleague, John; my children, Bernard, David, Katherine and Alessandra; and my parents, Reverend and Mrs. Bernardo C. Zapanta - to them I lovingly dedicate this
monograph.
The significant contributions of the following persons are acknowledged
with much appreciation and gratitude: for professional collaboration of
friends and colleagues in the work cited in this monograph: Drs. G. Bonel,
P. Cheng, G. Daculsi, M. Gregoire, M. Gineste, M. Heughebaert, B. Kerebel,
Trautz, M. Tung; for valuable technical assistance: T. Abergas, E. Aboutaleb,
X.-F. Chang, P. Go, W. Jia, D.J. LeGeros, M. Miravite, G. Quirolgico, M.
Retino, W. Torres, R. Zhang; for editorial help and encouragement: Dr.
H.M. Myers, Editor-in-Chief, Monographs in Oral Science; for photography:
G. Merlino, B. Mara, A. Zapanta; for word processing and secretarial help:
S. Yue and V. Fronjian.
The work of the author cited in this monograph was supported by the
National Institutes of Health (NIH), National Institute of Dental Research
(NIDR) Grant Nos. DE-04123 and DE-07223.

Racquel Zapanta LeGeros, PhD