

Biosynthetic Polymers for Medical Applications

Edited by L. Poole-Warren, P. Martens and R.Green

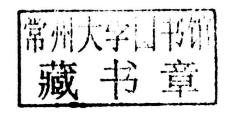


Woodhead Publishing Series in Biomaterials: Number 107

Biosynthetic Polymers for Medical Applications

Edited by

L. Poole-Warren, P. Martens and R. Green







Woodhead Publishing is an imprint of Elsevier 80 High Street, Sawston, Cambridge, CB22 3HJ, UK 225 Wyman Street, Waltham, MA 02451, USA Langford Lane, Kidlington, OX5 1GB, UK

Copyright © 2016 Elsevier Ltd. All rights reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Details on how to seek permission, further information about the Publisher's permissions policies and our arrangements with organizations such as the Copyright Clearance Center and the Copyright Licensing Agency, can be found at our website: www.elsevier.com/permissions.

This book and the individual contributions contained in it are protected under copyright by the Publisher (other than as may be noted herein).

Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

ISBN: 978-1-78242-105-4 (print) ISBN: 978-1-78242-113-9 (online)

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

Library of Congress Control Number: 2015951100

For information on all Woodhead Publishing publications visit our website at http://store.elsevier.com/



Biosynthetic Polymers for Medical Applications

Related titles

Durability and reliability of medical polymers (ISBN 978-1-84569-929-1)

Shape memory polymers for biomedical applications (ISBN 978-0-85709-698-2)

Modelling degradation of bioresorbable polymeric medical devices (ISBN 978-1-78242-016-3)

List of contributors

- D. Abdelhamid Minia University, Minia, Egypt
- **M.R. Abidian** Biomedical Engineering Department, University of Houston, Houston, TX, USA
- **R.** Adhikari Commonwealth Scientific and Industrial Research Organisation (CSIRO) Manufacturing Flagship, Clayton, VIC, Australia
- M. Asplund Freiburg Institute for Advanced Studies, Albert-Ludwigs Universität, Freiburg, Germany; IMTEK, Albert-Ludwigs Universität, Freiburg, Germany
- **J.A. Goding** Graduate School of Biomedical Engineering, University of New South Wales, Sydney, NSW, Australia
- **R.A. Green** Graduate School of Biomedical Engineering, University of New South Wales, Sydney, NSW, Australia
- **S.S. Griesser** Ian Wark Research Institute, University of South Australia, Mawson Lakes, SA, Australia
- **H.J. Griesser** Mawson Institute, University of South Australia, Mawson Lakes, SA, Australia
- **P.A. Gunatillake** Commonwealth Scientific and Industrial Research Organisation (CSIRO) Manufacturing Flagship, Clayton, VIC, Australia
- M. Haeussler CSIRO Materials Science and Engineering, Clayton, VIC, Australia
- K.E.S. Locock CSIRO Materials Science and Engineering, Clayton, VIC, Australia
- **P.J. Martens** Graduate School of Biomedical Engineering, University of New South Wales, Sydney, NSW, Australia
- L. Meagher CSIRO Materials Science and Engineering, Clayton, VIC, Australia
- **T.D. Michl** Ian Wark Research Institute, University of South Australia, Mawson Lakes, SA, Australia
- E.M. Moore Duke University, Durham, NC, USA
- B.A. Nsiah Duke University, Durham, NC, USA
- **B. Ozcelik** Commonwealth Scientific and Industrial Research Organisation (CSIRO), Clayton, VIC, Australia

List of contributors

A.J. Patton Graduate School of Biomedical Engineering, University of New South Wales, Sydney, NSW, Australia

- **L.A. Poole-Warren** Graduate School of Biomedical Engineering, University of New South Wales, Sydney, NSW, Australia
- **J.J. Roberts** Graduate School of Biomedical Engineering, University of New South Wales, Sydney, NSW, Australia
- L.C. Roudsari Duke University, Durham, NC, USA
- H. Thissen CSIRO Manufacturing Flagship, VIC, Australia
- K. Udipi Biopolymer Designs Inc., Santa Rosa, CA, USA
- K.E. Uhrich Rutgers University, Piscataway, NJ, USA
- N.K. Virdone Duke University, Durham, NC, USA
- J.L. West Duke University, Durham, NC, USA
- N. Yi Pennsylvania State University, PA, USA

Woodhead Publishing Series in Biomaterials

1	Sterilisation of tissues using ionising radiations				
	Edited by J. F. Kennedy, G. O. Phillips and P. A.	Williams			

2 Surfaces and interfaces for biomaterials Edited by P. Vadgama

- 3 Molecular interfacial phenomena of polymers and biopolymers Edited by C. Chen
- 4 Biomaterials, artificial organs and tissue engineering Edited by L. Hench and J. Jones
- 5 Medical modelling R. Bibb
- 6 Artificial cells, cell engineering and therapy Edited by S. Prakash
- 7 **Biomedical polymers** Edited by M. Jenkins
- 8 Tissue engineering using ceramics and polymers Edited by A. R. Boccaccini and J. Gough
- 9 **Bioceramics and their clinical applications** Edited by T. Kokubo
- 10 **Dental biomaterials**Edited by R. V. Curtis and T. F. Watson
- Joint replacement technology Edited by P. A. Revell
- 12 Natural-based polymers for biomedical applications Edited by R. L. Reiss et al.
- 13 **Degradation rate of bioresorbable materials** *Edited by F. J. Buchanan*
- 14 Orthopaedic bone cements Edited by S. Deb
- 15 **Shape memory alloys for biomedical applications** *Edited by T. Yoneyama and S. Miyazaki*
- 16 Cellular response to biomaterials Edited by L. Di Silvio
- 17 **Biomaterials for treating skin loss** *Edited by D. P. Orgill and C. Blanco*
- 18 **Biomaterials and tissue engineering in urology** *Edited by J. Denstedt and A. Atala*
- 19 Materials science for dentistry B. W. Darvell

20 Bone repair biomaterials

Edited by J. A. Planell, S. M. Best, D. Lacroix and A. Merolli

21 Biomedical composites

Edited by L. Ambrosio

22 Drug-device combination products

Edited by A. Lewis

23 Biomaterials and regenerative medicine in ophthalmology Edited by T. V. Chirila

24 Regenerative medicine and biomaterials for the repair of connective tissues Edited by C. Archer and J. Ralphs

25 Metals for biomedical devices

Edited by M. Niinomi

26 Biointegration of medical implant materials: Science and design Edited by C. P. Sharma

27 **Biomaterials and devices for the circulatory system** *Edited by T. Gourlay and R. Black*

28 Surface modification of biomaterials: Methods analysis and applications Edited by R. Williams

29 **Biomaterials for artificial organs** *Edited by M. Lysaght and T. Webster*

30 Injectable biomaterials: Science and applications Edited by B. Vernon

31 Biomedical hydrogels: Biochemistry, manufacture and medical applications *Edited by S. Rimmer*

32 Preprosthetic and maxillofacial surgery: Biomaterials, bone grafting and tissue engineering

Edited by J. Ferri and E. Hunziker

33 **Bioactive materials in medicine: Design and applications** Edited by X. Zhao, J. M. Courtney and H. Qian

34 Advanced wound repair therapies Edited by D. Farrar

35 Electrospinning for tissue regeneration Edited by L. Bosworth and S. Downes

36 Bioactive glasses: Materials, properties and applications Edited by H. O. Ylänen

37 Coatings for biomedical applications Edited by M. Driver

38 Progenitor and stem cell technologies and therapies Edited by A. Atala

39 **Biomaterials for spinal surgery** *Edited by L. Ambrosio and E. Tanner*

40 Minimized cardiopulmonary bypass techniques and technologies Edited by T. Gourlay and S. Gunaydin

41 Wear of orthopaedic implants and artificial joints Edited by S. Affatato

42 **Biomaterials in plastic surgery: Breast implants**Edited by W. Peters, H. Brandon, K. L. Jerina, C. Wolf and V. L. Young

43 **MEMS for biomedical applications** Edited by S. Bhansali and A. Vasudev 44 Durability and reliability of medical polymers

Edited by M. Jenkins and A. Stamboulis

45 Biosensors for medical applications

Edited by S. Higson

46 Sterilisation of biomaterials and medical devices Edited by S. Lerouge and A. Simmons

47 The hip resurfacing handbook: A practical guide to the use and management of modern hip resurfacings

Edited by K. De Smet, P. Campbell and C. Van Der Straeten

- 48 Developments in tissue engineered and regenerative medicine products J. Basu and J. W. Ludlow
- 49 Nanomedicine: Technologies and applications Edited by T. J. Webster
- 50 **Biocompatibility and performance of medical devices** *Edited by J-P. Boutrand*
- 51 Medical robotics: Minimally invasive surgery Edited by P. Gomes
- 52 Implantable sensor systems for medical applications Edited by A. Inmann and D. Hodgins
- Non-metallic biomaterials for tooth repair and replacement Edited by P. Vallittu
- 54 Joining and assembly of medical materials and devices Edited by Y. (Norman) Zhou and M. D. Breyen
- 55 **Diamond-based materials for biomedical applications** *Edited by R. Narayan*
- Nanomaterials in tissue engineering: Fabrication and applications Edited by A. K. Gaharwar, S. Sant, M. J. Hancock and S. A. Hacking
- 57 **Biomimetic biomaterials: Structure and applications** *Edited by A. J. Ruys*
- 58 Standardisation in cell and tissue engineering: Methods and protocols Edited by V. Salih
- 59 Inhaler devices: Fundamentals, design and drug delivery Edited by P. Prokopovich
- 60 **Bio-tribocorrosion in biomaterials and medical implants** *Edited by Y. Yan*
- 61 Microfluidic devices for biomedical applications Edited by X-J. James Li and Y. Zhou
- 62 **Decontamination in hospitals and healthcare** *Edited by J. T. Walker*
- 63 **Biomedical imaging: Applications and advances** *Edited by P. Morris*
- 64 Characterization of biomaterials

 Edited by M. Jaffe, W. Hammond, P. Tolias and T. Arinzeh
- 65 **Biomaterials and medical tribology**Edited by J. Paolo Davim
- 66 Biomaterials for cancer therapeutics: Diagnosis, prevention and therapy Edited by K. Park
- 67 New functional biomaterials for medicine and healthcare E. P. Ivanova, K. Bazaka and R. J. Crawford

- 68 **Porous silicon for biomedical applications** *Edited by H. A. Santos*
- 69 A practical approach to spinal trauma Edited by H. N. Bajaj and S. Katoch
- 70 Rapid prototyping of biomaterials: Principles and applications Edited by R. Narayan
- 71 Cardiac regeneration and repair Volume 1: Pathology and therapies Edited by R-K. Li and R. D. Weisel
- 72 Cardiac regeneration and repair Volume 2: Biomaterials and tissue engineering Edited by R-K. Li and R. D. Weisel
- 73 Semiconducting silicon nanowires for biomedical applications Edited by J. L. Coffer
- 74 Silk biomaterials for tissue engineering and regenerative medicine Edited by S. Kundu
- 75 Biomaterials for bone regeneration: Novel techniques and applications Edited by P. Dubruel and S. Van Vlierberghe
- 76 **Biomedical foams for tissue engineering applications** *Edited by P. Netti*
- 77 Precious metals for biomedical applications
 Edited by N. Baltzer and T. Copponnex
- 78 **Bone substitute biomaterials** *Edited by K. Mallick*
- 79 **Regulatory affairs for biomaterials and medical devices** *Edited by S. F. Amato and R. Ezzell*
- 80 **Joint replacement technology Second edition** *Edited by P. A. Revell*
- 81 Computational modelling of biomechanics and biotribology in the musculoskeletal system: Biomaterials and tissues *Edited by Z. Jin*
- 82 **Biophotonics for medical applications** *Edited by I. Meglinski*
- 83 Modelling degradation of bioresorbable polymeric medical devices Edited by J. Pan
- 84 Perspectives in total hip arthroplasty: Advances in biomaterials and their tribological interactions
 S. Affatato
- 85 Tissue engineering using ceramics and polymers Second edition Edited by A. R. Boccaccini and P. X. Ma
- 86 Biomaterials and medical-device associated infections Edited by L. Barnes and I. R. Cooper
- 87 Surgical techniques in total knee arthroplasty (TKA) and alternative procedures Edited by S. Affatato
- 88 Lanthanide oxide nanoparticles for molecular imaging and therapeutics G. H. Lee
- 89 Surface modification of magnesium and its alloys for biomedical applications Volume 1: Biological interactions, mechanical properties and testing Edited by T. S. N. Sankara Narayanan, I. S. Park and M. H. Lee

92

- 90 Surface modification of magnesium and its alloys for biomedical applications Volume 2: Modification and coating techniques Edited by T. S. N. Sankara Narayanan, I. S. Park and M. H. Lee
- 91 Medical modelling: the application of advanced design and rapid prototyping techniques in medicine Second edition

 Edited by R. Bibb, D. Eggbeer and A. Paterson
 - Switchable and responsive surfaces and materials for biomedical applications Edited by Z. Zhang
- 93 Biomedical textiles for orthopaedic and surgical applications: fundamentals, applications and tissue engineering

 Edited by T. Blair
- 94 Surface coating and modification of metallic biomaterials Edited by C. Wen
- 95 Hydroxyapatite (HAP) for biomedical applications

 Edited by M. Mucalo
- 96 Implantable neuroprostheses for restoring function Edited by K. Kilgore
- 97 Shape memory polymers for biomedical applications Edited by L. Yahia
- 98 Regenerative engineering of musculoskeletal tissues and interfaces Edited by S. P. Nukavarapu, J. W. Freeman and C. T. Laurencin
- 99 Advanced cardiac imaging
 Edited by K. Nieman, O. Gaemperli, P. Lancellotti and S. Plein
- 100 Functional marine biomaterials: properties and applications Edited by Se-Kwon Kim
- 101 Shoulder and elbow trauma and its complications: Volume 1: The Shoulder Edited by R. M. Greiwe
- 102 Nanotechnology-enhanced orthopedic materials: Fabrications, applications and future trends

 Edited by L. Yang
- 103 Medical devices: Regulations, standards and practices

 Edited by S. Ramakrishna, L. Tian, C. Wang, S. L. and T. Wee Eong
- 104 Biomineralisation and biomaterials: fundamentals and applications Edited by C. Aparicio and M. Ginebra
- 105 Shoulder and elbow trauma and its complications: Volume 2: The Elbow Edited by R. M. Greiwe
- 106 Characterisation and design of tissue scaffolds Edited by P. Tomlins
- 107 **Biosynthetic polymers for medical applications** *Edited by L. Poole-Warren, P. Martens and R. Green*

Contents

Woodhead Publishing Series in Biomaterials		
Pa	art One Introduction and fundamentals	1
1	Introduction to biomedical polymers and biocompatibility	3
	L.A. Poole-Warren, A.J. Patton	
	1.1 Introduction	3
	1.2 Natural or biological polymers	4
	1.3 Advantages and disadvantages of natural polymers	18
	1.4 Biosynthetic polymers	27
	1.5 Conclusion	28
	References	28
2	Nondegradable synthetic polymers for medical devices and	
	implants	33
	P.A. Gunatillake, R. Adhikari	
	2.1 Introduction	33
	2.2 Ultra-high molecular weight poly(ethylene) (UHMWPE)	34
	2.3 Polypropylene (PP)	40
	2.4 Poly(methyl methacrylate) (PMMA)	42
	2.5 Polyurethane (PU)	44
	2.6 Poly(dimethyl siloxane) (PDMS)	49
	2.7 Polyether ether ketone (PEEK)	53
	2.8 Future directions	55
	References	56
3	Biodegradable and bioerodible polymers for medical	
	applications	63
	K.E. Uhrich, D. Abdelhamid	
	3.1 Introduction	63
	3.2 Concepts and terminology	63
	3.3 Motivating factors for using polymer–drug conjugates	71
	3.4 Current and future trends	75
	Acknowledgments	78
	References	78

Pa	rt T	wo Coatings and surface modifications	85
4	T.D.	inspired antimicrobial polymers Michl, K.E.S. Locock, S.S. Griesser, M. Haeussler, L. Meagher, Griesser	87
	4.1	Introduction	87
	4.2	Naturally occurring AMPs	89
	4.3	Synthetic polymer mimics of AMPs	97
		Chitosan – a natural antimicrobial polysaccharide	110
	4.5	Neutral polymer brush layers for reducing bacterial attachment References	114 119
5	Plas	ma-based surface modification for the control	
		iointerfacial interactions	129
		Thissen	
	5.1	Introduction	129
		Plasma treatment of material surfaces	132
	5.3	Plasma polymer-based coatings	134
	5.4	Plasma polymer-based interlayers	136
	5.5	Plasma polymer-based patterning	137
	5.6	Functional plasma polymers	140
	5.7	Antimicrobial plasma polymer coatings	141
		Likely future trends	141
	5.9	Sources of further information	142
		References	142
6		at coatings for blood compatibility	145
		ldipi	272
		Introduction	145
		Stent development	145
		Thrombosis issue	147
		Drug-eluting stent coatings	153
	0.5	Conclusions	160
		Acknowledgment	160
		References	161
Pa	rt T	three Biosynthetic hydrogels	171
7	_	radable hydrogel systems for biomedical applications	173
		Introduction	172
	7.1 7.2		173 173
	7.3	Hydrogel precursors Desired hydrogel properties	175
	7.4	Desired hydrogel properties Degradable hydrogel systems	175
	7.4	Where to? – degradable hydrogels	184
	1.3	References	185
		11010101000	100

8	Angiogenesis in hydrogel biomaterials	189
	B.A. Nsiah, E.M. Moore, L.C. Roudsari, N.K. Virdone,	
	J.L. West	
	8.1 Introduction	189
	8.2 Biology of angiogenesis	189
	8.3 Protein hydrogels to support angiogenic activity	190
	8.4 Synthetic hydrogels to support angiogenic activity	191
	8.5 In vitro culture of vascular networks	196
	8.6 Inducing angiogenesis in host tissue	198
	8.7 Conclusions	199
	References	199
9	Engineering biosynthetic cell encapsulation systems	205
	J.J. Roberts, P.J. Martens	
	9.1 Introduction	205
	9.2 Natural polymers	208
	9.3 Synthetic polymers	216
	9.4 Biosynthetic polymers	221
	9.5 Future trends	229
	References	229
Pai	rt Four Conjugated conducting polymers	241
10	Conducting polymers and their biomedical applications N. Yi, M.R. Abidian	243
	10.1 Introduction	243
	10.2 Conducting mechanism	244
	10.3 Electrochemical polymerisation of conducting polymers	245
	10.4 Applications of conducting polymers in biomedical fields	251
	10.5 Conclusions	271
	References	271
11	Biosynthetic conductive polymer composites for tissue-engineering	
	biomedical devices	277
	R.A. Green, J.A. Goding	
	11.1 Introduction	277
	11.2 Conductive polymer composites	278
	11.3 Biological components in CP composites	286
	11.4 In vivo application of CP composites	290
	11.5 Summary and future directions	293
	References	294
12	Degradable conjugated conducting polymers and nerve guidance	299
	M. Asplund	
	12.1 Introduction	299
	12.2 Material challenges in neural engineering	300

	12.3	Processing of conducting polymers for the generation	
		of 3D scaffolds	300
	12.4	Biodegradable conducting polymers	308
	12.5	Biomolecular and topographical guidance	313
	12.6	Biological performance of CPs for neural regeneration	320
	12.7	Future trends and remaining challenges	321
	12.8	Sources for further information	323
		Abbreviations	324
		References	325
Ind	ex		331