MICRO AND NANOTECHNOLOGIES IN ENGINEERING STEM CELLS AND TISSUES

IEEE Press
445 Hoes Lane
Piscataway, NJ 08854

MICRO AND NANOTECHNOLOGIES IN ENGINEERING STEM CELLS AND TISSUES

Edited by

MURUGAN RAMALINGAM
ESMAIEL JABBARI
SEERAM RAMAKRISHNA
ALI KHADEMHOSSEINI

IEEE Engineering in Medicine and Biology Society, *Sponsor*

IEEE Press Series in Biomedical Engineering
Metin Akay, *Series Editor*

IEEE PRESS

Library of Congress Cataloging-in-Publication Data:

Micro and nanotechnologies in engineering stem cells and tissues / edited by Murugan Ramalingam ... [et al.].
p. ; cm.
Includes bibliographical references.
ISBN 978-1-118-14042-0 (cloth)
I. Ramalingam, Murugan. II. Institute of Electrical and Electronics Engineers.
[DNLM: 1. Cell Engineering–methods. 2. Stem Cells–physiology. 3. Microtechnology–methods. 4. Nanotechnology–methods. 5. Tissue Engineering–methods. QU 325]
612.6'4018–dc23

2012039996

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

CONTENTS

PREFACE

More than a million people worldwide are in need of an organ transplant while only 100,000 transplants are performed each year. More than 100,000 Americans need a transplant each year but only 25,000 transplants are performed. Tissue engineering has become increasingly important as an unlimited source of bioengineered tissues to replace diseased organs. Tissue engineering attempts to build body parts by assembling from the basic components of biological tissues, namely, the matrix, cells, and tissue morphogenetic growth factors. As tissue-specific cells are limited in quantity, stem cells with their ability for self-renewal and pluripotency are becoming increasingly important as a cell source in regenerative medicine. These cell sources include but are not limited to bone marrow–derived stromal cells and hematopoietic cells, umbilical cord–derived stem cells, and induced pluripotent stem cells. Top-down approaches utilizing porous scaffolds with random or well-defined pore structures, seeded with cells and growth factors, have been used, in some cases successfully, as cellular constructs in the clinically relevant length scale in regenerative medicine. However, top-down approaches cannot recreate the intricate structural characteristics of native tissues at multiple nano- and microscales, leading to the formation of less than optimal composition and distribution of the extracellular matrix. It should be emphasized that the hierarchical organization of native biological tissues is optimized by evolution to balance strength, cell–cell and cell–matrix interactions, growth factor presentation, and transport of nutrients. Consequently, bottom-up approaches to build a single modular unit to mimic the structural features of native tissues and to serve as a building block for assembly to a larger tissue scale have received more attention in recent years. The processes of cell adhesion, migration, differentiation, extracellular matrix formation, and cell maturation depend on interactions at multiple length scales between the cell surface receptors

and their corresponding ligands in the matrix. The success of engineered tissues as an unlimited source for replacement of damaged organs depends on our depth of understanding of those interactions and our ability to mimic those interactions using enabling nano- and microscale technologies and to build modular scalable units for implantation. This book provides an overview of enabling micro- and nanoscale technologies in designing novel materials to elucidate the complex cell–cell and cell–matrix interactions, leading to engineered stem cells and tissues for applications in regenerative medicine. The editors, Murugan Ramalingam, Esmaiel Jabbari, Seeram Ramakrishna, and Ali Khademhosseini, thank the authors for their contribution to this timely book.

Murugan Ramalingam
Centre for Stem Cell Research, India

Esmaiel Jabbari
University of South Carolina, USA

Seeram Ramakrishna
National University of Singapore, Singapore

Ali Khademhosseini
Harvard University, USA

CONTRIBUTORS

Samad Ahadian, WPI-Advanced Institute for Materials Research (WPI-AIMR), Tohoku University, Sendai, Japan

Bikramjit Basu, Laboratory for Biomaterials, Materials Research Center, Indian Institute of Science, Bangalore, India

Allison C. Bean, Center for Cellular and Molecular Engineering, Department of Orthopaedic Surgery, University of Pittsburgh School of Medicine, Pittsburgh, PA, USA

Kimberly M. Ferlin, Fischell Department of Bioengineering, University of Maryland, College Park, MD, USA; U.S. Food and Drug Administration, Center for Devices and Radiological Health, Silver Spring, MD, USA

John P. Fisher, Fischell Department of Bioengineering, University of Maryland, College Park, MD, USA

Esmaiel Jabbari, Chemical Engineering, University of South Carolina, SC, USA

John A. Jansen, Department of Biomaterials, Radboud University Nijmegen Medical Center, Nijmegen, the Netherlands

Yunqing Kang, Orthopedic Surgery, Stanford University, CA, USA

David S. Kaplan, U.S. Food and Drug Administration, Center for Devices and Radiological Health, Silver Spring, MD, USA

Ali Khademhosseini, WPI-Advanced Institute for Materials Research (WPI-AIMR), Tohoku University, Sendai, Japan; Center for Biomedical Engineering,

Department of Medicine, Brigham and Women's Hospital, Harvard Medical School, Cambridge, MA, USA; Harvard-MIT Division of Health Sciences and Technology, Massachusetts Institute of Technology, Cambridge, MA, USA

Gaurav Lalwani, Department of Biomedical Engineering, Stony Brook University, Stony Brook, NY, USA

Sander C.G. Leeuwenburgh, Department of Biomaterials, Radboud University Nijmegen Medical Center, Nijmegen, the Netherlands

Yubao Li, Research Center for Nano-Biomaterials, Analytical and Testing Center, Sichuan University, Chengdu, P.R. China

Yukiko T. Matsunaga, Institute of Industrial Science (IIS), The University of Tokyo, Japan; PRESTO, JST, Japan

Yuya Morimoto, Institute of Industrial Science (IIS), The University of Tokyo, Japan; Takeuchi Biohybrid Innovation Project, ERATO, JST, Japan

Shayanti Mukherjee, Division of Bioengineering, National University of Singapore, Singapore; HEM Laboratory, Nanoscience and Nanotechnology Initiative, Faculty of Engineering, National University of Singapore, Singapore

Serge Ostrovidov, WPI-Advanced Institute for Materials Research (WPI-AIMR), Tohoku University, Sendai, Japan

Molamma P Prabhakaran, HEM Laboratory, Nanoscience and Nanotechnology Initiative, Faculty of Engineering, National University of Singapore, Singapore

Michael Raghunath, Division of Bioengineering, National University of Singapore, Singapore; Department of Biochemistry, Yong Loo Lin School of Medicine, National University of Singapore, Singapore

Seeram Ramakrishna, HEM Laboratory, Nanoscience and Nanotechnology Initiative, Faculty of Engineering, National University of Singapore, Singapore; Department of Mechanical Engineering, National University of Singapore, Singapore; Institute of Materials Research and Engineering, a-star, Singapore

Murugan Ramalingam, Centre for Stem Cell Research (CSCR), (A unit of Institute for Stem Cell Biology and Regenerative Medicine, Bengaluru) Christian Medical College Campus, Vellore, India; Institut National de la Santé Et de la Recherche Médicale UMR977, Faculté de Chirurgie Dentaire, Université de Strasbourg, Strasbourg, France; WPI-Advanced Institute for Materials Research (WPI-AIMR), Tohoku University, Sendai, Japan

Jason Rashkow, Department of Biomedical Engineering, Stony Brook University, Stony Brook, NY, USA

Rajeswari Ravichandran, HEM Laboratory, Nanoscience and Nanotechnology Initiative, Faculty of Engineering, National University of Singapore, Singapore; Department of Mechanical Engineering, National University of Singapore, Singapore

A. Sai Ravi Shankar, Department of Cardiology, Narayana Medical College Hospital, Nellore, Andhra Pradesh, India

Azadeh Seidi, Technology Center, Okinawa Institute of Science and Technology, Onna-son, Okinawa, Japan

Balaji Sitharaman, Department of Biomedical Engineering, Stony Brook University, Stony Brook, NY, USA

Radhakrishnan Sridhar, HEM Laboratory, Nanoscience and Nanotechnology Initiative, Faculty of Engineering, National University of Singapore, Singapore

Ryan S. Stowers, Laboratory for Cardiovascular Tissue Engineering, Department of Biomedical Engineering, University of Texas at Austin, Austin, TX, USA

Gangapatnam Subrahmanyam, Department of Cardiology, Narayana Medical College Hospital, Nellore, Andhra Pradesh, India

Laura J. Suggs, Laboratory for Cardiovascular Tissue Engineering, Department of Biomedical Engineering, University of Texas at Austin, Austin, TX, USA

Shoji Takeuchi, Institute of Industrial Science (IIS), The University of Tokyo, Japan; Takeuchi Biohybrid Innovation Project, ERATO, JST, Japan

Yahfi Talukdar, Department of Biomedical Engineering, Stony Brook University, Stony Brook, NY, USA

Garima Tripathi, Laboratory for Biomaterials, Department of Material Science and Engineering, Indian Institute of Technology, Kanpur, India

Rocky S. Tuan, Center for Cellular and Molecular Engineering, Department of Orthopaedic Surgery, University of Pittsburgh School of Medicine, Pittsburgh, PA, USA

Jayarama Reddy Venugopal, HEM Laboratory, Nanoscience and Nanotechnology Initiative, Faculty of Engineering, National University of Singapore, Singapore

Huanan Wang, Department of Biomaterials, Radboud University Nijmegen Medical Center, Nijmegen, the Netherlands; Research Center for Nano-Biomaterials, Analytical and Testing Center, Sichuan University, Chengdu, P.R. China

Yunzhi Yang, Orthopedic Surgery, Stanford University, CA, USA