Drug Delivery

EDITED BY

Ashim K. Mitra, PhD
Chairman and Curator's Professor, Pharmaceutical Sciences
School of Pharmacy
University of Missouri-Kansas City
Kansas City, Missouri

Deep Kwatra, PhD
Postdoctoral Research Fellow
School of Medicine
University of Kansas Medical Center
Kansas City, Kansas

Aswani Dutt Vadlapudi, PhD
Scientist, Technical Services
Mylan Pharmaceuticals, Inc.
Morgantown, West Virginia

JONES & BARTLETT
LEARNING

World Headquarters
Jones & Bartlett Learning
5 Wall Street
Burlington, MA 01803
978-443-5000
info@jblearning.com
www.jblearning.com

Jones & Bartlett Learning books and products are available through most bookstores and online booksellers. To contact Jones & Bartlett Learning directly, call 800-832-0034, fax 978-443-8000, or visit our website, www.jblearning.com.

Substantial discounts on bulk quantities of Jones & Bartlett Learning publications are available to corporations, professional associations, and other qualified organizations. For details and specific discount information, contact the special sales department at Jones & Bartlett Learning via the above contact information or send an email to specialsales@jblearning.com.

Production Credits
Executive Publisher: William Brottmiller
Executive Editor: Rhonda Dearborn
Editorial Assistant: Sean Fabery
Production Editor: Louis C. Bruno, Jr.
Marketing Manager: Grace Richards
Art Development Editor: Joanna Lundeen
VP, Manufacturing and Inventory Control: Therese Connell
Composition: diacriTech
Cover Design: Michael O'Donnell
Rights and Photo Research Coordinator: Ashley Dos Santos
Cover Image: Illustration © Chronis Chamalidis/ ShutterStock, Inc.; photo © photomak/ShutterStock, Inc.
Printing and Binding: Edwards Brothers Malloy
Cover Printing: Edwards Brothers Malloy

To order this product, use ISBN: 978-1-284-02568-2

Library of Congress Cataloging-in-Publication Data
Drug delivery (Mitra)
Drug delivery / [edited by] Ashim K. Mitra, Deep Kwatra, and Aswani Dutt Vadlapudi. — First edition.
p. ; cm.
Includes bibliographical references.
ISBN 978-1-4496-7425-0 (alk. paper)
I. Mitra, Ashim K., 1954– editor. II. Kwatra, Deep, editor. III. Vadlapudi, Aswani Dutt, editor. IV. Title.
[DNLM: 1. Drug Delivery Systems. QV 785]
RM170
615'.6—dc23 2014008174

6048

Printed in the United States of America
18 17 16 15 14 10 9 8 7 6 5 4 3 2 1

Contents

Preface

Drug delivery is a concept closely integrated with dosage form and route of administration. This concept is often associated with rationale-based approaches, formulation strategies, drug development technologies, and carriers for facilitating transport of a drug molecule as needed to safely achieve its desired therapeutic effect. During the past two decades, numerous drug molecules with the potential of revolutionizing the treatment of life-threatening diseases have been developed. Despite remarkable advancements, many therapeutically active pharmaceutical ingredients have been dropped from initial screening portfolios because of the lack of an efficient drug delivery method. Recent progress in the field of biotechnology, however, has encouraged researchers and scientists to develop various methods employing effective delivery systems for the administration of biologics. Numerous other technologies are also addressing ways to minimize drug toxicity and reduce adverse effects while maintaining therapeutic drug concentrations and employing suitable therapeutic regimens.

Drug delivery as a field is rapidly expanding and is of vital importance to therapeutics. There is no single text, however, that covers all areas of drug delivery at a level suitable to the needs of undergraduate, graduate, and professional students as well as peers in academia and pharmaceutical research. The majority of current texts either limit themselves to conventional technologies or focus only on a single aspect of drug delivery. This book, therefore, has been designed to thoroughly examine pertinent areas and provide a platform for developing useful concepts for drug delivery.

ORGANIZATION OF THIS TEXT

As a glance at the Contents makes clear, this book provides a very comprehensive overview of the cutting-edge research being carried out in this field with a focus on drug targeting at the molecular, cellular, and organ levels.

The first chapter, "Drug Delivery: An Evolving Concept," helps the reader understand the evolution of drug delivery concepts and recognize the factors that have an impact on drug discovery and development in pharmaceutical arenas.

Chapter 2, "Barriers to Drug Delivery," emphasizes the challenges faced by drug delivery scientists. Various barriers to drug delivery and the strategies used to overcome or evade such barriers are discussed in detail. A basic comprehension of these barriers is required to understand the concept behind the design of the delivery systems developed to overcome them.

Chapter 3, "*In Vitro* Models in Drug Discovery and Delivery," discusses various *in vitro* and *in silico* models used in the estimation of pharmacokinetic parameters of drugs and formulations with a special emphasis on cell culture models.

Chapter 4, "Routes of Drug Delivery," provides a thorough understanding of the multiple routes of administration utilized to deliver the active ingredient from common pharmaceutical dosage forms. This understanding is important as the factors that must be considered in dosage form design and selection are based not only on the patient being treated but also on the biopharmaceutically relevant advantages and disadvantages of various drug delivery routes.

The focus of Chapter 5, "Novel Drug Delivery Systems," is the wide variety of novel drug delivery systems that are currently being investigated and currently on the market.

Chapter 6, "Controlled Drug Delivery," discusses the differences between conventional and controlled drug delivery technologies. This chapter also differentiates controlled dosage forms currently available in the clinic by mechanism of release.

Chapter 7, "Polymers in Drug Delivery," describes the pharmaceutical applications of polymers in various dosage forms. This chapter allows for better understanding of polymer properties based on composition, molecular weight, and arrangement to facilitate custom design of novel delivery systems.

Chapter 8, "Multifunctional Nanocarriers for Tumor Drug Delivery and Imaging," aims to provide an overview of recent progress in the rational design of and the engineering of multifunctional systems and to illustrate the cutting-edge technology being employed in such carriers with examples of multifunctional liposomes, micelles, and nanoparticles for cancer diagnosis and treatment.

In the later part of the book, we discuss various aspects of drug delivery technologies that are utilized for various dosing routes. We also discuss how the drugs can be delivered specifically to certain organs.

Chapter 9, "Oral Delivery," provides an overview of physicochemical and biological barriers in oral delivery. Various oral dosage forms and their performance with respect to bioavailability are extensively discussed.

Chapter 10, "Ocular Drug Delivery," delves into detailed anatomy and physiology of the eye, the importance of various routes of ocular drug administration, and constraints on conventional ocular therapy. This chapter will aid in acquiring sound knowledge of various approaches to increasing ocular drug absorption. It also discusses recent progress and specific developments relating to various formulation approaches. This chapter also discusses key advances in the application of nanotechnology for gene therapy to the eye.

Chapter 11, "Transmucosal Drug Delivery," provides an overview of the importance of the transmucosal route and its advantages over traditional methods of drug delivery. This chapter describes the structure of oral mucosa, permeability barriers to drug absorption, and methods of assessing oral mucosal absorption. The chapter also details various drug delivery systems and techniques being used to optimize the delivery across oral mucosa. Commercialized formulations currently available in the market are also detailed.

Chapter 12, "Transdermal Drug Delivery," describes the anatomical and physiological factors controlling drug transport across skin. Furthermore, active transdermal technologies available to enhance percutaneous absorption and various types of transdermal patches currently available on the market are covered. This chapter also provides methods for patient counseling with regard to the

proper use and precautions necessary with the application of a transdermal drug delivery system.

Chapter 13, "Pulmonary and Nasal Drug Delivery," reviews the anatomy and physiology of the respiratory tract that governs drug delivery via the nasal and pulmonary routes. This chapter allows the reader to learn pharmaceutical and physiological factors that may affect drug deposition and absorption upon nasal and pulmonary administration. Various devices used to administer drug formulations via the respiratory route are described. A detailed and comprehensive discussion of currently available dosage forms along with recent advancements in nebulizers and metered dose and dry powder inhalers are provided. This chapter will acquaint the reader with various spacer devices and their proper usage, advantages, and disadvantages. Various respiratory drug delivery devices and formulations, as well as patient counseling for inhalational devices and drug products, are also emphasized.

Chapter 14, "Vaginal Drug Delivery," offers basic understanding of anatomy and physiology of the vagina, physiological and physicochemical factors that may affect vaginal drug absorption, and characteristics of various vaginal drug delivery systems that are currently available on the market or are in the developmental stage.

Chapter 15, "Drug Delivery to the Central Nervous System: Breaking Down the Barrier," describes the structure and importance of the blood–brain barrier. This chapter offers a detailed understanding of anatomical, physiological, and pharmacological mechanisms by which the blood–brain barrier protects the central nervous system. Furthermore, current strategies for CNS drug delivery, flexibility of novel drug delivery systems, and how they can be tailor-designed to enhance CNS drug delivery are extensively discussed.

Chapter 16, "Gene Delivery: An Essential Component for Successful Gene Therapy," details the importance of gene therapy that uses a gene-coding sequence as a pharmaceutical agent. Gene therapy requires a method effective in delivering a therapeutic gene into cells and expressing proteins where treatment is needed. Several delivery systems including viral, chemical, and physical methods are discussed. Further, this chapter provides a summary on the pros and cons of each gene delivery system currently available and provides recent perspectives on remaining challenges for future development.

Chapter 17, "Peptide and Protein Drug Delivery," discusses physicochemical differences between small molecules and protein/peptide drugs. This chapter helps in understanding the challenges faced when formulating a protein/peptide drug for oral delivery and why parenteral delivery is most often needed with such drugs. An overview of the intricacies of insulin that make non-parenteral delivery challenging and the advantages and disadvantages of different alternative routes for delivering protein/peptide drugs are discussed.

Chapter 18, "Drug Metabolomics and Proteomics Analysis in Drug Delivery and Discovery," describes proteomics and mass spectrometric analysis including sample preparation, isolation, and purification techniques. This chapter also provides an overview of mass spectrometry instrumentation and ionization techniques. It describes top-down protein and bottom-up (shotgun) peptide sequencing and application of mass spectrometry in quantitative proteomics, that is, phosphorylation, glycosylation, and post-translational modifications.

FEATURES AND BENEFITS

Each chapter includes the following elements:

- *Learning Objectives* present the chapter's desired outcomes to the reader.
- *Chapter Outline* provides a preview of the material to be covered.
- *Review Questions* allow readers to apply what has been learned in the chapter and assess their understanding of the content.

INSTRUCTOR RESOURCES

Qualified instructors can receive the full suite of instructor resources, including the following:

- PowerPoint Presentations, featuring more than 350 slides
- Test Bank, containing more than 500 questions
- Instructor's Manual, including an Answer Key for the end-of-chapter Review Questions

STUDENT RESOURCES

The Navigate Companion Website features numerous study aids and learning tools to help students get the most out of their course and prepare for class, including the following:

- Chapter Quizzes
- Interactive Glossary
- Crossword Puzzles
- Interactive Flashcards
- Matching Exercises

ACKNOWLEDGMENTS

We are very grateful to all the individual authors for their excellent contributions and massive efforts in sharing their knowledge, concepts, and expertise in various aspects of drug delivery.

Finally, we would like to acknowledge the support of the publisher and thank the production team for their relentless efforts.

Ashim K. Mitra
Deep Kwatra
Aswani Dutt Vadlapudi

Foreword

Targeted and controlled drug delivery systems can have a massive impact on therapeutic efficacy and safety. These technologies enable maximum benefit from existing drugs and provide opportunities for successful transition to new drug entities. Such advancements have added an entirely new dimension to the pharmaceutical market with sales of these technologies now in the billions of dollars annually. Importantly, multidisciplinary training is needed to understand the interface of biology and chemistry to design novel drug delivery carriers and preparations that are effective and nontoxic. Within this book Dr. Ashim K. Mitra, Dr. Deep Kwatra, and Dr. Aswani Dutt Vadlapudi have done a great job assimilating large amounts of current information about this growing area, bringing together the foremost experts from their respective fields to yield a comprehensive look at drug delivery and its relevant issues.

Drug Delivery contains up-to-date material that will inform both novices as well as advanced learners in the field. A major strength of the book is its logical organization. For example, the human body provides multiple anatomical and physiological barriers to many drugs from easily reaching their target site. The book begins with detailed descriptions of the biological barriers to drug delivery and then covers drug delivery models, routes of administration, and controlled drug delivery systems, making sure the reader first grasps the basic concepts.

Critical for advancement of the field is the creation of novel polymeric materials, which is the subject of next chapter in the book. Here, the different types of polymers and their utilization to form nanoparticles and other novel drug delivery systems are described. The formation and characterization of multifunctional nanocarriers, which can be used for both controlled and targeted drug delivery, are also explained.

Next, specific issues with key routes of administration are detailed in individual chapters. For instance, parenteral, dermal, oral, ocular, pulmonary/nasal, mucosal, and vaginal drug delivery, and delivery to the central nervous system are all given specific attention.

Remarkably, this book also covers modern therapeutic modalities, including gene therapy as well as peptide and protein therapeutics such as antibodies. Delivery of these biologics via conventional carriers poses significant challenges, which are detailed, and numerous techniques are being developed to overcome these temporary hurdles. Moreover, a number of analytical tools are required to test delivery system efficiency, all of which are explained.

Taken together, this book is a very detailed and complete compilation of all the major topics in the field of drug delivery and will prove to be a handy "go-to" reference for students, teachers, and researchers in academia and the pharmaceutical industry.

W. Daniel Stamer, PhD
Joseph A. C. Wadsworth Professor of Ophthalmology
Professor of Biomedical Engineering
Duke University

About the Editors

Ashim K. Mitra

Ashim K. Mitra received his PhD in Pharmaceutical Chemistry in 1983 from the University of Kansas. He is currently a Curators' Professor of Pharmacy at the University of Missouri-Kansas City, as well as the Vice Provost for Interdisciplinary Research, Chairman of the Division of Pharmaceutical Sciences, and Co-director of the Vision Research Center at the University of Missouri-Kansas City School of Medicine. For the past three decades he has conducted extensive research in various drug delivery technologies, including ocular drug delivery. He and his research personnel have published more than 315 peer-reviewed research articles in high-impact international journals; published more than 550 abstracts at scientific meetings, including the annual conferences of the American Association of Pharmaceutical Scientists (AAPS), the Society of Toxicology, and The Association for Research in Vision and Ophthalmology (ARVO); have given more than 115 presentations to a wide audience (including several universities, pharmaceutical companies, and scientific organizations); and have been issued nine U.S. patents. Between 2013 and 2014 alone he has edited five books and contributed to more than 60 book chapters. Several of his articles have been recognized as being among the most downloaded articles in their respective journals.

Deep Kwatra

Deep Kwatra received his interdisciplinary PhD in Pharmaceutical Sciences and Molecular Biology & Biochemistry in 2011 from the University of Missouri-Kansas City. He is currently pursuing a postdoctoral fellowship at the University of Kansas Medical Center in the Department of Molecular and Integrative Physiology. He is also a pharmacist by training with a Bachelors of Pharmacy from Smriti College of Pharmaceutical Education in Indore, India. Over the past decade he has worked extensively towards development of *in vitro* cell culture models for better prediction of bioavailability of drugs and formulations. He has also developed prodrugs specifically targeted towards influx transporters on the eye for more efficient ocular drug delivery. Additionally, he has collaborated with many labs working on enhancing delivery of small molecules and biologics to the eye. He has published more than 20 peer-reviewed scientific research and review articles in high-impact international journals. He has also contributed to many books focused on different aspects of drug delivery. He has presented more than 50 abstracts at scientific meetings, including the annual American Association of Pharmaceutical Scientists (AAPS), The Association for Research in Vision and Ophthalmology (ARVO), and American Association of Cancer Research

(AACR) conferences. He was awarded the Young Investigator Award by the American Association of Indian Scientists in Cancer Research Foundation at the AACR 2012 annual meeting.

Aswani Dutt Vadlapudi

Aswani Dutt Vadlapudi received his PhD in Pharmaceutics and Drug Design in 2013 from the University of Missouri-Kansas City School of Pharmacy. He currently holds a Managerial Scientist position at Mylan Pharmaceuticals, Inc. Dr. Vadlapudi is actively engaged in improving drug delivery and drug development strategies with extensive experience in manufacturing of solid oral dosage forms, process optimization, scale-up, and investigations. His research accomplishments include transporter targeted drug delivery, prodrug development, and formulation approaches for improving oral and ocular drug absorption of both small molecules and macromolecules. He is an active member of the American Association of Pharmaceutical Scientists (AAPS) and The Association for Research in Vision and Ophthalmology (ARVO). Dr. Vadlapudi is a member of review committees and scientific boards of many international journals. He has authored and co-authored more than 25 peer-reviewed research and review articles in reputable international journals. Most of his publications are highly cited and recognized as being among the most downloaded articles in their respective journals. He has also contributed to many book chapters in the field of drug delivery and drug development.

Contributors

Chris E. Adkins, PhD
Postdoctoral Fellow
School of Pharmacy
Texas Tech University Health Sciences Center
Amarillo, Texas
Chapter 15

Fakhrul Ahsan, PhD
Graduate Program Advisor
School of Pharmacy
Texas Tech University Health Sciences Center
Amarillo, Texas
Chapter 13

Mohammad Al Saggar, BSc
PhD Candidate
College of Pharmacy
University of Georgia
Athens, Georgia
Chapter 16

Gabriella Baki, PhD
Visiting Assistant Professor
College of Pharmacy and Pharmaceutical Sciences
The University of Toledo
Toledo, Ohio
Chapter 14

Ajay K. Banga, PhD
Professor and Department Chair
College of Pharmacy and Health Sciences
Mercer University
Atlanta, Georgia
Chapter 12

Sai H. S. Boddu, PhD
Assistant Professor
College of Pharmacy and Pharmaceutical Sciences
The University of Toledo
Toledo, Ohio
Chapters 4 and 14

Kaci A. Bohn, PhD
Assistant Professor
College of Pharmacy
Harding University
Searcy, Arkansas
Chapter 15

Stephen Carl, PhD
Associate Director of Formulation Development
Enteris BioPharma, Inc.
Fairfield, New Jersey
Chapter 17

Kishore Cholkar, MS
Research Assistant
School of Pharmacy
University of Missouri—Kansas City
Kansas City, Missouri
Chapter 10

Supriya Reddy Dasari
Research Assistant
School of Pharmacy
University of Missouri—Kansas City
Kansas City, Missouri
Chapter 10

Patrick P. DeLuca, PhD
Professor Emeritus
College of Pharmacy
University of Kentucky
Lexington, Kentucky
Chapter 5

Ravinder Earla, PhD
Research Associate
School of Pharmacy
University of Missouri-Kansas City
Kansas City, Missouri
Chapter 18

Song Gao, PhD
Research Assistant Professor
College of Pharmacy
University of Houston
Houston, Texas
Chapter 9

Ripal Gaudana, PhD
Formulation Scientist
Par Pharmaceutical Companies, Inc.
Spring Valley, New York
Chapter 4

Olafur Gudmundsson, PhD
Director
Bristol-Myers Squibb
Princeton, New Jersey
Chapter 17

Meera Gujjar, BS
PhD Candidate
College of Pharmacy and Health Sciences
Mercer University
Atlanta, Georgia
Chapter 12

Nilesh Gupta
PhD Candidate
Chair-elect, AAPS Student Chapter
School of Pharmacy
Texas Tech University Health Sciences Center
Amarillo, Texas
Chapter 13

Anushree Kishor Herwadkar, PhD
Scientist I, PRD
Teva Pharamceuticals
Pomona, New York
Chapter 12

Ming Hu, PhD
Professor
College of Pharmacy
University of Houston
Houston, Texas
Chapter 9

Bhaskara Jasti, PhD
Professor and Chairman
Thomas J. Long School of Pharmacy

University of the Pacific
Stockton, California
Chapter 11

Wen Jiang
Graduate Student
College of Pharmacy
University of Houston
Houston, Texas
Chapter 9

Vamsi K. Karuturi
Research Assistant
University of Nebraska Medical Center
Omaha, Nebraska
Chapter 6

Navdeep Kaur, PhD
Research Assistant
Thomas J. Long School of Pharmacy
University of the Pacific
Stockton, California
Chapter 11

Varun Khurana, PhD
Formulation Scientist
Insys Therapeutics, Inc.
Chandler, Arizona
Chapter 3

Gregory Knipp, PhD
Associate Professor
College of Pharmacy
Purdue University
West Lafayette, Indiana
Chapter 17

Amit Kokate, PhD
Principal Scientist
Teva Pharmaceuticals
Pomona, New York
Chapter 11

Chris Kulczar
Graduate Student
College of Pharmacy
Purdue University
West Lafayette, Indiana
Chapter 17

Young Kwon, PhD
Assistant Professor
College of Pharmacy
Nova Southeastern University
Fort Lauderdale, Florida
Chapter 7

Xiaoling Li, PhD
Associate Dean and Professor
Thomas J. Long School of Pharmacy
University of the Pacific
Stockton, California
Chapter 11

Dexi Liu, PhD
Panoz Professor of Pharmacy
College of Pharmacy
University of Georgia
Athens, Georgia
Chapter 16

Paul R. Lockman, PhD
Chair, Basic Pharmaceutical Science
School of Pharmacy
Texas Tech University Health Sciences Center
Amarillo, Texas
Chapter 15

Yong Ma, BS
Graduate Student
College of Pharmacy
University of Houston
Houston, Texas
Chapter 9

Heidi M. Mansour, PhD
Assistant Professor
College of Pharmacy
The University of Arizona—Tucson
Tucson, Arizona
Chapter 5

David Mastropietro, BPharm, RPh
Research Assistant
College of Pharmacy
Nova Southeastern University
Fort Lauderdale, Florida
Chapter 7

Samantha A. Meenach, PhD
Assistant Professor
College of Engineering

University of Rhode Island
Kingston, Rhode Island
Chapter 5

Sara Movassaghian, PhD
Postdoctoral Fellow
Center for Pharmaceutical Biotechnology and Nanomedicine
Northeastern University
Boston, Massachusetts
Chapter 8

Srinath Muppalaneni, MS
Research Assistant
College of Pharmacy
Nova Southeastern University
Fort Lauderdale, Florida
Chapter 7

Gemma Navarro, PhD
Postdoctoral Fellow
Center for Pharmaceutical Biotechnology and Nanomedicine
Northeastern University
Boston, Massachusetts
Chapter 8

Jerry Nesamony, PhD
Assistant Professor
College of Pharmacy and Pharmaceutical Sciences
The University of Toledo
Toledo, Ohio
Chapter 14

Sanko Nguyen, PhD
Postdoctoral Fellow
College of Pharmacy and Pharmaceutical Sciences
The University of Toledo
Toledo, Ohio
Chapter 14

Mohamed Ismail Nounou, PhD
Postdoctoral Fellow
School of Pharmacy
Texas Tech University Health Sciences Center
Amarillo, Texas
Chapter 15

Hossein Omidian, PhD
Assistant Professor
College of Pharmacy
Nova Southeastern University
Fort Lauderdale, Florida
Chapter 7

Chun-Woong Park, PhD
Assistant Professor
College of Pharmacy
Chungbuk National University
Cheongju, Republic of Korea
Chapter 5

Kinam Park, PhD
Showalter Distinguished Professor of Biomedical Engineering
College of Pharmacy
Purdue University
West Lafayette, Indiana
Chapter 7

Brijeshkumar Patel, PhD
Research Assistant
School of Pharmacy
Texas Tech University Health Sciences Center
Amarillo, Texas
Chapter 13

Yun-Seok Rhee, PhD
Assistant Professor
College of Pharmacy
Gyeongsang National University
Jinju, Republic of Korea
Chapter 5

Wyatt Roth, PhD
Research Scientist
Eli Lilly and Company
Indianapolis, Indiana
Chapter 17

Sujay J. Shah, BPharm
Research Assistant
School of Pharmacy
University of Missouri-Kansas City
Kansas City, Missouri
Chapter 2

Sutthilug Sotthivirat, PhD
Department of Product Value Enhancement
Merck & Company, Inc.
West Point, Pennsylvania
Chapter 6

Shailendra B. Tallapaka, BPharm
Graduate Assistant
University of Nebraska Medical Center
Omaha, Nebraska
Chapter 6

Tori B. Terrell-Hall
School of Pharmacy
Texas Tech University Health Sciences Center
Amarillo, Texas
Chapter 15

Vladimir P. Torchilin, PhD
Director
Center for Pharmaceutical Biotechnology and Nanomedicine
Northeastern University
Boston, Massachusetts
Chapter 8

Ramya Krishna Vadlapatla, PhD
Scientist, Technical Services
Mylan Pharmaceuticals, Inc.
Morgantown, West Virginia
Chapter 2

Joseph A. Vetro, PhD
Assistant Professor
College of Pharmacy
University of Nebraska Medical Center
Omaha, Nebraska
Chapter 6

Zhen Xu, PhD
Postdoctoral Fellow
School of Pharmacy
University of Maryland
Baltimore, Maryland
Chapter 5

Zhen Yang
Graduate Student
College of Pharmacy
University of Houston
Houston, Texas
Chapter 9

Reviewers

Yun Bai, PhD
Assistant Professor
School of Pharmacy
Philadelphia College of Osteopathic Medicine
Suwanee, Georgia

Mark J. Chirico, PharmD
Director, Experiential Education
College of Pharmacy
Belmont University
Nashville, Tennessee

Sarah L. Clement, EdS
Program Coordinator
Pharmacy Technology Program
Forsyth Technical Community College
Winston-Salem, North Carolina

Denise Leach, PA-C
Assistant Professor
College of Physician Assistant Studies
Alderson Broaddus University
Philippi, West Virginia

Cristobal L. Miranda, PhD, MS, DVM
Research Assistant Professor
College of Pharmacy
Oregon State University
Corvallis, Oregon