Molecular Genetic Pathology

Liang Cheng
David Y. Zhang
John N. Eble
Editors

Molecular Genetic Pathology

Second Edition

Editors

Liang Cheng
Department of Pathology and Laboratory Medicine
Indiana University School of Medicine
Indianapolis, IN, USA

David Y. Zhang
Department of Pathology
Mount Sinai School of Medicine
New York, NY, USA

John N. Eble
Department of Pathology and Laboratory Medicine
Indiana University School of Medicine
Indianapolis, IN, USA

ISBN 978-1-4614-4799-3   ISBN 978-1-4614-4800-6 (eBook)
ISBN 978-1-4614-4801-3 (print and electronic bundle)
DOI 10.1007/978-1-4614-4800-6
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2012952466

© Springer Science+Business Media New York 2013

This work is subject to copyright. All rights are reserved 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. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.

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.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Since the first edition of this textbook, the field of molecular genetic pathology has expanded exponentially. The advent of complete cancer genome sequencing, emerging tests for identification of infectious agents, new diagnostic molecular tests, and biomarkers for targeted therapy have demonstrated the importance of molecular tools both in patient care and in the practice of pathology. Furthermore, the development of many new technologies, including various microarray platforms, nanotechnology, and next-generation sequencing, has revolutionized the practice of molecular genetic pathology. The rapid growth of this field has led to an expansion of knowledge of molecular processes and many more clinical applications in molecular diagnostics. Thus, we recognize the need to update this textbook and hope that the second edition of the *Molecular Genetic Pathology* will continue to be the best available “quick reference” for pathologists, oncologists, geneticists, primary care physicians, and other medical professionals with an interest in this specialty. In addition, it is our continued belief that a concise overview of the field of molecular genetic pathology, emphasizing its clinical applications, will help not only practicing physicians, but also those in training, including residents and fellows in various disciplines.

The first edition of the *Molecular Genetic Pathology* has received much positive feedback from its readers. The two main features of the book commended by readers are the concise bullet-point format and the many useful charts and figures. These remain in the second edition. It should also be noted that over 100 leading experts have contributed to this new edition. The second edition of the *Molecular Genetic Pathology* is composed of seven sections, and 46 chapters. Sections 1 and 2 explore the basic principles and methodology of molecular genetic techniques. Sections 3 through 7 focus on disease-based information, including genetic disorders, molecular microbiology, hematologic malignancy assessment, diagnosis of hematological disorders, specialized applications of molecular tools, and management of the molecular laboratory.

Assembling this diverse textbook has truly been a team effort, cutting across many traditional specialty boundaries. We are most grateful for all the contributors who have made this project possible and to the readers of the first edition who provided much valuable feedback. Our special thanks go to Ms. Tracey Bender, without whose outstanding work this textbook would have been an impossible achievement. We would like to thank Mr. Ryan P. Christy from the Multimedia Education Division of the

Department of Pathology at Indiana University, who has edited the illustrations for the handbook. We would also like to thank the staff at Springer, including Mr. Richard Hruska, Ms. Maureen Alexander, Ms. Neha Thapa, Ms. Saranya Jayakumar, and other colleagues for their assistance in the development and editing of this textbook.

January 2013

Liang Cheng, MD
David Y. Zhang, MD, PhD
John N. Eble, MD

Biography

Liang Cheng, MD, Professor of Pathology and Urology, Director of Molecular Pathology Laboratory, Chief of Genitourinary Pathology Division, Director, Fellowship in Urologic Pathology, Indiana University School of Medicine, Indianapolis, IN, USA

Dr. Liang Cheng is professor of pathology and urology at the Indiana University School of Medicine, Indianapolis, Indiana, USA. Currently, he is the chief of the Genitourinary Pathology Service, director of the Urologic Pathology Fellowship Program, and director of Molecular Diagnostics and Molecular Pathology Laboratories. Dr. Cheng is board certified in molecular genetic pathology and anatomic and clinical pathology by the American Board of Pathology. He graduated from Beijing Medical University, China. Dr. Cheng completed his pathology residency at Case Western Reserve University, Cleveland, Ohio, and his fellowship at the Mayo Clinic, Rochester, Minnesota, in 1998. Dr. Cheng has received numerous prestigious awards including the Stowell-Orbison Award from the United States and Canadian Academy of Pathology (USCAP) and the Koss Medal Award from the International Society of Urological Pathology (ISUP). In 2006, he was the Arthur Purdy Stout Prize recipient from the Arthur Purdy Stout Society of Surgical Pathologists in recognition of outstanding contributions to the field of surgical pathology by a surgical pathologist less than 45 years old. Dr. Cheng has published more than 500 peer-reviewed articles in

high-impact scientific journals. He was also the author of over 60 book chapters and several books. Currently, he is an active member of over 30 editorial boards. His research focuses on molecular genetics and biological predictors of genitourinary cancers.

David Y. Zhang, MD, PhD, MPH, Director, Molecular Pathology Laboratory, Professor, Departments of Pathology and Oncological Sciences, Mount Sinai School of Medicine, New York, NY, USA

David Y. Zhang MD, Ph.D., MPH, is the director of the Molecular Pathology Division. He obtained his MD from Norman Bethune School of Medicine of Jilin University, Ph.D. from New York University School of Medicine, and MPH from Mount Sinai School of Medicine. He subsequently completed his residency training in anatomic and clinical pathology as well as fellowship training in cytopathology and clinical microbiology at Mount Sinai School of Medicine, New York. He also completed second residency in preventive medicine (occupational medicine) at the Selikoff Center, Mount Sinai School of Medicine. He is licensed to practice medicine in New York and New Jersey and certified in anatomic and clinical pathology, cytopathology, molecular genetic pathology by the American Boards of Pathology and Medical Genetics as well as in preventive medicine by the American Board of Preventive Medicine. He currently practices surgical pathology, cytopathology, and molecular pathology with a strong interest in solid tumor pathology. His major research interest is to develop genomic and proteomic technologies for biomarker discovery and molecular diagnosis. He currently holds more than 10 US and international patents and has published more than 50 scientific papers in major peer-reviewed journals and more than 10 book chapters.

John N. Eble MD, MBA, FRCPA, Nordschow Professor and Chairman, Department of Pathology and Laboratory Medicine, Indiana University School of Medicine, Indianapolis, IN, USA

Dr. John Eble obtained his medical degree from the Indiana University School of Medicine, where he also took his residency in anatomic and clinical pathology. Following residency, he joined the faculty of the Department of Pathology and Laboratory Medicine of Indiana University and became the head of the clinical laboratories at the Roudebush VA Medical Center at the Indiana University Medical Center. While at the VA, he established the first diagnostic molecular pathology laboratory in Indiana. A few years later, he attended the Indiana University Graduate School of Business and received an MBA degree in 1990. Dr. Eble continued as the VA chief of service until 2000. In 1998, Dr. Eble was appointed chairman of the Department of Pathology and Laboratory Medicine of the Indiana University School of Medicine and chief pathologist of Indiana University Health. In addition to his leadership activities, Dr. Eble currently signs out the urologic surgical pathology cases of Indiana University Health one week a month. While these events were developing, Dr. Eble used the rich clinical material of the VA Medical Center and IU Health as a foundation upon which to study urologic pathology. He has published more than 225 peer-reviewed papers, more than 30 book chapters, and 3 books devoted to diseases of the organs of the urinary tract and male genital system. With Jonathan Epstein, Guido Sauter, and Isabell Sesterhenn, he edited the 2004 World Health Organization “blue book” *World Health Organization Classification of Tumours. Pathology and Genetics of Tumours of the Urinary System and Male Genital Organs*.

Dr. Eble has shared his knowledge of urologic pathology with thousands of pathologists and urologists around the world. He served on the faculty of the pathology review course of the American Urologic Association from 1991 to 2000. He gave a course on renal neoplasia (with David Grignon) for the American Society of Clinical Pathologists from 2005 to 2008, directed their 73rd annual Slide Seminar on Anatomic Pathology in 2005, and is presently on the faculty of their annual course *Contemporary Issues in Urologic Pathology*. He served on the faculty of the annual Harvard course *Urologic*

Surgical Pathology for the Practicing Pathologist since its inception in 1997 to 2011. He became active in the International Society for Urologic Pathology at the time it was founded in 1990. He served as a councillor from 1991 to 1995, as its treasurer from 1995 to 2001, and its president-elect and president from 2001 to 2005. The Society awarded him the Leopold Koss Medal for Distinguished Service in 2003. With David Bostwick, Dr. Eble gave his first short course for the USCAP, *Incipient Neoplasia in Diagnostic Urologic Pathology*, from 1994 to 1998. This was followed by *Tumors of the Kidneys and Ureters* (with Stephan Störkel) from 1997 to 2000. Next was *Renal Neoplasia: Diagnostic Problems and Newly Recognized Entities* (with Holger Moch) from 2005 to 2008. Most recently, he has given *Handling and Reporting of Tumor-containing Specimens in Urologic Pathology* (with David Grignon). In 2008, he directed the Long Course, *Tumors of the Kidneys and Urinary Bladder* with David Grignon. When Dr. Mills announced he would be stepping down as editor of *Modern Pathology*, Dr. Eble had been editing the quarterly *Journal of Urologic Pathology* for 3 years and was looking for an opportunity to edit a major monthly pathology journal and so he applied for the position. The Academy selected him and he became the fourth editor of *Modern Pathology* in 2000. The Academy honored Dr. Eble with the F.K. Mostofi Award for distinguished service in 2010. The Royal College of Pathologists of Australasia made Dr. Eble an honorary fellow in 2001.

Contents

Volume 1

Section 1	Basic Principles in Molecular Genetic Pathology	1
1	Clinical Molecular Biology: Principles Shaobo Zhang, Darrell D. Davidson, and Liang Cheng	3
2	Clinical Cytogenetics: Principles Stuart Schwartz	43
3	Conceptual Evolution in Cancer Biology Shaobo Zhang, Darrell D. Davidson, Rodolfo Montironi, Antonio Lopez-Beltran, Gregory T. MacLennan, and Liang Cheng	77
4	Genetic Inheritance and Population Genetics Tatiana Foroud and Daniel L. Koller	111
5	Clonality Analysis and Tumor of Unknown Primary: Applications in Modern Oncology and Surgical Pathology Liang Cheng, Shaobo Zhang, Federico A. Monzon, Timothy D. Jones, and John N. Eble	129
6	Modern Immunohistochemistry in Targeted Therapy Allen M. Gown	181
7	Systems Pathology José Costa and Michael J. Donovan	197
Section 2	Methodology in Molecular Genetic Pathology	209
8	Diagnostic Methodology and Technology in Molecular Genetic Pathology Josephine Wu, Fei Ye, Miao Cui, Robert Shibata, Ruliang Xu, Liang Cheng, and David Y. Zhang	211

9 Clinical Flow Cytometry in Molecular Genetic Pathology	301
Magdalena Czader	
10 Clinical Genomics in Oncology	335
Hugo M. Horlings, Thalia A. Farazi, and Marc J. van de Vijver	
11 Clinical Proteomics in Molecular Genetic Pathology	369
David H. Geho, Virginia Espina, Lance A. Liotta, Emanuel F. Petricoin, and Julia D. Wulfschlegel	
12 Nanotechnology in Molecular Diagnostics	383
Andrew N. Young and Brad A. Kairdolf	
13 Gene Therapy: Vector Technology and Clinical Applications	399
Sunyong Tang and Kenneth Cornetta	
14 Instrumentation for Molecular Testing	413
Jordan Laser, Miao Cui, Bruce E. Petersen, Fei Ye, and David Y. Zhang	
15 Tissue Microarrays and Biomarker Validation in Molecular Diagnostics	455
Martina Storz and Holger Moch	
16 Laser Capture Microdissection in Molecular Diagnostics	465
Liang Cheng, Shaobo Zhang, Darrell D. Davidson, Matthew Kuhar, Mingsheng Wang, Sean R. Williamson, David Y. Zhang, and Gregory T. MacLennan	
17 Human Tissue Biorepository	483
William E. Grizzle, Katherine C. Sexton, and Walter C. Bell	
18 Pathology Informatics	499
Roy E. Lee, Long Phi Le, and John Gilbertson	
Section 3 Genetic Disorders	515
19 Prenatal Cytogenetic and Cytogenomic Diagnosis	517
Ninette Cohen and Lisa Edelmann	
20 Molecular Medical Genetics	529
Lisa Edelmann, Stuart Scott, Liu Liu, and Ruth Kornreich	
 Volume 2	
21 Biochemical Genetics and Inborn Errors of Metabolism	561
Chunli Yu, Melissa P. Wasserstein, and George A. Diaz	

22	Molecular Genetics of Congenital Heart Disease	591
	Abigail S. Carey and Bruce D. Gelb	
23	Familial Cancer Syndrome	607
	Beth T. Harrison, Rodolfo Montironi, Antonio Lopez-Beltran, Michelle P. Elieff, and Liang Cheng	
24	Genetic Counseling	645
	Kimberly A. Quaid and Lisa J. Cushman	
Section 4	Molecular Microbiology	653
25	Molecular Virology	655
	Fei Ye, Miao Cui, Rame H. Khasawneh, Robert Shibata, Josephine Wu, Mona Sharaan, and David Y. Zhang	
26	Molecular Bacteriology and Mycobacteriology	733
	Jeong Hwan Shin, Mona Sharaan, Josephine Wu, Miao Cui, David Y. Zhang, and Yi-Wei Tang	
27	Molecular Parasitology and Mycology	781
	Vincent J. LaBombardi and Wei Wang	
28	Molecular Microbiology in Transplantation	795
	Adnan A. Alatoom and Robin Patel	
29	Molecular Microbiology Epidemiology	813
	Miao Cui, Fei Ye, and David Y. Zhang	
Section 5	Hematologic Malignancies	823
30	Immunoglobulin and T Cell Receptor Gene Rearrangement: Principle	825
	Jeffrey E. Miller	
31	Lymphoblastic Leukemia and Lymphoma: Molecular Diagnostics	857
	Dan Jones and Zeqiu J. Han	
32	Myeloid Neoplasms: Molecular Diagnostics	865
	C. Cameron Yin and Dan Jones	
33	Lymphoid Malignancies: Molecular Diagnostics	887
	Vasiliki Leventaki and Francisco Vega	
34	Myeloproliferative Neoplasms and Myelodysplastic Syndromes: Molecular Diagnostics	929
	Gerlinde Wernig and Daniel A. Arber	
35	Lymphoproliferative Disorders: Molecular Diagnostics ...	945
	Timothy C. Greiner	

Section 6 Hematological Disorders and Specialized Applications 953

- 36 Molecular Testing for Coagulation Abnormalities 955**
Veshana Ramiah and Thomas L. Ortel
- 37 Molecular Hemoglobinopathies 975**
Tina Y. Fodrie, Shaobo Zhang, Mina Patel,
Jodi A. Parks, and Liang Cheng
- 38 HLA System and Transfusion Medicine: Molecular Approach 993**
S. Yoon Choo
- 39 Clinical Pharmacogenomics 1009**
Catalina López-Correa and Lawrence M. Gelbert
- 40 Molecular Forensic Pathology 1033**
Stephen R. Dlouhy and P. Michael Conneally
- 41 Specimen Identification and Bone Marrow Engraftment Analysis 1049**
Loren Joseph
- 42 Circulating Tumor Cells: Liquid Biopsy for Molecular Pathology 1065**
Jeffrey S. Ross

Section 7 Laboratory Management in Molecular Genetic Pathology 1081

- 43 Molecular Testing: Ethical and Legal Issues 1083**
Kimberly A. Quaid
- 44 Molecular Testing: Regulatory Issues 1091**
Frank S. Ong, Wayne W. Grody, and Kingshuk Das
- 45 Molecular Pathology Reporting 1109**
Stacey S. O'Neill and Margaret L. Gulley
- 46 Laboratory Management: Quality Assurance and Inspection 1117**
Kristin M. Post and Liang Cheng
- Index 1129**

Contributors

Adnan A. Alatoom, MD, PhD, ABMM, FCAP Assistant Professor of Clinical Pathology and Microbiology, Department of Pathology, University of Texas Southwestern Medical Center, Dallas, TX, USA

Daniel A. Arber, MD Professor - Med Center Line, Pathology, Department of Pathology, Stanford University School of Medicine, Stanford, CA, USA

William C. Bell, MD Associate Professor, Department Anatomic Pathology, University of Alabama School of Medicine, Birmingham, AL, USA

Abigail S. Carey, MD Department of Pediatrics, Mount Sinai School of Medicine, New York, NY, USA

Liang Cheng, MD Professor of Pathology and Urology, Director of Molecular Pathology Laboratory, Chief of Genitourinary Pathology Division, Director, Fellowship in Urologic Pathology, Indiana University School of Medicine, Indianapolis, IN, USA

S. Yoon Choo, MD Associate Professor of Pathology and Medicine, Director of Immunogenetics and Associate Medical Director of Transfusion Medicine, Mount Sinai School of Medicine, New York, NY, USA

Ninette Cohen, PhD Assistant Professor, Mount Sinai School of Medicine, Genetic and Genomic Sciences, New York, NY, USA

P. Michael Conneally, PhD Professor of Medical and Molecular Genetics, Department of Medical and Molecular Genetics, Indiana University School of Medicine, Indianapolis, IN, USA

Kenneth Cornetta, MD Joe C. Christian Professor and Chair, Department of Medical and Molecular Genetics, Indiana University School of Medicine, Indianapolis, IN, USA

José Costa, MD Professor of Pathology and Medicine, Vice Chairman, Department of Pathology, Yale University School of Medicine, New Haven, CT, USA

Miao Cui, MD Associate Researcher of Pathology, Department of Pathology, Mount Sinai School of Medicine, New York, NY, USA

Lisa J. Cushman, PhD, CGC Hayes, Inc., Landsale, PA, USA

Magdalena Czader, MD, PhD Director, Division of Hematopathology, Director, Clinical Flow Cytometry Laboratory, Department of Pathology and Laboratory Medicine, Indiana University School of Medicine, Indianapolis, IN, USA

Kingshuk Das, MD Assistant Clinical Professor, Department of Pathology and Laboratory Medicine, UCLA David Geffen School of Medicine, Los Angeles, CA, USA

Darrell D. Davidson, MD, PhD Clinical Assistant Professor, Indiana University School of Medicine, IU Health Pathology Laboratory, Indianapolis, IN, USA

George A. Diaz, MD, PhD Associate Professor, Department of Genetics & Genomic Sciences, Mount Sinai School of Medicine, New York, NY, USA

Stephen R. Dlouhy, PhD Associate Research Professor, Department of Medical and Molecular Genetics, Indiana University School of Medicine, Indianapolis, IN, USA

Michael J. Donovan, PhD, MD Professor of Pathology, Director of Experimental Pathology, Mount Sinai School of Medicine, New York, NY, USA

John N. Eble, MD, MBA, FRCPA Nordschow Professor and Chairman, Department of Pathology and Laboratory Medicine, Indiana University School of Medicine, Indianapolis, IN, USA

Lisa Edelmann, PhD Associate Professor, Department of Genetic and Genomic Sciences, Mount Sinai School of Medicine, New York, NY, USA

Michelle Elieff, MD Forensic Pathologist, Sparrow Forensic Pathology Services, Lansing, MI, USA

Virgina Espina, MS Research Assistant Professor, George Mason University, Center for Applied Proteomics and Molecular Medicine, Manassas, VA, USA

Thalia A. Farazi, MD, PhD Instructor in Clinical investigation, Howard Hughes Medical Institute, Laboratory of RNA Molecular Biology, The Rockefeller University, New York, NY, USA

Tina Y. Fodrie, MT, MP(ASCP) Laboratory Manager, Translational Research and Clinical Coordinator, Laboratory for Personalized Molecular Medicine, San Diego, California, USA

Tatiana Foroud, PhD Chancellor's Professor, P. Michael Conneally Professor of Medical and Molecular Genetics, Director, Division of Hereditary Genomics, Department of Medical and Molecular Genetics, Indiana University School of Medicine, Indianapolis, IN, USA

David H. Geho, MD, PhD Associate Director, Imaging, Merck and Company, Inc., West Point, PA, USA

Bruce D. Gelb, MD Director, Child Health and Development Institute, New York, NY, USA; Professor of Pediatrics, Cardiology, Professor of Genetics & Genomic Sciences, Mount Sinai School of Medicine, New York, NY, USA

Lawrence Gelbert, PhD Managing Member at LMG PharmaTech, LLC, Indianapolis, IN, USA; Adjunct Professor of Pediatrics, Herman B Wells Center for Pediatric Research, Indiana University School of Medicine, Indianapolis, IN, USA

John Gilbertson, MD Associate Professor of Pathology, Harvard Medical School, Department of Pathology, The Massachusetts General Hospital, Boston, MA, USA

Allen M. Gown, MD Medical Director and Chief Pathologist, PhenoPath Laboratories, Seattle, WA, USA; Clinical Professor of Pathology, University of British Columbia, Vancouver, BC, Canada

Timothy C. Greiner, MD Professor, Department of Pathology and Microbiology, University of Nebraska Medical Center, Omaha, NE, USA

William E. Grizzle, MD, PhD Professor of Pathology, Head, Program for Translational Research in Neoplasia, Director, Tissue Procurement and Banking Facility, Senior Scientist, UAB Comprehensive Cancer Center; Center for Aging; Metabolic Bone Disease Research Center, Senior Editor, Clinical Cancer Research, Birmingham, AL, USA

Wayne W. Grody, MD, PhD Professor, Divisions of Medical Genetics and Molecular Pathology, Departments of Pathology and Laboratory Medicine, Pediatrics, and Human Genetics, UCLA School of Medicine, Los Angeles, CA, USA

Margaret L. Gulley, MD Professor of Pathology, University of North Carolina, Chapel Hill, NC, USA

Zequi J. Han, MD Department of Pathology, Quest Diagnostics Nichols Institute, Chantilly, VA, USA

Beth T. Harrison, MD Department of Pathology, NYU Langone Medical Center, New York, NY, USA

Hugo M. Horlings, MD, PhD Pathologist, Academic Medical Center, Amsterdam, The Netherlands

Dan Jones, MD, PhD Medical Director, Cancer Diagnostics Services, Quest Diagnostics Nichols Institute, Chantilly, VA, USA

Timothy D. Jones, MD Staff Pathologist, East Louisville Pathologists, PSC, Louisville, KY, USA

Loren Joseph, MD Director, Molecular Pathology Laboratory, Department of Pathology, University of Chicago Medical Center, Chicago, IL, USA

Brad A. Kairdolf, PhD Postdoctoral Fellow, Department of Biomedical Engineering, Emory University and Georgia Institute of Technology, Atlanta, GA, USA

Rame H. Khasawneh, MD Molecular Genetic Pathology Fellow, Department of Pathology, Mount Sinai School of Medicine, New York, NY, USA

Daniel L. Koller, PhD Assistant Research Professor, Department of Medical and Molecular Genetics, Indiana University School of Medicine, Indianapolis, IN, USA

Ruth Kornreich, PhD Research Assistant Professor of Human Genetics, Co-Director Genetic Testing Laboratory, Department of Human Genetics, Mount Sinai School of Medicine and the Mount Sinai Medical Center, New York, NY, USA

Matthew Kuhar, MD Associate Dermatopathologist, StrataDx & Strata Pathology Services, One Cranberry Hill, Lexington, MA, USA

Vincent J. LaBombardi, PhD Chief of Microbiology, New York Hospital-Queens, Flushing, NY, USA

Jordan Laser, MD Assistant Professor of Pathology, Director of Molecular Pathology, Department of Pathology and Laboratory Medicine, North Shore / Long Island Jewish Health System, Manhasset, NY, USA

Long Phi Le, MD, PhD Assistant Professor of Pathology, Harvard Medical School, Department of Pathology, The Massachusetts General Hospital, Boston, MA, USA

Roy E. Lee, MD Associate Medical Director for the Center of Pathology Informatics, Pathology and Laboratory Medicine Institute, The Cleveland Clinic, Cleveland, OH, USA

Vasiliki Leventaki, MD Hematopathology Fellow, Department of Hematopathology, The University of Texas MD Anderson Cancer Center, Houston, TX, USA

Lance A. Liotta, MD, PhD Professor, George Mason University, Center for Applied Proteomics and Molecular Medicine, Manassas, VA, USA

Antonio Lopez-Beltran, MD, PhD Professor of Anatomic Pathology, Unit of Anatomic Pathology, Department of Surgery, Cordoba University School of Medicine, Cordoba, Spain

Catalina López-Correa, MD, PhD Vice-présidente, Affaires scientifiques/CSO, Génome Québec, Montréal (Québec)

Liu Liu, PhD, FACMG Associate Lab Director, Assistant Professor, Cancer Genetics Laboratory, Baylor College of Medicine, Houston, TX, USA

Gregory T. MacLennan, MD Professor of Pathology, Director, Anatomic Pathology, Case Western Reserve University, Cleveland, OH, USA

Jeffrey E. Miller, PhD Chief Scientific & Chief Executive Officer of Invivoscribe Technologies, Inc, and the Laboratory for Personalized Molecular Medicine, LabPMM, San Diego, CA, USA

Holger Moch, MD Professor and Chairman, Institute of Surgical Pathology, Department Pathology, University Hospital Zürich, Zürich, Switzerland

Rodolfo Montironi, MD, FRCPath Professor of Pathology, Institute of Pathological Anatomy and Histopathology, Polytechnic University of the Marche Region (Ancona), School of Medicine, United Hospitals, Ancona, Italy

Federico Monzon, MD Associate Professor, Director of Molecular Pathology, Cancer Genetics Laboratory at Baylor College of Medicine, Departments of Pathology & Immunology and Molecular & Human Genetics at Baylor College of Medicine, Houston, TX, USA

Stacey S. O'Neill, MD, PhD Molecular Genetic Pathology Fellow, University of North Carolina, Chapel Hill, NC, USA

Frank S. Ong, MD Department of Pathology and Laboratory Medicine, Cedars-Sinai Medical Center, Los Angeles, CA, USA

Thomas L. Ortel, MD, PhD Professor of Medicine and Pathology, Hemostasis and Thrombosis Center, Duke University Medical Center, Durham, NC, USA

Jodi A. Parks, MD Department of Pathology and Laboratory Medicine, Indiana University School of Medicine, Indianapolis, IN, USA

Mina Patel, MT, MP(ASCP) Supervisor, Molecular Pathology Laboratory, Roudebush VA Medical Center, Indianapolis, IN, USA

Robin Patel, MD(CM), FRCP(C), D(ABMM), FIDSA, FACP, F(AAM) Professor of Microbiology and Medicine, Chair, Division of Clinical Microbiology, Consultant, Divisions of Clinical Microbiology and Infectious Diseases, Mayo Clinic, Rochester, MN, USA

Bruce E. Petersen, MD Assistant Professor, Pathology and Medicine, Mount Sinai School of Medicine, New York, NY, USA

Emanuel F. Petricoin, PhD Professor, George Mason University, Center for Applied Proteomics and Molecular Medicine, Manassas, VA, USA

Kristin M. Post, MT Department of Pathology and Laboratory Medicine, Indiana University School of Medicine, IU Health Pathology Laboratory, Indianapolis, IN, USA

Kimberly A. Quaid, PhD Professor of Medical and Molecular Genetics, Indiana University School of Medicine, Faculty Investigator, Indiana University Center for Bioethics, Indianapolis, IN, USA

Veshana Ramiah, MD Danville Regional Medical Center, Danville Hematology and Oncology, Danville, VA, USA

Jeffrey S. Ross, MD Cyrus Strong Merrill Professor and Chair, Department of Pathology and Laboratory Medicine, Albany Medical College, Albany, NY, USA; Medical Director, Foundation Medicine, Inc., Cambridge, MA, USA

Stuart Schwartz, PhD, FACMG Strategic Director, Cytogenetics, Cytogenetics Laboratory, Center for Molecular Biology and Pathology, Laboratory Corporation of America, Research Triangle Park, NC, USA

Stuart Scott, PhD Research Assistant Professor of Human Genetics, Department of Human Genetics, Mount Sinai School of Medicine and the Mount Sinai Medical Center, New York, NY, USA

Katherine C. Sexton, MBA Assistant Director, University of Alabama at Birmingham, Tissue Collection and Banking Facility, Southern Division, Cooperative Human Tissue Network, Birmingham, AL, USA

Mona Sharaan, MD Molecular Pathology Laboratory, Department of Pathology, Mount Sinai School of Medicine, New York, NY, USA

Robert Shibata, MD Molecular Genetic Pathology Fellow, Department of Pathology, Mount Sinai School of Medicine, New York, NY, USA

Jeong Hwan Shin, MD, PhD Associate Professor, Department of Laboratory Medicine, Inje University College of Medicine, Busan, South Korea

Martina Storz, MD Director of TMA Core Facility, Institute of Surgical Pathology, Department Pathology, University Hospital Zürich, Zürich, Switzerland

Sunyong Tang, PhD Indiana University Vector Production Facility, Department of Medical and Molecular Genetics, Indiana University School of Medicine, Indianapolis, IN, USA

Yi-Wei Tang, MD, PhD, F(AAM), FIDSA Chief of Clinical Microbiology Service, Memorial Sloan-Kettering Cancer Center, Professor of Laboratory Medicine and Pathology, Cornell University Weil College of Medicine, New York, NY, USA

Marc J. van de Vijver, MD, PhD Head, Division of Diagnostic Oncology, NKI, Amsterdam; Head, Department of Pathology, NKI, Amsterdam; Pathologist, Department of Pathology, Leiden University Medical Center, The Netherlands; Professor of Pathology, Department of Pathology, The Netherlands; Cancer Institute/Antoni van Leeuwenhoek Hospital, Amsterdam, Netherlands

Francisco Vega, MD, PhD Associate Professor and Lymphoma Section Head, Department of Hematopathology, The University of Texas MD Anderson Cancer Center, Houston, TX, USA

Mingsheng Wang, MD Associate Scientist, Department of Pathology and Laboratory Medicine, Indiana University School of Medicine, Indianapolis, IN, USA

Wei Wang, PhD Research Associate, Mount Sinai Medical Center, New York, NY, USA

Melissa P. Wasserstein, MD Associate Professor, Mount Sinai School of Medicine, New York, NY, USA

Gerlinde Wernig, MD Department of Pathology, Stanford University School of Medicine, Stanford Hospital and Clinics, Stanford, CA, USA

Sean R. Williamson, MD Department of Pathology and Laboratory Medicine, Indiana University School of Medicine, Indianapolis, IN, USA

Josephine Wu, DDS, CLSP(MB), CLDIR Assistant Professor of Pathology, Mount Sinai School of Medicine, New York, NY, USA

Julia D. Wulfschle, PhD Professor, George Mason University, Center for Applied Proteomics and Molecular Medicine, Manassas, VA, USA

Ruliang Xu, MD, PhD Associate Professor of Pathology, Director of Molecular Pathology, Director of Gastrointestinal and Liver Pathology, Department of Pathology, New York University Langone Medical Center, New York, NY, USA

Fei Ye, PhD Assistant Professor of Pathology, Assistant Director of Molecular Pathology, Department of Pathology, Mount Sinai School of Medicine, New York, NY, USA

C. Cameron Yin, MD, PhD Associate Professor, Department of Hematopathology, UT MD Anderson Cancer Center, Houston, TX, USA

Andrew N. Young, MD, PhD Associate Professor, Department of Pathology & Laboratory Medicine, Emory University School of Medicine, Laboratory Director, Grady Health System, Atlanta, GA, USA

Chunli Yu, MD Associate Professor, Department of Genetics & Genomic Sciences and Pediatrics, Mount Sinai School of Medicine, New York, NY, USA

David Y. Zhang, MD, PhD, MPH Professor of Pathology, Director of Molecular Pathology Laboratory, Department of Pathology, Mount Sinai School of Medicine, New York, NY, USA

Shaobo Zhang, MD Associate Scientist, Department of Pathology and Laboratory Medicine, Indiana University School of Medicine, Indianapolis, IN, USA