
Cerebrovascular and Endovascular Neurosurgery

Chirag D. Gandhi • Charles J. Prestigiacomo
Editors

Cerebrovascular and Endovascular Neurosurgery

Complication Avoidance and
Management

 Springer

Editors

Chirag D. Gandhi
Department of Neurosurgery
Westchester Medical Center/
NY Medical College
Valhalla, NY
USA

Charles J. Prestigiacomo
Department of Neurological Surgery
University of Cincinnati College of
Medicine
Cincinnati, OH
USA

ISBN 978-3-319-65204-7 ISBN 978-3-319-65206-1 (eBook)
<https://doi.org/10.1007/978-3-319-65206-1>

Library of Congress Control Number: 2018950603

© Springer International Publishing AG, part of Springer Nature 2018

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.

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, express 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.

Printed on acid-free paper

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature

The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

I dedicate this book to all that have helped me become better:

To all the patients and families who have taught me how to become a better physician and surgeon.

To all my mentors, colleagues, and authors of this book who have instilled in me the profound desire to forever learn and never stop seeking what is best for my patients, thus making me a better student of medicine.

To my closest friends who have grounded me and helped me grow to become a better colleague and partner.

Most of all, to my parents and brother, my in-laws, my dears, Cindy, Rachel, Laura, Michelle, Julie, (and yes, our cats and guinea pigs), for the constant, unconditional support that makes me a better person.

All that I am is because of all that you are.

C.J. Prestigiacomo

Firstly, to my patients and their families for providing me with a clarity of purpose.

To my parents and grandparents for the life pearls and setting me on the path.

To my in-laws for their gentle wisdom and the most precious of gifts.

To my students, residents, fellows, and colleagues for helping me practice the art.

And of course to my dearest Sedna, Ronan, and Gita whom I hold above all things.

C.D. Gandhi

Preface

Physicians and surgeons are human. We make mistakes. Patients are harmed by what we do and by what we do not do. Unintentional as it may be, it nonetheless has its consequences to the patient, the family, and to you. The one element that everyone can find solace in is that, hopefully, every mistake is a one-time event. It happens, we learn from it, others learn from it, and it never happens again.

In the event of a complication, the proceduralist will review what happened, first and foremost internally. In most cases, the error is identified and the steps to avoid such an error again are defined. Sometimes this occurs with the aid of an external forum of colleagues and peers. On occasion, the proceduralist will reach out to a mentor or partner and discuss the case in broad terms to gain insight into the events or perhaps garner wisdom from the mentor's prior experiences. In so doing, the proceduralist not only learns from his or her own errors but also gains the wisdom of his or her mentor in an attempt to avoid making similar errors in the future.

This is how this book was born.

We see this book as a venue for members of the cerebrovascular community to share their experience and expertise. Most importantly, it is a venue for the dissemination of the many nuances in complication avoidance and complication management for some of the most difficult procedures that are performed for cerebrovascular disease.

The book is divided into four major parts, each with a specific focus. The first part provides the reader a detailed view of what a complication is, what it is not, and the general principles in formally assessing and reviewing complications, adverse outcomes, and errors. It is meant to provide a fertile landscape for each reader to begin a formal approach to analyze complications within their respective institutions and within their own practice. The second, third, and fourth parts of the textbook respectively describe the technical nuances of specific surgical, endovascular, and radiosurgical procedures for vascular diseases of the central nervous system and head and neck. These chapters serve as the central focal point for the book. Each chapter discusses the methods for complication avoidance and complication management. The reader thus is able to gain valuable knowledge and experience from experts in the field and in so doing reduce the frequency of poor outcomes in his or her practice.

Complication avoidance and complication management requires teamwork and communication. A very unique and helpful feature of this textbook is the presence of checklists for procedures and for complication management in the "techniques"

chapters. These checklists are made to be freely duplicated or modified and incorporated into an emergency procedures binder for the operating room, the endovascular suite, or the radiosurgery center. By turning to the specific checklists and reviewing them with the team prior to the procedure, the team gets “prepped and primed” for anything that may happen. The presence of a Table of Complication Avoidance and Management Principles also provides a necessary summary that enhances the team’s preparation.

We should never forget our complications or those to whom it happened. We should use the experience to strengthen us and make us better. It is our hope that this textbook will help the reader improve patient outcomes through a greater understanding of the nuances of all neurovascular procedures. It is our hope that the checklists and tables will become a living document for each institution, dedicated to improving communication and teamwork among the many disciplines that care for these complex patients. It is our hope that this textbook will help all of us to decrease complications in our patients and help us to continue striving to do no harm.

Cincinnati, OH
Valhalla, NY

Charles J. Prestigiacomo
Chirag D. Gandhi

Contributing Editor

I. Paul Singh, M.D., M.P.H. Departments of Neurosurgery, Neurology, and Radiology,
Mount Sinai Hospital, New York, NY, USA

Contents

Part I General Aspects

1 What Is a Complication? The Philosophical and Psychological Aspects	3
Neil Majmundar, Celina Crisman, and Charles J. Prestigiacomo	
2 Medicolegal Aspects of Complications	9
Michael P. Marks	
3 Residency/Fellowship Training and the Complication	17
Celina Crisman, Raghav Gupta, Neil Majmundar, and Chirag D. Gandhi	
4 Analyzing Complications	25
Aditya V. Karhade, Matthew J. Koch, Christopher J. Stapleton, and Aman B. Patel	
5 Quality Assurance	35
Alon Orlev and Ketan R. Bulsara	
6 Quality Improvement	41
Mary In-Ping Huang Cobb, Ali R. Zomorodi, and L. Fernando Gonzalez	
7 Training and Standards	49
Ephraim W. Church and Kevin M. Cockroft	
8 Complication Avoidance and Management Research	65
Mithun G. Sattur, Chandan Krishna, Aman Gupta, Matthew E. Welz, Rami James N. Aoun, Patrick B. Bolton, Brian W. Chong, Bart M. Demaerschalk, Pelagia Kouloumberis, Mark K. Lyons, Jamal Mcclendon Jr., Naresh Patel, Ayan Sen, Kristin Swanson, Richard S. Zimmerman, and Bernard R. Bendok	
9 The Checklist	79
Charles J. Prestigiacomo	

10 Alternatives to the Checklist	89
Stephan A. Munich and Michael Chen	

11 Prepping the Environment	95
Ahmad M. Thabet and I. Paul Singh	

Part II Surgical Procedures

12 Carotid Endarterectomy	109
Christopher M. Loftus	

13 Aneurysms of the Anterior Circulation	119
Jason A. Ellis, Robert A. Solomon, and E. Sander Connolly Jr.	

14 Aneurysms of the Posterior Circulation	137
Vernard S. Fennell and Peter Nakaji	

15 Arteriovenous Malformations of the Anterior Fossa	155
Srikanth R. Boddu, Thomas W. Link, Jared Knopman, and Philip E. Stieg	

16 Arteriovenous Malformations of the Posterior Fossa	175
Wuyang Yang, Rafael J. Tamargo, and Judy Huang	

17 Cavernous Malformations	187
Cameron M. McDougall, Babu G. Welch, and H. Hunt Batjer	

18 Direct Bypass Surgery: Principles, Nuances, and Complication Avoidance	205
Brian P. Walcott and Michael T. Lawton	

19 Indirect Bypass Surgery	215
Christopher Kellner and Joshua Bederson	

20 Spinal Vascular Malformation Surgery	225
Nina Z. Moore, Mark Bain, and Peter A. Rasmussen	

Part III Endovascular Procedures

21 Access and Closure	241
Ahmad M. Thabet and I. Paul Singh	

22 Iatrogenic Large Vessel Injury	251
Jay Ashok Vachhani, Adam Stephen Arthur, and Daniel Alan Hoit	

23 Stenting of the Great Vessels	265
John F. Morrison, Hakeem J. Shakir, Jason M. Davies, and Elad I. Levy	

24 Complications in the Coiling of Cerebral Aneurysms	279
Waleed Brinjikji and Giuseppe Lanzino	

25	Balloon- and Stent-Assisted Endovascular Occlusion of Intracranial Aneurysms	293
	Brian J. A. Gill, Jason A. Ellis, and Philip M. Meyers	
26	Aneurysm Treatment with Flow Diverters	307
	Brian P. Walcott, Ki-Eun Chang, Robin Babadjouni, and William J. Mack	
27	Aneurysm Treatment with Liquid Embolics	321
	Andrew J. Ringer and Ralph Rahme	
28	Treatment of Arteriovenous Malformations with Cyanoacrylate . . .	335
	Matthew D. Alexander, Daniel L. Cooke, and Steven W. Hetts	
29	Endovascular Treatment of Arteriovenous Malformations Using Ethylene Vinyl Alcohol Copolymer	355
	Bruno C. Flores, Bradley A. Gross, and Felipe C. Albuquerque	
30	Principles for Complication Avoidance and Management in Thrombectomy for Ischemic Stroke	375
	Alexander G. Chartrain, Ahmed J. Awad, and J Mocco	
31	Endovascular Embolization of Head and Neck Tumors	397
	Jonathan R. Lena, M. Imran Chaudry, Raymond D. Turner, Alejandro Spiotta, and Aquilla S. Turk	
32	Management of Complications Following Embolization for Intractable Epistaxis	413
	Raghav Gupta, Aakash M. Shah, Fawaz Al-Mufti, and Chirag D. Gandhi	
33	Sclerotherapy of Vascular Malformations	423
	Mark W. Stalder, Chad A. Perlyn, and Guilherme Dabus	
Part IV Radiosurgical Procedures		
34	Radiation Physics: Stereotactic Radiosurgery for Arteriovenous Malformations	439
	Krishna Amuluru and Christopher G. Filippi	
35	Radiobiology of Stereotactic Radiosurgery in the Treatment of Arteriovenous Malformations	453
	Rachel Pruitt and Michael Schulder	
36	Radiosurgery for Arteriovenous Malformations	461
	Amparo Wolf and Douglas Kondziolka	
	Index	471

Contributors

Felipe C. Albuquerque, M.D. c/o Neuroscience Publications, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, AZ, USA

Matthew D. Alexander, M.D. UCSF Department of Radiology and Biomedical Imaging, San Francisco, CA, USA

Fawaz Al-Mufti, M.D. Rutgers University- Robert Wood Johnson Medical School, New Brunswick, NJ, USA

Krishna Amuluru, M.D. Department of Interventional Neuroradiology, University of Pittsburgh Medical Center - Hamot, Erie, PA, USA

Rami James N. Aoun, M.D., M.P.H. Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Precision Neuro-Therapeutics Innovation Lab, Mayo Clinic, Phoenix, AZ, USA

Neurosurgery Simulation and Innovation Lab, Mayo Clinic, Phoenix, AZ, USA

Adam Stephen Arthur, M.D., M.P.H. Semmes-Murphey Clinic, Memphis, TN, USA

Ahmed J. Awad Mount Sinai Health System, New York, NY, USA

Robin Babadjouni Department of Neurological Surgery, University of Southern California, Los Angeles, CA, USA

Mark Bain, M.D., M.S. Department of Neurosurgery, Cerebrovascular Center, Cleveland Clinic Foundation, Cleveland, OH, USA

H. Hunt Batjer, M.D. University of Texas Southwestern, Dallas, TX, USA

Joshua Bederson, M.D. Department of Neurosurgery, Mount Sinai Health System, New York, NY, USA

Bernard R. Bendok, M.D., M.S.C.I. Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Precision Neuro-Therapeutics Innovation Lab, Mayo Clinic, Phoenix, AZ, USA

Neurosurgery Simulation and Innovation Lab, Mayo Clinic, Phoenix, AZ, USA

Department of Radiology, Mayo Clinic, Phoenix, AZ, USA

Department of Otolaryngology, Mayo Clinic, Phoenix, AZ, USA

Srikanth R. Boddu, M.Sc., M.R.C.S., F.R.C.R., M.D. Division of Interventional Neuroradiology, Department of Neurological Surgery, Weill Cornell Medical Center/ New York Presbyterian Hospital, New York, NY, USA

Patrick B. Bolton, M.D. Department of Anesthesia and Periop Med, Mayo Clinic, Phoenix, AZ, USA

Waleed Brinjikji, M.D. Department of Radiology, Mayo Clinic, Rochester, MN, USA

Department of Neurosurgery, Mayo Clinic, Rochester, MN, USA

Ketan R. Bulsara, M.D., M.B.A. Division of Neurosurgery, University of Connecticut, Farmington, CT, USA

Ki-Eun Chang, M.D. Department of Neurological Surgery, Keck School of Medicine, University of Southern California, Los Angeles, CA, USA

Alexander G. Chartrain Mount Sinai School of Medicine, New York, NY, USA

M. Imran Chaudry, M.D. Neurointerventional Radiology, Medical University of South Carolina, Charleston, SC, USA

Michael Chen, M.D. Departments of Neurological Surgery, Neurology and Radiology, Rush University Medical Center, Chicago, IL, USA

Brian W. Chong, M.D., F.R.C.P.(C) Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Department of Radiology, Mayo Clinic, Phoenix, AZ, USA

Ephraim W. Church, M.D. Department of Neurosurgery, Penn State Milton S. Hershey Medical Center and Penn State University College of Medicine, Hershey, PA, USA

Mary In-Ping Huang Cobb, M.D. Department of Neurosurgery, Duke University Hospitals, Durham, NC, USA

Kevin M. Cockroft, MD, MSc, FAANS, FACS, FAHA Department of Neurosurgery, Penn State Milton S. Hershey Medical Center and Penn State University College of Medicine, Hershey, PA, USA

E. Sander Connolly, Jr. Department of Neurological Surgery, Columbia University Medical Center, New York, NY, USA

Daniel L. Cooke, M.D. UCSF Department of Radiology and Biomedical Imaging, San Francisco, CA, USA

Celina Crisman, M.D. Department of Neurosurgery, Rutgers University-NJ Medical School, Newark, NJ, USA

Guilherme Dabus, M.D., F.A.H.A. Wertheim College of Medicine, Florida International University, Miami, FL, USA

Miami Cardiac and Vascular Institute and Baptist Neuroscience Center, Miami, FL, USA

Jason M. Davies, M.D., Ph.D. Department of Neurosurgery, Jacobs School of Medicine and Biomedical Sciences, University at Buffalo, State University of New York, Buffalo, NY, USA

Gates Vascular Institute at Kaleida Health, Buffalo, NY, USA

Department of Biomedical Informatics, Jacobs School of Medicine and Biomedical Sciences, University at Buffalo, State University of New York, Buffalo, NY, USA

Bart M. Demaerschalk, M.D., MSc., F.R.C.P.(C) Department of Neurology, Mayo Clinic, Phoenix, AZ, USA

Jason A. Ellis, M.D. Department of Neurological Surgery, Columbia University Medical Center, New York, NY, USA

Vernard S. Fennell, M.D. Department of Neurosurgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, AZ, USA

L. Fernando Gonzalez, M.D. Department of Neurosurgery, Duke University Hospitals, Durham, NC, USA

Christopher G. Filippi, M.D. Department of Radiology, Hofstra Northwell School of Medicine, Manhasset, NY, USA

Department of Neurology, University of Vermont School of Medicine, Burlington, VT, USA

Bruno C. Flores, M.D. Department of Neurosurgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, AZ, USA

Chirag D. Gandhi, M.D. Westchester Medical Center/New York Medical College, Valhalla, NY, USA

Brian J.A. Gill Department of Neurological Surgery, Columbia University Medical Center, New York, NY, USA

Bradley A. Gross, M.D. Department of Neurosurgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, AZ, USA

Raghav Gupta, B.S. Rutgers University- NJ Medical School, Newark, NJ, USA

Aman Gupta, M.B.B.S. Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Precision Neuro-Therapeutics Innovation Lab, Mayo Clinic, Phoenix, AZ, USA

Neurosurgery Simulation and Innovation Lab, Mayo Clinic, Phoenix, AZ, USA

Steven W. Hetts, M.D. UCSF Department of Radiology and Biomedical Imaging, San Francisco, CA, USA

Daniel Alan Hoit, M.D. Semmes-Murphey Clinic, Memphis, TN, USA

Judy Huang, M.D. Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, MD, USA

Aditya V. Karhade, B.E. Department of Neurosurgery, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Christopher Kellner, M.D. Department of Neurosurgery, Mount Sinai Health System, New York, NY, USA

Jared Knopman, M.D. Division of Interventional Neuroradiology, Department of Neurological Surgery, Weill Cornell Medical Center/New York Presbyterian Hospital, New York, NY, USA

Matthew J. Koch, M.D. Department of Neurosurgery, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Douglas Kondziolka, MD, MSc, FRCSC, FACS Department of Neurosurgery, New York University, NYU Langone Medical Center, New York, NY, USA

Pelagia Kouloumberis, M.D. Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Chandan Krishna, M.D. Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Giuseppe Lanzino, M.D. Department of Radiology, Mayo Clinic, Rochester, MN, USA

Department of Neurosurgery, Mayo Clinic, Rochester, MN, USA

Michael T. Lawton, M.D. Department of Neurological Surgery, Barrow Neurological Institute, San Francisco, CA, USA

Jonathan R. Lena Medical University of South Carolina, Charleston, SC, USA

Elad I. Levy, M.D., M.B.A., F.A.C.S., F.A.H.A. Department of Neurosurgery, Jacobs School of Medicine and Biomedical Sciences, University at Buffalo, State University of New York, Buffalo, NY, USA

Gates Vascular Institute at Kaleida Health, Buffalo, NY, USA

Department of Biomedical Informatics, Jacobs School of Medicine and Biomedical Sciences, University at Buffalo, State University of New York, Buffalo, NY, USA

Department of Radiology, Jacobs School of Medicine and Biomedical Sciences, University at Buffalo, State University of New York, Buffalo, NY, USA

Toshiba Stroke and Vascular Research Center, Buffalo, NY, USA

Thomas W. Link, M.D., M.S. Division of Interventional Neuroradiology, Department of Neurological Surgery, Weill Cornell Medical Center/New York Presbyterian Hospital, New York, NY, USA

Christopher M. Loftus, M.D., Dr. h.c. (Hon), F.A.A.N.S. Temple University
Lewis Katz School of Medicine, Philadelphia, PA, USA

Mark K. Lyons, M.D. Department of Neurological Surgery, Mayo Clinic, Phoenix,
AZ, USA

William J. Mack Department of Neurological Surgery, University of Southern
California, Los Angeles, CA, USA

Neil Majmudar, M.D. Department of Neurosurgery, Rutgers University-NJ
Medical School, Newark, NJ, USA

Michael P. Marks, M.D. Stanford University Medical Center, Stanford, CA, USA

Jamal McClendon, Jr., M.D. Department of Neurological Surgery, Mayo Clinic,
Phoenix, AZ, USA

Cameron M. McDougall, M.D. University of Texas Southwestern, Dallas, TX,
USA

Philip M. Meyers Department of Neurological Surgery, Columbia University
Medical Center, New York, NY, USA

J. Mocco Mount Sinai Health System, New York, NY, USA

Nina Z. Moore, M.D., M.S.E. Department of Neurosurgery, Cerebrovascular
Center, Cleveland Clinic Foundation, Cleveland, OH, USA

John F. Morrison, M.D. Department of Neurosurgery, Jacobs School of Medicine
and Biomedical Sciences, University at Buffalo, State University of New York,
Buffalo, NY, USA

Gates Vascular Institute at Kaleida Health, Buffalo, NY, USA

Stephan A. Munich, M.D. Departments of Neurological Surgery, Neurology and
Radiology, Rush University Medical Center, Chicago, IL, USA

Peter Nakaji, M.D. c/o Neuroscience Publications, Department of Neurosurgery,
Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix,
AZ, USA

Alon Orlev Department of Neurosurgery, Rabin Medical Center, Petach Tikva,
Israel

Aman B. Patel, M.D. Department of Neurosurgery, Massachusetts General
Hospital, Harvard Medical School, Boston, MA, USA

Naresh Patel, M.D. Department of Neurological Surgery, Mayo Clinic, Phoenix,
AZ, USA

Chad A. Perlyn, M.D. Department of Plastic and Reconstructive Surgery, Nicklaus
Children's Hospital, Miami, FL, USA

Wertheim College of Medicine, Florida International University, Miami, FL, USA

Charles J. Prestigiacomo, M.D. Department of Neurological Surgery, University of Cincinnati College of Medicine, Cincinnati, OH, USA

Rachel Pruitt, M.D. Department of Neurosurgery, Hofstra Northwell School of Medicine, Hempstead, NY, USA

Ralph Rahme, M.D. Director of Neurosurgery, Good Samaritan Hospital, Cincinnati, OH, USA

Chief of Neurosciences, TriHealth System, Cincinnati, OH, USA

Mayfield Brain and Spine, Cincinnati, OH, USA

Division of Neurosurgery, Lenox Hill Hospital, Northwell Health, New York, NY, USA

Peter A. Rasmussen, M.D. Department of Neurosurgery, Cerebrovascular Center, Cleveland Clinic Foundation, Cleveland, OH, USA

Andrew J. Ringer, M.D. Director of Neurosurgery, Good Samaritan Hospital, Cincinnati, OH, USA

Chief of Neurosciences, TriHealth System, Cincinnati, OH, USA

Mayfield Brain and Spine, Cincinnati, OH, USA

Division of Neurosurgery, Lenox Hill Hospital, Northwell Health, New York, NY, USA

Mithun G. Sattur, M.D. Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Precision Neuro-Therapeutics Innovation Lab, Mayo Clinic, Phoenix, AZ, USA

Neurosurgery Simulation and Innovation Lab, Mayo Clinic, Phoenix, AZ, USA

Michael Schulder, M.D. Department of Neurosurgery, Hofstra Northwell School of Medicine, Hempstead, NY, USA

Ayan Sen, M.D. Department of Critical Care Medicine, Mayo Clinic, Phoenix, AZ, USA

Aakash M. Shah, B.S. Rutgers University- NJ Medical School, Newark, NJ, USA

Hakeem J. Shakir, M.D. Department of Neurosurgery, Jacobs School of Medicine and Biomedical Sciences, University at Buffalo, State University of New York, Buffalo, NY, USA

Gates Vascular Institute at Kaleida Health, Buffalo, NY, USA

I. Paul Singh, M.D., M.P.H. Departments of Neurosurgery, Neurology, and Radiology, Mount Sinai Hospital, New York, NY, USA

Robert A. Solomon Department of Neurological Surgery, Columbia University Medical Center, New York, NY, USA

Alejandro Spiotta Medical University of South Carolina, Charleston, SC, USA

Mark W. Stalder, M.D. Department of Plastic and Reconstructive Surgery, Nicklaus Children's Hospital, Miami, FL, USA

Christopher J. Stapleton, M.D. Department of Neurosurgery, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Philip E. Stieg, M.D., Ph.D. Division of Interventional Neuroradiology, Department of Neurological Surgery, Weill Cornell Medical Center/New York Presbyterian Hospital, New York, NY, USA

Kristin Swanson, Ph.D. Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Precision Neuro-Therapeutics Innovation Lab, Mayo Clinic, Phoenix, AZ, USA

Rafael J. Tamargo, M.D. Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, MD, USA

Ahmad M. Thabet, M.D. Department of Neurosurgery, Westchester Medical Center/New York Medical College, Valhalla, NY, USA

Aquilla S. Turk Medical University of South Carolina, Charleston, SC, USA

Raymond D. Turner Medical University of South Carolina, Charleston, SC, USA

Jay Ashok Vachhani, M.D. Semmes-Murphey Clinic, Memphis, TN, USA

Brian P. Walcott, M.D. Department of Neurological Surgery, University of Southern California, Los Angeles, CA, USA

Babu G. Welch, M.D. University of Texas Southwestern, Dallas, TX, USA

Matthew E. Welz, M.S. Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Precision Neuro-Therapeutics Innovation Lab, Mayo Clinic, Phoenix, AZ, USA

Neurosurgery Simulation and Innovation Lab, Mayo Clinic, Phoenix, AZ, USA

Amparo Wolf, M.D., Ph.D. Department of Neurosurgery, New York University, NYU Langone Medical Center, New York, NY, USA

Wuyang Yang, M.D. Department of Neurosurgery, Johns Hopkins University School of Medicine, Baltimore, MD, USA

Richard S. Zimmerman, M.D. Department of Neurological Surgery, Mayo Clinic, Phoenix, AZ, USA

Ali R. Zomorodi, M.D. Department of Neurosurgery, Duke University Hospitals, Durham, NC, USA