Nanotechnologies for the Life Sciences

Edited by Challa Kumar

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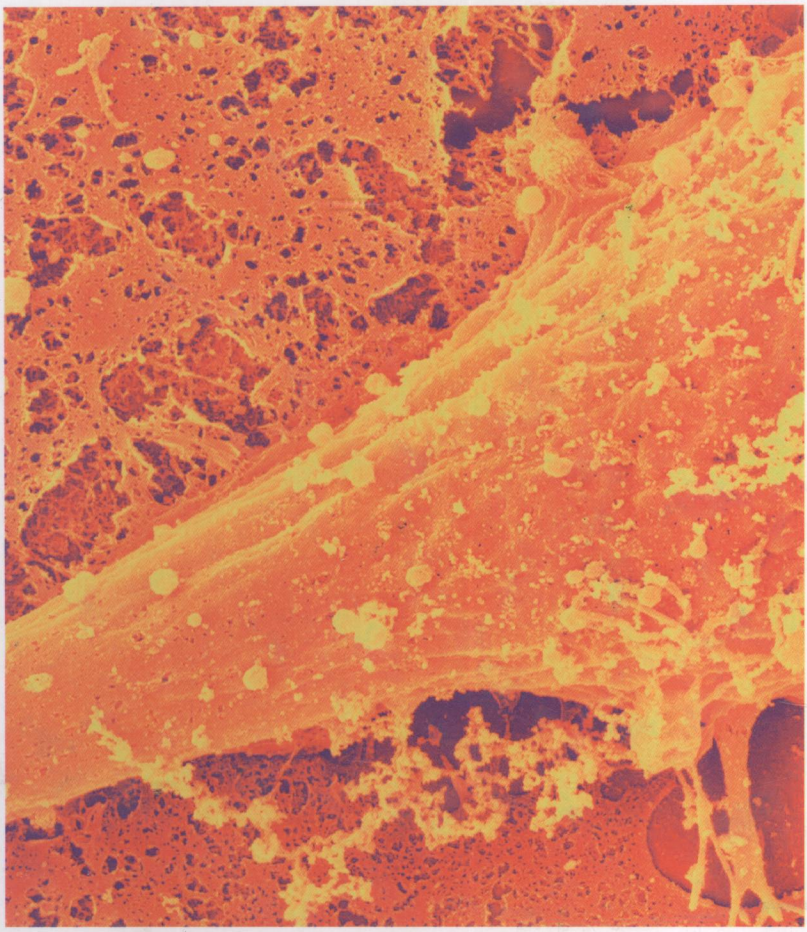
Nanomaterials for Medical Diagnosis and Therapy



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Volume 10

Nanomaterials for Medical Diagnosis and Therapy

Edited by
Challa S. S. R. Kumar

1st Edition

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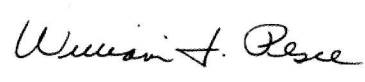

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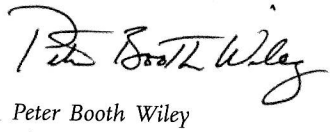

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Foreword

As the traditional compartmentalization of science and engineering into discrete disciplines dissolves, scientists of all backgrounds find that their work is part of a bigger, much more magnificent picture, unrestricted by doctrine, educational plans or other previous, tangible constraints. Hence, nanotechnology and the life sciences enjoy a growing synergy of materials, methods, and mechanisms common or beneficial to both, giving rise to new ideas, novel approaches, understanding of phenomena and a fertile exchange of concepts, strategies and goals.

Although this rapidly growing and evolving field is still in a nascent stage, recent successes are fuelling the vision of "bottom-up" fabrication and assembly processes and man's ability to purposefully control events when nanostructured materials and biological entities encounter each other on the nanoscale.

Some significant functional materials and devices have been realized, especially on the diagnostic front, and an even larger number are waiting to be discovered by pioneering work to come, based upon the foundations laid today.

It is this vision which needs to be transported – between the disciplines, from teachers to pupils, from scientists to policy makers, from experts to the general public, and, especially, from colleague to colleague for fruitful collaboration and success in the search for further pieces of the magnificent puzzle of Everything: Nature, Life, and the Universe.

Nanotechnologies for the Life Sciences (NtLS) aims to fulfill this quest for passing on knowledge to the mutual benefit of its authors and readers by stimulating scientific exchange and disseminating vital knowledge to provide insight into the ongoing exploration of the potent opportunities around the corner.

With over 4600 pages in 124 chapters, these ten volumes are the first major effort to cover the whole breadth and width of this highly dynamic and exciting field, and in leading this effort, Challa S. S. R. Kumar and his numerous authors have brought together an exciting, provocative, and informative source of knowledge and stimulation for all those active in this field or wanting to become so.

Evanston, November 2006 *Chad Mirkin*

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Preface

From the time the human mind emerged, about fifty thousand years ago, our understanding of the human body and of ways and means to protect ourselves better from both natural degradation as well as diseases has been continuously growing. The human mind has been responsible for triggering creative technological breakthroughs at different intervals, significantly improving our quality of life at each of these stages. We are again standing on the threshold of yet another technological mastery with the ability to create nanomaterials akin to natural sub-micron biomolecules for the protection of our body and to prolong its life. The purpose of this book, *Nanomaterials for Medical Diagnosis and Therapy*, is to reveal for the first time how man-made nano-sized materials are being judiciously combined with biological molecules in order to find hitherto unimaginable, superior diagnostic tools and novel therapeutic approaches to alleviate human suffering. Most of what you will read here will provide you with a broader perspective to how nanotechnology is going to revolutionize medicine in the close future. You are unlikely to get such a perspective reading individual articles from the scientific journals. This is the final volume in the ten-volume series on *Nanotechnologies for the Life Sciences (NtLS)* and in a way reflects the ultimate goal of all life scientists, with the other nine volumes as guide posts, to improve our health and quality of living. The book has sixteen chapters, covering all aspects of medical diagnosis and therapy except cancer as this subject is covered in volumes six and seven. With over 700 pages, it is the largest of all the ten volumes. Before I go ahead with giving you details of individual chapters in this final volume, I would like to take this opportunity to provide you glimpses of the information contained in the first nine volumes, which many of you may have already read.

The first volume in the series *Biofunctionalization of Nanomaterials*, with eleven chapters, dealt with various approaches to attach biomolecules to nanomaterials for applications in the life sciences, and the second volume *Biological and Pharmaceutical Nanomaterials*, with twelve chapters, focused on natural nanomaterials that are relevant to the life sciences. The ability to characterize systems in nanoscale is pivotal to the success of nanotechnology, and the third volume *Nanosystem Characterization Tools for the Life Sciences*, with eleven chapters, is a useful source of information both for life scientists interested in nanoscale systems and for characterization specialists interested in applying their tools in biological systems. The

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fourth volume of the series, *Nanodevices for the Life Sciences*, contains thirteen chapters and is a compendium of the exciting possibilities that exist in the world of tiny devices. The fifth volume, entitled *Nanomaterials – Toxicity, Health and Environmental Issues*, reviews some of the critical risk assessment issues, which are crucial in life sciences, that are currently being investigated by the health & environmental nano researchers, and has twelve chapters. The sixth and the seventh volumes, *Nanomaterials for Cancer Therapy* and *Nanomaterials for Cancer Diagnosis*, with a total of twenty-two chapters, captured nanotechnological approaches for the treatment of cancer and their utility in developing tools and materials for sensitive and early diagnosis of this serious affliction. While the eighth volume, *Nanomaterials for Biosensors*, containing thirteen chapters, touches upon biomolecular sensing using a variety of Nanomaterials, the ninth volume *Tissue, Cell and Organ Engineering* with its twelve chapters is an encyclopedia on nanotechnological approaches to the engineering of biologically functional matter capable of serving as tissue or organ replacement. The ten volume series on *Nanotechnologies for the Life Sciences* with 122 chapters contributed by about 150 researchers across the globe totaling some 4600 pages comes to conclusion with the publication of the tenth volume.

This tenth volume begins with the chapter entitled *Nanotechnologies for Diagnosis – Present and Future*, which is a contribution by Gareth A. Hughes of Zyvex Corporation in Richardson, Texas, USA. In this chapter, a general discussion on various aspects of diagnostics including *in vitro* diagnostics (IVDs), implantable sensors and imaging techniques is presented in addition to touching upon regulatory and ethical considerations. Moving to a more specific diagnostic tool, authors lead by Jean-Marc Idée from Guerbet, Aulnay-sous-Bois, France, brings out the importance of Superparamagnetic Iron Oxide Nanoparticles (SPIONs) as contrast agents in Magnetic resonance Imaging. The chapter, *Superparamagnetic Nanoparticles of Iron Oxides for Magnetic Resonance Imaging Applications*, is a comprehensive source of information on the unique capability of SPIONs as contrast agents for MRI of the gastrointestinal tract, liver & spleen, lymph node, blood pool, and atheromatous plaque.

The third chapter, *Carbon Nanotube-based Vectors for Delivering Immunotherapeutics and Drugs*, reviews the application of carbon nanotubes in drug delivery and biosensing. Alberto Bianco and co-workers from the Insititute of Molecular and Cellular Biology in Strasbourg, France, have done a commendable job in delineating the pros and cons of utilizing the unique property of CNTs, the penetration ability with capacity for high loading, for innovative medical diagnosis and therapies. The team lead by Soon Hong Yuk from Hannam University in Taejeon, Korea, contributed the fourth chapter, entitled *Core-Shell Nanoparticles for Drug Delivery and Molecular Imaging*. In this chapter, the authors focus on core-shell nanoparticle architecture with a layer of polymeric materials surrounding an organic or inorganic nanoparticle core, and demonstrate that such architectures provide improved stability and a sustained release pattern of protein drug and decreased cytotoxicity. In the fifth chapter, *Nanotechnologies for Targeted Delivery of Drugs*, various aspects of targeted delivery utilizing different types of nanomaterials are highlighted. Authors Pavel Brož and Patrick Hunziker from the Medical Inten-

sive Care unit of Basel University Hospital in Switzerland present successful targeting strategies employed that use both 'natural nanostructures' (such as bacteria and viruses) and 'artificial nanostructures' (lipid-based ones such as liposomes and micelles, protein-based ones such as dendrimers, and polymer-based ones such as nanoparticles, nanospheres and nanocontainers) in areas other than cancer.

The sixth chapter, *Nanoporous and Nanosize Materials for Drug Delivery Systems*, written by Yoshinobu Fukumori, Kanji Takada and Hirofumi Takeuchi from Kyoto Pharmaceutical University, Japan, covers application of a number of inorganic, organic and natural nanoporous materials in general and nanoporous silica-based materials in particular for medical therapy. Continuing on the theme of core-shell nanoparticles as described in a general way in the fourth chapter, Yoko Yamaguchi and Rie Igarashi from the Institute of Medical Science of St Marianna University in Kanagawa, Japan, present their efforts in the seventh chapter towards the development of a specific non-spherical core-shell product, NanoEgg™, for dermatological applications. The chapter, *NanoEgg™ Technology for Drug Delivery*, describes the commercialization of these particles for overcoming the limitations of classical ATRA (all-*trans* retinoic acid) treatment through controlled release.

Polymeric nanomaterials have been receiving a lot of attention as materials of choice for both drug delivery as well as diagnostic tools due to their unique physicochemical characteristics that allow for controlling the fate of a drug within the patient. Three chapters, 8, 9 and 10, have been dedicated to bring out comprehensively the information present in the literature on different facets and types of polymeric nanomaterials for application in medical diagnosis and therapy. The eighth chapter, *Polymeric Nanomaterials – Synthesis, Functionalization and Applications in Diagnosis and Therapy*, a contribution from the laboratories of Rachel Auzély-Velty from the Centre de Recherches sur les Macromolécules Végétales (CERMAV) in Grenoble, France, focuses on 'frozen', non-dynamic polymeric nanomaterials, where an exchange between individual polymer chains and polymer chains of the nanoobject cannot take place, unlike the dynamic systems such as micelles and liposomes. On the other hand, the ninth chapter, *Polymeric Nanoparticles for Drug Delivery*, authored by P. Kallinteri and M. C. Garnett from the School of Pharmacy of Nottingham University, UK, brings out the physiology and anatomy underlying the diseases which may be treatable using polymeric nanomaterials and the way these are handled by the body. In the tenth chapter, *Solid Lipid and Polymeric Nanoparticles for Drug Delivery*, the authors José Luis Pedraz and co-workers from the University of Basque Country in Vitoria, Spain, present a comparative analysis of solid lipid nanoparticles (SLNs) and polymeric nanoparticles with reference to their production processes, characterization, and a wide ranging therapeutic applications.

Chapter eleven by Zach Hilt from the University of Kentucky in Lexington, USA, explores the relatively underdeveloped field of hydrogels. In this chapter aptly titled as *Intelligent Hydrogels in Nanoscale Sensing and Drug Delivery Applications*, the author has done a great job in providing an up-to-date review on the application of intelligent hydrogels such as ionic and temperature-responsive, biohybrid and imprinted hydrogels in micro/nanoscale sensing and drug delivery. In the twelfth chapter, *Nanoshells for Drug Delivery*, a layer-by-layer self assembly approach to

nanoshell formation is described in addition to the utility of nanoshells in controlled release of pharmaceutical ingredients. Authors Melgardt M. De Villiers and Yuri Lvov from the University of Wisconsin and Louisiana Tech University respectively, compare in a systematic fashion two types of nanoshells – metallic nanoparticles composed of a dielectric core (e.g. silica) coated with an ultra thin metallic layer (e.g. gold) and nanoshells formed by electrostatic layer-by-layer molecular self-assembling (E-LbL) for drug delivery applications. L. Andrew Lee, Hannah N. Barnhill and Qian Wang from University of South Carolina provide an overview on the topic of the programming of the Bionanoparticles (BNPs) and current research on their biomedical applications in the thirteenth chapter entitled *Bionanoparticles and their Biomedical Applications*. This chapter is a must-read for all those interested in BNPs and how they can be exploited for generating novel biotemplates in the nanometer range for a myriad of biomedical applications.

As we reach the end of the book, the last three chapters assume special importance. While chapter fourteen contributed by Hironori Nakagami, Yasuhiko Tabata and Yasufumi Kaneda from Osaka University, Japan, reiterates the importance of nanotechnologies in gene therapy, the fifteenth chapter, written by S. M. Moghimi from the University of Brighton, UK, cautions about the possible toxic effects of a well-known gene transfer vector. The titles of the two chapters are *Nanotechnology for Gene Therapy – HVJ-E Vector* and *Nanotoxicology of Synthetic Gene Transfer Vectors: Poly (ethyleneimine) – and Polyfectin-mediated Membrane Damage and Apoptosis in Human Cell Lines*, respectively. The final chapter by Gang Liu and Ping Men from the University of Utah in Salt Lake City, USA, entitled *Nanoparticles for the Treatment of Alzheimer's Disease: The Theoretical Rationale, Present Status and Future Perspectives* indicates that nanotechnology has potential to treat Alzheimer's disease (AD), the most devastating neurodegenerative disorder with progressive and irreversible damage to thought, memory and language. I am very confident that the information that is presented in these sixteen chapters in this tenth volume will help in furthering the utility of nanotechnological approaches in medical diagnosis and therapy. I am, as always, very grateful to all the authors for their scholarly presentations of their topics, providing timely inputs and corrections in making the final volume in this series a reality.

As I conclude this ten-volume series, I would like to reinforce some of the comments that I made in my preface to the first volume. As I said, nanotechnology's greatest gift to mankind, in my view, is its ability to promote lateral thinking amongst not only scientists, but all those who are associated with this new approach, the so called 'nano thinking' to problem solving. On behalf of all the authors who have made contributions to this exciting series, it is my privilege to play the role of a catalyst in inculcating this new thinking by providing a multipronged base of knowledge in nanotechnologies for the life sciences. It is my hope that this book series will help in stretching the limits of thinking in all those who come in contact with it.

It is yet another opportunity for me to convey my thanks to each and every person (unfortunately due to lack of space I am unable to mention all the names) with whom I had the privilege of interacting and who have helped me directly or in-

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directly during the course of the publication of the whole series. I would like to express my gratitude to the following people for their support and assistance. My employer and colleagues at the Center for Advanced Microstructures and Devices, graduate advisor Prof. N.R. Krishnaswamy who laid the foundation to my career, family and friends, and the Wiley-VCH publishing team, Martin Ottmar, Esther Dörring, Nele Denzau and Eva Wille, with whom I had great pleasure in working.

Finally, my special thanks to you, the readers, for ensuring that the knowledge base provided in this book series will be a building block for further understanding of nanoscience. I do realize that there is a lot of scope for improvement and need to add new topics to this book series. I am hoping that I will be able to, with your comments and suggestions, take this series to a new level in the near future.

October 2006, Baton Rouge *Challa S.S.R. Kumar*

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