Nanorobotics and Nanodiagnostics in Integrative Biology and Biomedicine

Ki-Taek Lim • Kamel A. Abd-Elsalam
Editors

Nanorobotics and Nanodiagnostics in Integrative Biology and Biomedicine

Springer

Editors
Ki-Taek Lim
Department of Biosystems Engineering
Kangwon National University
Chuncheon, (Republic of Korea)

Kamel A. Abd-Elsalam
Agricultural Research Center
Plant Pathology Research Institute
Giza, Egypt

ISBN 978-3-031-16083-7 ISBN 978-3-031-16084-4 (eBook)
https://doi.org/10.1007/978-3-031-16084-4

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2023
This work is subject to copyright. All rights are solely and exclusively licensed 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, expressed 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

Preface

Nanorobotics and nanodiagnostics are the emerging tools in the history of nanotechnology to combat several animal and plant diseases. Nanorobots or nanobots of approximately 50–100 nm wide can perform various works, such as targeted drug delivery, biosensing, tumor clearance, and surgery. Nanodiagnostics uses various nano-biosensors acting as biological recognition elements for detecting various analytes (glucose, antibiotics, toxins, etc.). Robotically coupled nano-micromotors inserted into the blood may be able to sense, detect, and eliminate potential microorganisms, tumor cells, or toxic substances. The nanorobotics and nanodiagnostics are integrated parts of human health and the agroecosystem. Nanorobotic agriculture tools include nonporous platforms, wearable devices, micro-nanoneedle patches, nanoparticle-based sensors, quantum dots, and CRISPR/Cas9-based tools that can precisely sense and eliminate plant pathogens for sustainable agriculture and the food industry. This book, *Nanorobotics and Nanodiagnostics in Integrated Biology and Biomedicine*, is the first volume of the original book series approved by Springer Publishing Ltd. More specifically, this book focuses on the recent developments and significant breakthroughs in nanorobotics and nanodiagnostics based on various nano- or biopolymer materials, Lab-on-a-chip devices, printed nanobots, biomolecule sensors, and advanced stimuli-responsive nanodevices, beneficial for human health and agriculture. The present volume comprises 18 chapters prepared by magnificent authors from Brazil, China, Pakistan, Egypt, India, South Africa, South Korea, Saudi Arabia, and the United States. We hope that a combination of 18 outstanding chapters written by professionals and experts represents an extensive knowledge of nanorobotics and nanodiagnostics techniques. We express our sincere gratitude to all the contributing authors who helped us and made their comments about editing the entire book. Without their excellent skills, extensive efforts, and support, writing this book might not have been possible. We hope that the present volume not only encourages the people working in this field but also inspires young scientists and researchers to enlighten the future nanorobotics and nanodiagnostics skills. Last but not least, we would like to thank Springer Publishers for supporting and helping us throughout the journey. We express our sincere gratitude to the Springer staff, editorial directors

(Paul Ross and Guido Zosimo-Landolfo), senior editor (Eric Stannard), and managing staff for their tremendous efforts and assistance. We also want to thank all the reviewers for spending their precious time during the review of chapters. We would also like to thank our family members and colleagues for their continuous support and assistance.

Chuncheon, (Republic of Korea) Ki-Taek Lim
Giza, Egypt Kamel A. Abd-Elsalam

Contents

1 Nanorobotics and Nanodiagnostics in Integrative Biology and Biomedicine: A Note from the Editors 1
Ki-Taek Lim and Kamel A. Abd-Elsalam
1.1 Introduction 1
1.2 Historical Background 5
1.3 Overview of the Book 8
1.4 Conclusion 10
References 10

2 Nanorobots for Drug Delivery, Surgery, and Biosensing 15
Qing Ye and Jianfei Sun
2.1 Introduction 15
2.2 Design of Nanorobots 17
2.3 Application 21
2.3.1 Drug Delivery 21
2.3.2 Surgery 23
2.3.3 Biosensing 25
2.4 Conclusion 27
References 28

3 Biomolecule-Based Nanorobot for Targeted Delivery of Therapeutics 35
Keya Ganguly, Sayan Deb Dutta, Dinesh K. Patel, Tejal V. Patil, Rachmi Luthfikasari, and Ki-Taek Lim
3.1 Introduction 35
3.2 DNA and Proteins 36
3.3 CAD Systems for Bio-nanorobotics Simulation 38
3.4 Biomolecule-Loaded Therapeutic Delivery 39
3.4.1 Pharmaceuticals 39
3.4.2 Biologics and Genes 41
3.4.3 Living Cell-Based Therapies 42
3.5 Selected Diseases 45

3.5.1 Cancer 45
3.6 Challenges and Prospects 48
References 48

4 Printable Nanorobots and Microswimmers for Therapeutic Advancement: Present Status and Future Opportunities 53
Sayan Deb Dutta, Keya Ganguly, Dinesh K. Patel, Tejal V. Patil, Rachmi Luthfikasari, and Ki-Taek Lim
4.1 Introduction 53
4.2 Overview of 3D Printing Techniques for Nanorobot Fabrication . 54
4.2.1 Powder-Bed Fusion 55
4.2.2 Vat Polymerization 56
4.2.3 Inkjet Printing 57
4.2.4 Extrusion and Direct-Ink-Writing Printing 57
4.2.5 Direct Laser Writing Printing 58
4.3 Materials for 3D Printing of Micro-/Nanomotors 60
4.4 Shape Reconfiguration for Tunable Multifunctionality 61
4.5 Types of Nanomotors and Their Function 63
4.5.1 Helical Micro-/Nanoswimmers 63
4.5.2 Tubular Micro-/Nanoswimmers 64
4.5.3 Micro-/Nanomotors with Mixed Functions 66
4.6 Propulsion Mechanism of Nanomotors 66
4.6.1 Chemical and Biological Propulsion 66
4.6.2 Magnetic Propulsion 67
4.6.3 Ultrasonic Propulsion 69
4.7 Therapeutic Applications 69
4.8 Key Challenges and Future Outlook 70
4.9 Concluding Remarks 73
References 74

5 Fundamental in Polymer-/Nanohybrid-Based Nanorobotics for Theranostics 79
Tejal V. Patil and Ki-Taek Lim
5.1 Introduction 79
5.2 Polymers 82
5.2.1 Natural Polymers 83
5.2.2 Synthetic Biopolymer 87
5.3 Fabrication of Theranostic Nanorobots 90
5.3.1 Magnetic Nanoparticle-Based Theranostics 90
5.3.2 Micelles 91
5.3.3 Dendrimers 92
5.3.4 Nanogels 94
5.3.5 Hybrid Conjugates 96
5.4 Bioconjugation Process 97
5.5 Application in Theranostics 98
5.5.1 Cancer Diagnosis and Therapy 98

5.5.2 Bacterial Infections and Wound Healing 100
5.6 Conclusion 101
References 101

6 Magneto-Responsive Nanohybrids for Bioimaging 109
S. T. Mhaske, D. A. Patil, and S. U. Mestry
6.1 Introduction 109
6.2 Nanohybrids 111
6.2.1 Carbon-Carbon NHs 112
6.2.2 Carbon-Metal NHs 113
6.2.3 Metal-Metal NHs 114
6.2.4 Organic Molecule-Coated NHs 114
6.2.5 Virus Nanoparticles (VNPs) 121
6.3 Characterizations of Nanohybrids 124
6.3.1 ICP-MS and ICP-OES 124
6.3.2 EDS 128
6.3.3 SEM and TEM 129
6.3.4 XRD 131
6.3.5 Magnetic Properties of Nanohybrids 131
6.4 Conclusion 134
References 135

7 Photothermal Nanomaterials for Wound Monitoring and Cancer Biomedicine 139
Ashwini Shinde, Kavitha Illath, Sayan Deb Dutta, Ki-Taek Lim, and Tuhin Subhra Santra
7.1 Introduction 139
7.2 Photothermal Nanomaterials: Application for Wound Healing and Monitoring 142
7.2.1 Photothermal and Photodynamic Therapy for Wound Healing 143
7.2.2 Photothermal Nanomaterials for Skin Wound Healing 144
7.2.3 Photothermal Nanomaterials for Bone and Cartilage Defects 149
7.3 Photothermal Nanomaterials: Applications for Cancer Biomedicine 154
7.3.1 Photothermal Therapy Using Metal Nanomaterials 154
7.3.2 Photothermal Therapy Using Semiconductor Nanomaterials 156
7.3.3 Photothermal Therapy Using Carbon-Based Nanomaterials 158
7.3.4 Photothermal Therapy Using Conducting Polymers 159
7.4 Limitations and Future Prospect 161
7.5 Conclusion 163
References 163

8 Polymer Nanohybrid-Based Smart Platforms for Controlled Delivery and Wound Management . . . 171
Dinesh K. Patel, Tejal V. Patil, Keya Ganguly, Sayan Deb Dutta, Rachmi Luthfikasari, and Ki-Taek Lim
- 8.1 Introduction . . . 171
- 8.2 Classification of the Polymers . . . 173
  - 8.2.1 Natural Polymers . . . 173
  - 8.2.2 Synthetic Polymers . . . 174
- 8.3 Kinds of Nanomaterials . . . 174
  - 8.3.1 0D and 1D Nanomaterials . . . 174
  - 8.3.2 2D and 3D Nanomaterials . . . 178
- 8.4 Application of Polymer Nanohybrid-Based Smart Platforms . . . 179
  - 8.4.1 Delivery of Active Molecules . . . 179
  - 8.4.2 Wound Management . . . 185
- 8.5 Conclusion . . . 192
- References . . . 194

9 Development of Efficient Strategies for Physical Stimuli-Responsive Programmable Nanotherapeutics . . . 201
Pravin P. Upare, Hyung Sub Shin, Jun Hak Lee, and Byung Gyu Park
- 9.1 Introduction . . . 201
- 9.2 Stimuli-Responsive Nanomaterials . . . 203
  - 9.2.1 Temperature-Responsive Nanomaterial . . . 203
  - 9.2.2 Ultrasound-Responsive Materials . . . 212
  - 9.2.3 Magnetic Field-Responsive Nanomaterials . . . 216
- 9.3 Concluding Remarks and Future Perspectives . . . 221
- References . . . 222

10 The Flexible and Wearable Pressure Sensing Microsystems for Medical Diagnostics . . . 229
Hui Li, Ronghua Lan, Jing Chen, and Lin Li
- 10.1 Introduction . . . 229
- 10.2 Materials . . . 230
  - 10.2.1 Substrate Materials . . . 232
  - 10.2.2 Active Materials . . . 233
- 10.3 Fundamentals of Pressure Sensors . . . 235
  - 10.3.1 Sensing Mechanisms . . . 235
  - 10.3.2 Key Parameters of Pressure Sensor . . . 238
- 10.4 Applications for Flexible Pressure Sensors . . . 241
  - 10.4.1 Detecting Heart Rate or Pulse . . . 243
  - 10.4.2 Detecting Pressure In Vivo . . . 245
  - 10.4.3 Gait Monitoring . . . 246
  - 10.4.4 Recognition of Sound Signal . . . 248
  - 10.4.5 Breath Detection . . . 250

10.4.6 Tactile Perception 252
10.5 Conclusions and Perspectives 253
References 255

11 Microfluidics and Lab-on-a-Chip for Biomedical Applications 263
Dinesh K. Patel, Maria Mercedes Espinal, Tejal V. Patil, Keya Ganguly, Sayan Deb Dutta, Rachmi Luthfikasari, and Ki-Taek Lim
11.1 Introduction 263
11.2 Fabrication of Microfluidic System 267
11.3 Significance of Nonlinear Process in Microfluidics 268
11.4 Significance of Microfluidic Systems 271
11.5 Biomedical Applications 273
11.5.1 Organs-on-Chips (OoCs) 273
11.5.2 Lung-on-a-Chip (LuoC) 274
11.5.3 Brain-on-a-Chip (BoC) 276
11.5.4 Joint/Muscle-on-a-Chip (JoC) and Human-on-a-Chip (HoC) 277
11.6 Conclusion and Future Perspectives 279
References 279

12 Lab-on-a-Chip Devices for Medical Diagnosis II: Strategies for Pathogen Detection 285
Rachmi Luthfikasari, Tejal V. Patil, Dinesh K. Patel, Keya Ganguly, Sayan Deb Dutta, and Ki-Taek Lim
12.1 Introduction 285
12.2 LoC Fabrication for Medical Diagnosis 286
12.3 Pathogen Diagnosis 291
12.4 Conclusion and Future Perspective 295
References 296

13 Nanodiagnostics: New Tools for Detection of Animal Pathogens 299
Atef A. Hassan, Rasha M. H. Sayed-ElAhl, Ahmed M. El Hamaky, Mogda K. Mansour, Noha H. Oraby, and Mahmoud H. Barakat
13.1 Introduction 299
13.2 Traditional Methods for Detection of Animal Diseases 300
13.3 Recent Approaches of Nanomaterial Applications in Detection of Animal Diseases 301
13.3.1 Types of Nanodiagnostics 301
13.3.2 Biomedical Applications of Nanodiagnostics 302
13.4 Methods of Nanoparticle Functionalization for Disease Diagnosis 306
13.4.1 Immuno-Based Methods 307
13.4.2 Molecular-Based Methods 310
13.5 Nano Biosensors Using Biomarkers 311
13.5.1 Types of Biosensors 311
13.5.2 Optical Biosensor 313

13.5.3 Mass-Based Biosensor 313
13.5.4 Calorimetric Biosensor. 314
13.5.5 Detection of Antibody Markers 314
13.5.6 DNA Sensors 314
13.5.7 Aptasensors 315
13.5.8 Immunosensors 315
13.5.9 Miscellaneous. 316
13.6 Conclusions and Future Prospective 316
References. 317

14 Nano-Based Robotic Technologies for Plant Disease Diagnosis 327
Farah K. Ahmed, Mousa A. Alghuthaymi, Kamel A. Abd-Elsalam, Mythili Ravichandran, and Anu Kalia
14.1 Introduction 327
14.2 Pathogen Detection Methods 329
14.2.1 Morphological Tools 330
14.2.2 Molecular Tools 330
14.2.3 Omics Tools 330
14.2.4 Nano-Based Diagnostics Tools 331
14.2.5 Nanobiosensors 336
14.2.6 Nanochips. 339
14.2.7 Nanopore-Based Detection 339
14.3 Robotics Techniques for Plant Pathogens Detection 340
14.4 Nanotools for Detection of Plant Pathogens 342
14.4.1 Detection of Bacterial Pathogens. 343
14.4.2 Fungal Pathogens Detection. 344
14.4.3 Viral Pathogen Detection 345
14.5 Diagnosis of the Plant Varieties and Other Forms 346
14.6 Challenges 349
14.7 Future Trends. 351
14.8 Conclusions 351
References. 352

15 Nanodiagnostic Tools for Mycotoxins Detection 361
Velaphi C. Thipe, Giovanna de Oliveira Asenjo Mendes, Victoria M. Alves, Thayna Souza, Rachel Fanelwa Ajayi, Ademar B. Lugao, and Kattesh V. Katti
15.1 Introduction 362
15.2 Conventional Diagnostics for Mycotoxins in Agriculture 363
15.3 Nanosurveillance to Mitigate Mycotoxins. 365
15.4 Nanodiagnostics for Mycotoxins. 366
15.4.1 Sensors Based on Nanomaterials for Mycotoxin Surveillance 366
15.4.2 Metallic Nanoparticles. 367

15.5 Smart Nanosensors . . . 367
  15.5.1 Nanoparticles with Conductivity-Based Sensors . . . 367
  15.5.2 Antibody-Coupled Nanomaterials . . . 370
15.6 Smart and Antifungal Packaging Nanosurveillance . . . 376
15.7 Concluding Remarks . . . 377
References . . . 378

16 CRISPR/Cas Systems: A New Biomedical and Agricultural Diagnostic Devices for Viral Diseases . . . 383
Aftab Ahmad, Sabin Aslam, Ahmad Munir, Farah K. Ahmed, and Kamel A. Abd-Elsalam
16.1 Introduction . . . 383
16.2 CRISPR/Cas-Based Diagnostic Tools . . . 385
  16.2.1 CRISPR: An Introduction . . . 385
  16.2.2 Applications of CRISPR . . . 385
  16.2.3 CRISPR/Cas . . . 386
  16.2.4 CRISPR/Cas Mechanism . . . 386
  16.2.5 CRISPR/Cas System . . . 388
  16.2.6 CRISPR Methods and Techniques . . . 390
  16.2.7 CRISPR/Cas Diagnostic Tools . . . 392
  16.2.8 Challenges . . . 405
  16.2.9 Conclusion and Future Outlook . . . 407
References . . . 407

17 DNA-Nanosensors for Environmental Monitoring of Heavy Metal Ions . . . 411
Heba Elbasiouny, Nahed S. Amer, Sherifa F. M. Dawoud, Amina M. G. Zedan, and Fathy Elbehiry
17.1 Introduction . . . 411
17.2 Heavy Metals Pollution and Detection . . . 413
17.3 Nanobiosensors and Pollution Detection . . . 414
17.4 DNA Biosensor and DNA Nanobiosensors . . . 418
17.5 Nanosensors and DNA Nanosensors for Heavy Metals Detection . . . 421
17.6 Challenges . . . 426
17.7 Conclusion and Future Prospective . . . 427
References . . . 428

18 Smart Nanosensors for Pesticides and Heavy Metals Detection . . . 433
Nilesh Satpute, Kamlesh Shrivas, and Khemchand Dewangan
18.1 Introduction . . . 433
18.2 Overview of Sensing Techniques . . . 435
  18.2.1 The Need for Smart and Intelligent Nanosensors . . . 435
  18.2.2 Smart Nanosensors and Nanobiosensors . . . 436
  18.2.3 Operation Modes of Nanosensors . . . 436

- 18.3 Nanomaterials and their Types . . . 437
  - 18.3.1 General Aspect of Nanomaterials . . . 437
  - 18.3.2 Type of Nanomaterials . . . 438
- 18.4 Nanomaterial-Based Nanosensors/Nanobiosensors and Their Applications . . . 439
  - 18.4.1 Nanosensors for Pesticides and Heavy Metal Detection . . . 440
  - 18.4.2 Nanobiosensors for Pesticides and Heavy Metal Detection . . . 443
- 18.5 Conclusion and Future Prospective . . . 447
- References . . . 448

Index . . . 453