
Contemporary Medical Imaging

Series Editor

U. Joseph Schoepf

More information about this series at:
<http://www.springer.com/series/7687>

Mark R. Harrigan • John P. Deveikis

Handbook of Cerebrovascular Disease and Neurointerventional Technique

Third Edition

 Humana Press

Mark R. Harrigan
Departments of Neurosurgery
Neurology and Radiology
University of Alabama at Birmingham
Birmingham
Alabama
USA

John P. Deveikis
Department of Neurosurgery and
Radiology
University of Alabama at Birmingham
Birmingham
Alabama
USA

Originally published by Humana Press, USA 2009
Contemporary Medical Imaging
ISBN 978-3-319-66777-5 ISBN 978-3-319-66779-9 (eBook)
<https://doi.org/10.1007/978-3-319-66779-9>

Library of Congress Control Number: 2018934717

© Springer International Publishing AG 2009, 2013, 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 Humana Press imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Acknowledgements

Jerzy P. Szaflarski
Beth Erwin
Kimberly Kicielinski
Paul Foreman
Christoph Grissenauer
Joel K. Curé
Patricia Harrigan
Casey C. May
Stephanie Falatko
Philip Schmalz
David Fisher

Introduction

To the astonishment of the authors of this handbook, the publisher agreed to yet another edition.

This edition is much more than an update. For the first time, the authors recognize intracerebral hemorrhage as a cerebrovascular disorder and have dedicated a chapter to it. *Kids Korner!* have been inserted throughout the handbook to highlight pediatric-specific aspects of the field. A principal finding statement, in bold, has been added to each important clinical study summary.

Neurointervention is a rarified and complex field, with a set of techniques and a knowledge base that are distinct from other fields within medicine. At the same time, clinicians from an assortment of disciplines have come to practice neurointerventional radiology, with backgrounds ranging from radiology to neurosurgery, neurology, cardiology, and vascular surgery. Presently, there are more people training to become neurointerventionalists than there ever have been before in history. These developments created a need for a practical, unified handbook of techniques and essential literature.

This purpose of this handbook is to serve as a practical guide to endovascular methods, as a reference work for neurovascular anatomy, and as an introduction to the cerebrovascular literature. We have striven to cover the essential aspects of the entire fields of neurointervention and cerebrovascular disease. It is particularly challenging to sift through the cerebrovascular literature because of the uneven quality; badly done and poorly written studies appear side-by-side with high quality publications in even the most prestigious journals. Indeed, so-called “meta-analysis” and “guidelines” publications are notorious for variability and poor quality. Therefore, this handbook should not be a substitute for reading the primary literature. We encourage readers to read the primary research papers, scrutinize them carefully, and form their own opinions.

We attempted to enhance the accessibility and ease use of this handbook by arranging it in a semi-outline format. Dense narrative passages have been avoided wherever possible (who has time to read long, thick chapters, anyway?). In that spirit, the rest of this *Introduction* will be presented in the style of this book.

1. This book is divided into three parts.
 - (a) *Fundamentals*
 - (i) Essential neurovascular anatomy and basic angiographic techniques provide the foundation of the first section.
 - The focus of Chap. 1 (*Essential Neurovascular Anatomy*) remains on vascular anatomy that is pertinent to day-to-day clinical practice. Embryology and discussions of angiographic shift, which is less pertinent these days because of widely available noninvasive intracranial imaging, are left out. Discussions of anatomic variants include both normal variants and anomalies.
 - New for the second edition are some Angio-Anatomic Correlates that illustrate anatomic structures with angiographic pictures.
 - Chapters 2 and 3 cover diagnostic angiographic techniques.
 - Chapter 4 is an introduction to basic interventional access techniques with an appendix on the Neurointerventional Suite, primarily intended for newcomers to the angio suite and for experienced interventionalists planning a new suite.
 - (ii) *Techniques*
 - (i) Endovascular methods, device information, and tips and tricks are detailed.
 - The second edition is packed with new information on evolving technology.
 - (iii) *Specific disease states*
 - (i) Essential, useful information about each commonly encountered condition is presented.
 - Significant clinical studies are summarized and placed into context.
 - Interesting and novel facts (and “factlets”) are included here and there.
 - (ii) The term “systematic review” is used to refer to useful publications that have analyzed published clinical data in an organized way. The term “meta-analysis” is avoided because it refers to a specific statistical technique that is not always present in review articles purporting to be a meta-analysis.
 - (iii) For readers with extra time on their hands, *A Brief History of...* sections describe the background and evolution of various techniques.
 - (b) *Techniques*
 - (i) Endovascular methods, device information, and tips and tricks are detailed.
 - The second edition is packed with new information on evolving technology.
 - (c) *Specific disease states*
 - (i) Essential, useful information about each commonly encountered condition is presented.
 - Significant clinical studies are summarized and placed into context.
 - Interesting and novel facts (and “factlets”) are included here and there.
 - (ii) The term “systematic review” is used to refer to useful publications that have analyzed published clinical data in an organized way. The term “meta-analysis” is avoided because it refers to a specific statistical technique that is not always present in review articles purporting to be a meta-analysis.
 - (iii) For readers with extra time on their hands, *A Brief History of...* sections describe the background and evolution of various techniques.
2. *Core philosophy.* Within the practical information contained within this book, we hope to impart our underlying patient-oriented clinical philosophy. In our view, each patient’s welfare is paramount. The clinical outcome of each case takes priority over “pushing the envelope” by trying out new devices or techniques, generating material for the next clinical series or case report, or satisfying the device company representatives standing in the control room. In practical terms, clinical decision-making should be based on sound judgment and the best available clinical data. Moreover, new medical technology and drugs should be used *within reason*, and

whenever possible, based on established principles of sound practice. Thus, while we have the technology and the ability to coil aneurysms in very old patients with Hunt Hess V subarachnoid hemorrhage, embolize asymptomatic and low-risk dural AV fistulas, and perform carotid angioplasty and stenting in patients with asymptomatic stenosis, we should recognize the value of conservative management when it is called for. We hope that this cautious and commonsensical outlook is reflected throughout this book.

3. *Cookbook presentation.* We have made every attempt to present procedures in a plainly written, how-to-do-it format. Although some readers may take issue with the reduction of a field as complex as neurointervention to a relatively simplistic how-to manual, we feel that structure and standardization of technique can only serve to benefit the field in the long run. For comparison, consider commercial air travel in the present era. Air travel fatalities are extremely rare, due to pilot training, standardization of flying techniques, and meticulous aircraft maintenance. Even the most skilled and careful neurointerventionalists cannot hold a candle to the stellar safety record obtained by the airline industry.
4. *Conventions used in this book:*
 - (a) Terminology can be confusing. The authors have adopted the most current and commonly used terms; synonymous terms are listed in parentheses after “aka,” for *also known as*.
 - (b) We have limited the use of abbreviations to those commonly used in everyday conversation, such as “ICA” and “MCA.” Excessive use of abbreviations, particularly for uncommon terms, can clutter the text and make it difficult to read.
 - (c) The terms, *see below* and *see above*, are used to indicate other material within the same chapter.
5. *New for the third edition:*
 - (a) *Kids Korner!* sections to highlight pediatric aspects.
 - (b) A dedicated chapter on intracerebral hemorrhage.
 - (c) Fewer typographical errors (hopefully) than the first two editions.
 - (d) Astute readers will also find many new pearls of wisdom and a few sparks of levity.
6. *Medicolegal disclaimer.* This book is meant to serve as a guide to the use of a wide variety of medical devices and drugs. However, the authors and the publisher cannot be held responsible for the use of these devices and drugs by readers, or for failure by the readers of this book to follow specific manufacturer specifications and FDA guidelines.
7. Lastly, we would like to mention six simple truths that have emerged in our field since the last edition:
 - (a) Endovascular treatment of acute ischemic stroke is strongly indicated for selected patients.
 - (b) Routine general anesthesia for acute ischemic stroke cases is not indicated; general anesthesia should be reserved for the subset of stroke cases that are not feasible or safe without it.
 - (c) CTA has replaced catheter angiography for the initial evaluation of spontaneous subarachnoid hemorrhage.

- (d) Routine catheter angiography for follow-up surveillance imaging of coiled aneurysms is not indicated, as MRA is adequate and often superior than angiography for most cases.
- (e) Joint Commission-certified Primary and Comprehensive Stroke Centers in the United States, and regionalization of stroke care around the world, have revolutionized the care of patients with cerebrovascular disease and underscore the importance of organized and specialized stroke care.
- (f) Although *live case demonstrations* have become popular, they have little actual educational value and exist mainly for self-promotion by certain physicians and as a form of entertainment for the audience. Operators are distracted during live case demonstrations and complications are more likely. We hope that live case demonstrations turn out to become a passing fad.

Mark R. Harrigan, M.D.
Departments of Neurosurgery
Neurology and Radiology
University of Alabama at Birmingham
Birmingham, AL, USA

John P. Deveikis, M.D.
Department of Neurosurgery
and Radiology
University of Alabama at Birmingham
Birmingham, Alabama, USA

Abbreviations

ACAS	Asymptomatic Carotid Atherosclerosis Study
ACCP	American College of Chest Physicians
ACE	Angiotensin converting enzyme
A-comm	Anterior communicating artery
ACST	Asymptomatic Carotid Surgery Trial
ACT	Activated clotting time
ACTH	Adrenocorticotrophic hormone
ADC	Apparent diffusion coefficient
ADH	Antidiuretic hormone
ADPKD	Autosomal dominant polycystic kidney disease
AED	Antiepileptic drug
AF	Atrial fibrillation
AHA	American Heart Association
AICA	Anterior inferior cerebellar artery
aka	Also known as
ALT	Alanine aminotransferase
AMA	Accessory meningeal artery
ANA	Antinuclear antibody
ANP	Atrial natriuretic peptide
ARCHeR	Acculink for Revascularization of Carotids in High-Risk patients
ARR	Absolute risk reduction
ARUBA	A Randomized trial of Unruptured Brain Arteriovenous malformations
ASA	Aspirin (acetylsalicylic acid)
ASAN	Atrial septal aneurysm
ASITN	American Society of Interventional and Therapeutic Neuroradiology
ASNR	American Society of Neuroradiology
atm	Atmosphere
AV	Arteriovenous
AVF	Arteriovenous fistula
AVM	Arteriovenous malformation
BA	Basilar artery
BE	Bacterial endocarditis
BEACH	Boston Scientific EPI-A Carotid stenting trial for High risk surgical patients

bFGF	Basic fibroblast growth factor
BNP	Brain natriuretic peptide
BRANT	British Aneurysm Nimodipine Trial
CAA	Cerebral amyloid angiopathy
CABERNET	Carotid Artery Revascularization Using the Boston Scientific FilterWire EX/EZ and the EndoTex NexStent
CADASIL	Cerebral autosomal dominant arteriopathy with subcortical infarcts and leukoencephalopathy
CADISS	Cervical Artery Dissection in Stroke Study
cANCA	Circulating antineutrophil cytoplasmic antibody
CAPTURE	Carotid Acculink/Accunet Post-Approval Trial to Uncover Rare Events
CARASIL	Cerebral autosomal recessive arteriopathy with subcortical infarcts and leukoencephalopathy
CaRESS	Clopidogrel and Aspirin for Reduction of Emboli in Symptomatic Carotid Stenosis
CAS	Carotid angioplasty and stenting
CASANOVA	Carotid Artery Stenosis with Asymptomatic Narrowing: Operation versus Aspirin
CASES-PMS	Carotid Artery Stenting with Emboli Protection Surveillance—Post-Marketing Study
CBC	Complete blood count
CBF	Cerebral blood flow
CBV	Cerebral blood volume
CCA	Common carotid artery
CCF	Carotid cavernous fistula
CCM	Cerebral cavernous malformation
CCSVI	Chronic cerebrospinal venous insufficiency
CEA	Carotid endarterectomy
CI	Confidence interval
CK	Creatine kinase
CK-MB	Creatine kinase—MB isoenzyme (cardiac-specific CK)
CM	Cardiomyopathy; centimeter
CMS	Centers for Medicare and Medicaid Services
CN	Cranial nerve
CNS	Central nervous system
COSS	Carotid Occlusion Surgery Study
CPA	Cerebral proliferative angiopathy
CPAP	Continuous positive airway pressure
CPK	Creatine phosphokinase
CPP	Cerebral perfusion pressure
Cr	Creatinine
CREATE	Carotid Revascularization with ev3 Arterial Technology Evolution
CREST	Calcinosis, Raynaud’s phenomenon, esophageal dysmotility, sclerodactyly, and telangiectasia; Carotid Revascularization, Endarterectomy versus Stenting Trial
CRH	Corticotropin releasing hormone

CRP	C-reactive protein
CRT	Cathode ray tube
CSC	Comprehensive stroke center
CSF	Cerebrospinal fluid
CSW	Cerebral salt wasting
CTA	CT angiography
CVP	Central venous pressure
CVT	Cerebral venous thrombosis
DAC	Distal access catheter
dAVF	Dural arteriovenous fistula
DMSO	Dimethyl sulfoxide
DPD	Distal protection device
DSA	Digital subtraction angiography
DSPA	<i>Desmodus rotundus</i> salivary plasminogen activator
DVA	Developmental venous anomaly
DVT	Deep venous thrombosis
DWI	Diffusion weighted imaging
EBV	Epstein Barr Virus
ECA	External carotid artery
EC-IC	Extracranial to intracranial
ECST	European Carotid Surgery Trial
EDAMS	Encephalo-duro-arterio-myo-synangiosis
EDAS	Encephalo-duro-arterio-synangiosis
EDS	Ehlers-Danlos syndrome
EEG	Electroencephalogram
EEL	External elastic lamina
EJ	External jugular vein
EKG	Electrocardiogram
EMG	Electromyography
EMS	Encephalo-myo-synangiosis
EPD	Embolic protection device
ESPS	European Stroke Prevention Study
ESR	Erythrocyte sedimentation rate
EVA-3S	Endarterectomy vs. Angioplasty in Patients with Symptomatic Severe Carotid Stenosis
EXACT	Emboshield and Xact Post Approval Carotid Stent Trial
F	French
FDA	Food and Drug Administration
FLAIR	Fluid attenuated inversion recovery
FMD	Fibromuscular dysplasia
fps	Frames per second
GCS	Glasgow coma scale
GESICA	Groupe d'Etude des Sténoses Intra-Crâniennes Athéromateuses symptomatiques
GIST-UK	United Kingdom Glucose Insulin in Stroke Trial
GP	Glycoprotein
Gy	Gray
HbF	Fetal hemoglobin

HbS	Hemoglobin S
HbSS	Hemoglobin S homozygosity
HDL	High density lipoprotein
HERS	Heart and Estrogen/Progestin Study
HIPAA	Health Insurance Portability and Accountability Act
HIT	Heparin-induced thrombocytopenia
HMG CoA	3-Hydroxy-3-methylglutaryl coenzyme A
HRT	Hormone replacement therapy
IA	Intra-arterial
ICA	Internal carotid artery
ICE	Intentional cerebral embolism
ICG	Indocyanine green
ICH	Intracerebral hemorrhage
ICP	Intracranial pressure
ICSS	International Carotid Stenting Study
ICU	Intensive care unit
IEL	Internal elastic lamina
IEP	Intracranial embolization procedure
II	Image intensifier
IIH	Idiopathic intracranial hypertension
IJ	Internal jugular vein
IMA	Internal maxillary artery
IMT	Intima media thickness
INR	International Normalized Ratio
IPS	Inferior petrosal sinus
IPSS	Inferior petrosal sinus sampling
IRB	Institutional Review Board
ISAT	International Subarachnoid Aneurysm Trial
IV	Intravenous
IVH	Intraventricular hemorrhage
KHE	Kaposiform hemangioendotheliomas
KSS	Kearns-Sayre syndrome
KTS	Klippel-Trenaunay syndrome
LDL	Low density lipoprotein
LINAC	Linear accelerator (radiosurgery)
LMWH	Low molecular weight heparin
LOC	Level of consciousness; loss of consciousness
LV	Left ventricle
MA	Maxillary artery
MAC	Mitral annular calcification
MACE	Major adverse cerebrovascular events
MATCH	Management of Atherothrombosis with Clopidogrel in High-Risk patients
MAVERiC	Medtronic AVE Self-Expanding Carotid Stent system with Distal Protection in the Treatment of Carotid Stenosis
MCA	Middle cerebral artery
MELAS	Mitochondrial encephalomyopathy, lactic acidosis, stroke-like episodes

MERFF	Myoclonic epilepsy and ragged red fibers
MI	Myocardial infarction
mm	Millimeter
MRA	Magnetic resonance angiography
MRI	Magnetic resonance imaging
mRS	Modified Rankin Scale
MRV	Magnetic resonance venography
MTT	Mean transit time
MVP	Mitral valve prolapse; most valuable player
NA	Not available
NASCET	North American Symptomatic Carotid Endarterectomy Trial
NBCA	<i>N</i> -butyl-2-cyanoacrylate
NBTE	Nonbacterial thrombotic endocarditis
NCRP	National Council on Radiation Protection and Measurements
NCS	Nerve conduction study
NEMC-PCR	New England Medical Center Posterior Circulation Registry
Newt	Newton
NG	Nasogastric
NICU	Neurological intensive care unit
NIH-SS	National Institutes of Health Stroke Scale
NNH	Number needed to harm
NNT	Number needed to treat
NPH	Neutral Protamine Hagedorn insulin
NPO	Nil per os (no feeding)
NS	Not significant
NSAID	Nonsteroidal anti-inflammatory drug
OA-MCA	Occipital artery to middle cerebral artery
OCP	Oral contraceptive
oCRH	ovine corticotrophin releasing hormone
OEF	Oxygen extraction fraction
OSA	Obstructive sleep apnea
OTW	Over-the-wire
PA	Postero-anterior
PAC	Partial anterior circulation stroke
PAN	Polyarteritis nodosa
PASCAL	Performance And Safety of the Medtronic AVE Self-Expandable Stent in the Treatment of Carotid Artery Lesions
PCA	Posterior cerebral artery
P-comm	Posterior communicating artery
PCR	Polymerase chain reaction
PCWP	Pulmonary capillary wedge pressure
PCXR	Portable chest X-ray
PEEP	Positive end-expiratory pressure
PFO	Patent foramen ovale

PICA	Posterior inferior cerebellar artery
PKD	Polycystic kidney disease
PNS	Peripheral nervous system
POC	Posterior circulation stroke
PPRF	Paramedian pontine reticular formation
PROACT	Prolyse in Acute Cerebral Thromboembolism
Pro-UK	Prourokinase
PSA	Posterolateral spinal arteries
PSV	Peak systolic velocity
PT	Prothrombin time
PTA	Percutaneous transluminal angioplasty
PTE	Pulmonary thromboembolism
PTT	Partial thromboplastin time
PVA	Polyvinyl alcohol
RA	Rheumatoid arthritis
rem	roentgen-equivalent-man, rapid eye movement sleep stage
RHV	Rotating hemostatic valve (aka Y-adaptor, aka Touhy-Borst Valve)
RIND	Reversible ischemic neurological deficit
RPR	Rapid plasma reagin
RR	Risk reduction
RRR	Relative risk reduction
RVAS	Rotational vertebral artery syndrome
RX	Rapid exchange
SAMMPRIS	Stenting vs. Aggressive Medical Management for Preventing Recurrent Stroke in Intracranial Stenosis
SAPPHIRE	Stenting and Angioplasty with Protection in Patients at High Risk for Endarterectomy
SBP	Systolic blood pressure
SCA	Superior cerebellar artery
SCD	Sickle cell disease
SCIWORA	Spinal cord injury without radiographic abnormality
SDH	Subdural hematoma
SECURITY	Study to Evaluate the Neuroshield Bare Wire Cerebral Protection System and XAct Stent in Patients at High Risk for Endarterectomy
SIADH	Syndrome of inappropriate antidiuretic hormone secretion
SIM	Simmons catheter
SIR	Society of Interventional Radiology
SLE	Systemic lupus erythematosus
SOV	Superior ophthalmic vein
SPACE	Stent-Protected Percutaneous Angioplasty of the Carotid versus Endarterectomy
SPARCL	Stroke Prevention by Aggressive Reduction in Cholesterol Levels
SPECT	Single photon emission computed tomography
SSS	Superior sagittal sinus

SSYLVIA	Stenting of Symptomatic Atherosclerotic Lesions in the Vertebral or Intracranial Arteries
STA	Superficial temporal artery
STA-MCA	Superficial temporal artery to middle cerebral artery bypass
TAC	Total anterior circulation stroke
TASS	Ticlopidine Aspirin Stroke Study
TCD	Transcranial Doppler ultrasonography
TEE	Transesophageal echocardiography
TGA	Transient global amnesia
TIA	Transient ischemic attack
TOAST	Trial of ORG 10172 in Acute Stroke Treatment
tPA	Tissue plasminogen activator
TTE	Transthoracic echocardiography
TTP	Time to peak; thrombotic thrombocytopenic purpura
U	Unit
UAC	Umbilical artery catheter
UOP	Urinary output
USA	United States of America
VACS	Veterans Affairs Cooperative Study on Symptomatic Stenosis
VAST	Vertebral Artery Stenting Trial
VBI	Vertebrobasilar insufficiency
VDRL	Venereal Disease Research Laboratory
VERiTAS	Vertebrobasilar Flow Evaluation and Risk of Transient Ischemic Attack and Stroke
VERT	Vertebral
VIVA	ViVEXX Carotid Revascularization Trial
VOGM	Vein of Galen malformation
VZV	Varicella zoster virus
WASID	Warfarin versus Aspirin for Symptomatic Intracranial Disease
WEST	Women Estrogen Stroke Trial
WHI	Women's Health Initiative

Contents

Part I Fundamentals

1	Essential Neurovascular Anatomy	3
2	Diagnostic Cerebral Angiography	111
3	Spinal Angiography	147
4	General Considerations for Neurointerventional Procedures	167

Part II Interventional Techniques

5	Intracranial Aneurysm Treatment	249
6	Intracranial Embolization	333
7	Extracranial and Spinal Embolization	395
8	Treatment of Acute Ischemic Stroke	431
9	Extracranial Angioplasty and Stenting	501
10	Endovascular Treatment of Intracranial Stenosis and Vasospasm	531
11	Venous Procedures	549

Part III Specific Disease States

12	Intracranial Aneurysms and Subarachnoid Hemorrhage	601
13	Arteriovenous Malformations	713
14	Dural Arteriovenous Fistulas	755
15	Venous Disorders and Cavernous Malformations	787
16	Ischemic Stroke	827
17	Intracerebral Hemorrhage	919
18	Extracranial Cerebrovascular Occlusive Disease	957

19 Intracranial Cerebrovascular Occlusive Disease 1015
20 Spinal Vascular Lesions 1049
Index 1073