Handbook of Cerebrovascular Disease and Neurointerventional Technique

Mark R. Harrigan
John P. Deveikis

Fourth Edition

Humana Press

Contemporary Medical Imaging

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Mark R. Harrigan • John P. Deveikis

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Introduction

To our enduring disbelief, the publisher agreed to yet another edition of this handbook. The global cerebrovascular community enjoys an advantage that few fields within medicine can match: An ongoing deluge of very high-quality scientific data, derived by numerous well designed randomized clinical trials and multicenter registries. These data inform daily management of patients and have contributed to the steady evolution of the field. Proof of this is seen in the steadily declining mortality from stroke over the last several decades.

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.

(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 common sensical 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 neurointerven-

tion 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. *Medico legal 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.
6. 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) CTA has replaced catheter angiography for the initial evaluation of spontaneous subarachnoid hemorrhage.
   (c) 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.
   (d) 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.
   (e) 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.
   (f) The field is continuing to rapidly evolve making it vital for practitioners (including the authors) to keep abreast of the literature.

Birmingham, AL, USA — Mark R. Harrigan
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Contents

Part I Fundamentals

Abbreviations

A	Amperes
AC	Alternating current
ACAS	Anterior cerebral artery
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	Adrenocorticotropic hormone
ADAPT	A direct aspiration first pass technique
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
ANGEL-ASPECT	Endovascular therapy in acute anterior circulation large vessel occlusive Patients with Large Infarct Core
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), American Stroke Association
ASAN	Atrial septal aneurysm
ASITN	American Society of Interventional and Therapeutic Neuroradiology
ASNR	American Society of Neuroradiology

ASPECTS	Alberta Stroke Program Early CT Score
ATACH-2	Antihypertensive Treatment of Acute Cerebral Hemorrhage 2 Trial
atm	Atmosphere
AV	Arterio-venous
AVF	Arteriovenous fistula
AVM	Arteriovenous malformation
BA	Basilar artery
BADDASS	Balloon guide with large bore distal access catheter with dual aspiration with stent-retriever as standard approach
BAER	Brainstem auditory evoked potential
BAOCHE	Basilar artery occlusion Chinese endovascular trial
BASICS	Basilar Artery International Cooperative Study
BCNU	1,3 Bis (2-chloroethyl) 1-nitrosourea. AKA: carmustine
BE	Bacterial endocarditis
BEACH	Boston Scientific EPI-A carotid stenting trial for high-risk surgical patients
BEAST	Biorepository to establish the etiology of sinovenous thrombosis
bFGF	Basic fibroblast growth factor
BNP	Brain natriuretic peptide
BRANT	British Aneurysm Nimodipine Trial
BRAT	Barrow Ruptured Aneurysm 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
CAPRIE	Clopidogrel vs. Aspirin in Patients at Risk of Ischemic Events
CAPTIVE	Continuous aspiration prior to intracranial vascular embolectomy
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
CCNU	1-(2-chloroethyl)-3-cyclohexyl-1-nitosourea. Aka: Lomustine
CCSVI	Chronic cerebrospinal venous insufficiency
CEA	Carotid endarterectomy
CHADS-VASC	Congestive heart failure, hypertension, age, diabetes, stroke, vascular disease, age, sex
CHANCE	Clopidogrel in high-risk patients with acute non-disabling cerebrovascular events trial
CHF	Congestive heart failure
CHOICE	Chemical optimization of cerebral embolectomy
CI	Confidence interval
CISS	3D-constructive interference in steady-state MRI
CK	Creatine kinase
CK-MB	Creatine kinase - MB isoenzyme (cardiac-specific CK)
CLEAR-IVH	Clot lysis evaluating accelerated resolution of intraventricular hemorrhage
CM	Cardiomyopathy; centimeter
CMS	Centers for Medicare and Medicaid Services
CN	Cranial nerve
CNS	Central nervous system
COSS	Carotid occlusion surgery study
COVID 19	Coronavirus Disease of 2019
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, Raynauds 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

CT	Computed tomography
CTA	CT angiography
CVP	Central venous pressure
CVT	Cerebral venous thrombosis
DAC	Distal access catheter
DAPT	Dual antiplatelet
dAVF	Dural arteriovenous fistula
DAWN	DWI or CTP assessment with clinical mismatch in the triage of wake-up and late presenting strokes undergoing neurointervention with Trevo Trial
DDAVP	Desmopressin
DEFUSE-3	Endovascular therapy following imaging evaluation for ischemic stroke
DEVT	Direct endovascular treatment
DM	Diabetes mellitus
DMSO	Dimethyl sulfoxide
DOAC	Direct oral anticoagulant
DPD	Distal protection device
DSA	Digital subtraction angiography
DSPA	*Desmodus rotundus* salivary plasminogen activator
DVA	Developmental venous anomaly
DVT	Deep venous thrombosis
DWI	Diffusion weighted imaging
EAGLE	European Assessment Group for Lysis in the Eye
EBV	Epstein–Barr Virus
ECA	External carotid artery
ECASS	European Cooperative Acute Stoke Study
ECG	Electrocardiogram
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-synagiosis
ENRICH	Early Minimally Invasive Removal of Intracerebral Hemorrhage Trial
EPD	Embolic protection device
ESCAPE	Endovascular treatment for Small Core and Anterior circulation Proximal occlusion with Emphasis on minimizing CT to recanalization times.
ESPS	European Stroke Prevention Study

ESR	Erythrocyte sedimentation rate
EVA-3S	Endarterectomy vs. Angioplasty in Patients with Symptomatic Severe Carotid Stenosis
EVOH	Ethylene vinyl copolymer. AKA :EVAL
EXACT	Emboshield and Xact Post Approval Carotid Stent Trial
EXTEND-IA	Extending the Time for Thrombolysis in Emergency Neurological Deficits-IntraArterial
F	French
FDA	Food and Drug Administration
FEIBA	Factor eight inhibitor bypassing activity
FFP	Fresh frozen plasma
FLAIR	Fluid attenuated inversion recovery
FMD	Fibromuscular dysplasia
fMRI	Functional magnetic resonance imaging
fps	Frames per second
GCS	Glasgow coma scale
GDC	Guglielmi detachable coil
GESICA	Groupe d'Etude des Sténoses Intra-Crâniennes Athéromateuses symptomatiques
GI	Gastrointestinal
GIST-UK	United Kingdom Glucose Insulin in Stroke Trial
GP	Glycoprotein
GRASP	Glucose regulation in acute stroke trial
Gy	Gray
HbF	Fetal hemoglobin
HbS	Hemoglobin S
HbSS	Hemoglobin S homozygosity
HDL	High density lipoprotein
HeadPoST	Head Position in Stroke Trial
HEMA	2-hydroxyethyl methacrylate
HERMES	Highly effective reperfusion evaluated in multiple endovascular stroke trials
HERS	Heart and Estrogen/progestin study
HHT	Hereditary hemorrhagic telangiectasia
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
ICAD	Intracranial atherosclerotic disease
ICE	Intentional cerebral embolism
ICG	Indocyanine green
ICH	Intracerebral hemorrhage
ICP	Intracranial pressure
ICP	Intracranial pressure

ICSS	International Carotid Stenting Study
ICU	Intensive care unit
ID	Internal diameter
IEL	Internal elastic lamina
IEP	Intracranial embolization procedure
II	Image intensifier
IIH	Idiopathic intracranial hypertension
IJ	Internal jugular vein
IMA	Internal maxillary artery
IMS III	Interventional Management of Stroke III
IMT	Intima media thickness
INR	International normalized ratio
INTERACT2	Intensive blood pressure reduction in acute cerebral hemorrhage 2 trial
IPS	Inferior petrosal sinus
IPSS	Inferior petrosal sinus sampling
IRB	Institutional review board
ISAT	International Subarachnoid Aneurysm Trial
ISUIA	International Study of Unruptured Intracranial Aneurysms
IV	Intravenous
IVH	Intraventricular hemorrhage
JAM	Japan Adult Moyamoya Trial
JUPITER	Justification for the use of statins in prevention: an intervention trial evaluating rosuvastatin
KHE	Kaposiform hemangioendotheliomas
KSS	Kearns-Sayre syndrome
KTS	Klippel Trenaunay syndrome
kV	Kilovolt
kW	Kilowatt
LDL	Low density lipoprotein
LDS	Loeys-Dietz syndrome
LINAC	Linear accelerator (radiosurgery)
LMWH	Low molecular weight heparin
LOC	Level of consciousness; loss of consciousness
LV	Left ventricle
LVAD	Left ventricular assist device
LVEF	Left ventricular ejection fraction
LVO	Large vessel occlusion
MA	Maxillary artery
MAC	Mitral annular calcification
MACE	Major adverse cerebrovascular events
MATCH	Management of AtheroThrombosis with Clopidogrel in High-risk patients
MAUDE	Manufacturer and User facility Device Experience
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
MEP	Motor evoked potential
MERFF	Myoclonic epilepsy and ragged red fibers
MI	Myocardial infarction
MISTIE	Minimally Invasive Surgery Plus Alteplase for Intracerebral Hemorrhage Evacuation
mm	Millimeter
MMA	Middle meningeal artery
MR CLEAN	Multicenter Randomized Clinical Trial of Endovascular Treatment for Acute Ischemic Stroke in the Netherlands
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
MyRIAD	Mechanisms of Early Recurrence in Intracranial Atherosclerotic Disease Study
NA	Not available
NASCET	North American Symptomatic Carotid Endarterectomy Trial
NBCA	*N*-butyl-2-cyanoacrylate. Aka: Glue
NBTE	Nonbacterial thrombotic endocarditis
NCRP	National Council on Radiation Protection and Measurements
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
NOACs	Novel oral anticoagulants, non-vitamin K antagonist oral anticoagulants
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

OD	Outer diameter
OEF	Oxygen extraction fraction
OKM	O'Kelly-Marotta scale
OSA	Obstructive sleep apnea
OTW	Over-the-wire
PA	Posteroanterior
PAC	Partial anterior circulation stroke
PACS	Picture archiving and communication system
PAN	Polyarteritis nodosa
PASCAL	Performance and Safety of the Medtronic AVE Self-Expandable Stent in the treatment of Carotid Artery Lesions
PATCH	Platelet Transfusion in Cerebral Hemorrhage Trial
pAVF	Pial arteriovenous fistula
PCA	Posterior cerebral artery
PCC	Prothrombin complex concentrate
P-comm	Posterior communicating artery
PCR	Polymerase chain reaction
PCWP	Pulmonary capillary wedge pressure
PCXR	Portable chest X-ray
PEEP	Positive end-expiratory pressure
PET	Positron emission tomography
PFO	Patent foramen ovale
PHASES	Population hypertension age size earlier site
PICA	Posterior inferior cerebellar artery
PKD	Polycystic kidney disease
PNS	Peripheral nervous system
POC	Posterior circulation stroke
POINT	Platelet-Oriented Inhibition in New TIA and Minor Ischemic Stroke Trial
PPI	Proton pump inhibitor
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
PVP	Polyvinylpyrollidone
RA	Rheumatoid arthritis
RCVS	Reversible cerebrovascular constriction syndrome
RECANALISE	Recanalization using combined intravenous Alteplase and neurointerventional algorithm for acute ischemic stroke

REGARDS	Reasons for Geographic and Racial Differences in Stroke Study
rem	Roentgen-equivalent-man, rapid eye movement sleep stage
RESCUE Japan LIMIT	Recovery by Endovascular Salvage for Cerebral Ultra-acute Embolism-Japan Large Ischemic Core Trial
REVASCAT	Endovascular REVAscularlization with a Solitaire Device versus best medical management in Anterior Circulation Stroke Within 8 Hours.
REVERSE-AD	Reversal Effects of Idarucizumab on Active Dabigatran study
RHV	Rotating hemostatic valve (aka Y-adapter, aka Touey-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
SAH	Subarachnoid hemorrhage
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
SAVE	Stent-retriever assisted vacuum-locked extraction
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
SELECT2	Randomized Controlled Trial to Optimize Patients selection for Endovascular Treatment in Acute Ischemic Stroke
SIADH	Syndrome of inappropriate antidiuretic hormone secretion
SIM	Simmons catheter
SIR	Society of Interventional Radiology
SKIP	Direct Mechanical Thrombectomy in Acute LVO Stroke study
SLE	Systemic lupus erythematosus
SOV	Superior ophthalmic vein

SPACE	Stent-Protected Percutaneous Angioplasty of the Carotid versus Endarterectomy
SPACEMAN	Stent-pass-aspiration-rescue-microwire-angioplasty
SPARCL	Stroke Prevention by Aggressive Reduction in Cholesterol Levels
SPECT	Single photon emission computed tomography
SSEP	Somatosensory evoked potential
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
STICH	Surgical Trial in Lobar Intracerebral Hemorrhage
SWIFT PRIME	Solitaire with the intention for thrombectomy as primary endovascular treatment
TAC	Total anterior circulation stroke
TASS	Ticlopidine Aspirin Stroke Study
TCAR	Transcarotid arterial revascularization
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
TRA	Transradial access
TSAT	Two-stage aspiration technique
TTE	Transthoracic echocardiography
TTP	Time to peak; thrombotic thrombocytopenic purpura
U	Unit
UAC	Umbilical artery catheter
UOP	Urinary output
USA	United States of America
V	Volts
VACS	Veterans Affairs Cooperative Study on Symptomatic Stenosis
VAST	Vertebral Artery Stenting Trial
VBI	Vertebrobasilar insufficiency
VDRL	Venereal Disease Research Laboratory
VEGF	Vascular Endothelial Growth Factor
VERiTAS	Vertebrobasilar Flow Evaluation and Risk of Transient Ischemic Attack and Stroke.
VERT	Vertebral
VISSIT	Vitesse Intracranial Stent Study
VIVA	ViVEXX Carotid Revascularization Trial
VOGM	Vein of Galen malformation
VZV	Varicella zoster virus

WASID	Warfarin versus Aspirin for Symptomatic Intracranial Disease
WEAVE	Wingspan Stent System Post Market Surveillance
WEB	Woven endobridge
WEST	Women Estrogen Stroke Trial
WHI	Women's Health Initiative
WOVEN	Wingspan One Year Vascular Events and Neurological Outcomes
WSS	Wall Shear Stress

Part I

Fundamentals

Essential Neurovascular Anatomy

1

1.1 Aortic Arch and Great Vessels

Aortic arch anatomy is pertinent to neuroangiography because variations of arch anatomy can affect access to the cervicocranial circulation.

1. Branches
   (a) Innominate (aka brachiocephalic) artery
   (b) Left common carotid artery (CCA)
   (c) Left subclavian artery
2. Variants (Fig. 1.1)
   (a) Bovine arch (Figs. 1.1b and 1.2). The innominate artery and left common carotid artery (CCA) share a common origin (up to 27% of cases), or the left CCA arises from the innominate artery (7% of cases) [1]. The bovine variant is more common in blacks (10–25%) than whites (5–8%) [2].
   (b) Aberrant right subclavian artery. The right subclavian artery arises from the left aortic arch, distal to the origin of the left subclavian artery. It usually passes posterior to the esophagus on its way to the right upper extremity. This is the most common congenital arch anomaly; incidence: 0.4–2.0% [3] associated with Down syndrome.
   (c) Origin of the left vertebral artery from the arch is seen in 0.5% of cases [1].
   (d) Less common variants (Fig. 1.3). Some of these rare anomalies can lead to formation of a vascular ring in which the trachea and esophagus are encircled by connecting segments of the aortic arch and its branches.
3. Effects of aging and atherosclerosis on the aortic arch and great vessels. The aortic arch and great vessels become elongated and tortuous with age (Fig. 1.4); this can have practical implications for neurointervention in the elderly, as a tortuous vessel can be difficult to negotiate with wires and catheters. Although atherosclerosis has been implicated in the etiology of this phenomenon, more recent data suggest that the cervical internal carotid artery (ICA) may undergo *metaplastic transformation*, in which elastic and muscular tissue in the artery wall is replaced by loose connective tissue [4].

The most common subclavian artery configuration is shown in Fig. 1.5. Major branches are:

1. Vertebral artery (1)
2. Thyrocervical trunk
   (a) Inferior thyroid artery (2)
   (b) Ascending cervical artery (most commonly a branch of transverse cervical) (3)
   (c) Transverse cervical artery (4)
   (d) Suprascapular artery (5)

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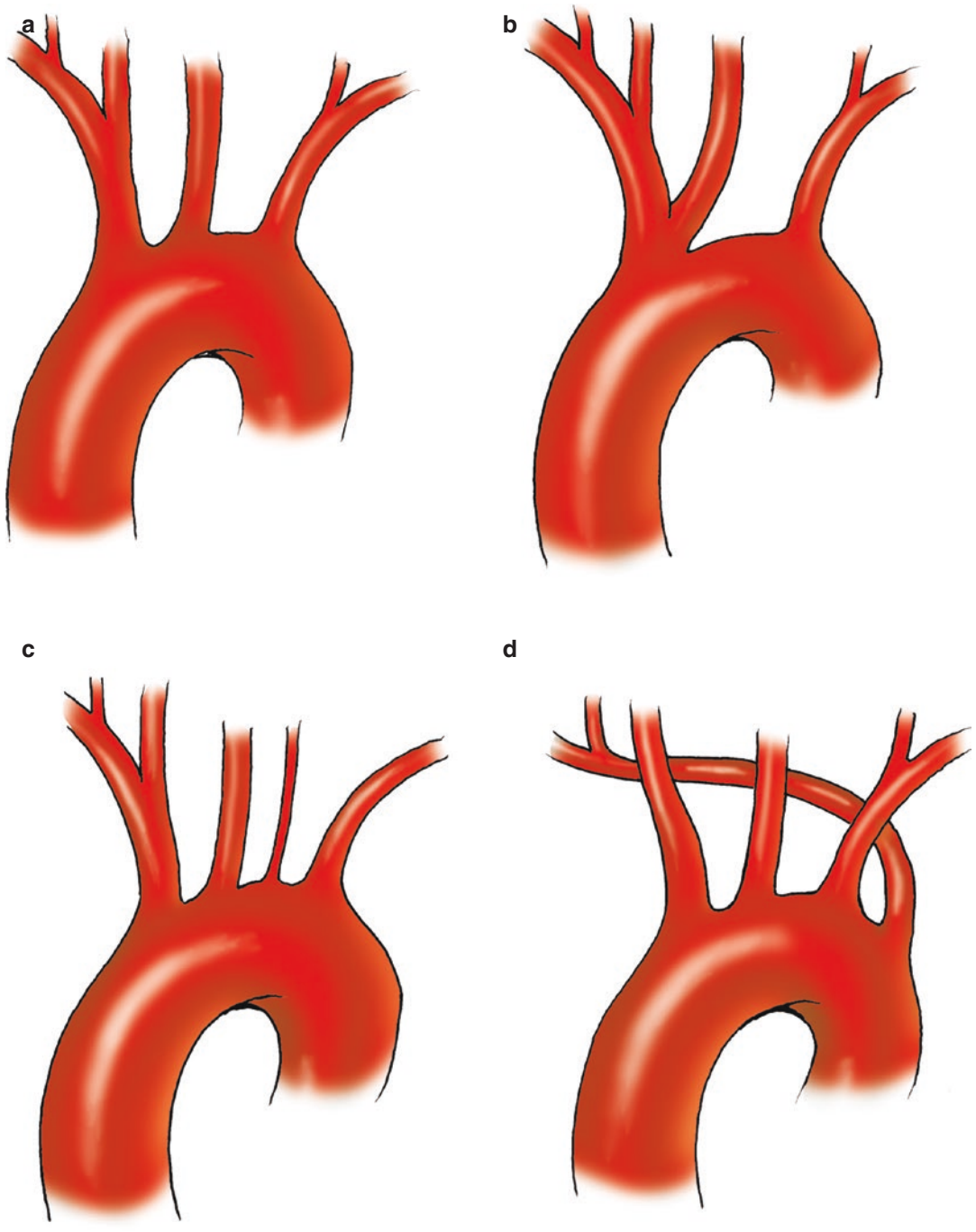

Fig. 1.1 Common aortic arch configurations. *Clockwise from upper left*: (**a**) Normal arch; (**b**) bovine arch; (**c**) aberrant right subclavian artery; and (**d**) origin of the left vertebral artery from the arch