

Dental Applications of Nanotechnology

Ramesh S. Chaughule
Editor

Dental Applications of Nanotechnology

 Springer

Editor

Ramesh S. Chaughule
Ramnarain Ruia College
Mumbai, India

ISBN 978-3-319-97633-4 ISBN 978-3-319-97634-1 (eBook)
<https://doi.org/10.1007/978-3-319-97634-1>

Library of Congress Control Number: 2018950210

© Springer Nature Switzerland AG 2018, corrected publication 2018

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

*This book is dedicated to
Professor R. Vijayaraghavan
Ex Dean, Tata Institute of Fundamental
Research, Mumbai, India
A Mentor, Teacher, Advisor, Inspirator and
Everything*

*And my wife
Kshama
A constant spirit, Supporting and Delightful
partner through thick or thin in life*

Foreword I

Imagine a day when a drop of medicine could be placed on a cavity to kill bacteria and then regenerate the parts of the tooth that were destroyed by microorganisms, or when an injection of stem cells could be placed into the jaw of a car driver just after a car accident to rebuild broken bones, or when an injection of a unique nanomedicine could be placed near wisdom teeth to degrade them so that invasive surgery to remove them would not be necessary. What a change in dental health care these advances would be! These are true revolutions in dental medicine, and are the advances we need to help millions of people around the globe have better dental health, and to promote proper nutrition, self-esteem, and life expectancy.

These and so many more ideas are brought to life in this exciting new book by Dr. Ramesh Chaughule entitled *Dental Applications of Nanotechnology*. Dr. Chaughule brilliantly intertwines material science with medicine to highlight unprecedented growth areas across all of dental medicine. The focus of such advances relies on nanotechnology, not the unrealistic vision of nanorobots in the body surveying and healing diseases at will, but the more realistic design and use of materials in medicine with dimensions less than 10^{-9} m. For those of you having trouble understanding this dimension, consider that the diameter of a single strand of hair is about 80,000–100,000 nm and we cannot even discern nanometer resolution with your unaided eye. This is small and powerful!

Nanomaterials are excellent candidates for dental medicine, since our teeth, jaw bones, and all tissues in the body are composed of nanomaterials, like proteins and calcium phosphate. Cells in our bodies make nanomaterials every second and live in nanomaterials every day. Dr. Chaughule acknowledges this and emphasizes in this book how to leverage this simple fact to improve all aspects of dental health. It is because of these reasons that nanomedicine is experiencing a boom in research and activity across all of medicine. As just one of many examples, nanomedicine is projected to be a global market worth \$528 billion by 2019, which is almost double

that from 2014.¹ We have not even reached the tip of the iceberg in the capabilities what nanomedicine can bring. Moreover, with over a hundred nanomedicine products approved by the FDA, it is clear that nanomedicine is here to stay and will continue to revolutionize medicine. This pioneering book highlights just that.

This book covers fundamental research, applied clinical studies, and commercialization potential across all of dental medicine. It is comprehensive and presents ideas we need to improve dental care for patients and, most importantly, stimulates new ideas rarely discussed in other books. It is an excellent resource for any educator, medical device industry person, entrepreneur, clinician, and simply any person interested in science, engineering, and medicine. After reading this book, it is hard to imagine anyone not seeing the promise nanomedicine will have in dentistry!

So, do not put away that toothpaste just yet, but a nanomedicine revolution in dental care is right around the corner—this book shows it! Dr. Chaughule's pioneering book in this area gets us all thinking how dental care will significantly change in the coming years, and we all need to pay close attention!

Boston, MA USA

Thomas J. Webster, Ph.D.
Art Zafiropolou Chair; Department
Chair, Chemical Engineering,
Past-President, US Society For
Biomaterials; Fellow, AANM,
AIMBE, BMES, IUSB, and NAI
Northeastern University

¹Commercialization of New Technologies Driving Big Market Growth in Nanomedicine, BCC Research LLC; accessed May 25, 2018, at <https://www.bccresearch.com/pressroom/hlc/commercialization-of-new-technologies-driving-big-market-growth-in-nanomedicine>.

Foreword II

It gives me great pleasure to write the foreword for this book which presents a collection of topics from eminent authors on the role of nanotechnology and nanobiomaterials in dental health.

From its humble beginnings in the 1970s, nanotechnology has today become mainstream in almost every aspect of science and engineering. Nanotechnology involves the manipulation of individual atoms and molecules in the 1–100 nm range to produce unique and interesting structures with myriad applications in physical, chemical, and biological systems. To date, it has had a huge impact in fields as diverse as semiconductors and electronic devices, production of fuels, electrochemical energy conversion and storage, advanced composite structures for the aerospace industry, improving air and water quality, as well as medical applications including diagnostics and therapeutics. In particular, nanotechnology has arguably had the greatest impact in medicine, for example, with the use of nanoparticles to deliver chemotherapy drugs or vaccines to specifically targeted cells, insulin release via nanocapsules, the removal of toxins from the bloodstream via nanosponges, use of nanoparticles as free radical scavengers, as well as diagnostic tools such as the use of carbon nanotubes coated with antibodies to detect cancer cells, monitor the level of blood-borne gases, and many others. This book now extends the field of nanotechnology and nanobiomaterials to new and exciting applications in dental health.

Written by a group of leading experts, this book presents several important chapters that address dental applications of nanotechnology. Periodontal disease and tooth decay represent two of the biggest threats to dental health. Apart from local infections of the structures around the teeth, periodontal disease has also been linked to other health problems such as heart disease, diabetes, and respiratory disease. Therefore, improving dental health can benefit not just one's teeth and

gums, but also the entire body. Two chapters contained herein describe the therapeutic applications of nanomaterials to reduce the inflammation of the dental tissues and promote bone regeneration. Prosthodontics is also a major focus; three chapters relate the application of nanobiomaterials to the improvement of oral function and appearance of patients with deficient teeth, oral, and maxillofacial tissues. Similarly, orthodontics is covered by two chapters which address the use of nanotechnology-tailored agents to combat biofilms, for example. Other chapters delve into the application of nanomaterials to the soft inner tissue of the teeth or pulp, the properties of advanced dental nanocomposites, and the role of nanomedicine in the assessment and treatment of oral biofilms, as well as diagnosis and therapeutic drug delivery in dentistry.

The editor, Dr. Chaughule, should be commended for assembling a group of experts from across the globe to present a comprehensive and timely book on the dental applications of nanotechnology. The book should appeal equally to scientists and researchers, students, and practitioners in the field. I fully expect that the readers will find the material useful and enjoyable.

Newark, DE, USA

Ajay K. Prasad
Engineering Alumni Distinguished
Professor and Chair
Department of
Mechanical Engineering
University of
Delaware
prasad@udel.edu

Preface

Nanotechnology has immense applications in almost all the fields of science and human life. Nanoparticles constitute a crucial and technology-intensive area of research and development in the burgeoning field of nanotechnology and nanoscience. Scientists are exploring many research areas to understand bulk materials at the nanoscale. Engineered nanoparticles with promising properties have been tailored and produced on a technical scale. Nanotechnology is one of the most popular areas of current research and has developed in multiple disciplines, including dentistry. The foremost goal of dentistry is the rehabilitation of the stomatognathic system. Nanotechnology-based treatment modalities like nanomaterials and nanorobots are finding their way in routine dental health care. Unlike bulk materials, nano-sized particles are quite unique in nature because of the increase in surface-to-volume ratio which alters their physical, chemical, and biological properties which trigger chemical activity with distinct crystallography. Nanoparticles comprise a size range from 10 to 100 nm in diameter. Various methods have been employed for the synthesis of the nanoparticles. The two approaches mainly used are bottom-up and top-down (more details are given in the book). The primary aim of restorative dentistry is to restore the form and function of the tooth. The extensive range of restorative materials being manufactured should combine innovation with long-lasting clinical success. The physical properties and handling characteristics of these restorative materials should constantly improve with time, enabling dental professionals to meet the varying demands of dental patients and the different requirements of practice. Nanotechnology has made significant inroads into the fields of preventive, reconstructive, regenerative, restorative, rehabilitative, and diagnostic domains.

I am pleased to introduce this book, “Dental Applications of Nanotechnology,” to aspiring and working scientists, dental practitioners, and as a ready reference for the dental students to understand the principles of nanotechnology, its applications, and latest techniques. This book covers important topics such as pulp/periodontal regeneration, tissue engineering, restorative dentistry, endodontics, prosthodontics, orthodontics, and therapeutics.

Implantable nanomaterials can be applied in various fields, such as tissue healing and substitution, coatings for implants, tissue regeneration scaffolds, implant materials, osseous repair, bioresorbable materials, smart materials, and diagnostic and therapeutic devices. The chapter by Porenczuk discusses tissue engineering processes that require cell lines, bioactive molecules, and supporting matrices, such as synthetic polymers, including bioglass, to be used as regenerative treatment of the pulps. The use of nano-bioglass and hydroxyapatite nanocomposites in the field of regenerative endodontics is also introduced. Periodontal regeneration leads to the formation of new bone, cementum, and periodontal ligament on a previously diseased root surface. Deepa and Arunkumar in their chapter discuss this issue using various sizes of nanoparticle graft materials in the treatment of intrabony defects, bone regeneration around implants, and its role in tissue engineering. Recent developments in nanomaterials and nanotechnology have provided a promising insight into the commercial applications of nanomaterials in the management of periodontal diseases. The Chapter by Arjunker discusses the various ways in which nanotechnology has influenced the field of periodontics, in the form of nanodentifrices, dental hypersensitivity cure, drug delivery systems, antibiofilm approaches and resolution of inflammation. Dental restorative resins are explored to further enhance their physical and mechanical properties, as the traditional dental materials usually show weak mechanical properties, elastic modulus, and poor abrasion resistance. Nanomaterials are used in the preparation of nanocomposites. These are resin-based composites with inorganic filler particles, a coupling agent, and polymerization initiator. Chaughule et al. have synthesized the composites using titania to show enhanced mechanical, chemical, and biological properties than that of materials available in the market. The Chapter by Hend Mahmoud Abou El Nasr and Makbule Bilge Akbulut shows how nanotechnology has invaded every aspect in endodontics. This includes improvement in radiography, local anesthesia, dentin hypersensitivity, root canal disinfection, endodontic filling materials, and functionalization/conjugation. Regenerative endodontics and endodontic surgery are also improved by using nanobiomaterials. Nanomaterials play an important role in innovation and clinical technological changes in the field of prosthodontics. It is an important branch of oral health care and rehabilitation. The chapter by Jadhav mainly focuses on the various applications of novel nanomaterials in the field of dentistry and the advances in nanotechnology, with a focus on promising applications in prosthodontics. Using silver nanoparticles, she has explored suitable applications in acrylic resin, tissue conditioner, dental adhesives, dental porcelain, dental composites, dental cements, implants, and maxillofacial prosthesis. The chapter by Aeran and Seth illustrates that nanotechnology applied to implants also increased osseointegration by 150%, which is quite a significant result. In their chapter, they have discussed the applications of nanometals, nanoceramics, nanoresin, and other nanomaterials in prosthodontics. The performance of composites can also be enhanced by adding appropriate nanomaterials. Nanomaterials have been playing a significant role in basic scientific innovation and clinical

technological change of prosthodontics. In another chapter on prosthodontics, Praveena and her coauthors have elucidated how bulk materials, when reduced to the nanoscale, change the physicochemical properties of materials. They also present comprehensive information regarding the recent advancements of nanobio-materials with respect to removable, fixed, and maxillofacial prosthodontics and their advantages and limitations. In addition, they have discussed the significance of nanotechnology in the field of implant prosthodontics. Orthodontics is a field of dentistry that deals primarily with malpositioned teeth and jaws. The chapter by Lekhadia enlightens the application of nanotechnology in biomaterials and biomechanics in orthodontics and its use to improve and speed up orthodontic treatment. Another chapter on orthodontics by Batra focuses on various materials whose properties can be modified by the application of nanoparticles, and describes tests that can be performed to detect the physical and biological properties of the new materials. She discusses the advantages and disadvantages of using nanoparticles, and the precautions that one needs to take while researching with nanoparticles. Biofilms form when bacteria adhere to surfaces in some form of watery environment and begin to excrete a slimy, glue-like substance that can stick to implant materials, biological tissues, etc. One promising approach to combating these biofilms is based on nanotechnology-tailored agents. Shetty and Gupta have explored this technique by conventional approaches that could be augmented by interference with the factors that enable the cariogenic bacteria to escape from the normal homeostatic mechanisms to restrict their growth in plaque and outcompete the organisms associated with health. Further, they focus on recent research on the creation, characterization, and evaluation of nanoparticles for the prevention or treatment of biofilms in the oral cavity.

Nanotechnology presently faces many technical, ethical, and biological challenges. Particularly, due to their small size, nanoparticles can cause various adverse health effects. Hence, there is a critical requirement to standardize nanotechnology-based products and devices and improve our understanding of how to exploit the benefits while diminishing the risks. Bhardwaj et al. have enlightened this situation in their chapter by describing nanotechnology in depth and explain the importance of nanoencapsulation and nanotherapeutics used in dental drug delivery systems. Besides technology improvements, there are also risk safety assessments of crucial interest for further developments in this field. Dental materials should be harmless to all oral tissues, and should not contain leachable and diffusible toxic substances, which could pass into circulatory system and contribute to systemic toxicity responses. The chapter by Dragana et al. deals with the construction and physical characteristics, biocompatibility, bioactivity, and biofunctionality of new materials based on active silicate systems and hydroxyapatite. They have suggested the use of endodontic cement based on dicalcium and tricalcium silicate and hydroxyapatite for further clinical trials.

The editor wishes to thank all the distinguished and expert contributors for their enthusiastic participation in this endeavor. I am confident that the book will serve as a valuable guide for researchers and students of dentistry, materials engineering,

bioengineering, and medicine. Support from Dr. Suhas Pednekar, Principal, Ramnarain Ruia College, Mumbai, and my family members is gratefully acknowledged. Last but not least, the editor sincerely thanks the Springer staff for showing faith in bringing out this book to their expectations.

Mumbai, India

Ramesh S. Chaughule

Contents

1	Nano-materials in Regenerative Pulp Treatment	1
	Alicja Porenczuk	
2	Nanobiomaterials and Their Role in Periodontal Rehabilitation	23
	D. Deepa and K. V. Arunkumar	
3	Advanced Nanomaterials and Their Functionalization in Clinical Endodontics	37
	Hend Mahmoud Abou El Nasr and Makbule Bilge Akbulut	
4	Nanocomposites and Their Use in Dentistry	59
	Ramesh Chaughule, Dipika Raorane, Suhas Pednekar and Rajesh Dashaputra	
5	Applications of Nanoparticles in Orthodontics	81
	Panchali Batra	
6	Nanomaterials: A Boon to Prosthodontics	107
	Rajashree Dhananjay Jadhav	
7	Nanomaterials: The Changing Phase of Prosthodontics	121
	Himanshu Aeran and Jyotsna Seth	
8	Nanostructures in Dentistry: In Diagnosis, Drug Delivery and Oral Cancer Therapy, and their Biocompatibility	133
	Archana Bhardwaj, Abhishek Bhardwaj and R. Nageswar Rao	
9	Nanotechnology in Orthodontics—Futuristic Approach	155
	Dhaval Ranjitbhai Lekhadia	
10	Nanobiomaterials and Their Application in Prosthodontics	177
	Channamsetty Praveena, Prakash Manne, Lohitha Kalluri and Ravikanth Anne	

11	Nanomaterials for the Management of Periodontal Diseases	203
	Radhika Arjunkumar	
12	Oral Biofilms: From Development to Assessment and Treatment	217
	Heeresh Shetty and Pankaj Gupta	
13	Physical Properties and Biocompatibility of Nanostructural Biomaterials Based on Active Calcium Silicate Systems and Hydroxyapatite	247
	Opačić-Galić Vanja, Petrović Violeta, Popović-Bajić Marijana, Jokačević Vukoman, Živković Slavoljub, Nikolić Biljana and Mitić-Ćulafić Dragana	
	Correction to: Advanced Nanomaterials and Their Functionalization in Clinical Endodontics	E1
	Hend Mahmoud Abou El Nasr and Makbule Bilge Akbulut	
	Index	273