Nanotechnologies for the Life Sciences

Edited by Challa Kumar

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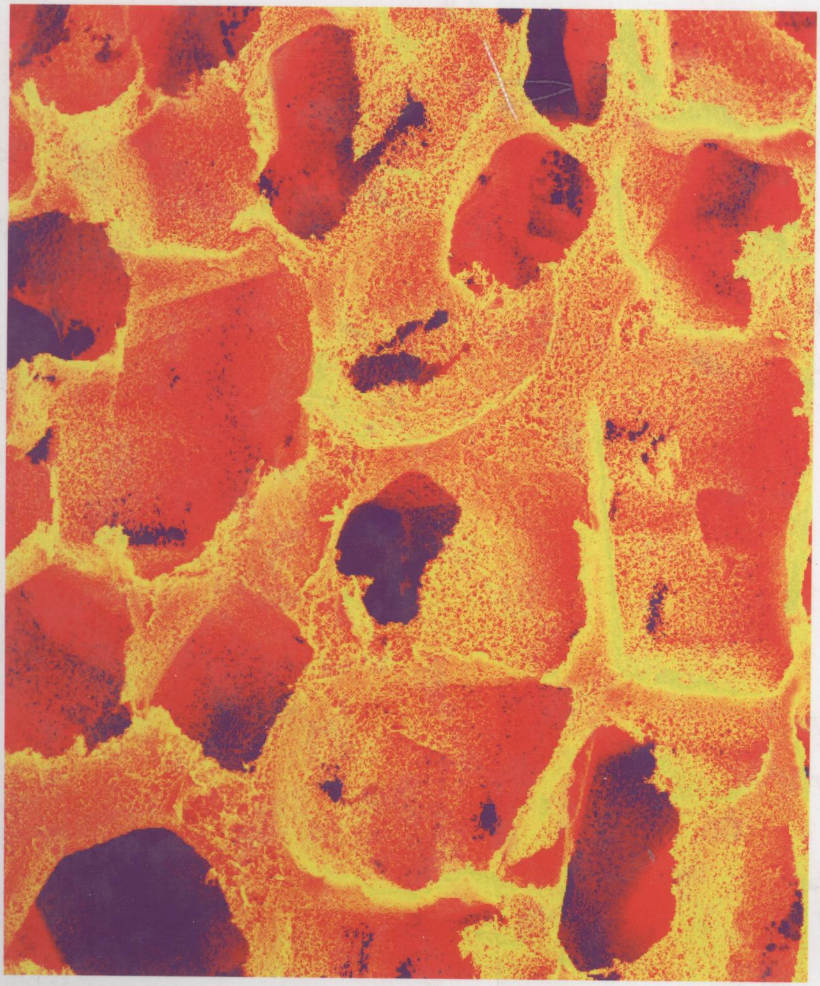
Tissue, Cell and Organ Engineering



NtLS

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The Editor

Dr. Challa S. S. R. Kumar
The Center for Advanced
Microstructures and Devices
(CAMD)
Louisiana State University
6980 Jefferson Highway
Baton Rouge, LA 70806
USA

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Sciences, University of Michigan, USA.

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Preface

Tissue Cell and Organ Engineering is the title of the ninth volume of the series on Nanotechnologies for the Life Sciences. As the title indicates the book can be considered as an encyclopedia on nanotechnological approaches to tissue, cell and organ engineering. The publication of the book is timely for a number of reasons. First, with the increase in life expectancy there is an unfulfilled demand for replacing non functional tissues and organs. Second, life time for implants and vascular grafts made from conventional synthetic materials (with constituent dimensions greater than 1 micron) is limited ranging from 5 to 15 years. Third, utilization of living tissue/organ for replacement is not a practical solution as evidenced by the fact that millions of surgeries are performed annually to treat tissue and organ failure and the number of people waiting for such transplantations are more than 80,000 at any time. Fourth, there is the ever-increasing cost of health care related to tissue loss or end-stage organ failure exceeding 400 billion US dollars. Furthermore, laboratory experiments to date suggest that nanomaterials have great potential for tissue, cell and organ engineering. Until the publication of this book, there is no single source of information about how nanotechnologies are impacting various facets of tissue engineering. With close to five hundred pages, the book has turned out to be a comprehensive source of information covering different types of nanomaterials being investigated for tissue, cell and organ engineering in addition to innovative strategies for assembling functional and structural artificial tissues.

I am extremely pleased with the final product, which is a tribute to harmonious integration of tissue engineering and nanomaterials science. Such an integration is only possible due to the scholarly presentations from some thirty researchers around the world, spanning twelve chapters. My special thanks to all of them for making this project a reality. I am always grateful to my employer, family, friends and Wiley-VCH publishers, who are part and parcel of this long journey into the union of nanomaterials and life sciences. I am thankful to you, the reader, who has taken time to join this journey. I do hope you will enjoy reading the book and will find it useful in your future endeavors. Let me first give you a bird's eye view of the various facets of tissue engineering being touched by nanomaterials prior to your plunging into the more specific topics.

In comparison with nanomaterials such as nanoparticles and nanotubes, nanofibers are more suitable for use as scaffolds in tissue engineering as they are

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morphologically similar to natural scaffolds and possess suitable properties such as high porosity, various pore-size distributions, and high surface-to-volume ratio. The majority of the investigations being carried out by tissue engineering researchers centers on utilization of nanofibers for development of artificial tissues. Therefore, the first four chapters in the book have been dedicated to provide an understanding of various aspects of nanofibers with respect to tissue engineering. The book begins with a chapter on *Nanotechnology and Tissue Engineering: The Scaffold Based Approach* providing an overview of the importance of nanotechnologies in developing scaffolds that closely mimic the structure and functions of the extra cellular matrix (ECM). Lakshmi S. Nair, Subhabrata Bhattacharyya and Cato T. Laurencin from the University of Virginia, USA, have demonstrated the importance of the scaffold approach for utilizing nanostructured materials in engineering ECM replacements. Of the various types of nanofibers currently under investigation for tissue engineering, polymeric nanofibers have been attracting a great deal of attention especially for applications in the area of ophthalmology, hepatic biology, nerve, skin, bone and cartilage regeneration, heart and vascular grafts, and stem cell research. Researchers Seow Hoon Saw, Karen Wang, Thomas Yong and Seeram Ramakrishna from the National University of Singapore have contributed the second chapter by bringing out an exhaustive review on *Polymeric Nanofibers for Ttissue Engineering* covering different types of nanofibers, fabrication methodologies, degradation kinetics, biocompatibility and their applications in regeneration of several types of tissues. Focusing more specifically on electrospinining technology, researchers Wan-Ju Li, Rabie M. Shanti and Rocky S. Tuan from the National Institute of Arthritis, and Musculoskeletal and Skin Diseases in Bethseda, USA, demonstrate that this technology is a useful, economical, and easily set-up method for the fabrication of three-dimensional, highly porous and nanofibrous scaffolds which have been shown to support cellular activities and tissue formation. Their contribution in the third chapter, *Electrospinning Technology in Tissue Engineering*, is a thorough review on not only electrospinning technology per se but also on various chemical, physical and biological properties of nanofibers prepared using this technology. In the fourth chapter, electrospinning technology is compared with two other well known approaches, namely self-assembly and phase separation for fabrication of nano-fibrous scaffolds. Researchers from the University of Michigan in Ann Arbor, USA, systematically analyze the differences and unique characteristics of the three approaches for the development of scaffolds and their applications in tissue engineering. This chapter, *Nano-fibrous Scaffolds and their Biological Effects*, reviewed by Laura A. Smith, Jonathan A. Beck and Peter X. Ma provides some useful insights into achieving the dream of engineering three-dimensional tissue formations.

The fifth chapter in the book, *Nanophase Biomaterials for Tissue Engineering*, contributed by R. Murugan and S. Ramakrishna from the National University of Singapore is a source of information on nanoscale biomaterials in particular, ceramic and polymer-based materials that are being investigated for tissue engineering applications. In addition to the fabrication techniques for nanobiomaterials, the chapter also provides information related to their influence on cells and cell growth. In the next chapter, the sixth, reader's attention is brought to nanotechnologies that are bringing solutions to long-standing problems with current orthopedic implants. The chapter, *Orthopedic Tissue Engineering using Nanomaterials*, written by Michiko Sato and Thomas J. Webster from Purdue University and Brown University respectively in West Lafayette, USA, discusses the effect of ceramic, metallic, polymeric, and composite nanomaterials on cellular functions particularly related to the bone. Norberto Roveri and Barbara Palazzo from the University of Bologna in Italy provide an up to date review on hydroxyapatite nanoparticles, which are being thoroughly investigated as materials for bone substitution. In the seventh chapter, entitled *Hydroxyapatite Nanocrystals as Bone Tissue Substitute*, they describe morphological, structural, chemical-physical, and surface characteristics of hydroxyapatite nanocrystals, followed by research investigations leading to understanding their high bioactivity and ability to induce bone regeneration and remodeling.

Moving away from nanofibers, ceramic nanomaterials and hydroxyapatite nanocrystals, the eighth chapter, *Magnetic Nanoparticles for Tissue Engineering*, authored by Akira Ito and Hiroyuki Honda from Kyushu University and Nagoya University respectively in Japan contains research investigations about application of the magnetic force-based tissue engineering technique (Mag-TE) to cell-seeding (termed "Mag-seeding") and its effectiveness in enhancing cell-seeding efficiency, leading to three-dimensional porous scaffolds for tissue engineering. In addition to magnetic nanomaterials, carbon nanotubes (CNTs) have been attracting the attention of life scientists. Due to their extraordinary physical, chemical, mechanical and electrical properties, in parrticular single-walled carbon nanotubes (SWNTs) are being touted as materials that have immense potential to interface directly with biological systems leading to innovative applications. In the ninth chapter, Peter S. McFetridge and Matthias U. Nollert from the University of Oklahoma in Norman, USA, delve deeply into the applications of SWNTs in the field of tissue engineering. The chapter, *Applications and Implications of Single-Walled Carbon Nanotubes in Tissue Engineering*, provides the history behind the electrical stimulation of cells and the reasoning behind the use of SWNTs as a conductive material to support or promote organ regeneration with specific examples of applications of SWNT in tissue engineering from the literature.

Cellular engineering is conceptually more fundamental to tissue engineering and nanotechnologies are helping in modulating cellular functions as well. In the tenth chapter, a more specific case of the effect of nanomaterials on cellular engineering related to free radical mediated oxidative stress is examined. The chapter, *Nanoparticles for Cell Engineering—A Radical Concept*, is a contribution from the laboratories of Beverly A. Rzigalinski at Virginia College of Osteopathic Medicine and Virginia Polytechnic & State University in Blacksburg, USA. The authors describe in detail potential application of three nanoparticle redox reagents viz rare earth oxide nanoparticles (particularly cerium), fullerenes and their derivatives and carbon nanotubes in preservation of cellular redox status and treatment of disease. Adding to the specifc case of cellular engineering described in the tenth chapter, Jessica Winter from Ohio State University in Columbus, USA, presents in the eleventh chapter an exhaustive review on engineering of cells using nanotechnologies. The chapter aptly entitled *Nanoparticles and Nanowires for Cellular Engineering* is a one-stop source of information on applications of nanostructures to cellular engineering in general and for manipulating specific cellular components. The chapter deals with a gamut of issues on nanomaterial-based cellular engineering related to a wide spectrum of biomedical applications ranging from tissue engineering, intracellular tracking, biosensing and drug delivery. The final chapter of the book is an excellent review on *Nanoengineering of Biomaterial Surfaces* contributed by Ashwath Jayagopal and V. Prasad Shastri from Vanderbilt University in Nashville, USA. In this chapter, a variety of surface engineering techniques are presented for achieving micro- and nanoscale surface features, in addition to their applicability in the construction of hard and soft materials and three-dimensional geometries relevant to cellular and tissue engineering. This chapter brings to close the first comprehensive treatise on nanotechnological approaches for tissue, cell and organ engineering and I am very confident that the book will be a knowledge base for further advances that are bound to take place in the near future.

June 2006 *Challa S. S. R. Kumar*
Baton Rouge, USA

List of Authors

Jonathan A. Beck
University of Michigan
Department of Biomedical Engineering
Ann Arbor, MI 48019
USA

Subhabrata Bhattacharyya
Department of Chemistry
University of Virginia
Charlottesville, VA 22903
USA

Courtney A. Cohen
Virginia College of Ostheopathic Medicine
NanoEuroLab
Research II Bldg – 1861 Pratt Drive
Blacksburg, VA 24060
USA

Igor Danelisen
Virginia College of Ostheopathic Medicine
NanoEuroLab
Research II Bldg – 1861 Pratt Drive
Blacksburg, VA 24060
USA

Hiroyuki Honda
Nagoya University
Department of Biotechnology
School of Engineering
Furo-cho, Chikusa-ku
Nagoya 464-8603
Japan

Akira Ito
Kyshu University
Department of Chemical Engineering
744 Motooka, Nishi-ku
Fukuoka 819-0395
Japan

Ashwath Jayagopal
Biomaterials, Drug Delivery, and
Tissue Engineering Laboratory
Department of Biomedical Engineering
Vanderbilt University
5924 Stevenson Center
Nashville
Tennessee 37232
USA

Cato T. Laurencin
Departments of Orthopaedic Surgery
Biomedical Engineering
and Chemical Engineering
University of Virginia
Charlottesville, VA 22903
USA

Wan-Ju Li
National Institutes of Health, National
Institute of Arthritis, and Musculoskeletal and
Skin Diseases
Cartilage Biology and Orthopaedics Branch
50 South Drive, Bldg. 50, Room 1314
Bethesda, MD 20892
USA

Chengya Liang
Virginia College of Osteopathic Medicine
NanoEuroLab
Research II Bldg – 1861 Pratt Drive
Blacksburg, VA 24060
USA

Peter X. Ma
The University of Michigan
Department of Biologic and Materials Sciences
Department of Biomedical Engineering
Macromolecular Science and Engineering
Center
1011 North University Ave., Room 2211
Ann Arbor, Mi 48019-1078
USA

Peter S. McFetridge
School of Chemical, Biological and
Materials Engineering
and the University of Oklahoma
Bioengineering Center
University of Oklahoma
Norman
Oklahoma 73019-1004
USA

R. Murugan
Division of Bioengineering
National University of Singapore
9 Engineering Drive 1
Singapore 117576

Lakshmi S. Nair
Department of Orthopaedic Surgery
University of Virginia
Charlottesville, VA 22903
USA

Matthias U. Nollert
School of Chemical, Biological and
Materials Engineering
and the University of Oklahoma
Bioengineering Center
University of Oklahoma
Norman
Oklahoma 73019-1004
USA

Barbara Palazzo
Department of Chemistry "G. Ciamician"
Alma Mater Studiorum
University of Bologna
via Selmi 2
Bologna 40126
Italy

Seeram Ramakrishna
Division of Bioengineering
Block E3-05-29
9 Engineering Drive 1
National University of Singapore
Singapore 117576

Norberto Roveri
Department of Chemistry "G. Ciamician"
Alma Mater Studiorum
University of Bologna
via Selmi 2
Bologna 40126
Italy

Beverly A. Rzigalinski
Nanobiology Laboratories
Virginia College of Osteopathic Medicine
and Virginia Polytechnic & State University
Virginia-Maryland Regional College of
Veterinary Medicine
Blacksburg
Virginia 24060
USA

Michiko Sato
Purdue University
School of Materials Engineering
600 Central Drive
West Lafayette, IN 47907
USA

Seow Hoon Saw
Division of Bioengineering
Block E3-05-29
2 Engineering Drive 3
National University of Singapore
Singapore 117576

Rabie M. Shanti
HHMI-NIH Research Scholar
National Institutes of Health, National
Institute of Arthritis, and Musculoskeletal and
Skin Diseases
Cartilage Biology and Orthopaedics Branch
Bethesda, MD 20892
USA

V. Prasad Shastri
Biomaterials, Drug Delivery, and
Tissue Engineering Laboratory
Department of Biomedical Engineering
Vanderbilt University
5924 Stevenson Center
Nashville
Tennessee 37232
USA

Laura A. Smith
University of Michigan
Department of Biomedical Engineering
Ann Arbor, MI 48109
USA

Elizabeth T. Strawn
Virginia College of Osteopathic Medicine
NanoEuroLab
Research II Bldg – 1861 Pratt Drive
Blacksburg, VA 24060
USA

Rocky S. Tuan
National Institutes of Health, National Institute of Arthritis and Musculoskeletal and Skin Diseases
Cartilage Biology and Orthopaedics Branch
Bethesda, MD 20892
USA

Karen Wang
Nanoscience and Nanotechnology Initiative
Block E3-05-29
2 Engineering Drive 3
National University of Singapore
Singapore 117576

Thomas J. Webster
Brown University
Division of Engineering and Orthopaedics
184 Hore Street
Providence, RI 02912
USA

Jessica O. Winter
The Ohio State University
Department of Chemical Engineering
335 Kottolt Laboratories
140 W 19th Avenue
Columbus, OH 43210
USA

Thomas Yong
Division of Bioengineering
Block E3-05-29
2 Engineering Drive 3
National University of Singapore
Singapore 117576

Contents

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