Handbook of Cerebrovascular Disease and Neurointerventional Technique

Third Edition

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Humana Press

Contemporary Medical Imaging

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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 Korners!* 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.
   (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.

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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	Adrenocorticotropic 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	*Desmodus rotundus* 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-synagiosis
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	*N*-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-adapter, 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

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
   (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].

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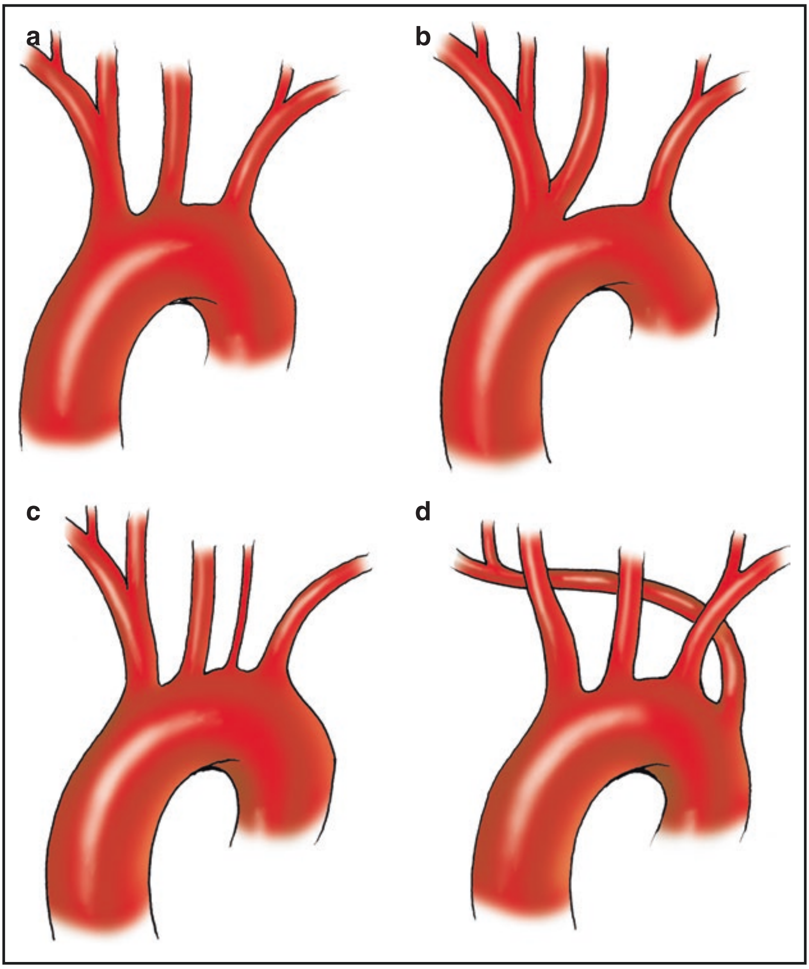

Fig. 1.1 Common aortic arch configurations. *Clockwise from upper left*: (**a**) Normal arch; (**b**) bovine arch; (**c**) aberrant right subclavian artery, and (**d**) origin of the left vertebral artery from the arch

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)
3. Costocervical trunk
   (a) Deep cervical artery (6)
   (b) Supreme or highest intercostal artery (7)
4. Dorsal scapular artery (may also arise from transverse cervical) [5] (8)
5. Internal thoracic (mammary) artery (9)

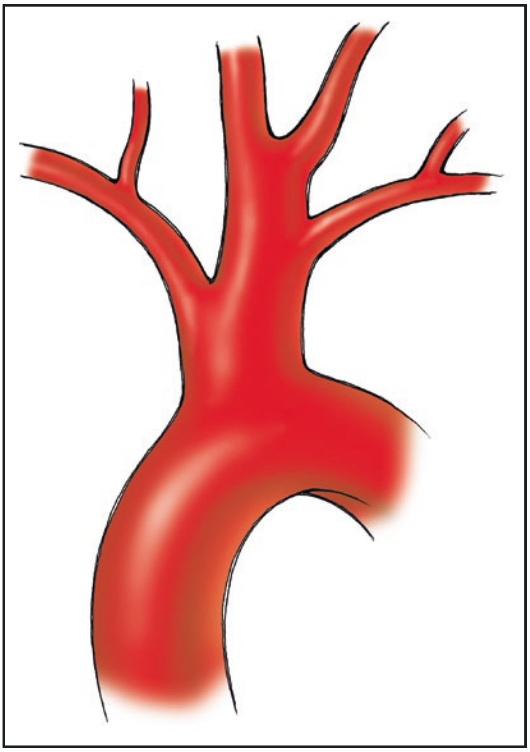

Fig. 1.2 What exactly is a "bovine arch?" Drawing of an arch from a cow. In cattle, a single great vessel originates from the aortic arch [315]. Presumably, the long brachiocephalic artery is due to the relatively long distance from the aorta to the thoracic inlet in cattle. Because humans do not have a true "bovine arch," Layton and colleagues proposed that the more precise term, "common-origin-of-the-innominate-artery-and-left-common-carotid-artery" and "origin-of-the-left-common-carotid-artery-from-the-innominate-artery" supplant the term bovine arch [316]. This is akin to proposing that the universally understood term, "P-comm aneurysm," be replaced by the more accurate "aneurysm-arising-from-the-internal-carotid-artery-adjacent-to-the-origin-of-the-posterior-communicating-artery." The authors of this handbook will continue to use the well-understood but anatomically imprecise terms, bovine arch and P-comm aneurysm

1.2 Common Carotid Arteries

The CCAs travel within the carotid sheath, which also contains the internal jugular vein and the vagus nerve. The right CCA is usually shorter than the left. The CCAs typically bifurcate at the C3 or C4 level (upper border of the thyroid cartilage), although the bifurcation may be located anywhere between T2 and C2 [6]. The CCAs do not usually have branches, although anomalous branches can include the superior thyroid, ascending pharyngeal, or occipital arteries [1].

1.3 External Carotid Artery

The external carotid artery (ECA) originates at the common carotid bifurcation. From its origin, the ECA usually curves forward medial to the internal carotid, and then immediately begins a cephalad ascent, curving laterally and slightly posteriorly until it ends behind the mandible in its terminal

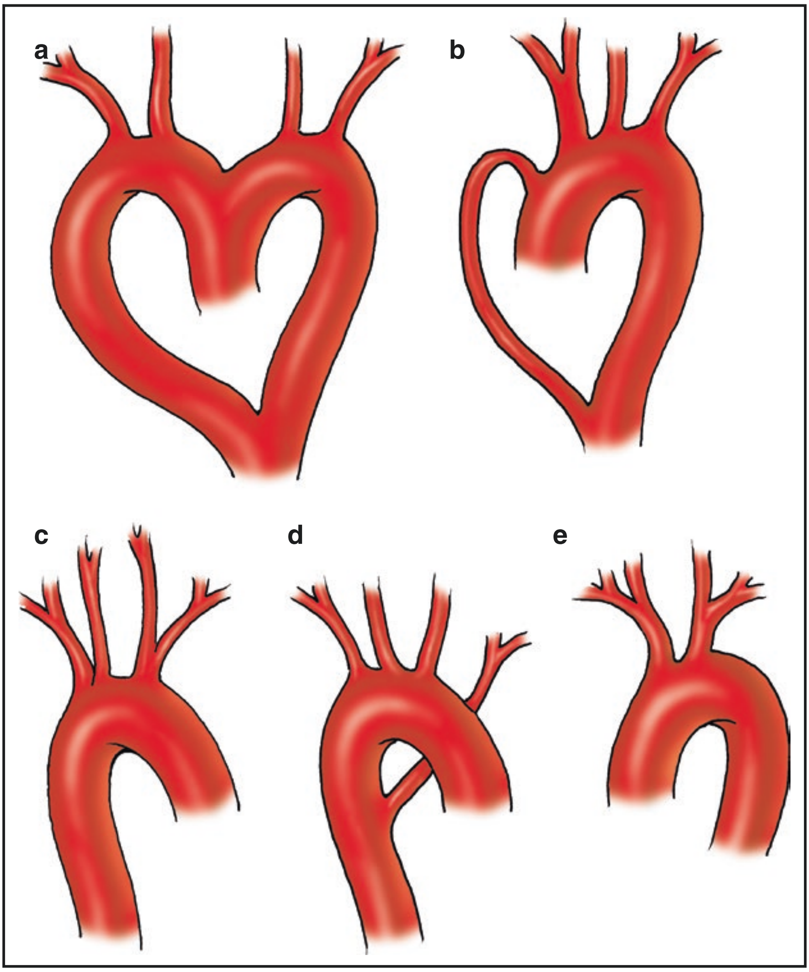

Fig. 1.3 Selected aortic arch anomalies. (**a**) Double-aortic arch. The arches encircle the trachea and esophagus to form the descending aorta, which is usually on the *left*. The *right arch* is larger than the *left* in up to 75% of cases [1]. (**b**) Double-aortic arch with left arch atresia. (**c**) Right aortic arch with a mirror configuration. The descending aorta is on the *right side* of the heart. This anomaly does not form a vascular ring, but is associated with other anomalies such as tetralogy of Fallot [1]. (**d**) Right aortic arch with a nonmirror configuration and an aberrant left subclavian artery. The descending aorta is on the *right side* of the heart, and the left subclavian artery arises from the proximal aorta. A common cause of a symptomatic vascular ring [317]. (**e**) Bi-innominate artery

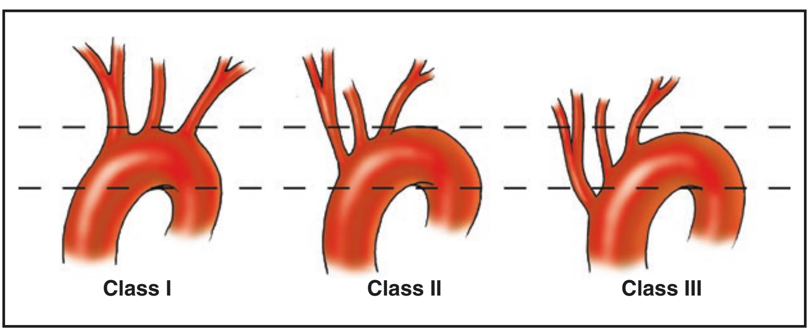

Fig. 1.4 Aortic arch elongation classification scheme

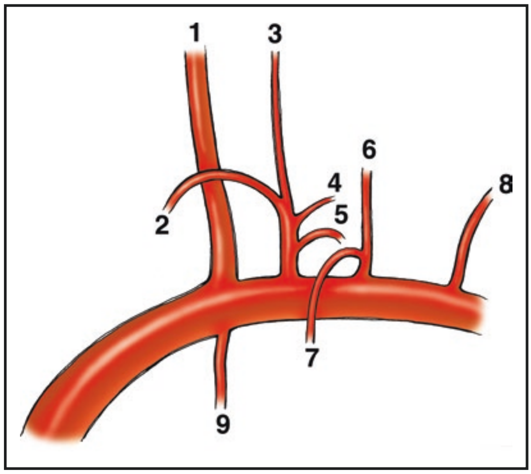

Fig. 1.5 Subclavian artery. (*1*) Vertebral artery; (*2*) inferior thyroid artery; (*3*) ascending cervical artery; (*4*) transverse cervical artery; (*5*) suprascapular artery; (*6*) deep cervical artery; (*7*) supreme intercostal artery; (*8*) dorsal scapular artery; (*9*) internal mammary artery

bifurcation into the maxillary and superficial temporal arteries [7]. Thus, on a frontal radiographic view, the external carotid begins medially and swings cephalad and laterally, and on a lateral view it begins anteriorly and then ascends, angling slightly posteriorly.

Mnemonic for the External Carotid Branches

After reading this book …

Some **a**doring **l**inguists **f**ind **o**ur **p**aragraphs

Somewhat **m**esmerizing

Superior thyroid
Ascending pharyngeal
Lingual
Facial
Occipital
Posterior auricular
Superficial temporal
Maxillary

More amusing and off-color mnemonics are available to assist the novice in remembering these branches. If the readers' imaginations fail them, the authors would be more than happy to supply additional memory aids for this purpose

1. Branches

   There are eight major branches of the ECA (Fig. 1.6). Commonly, the branches are listed in order by their point of origin from proximal to distal.

   (a) Superior thyroid artery
   (b) Ascending pharyngeal artery
   (c) Lingual artery
   (d) Facial artery
   (e) Occipital artery

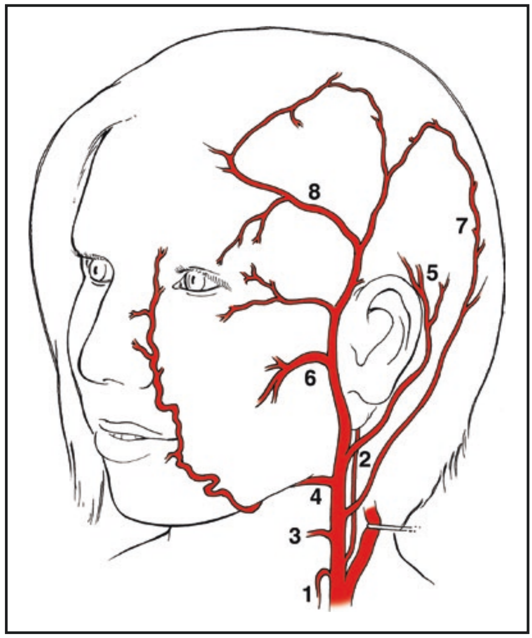

Fig. 1.6 External carotid artery. (*1*) Superior thyroid artery; (*2*) ascending pharyngeal artery; (*3*) lingual artery; (*4*) facial artery; (*5*) posterior auricular artery; (*6*) maxillary artery; (*7*) occipital artery; (*8*) superficial temporal artery

(f) Posterior auricular artery
(g) Superficial temporal artery
(h) Maxillary artery

Occasionally, these branches arise from the ECA trunk. The ventral group arises anteriorly from the ECA and the dorsal group of branches arises posteriorly from the ECA. Therefore, grouping the ECA branches based on their ventral or dorsal axis is more useful and more consistent.

Ventral external carotid branches:

(a) Superior thyroid artery
(b) Lingual artery
(c) Facial artery
(d) Maxillary artery

Dorsal external carotid branches

(a) Ascending pharyngeal artery
(b) Occipital artery
(c) Posterior auricular artery
(d) Superficial temporal artery

2. Territories
The ECA supplies much of the soft tissue and bony structures of the head and face, the deep structures of the upper aero-digestive tract, and much of the dura of the intracranial compartment. Numerous anastomoses are present between ECA branches and branches of the internal carotid and vertebral arteries. These anastomoses provide collateral flow to the vascular territories distal to a proximal occlusion. Anastomoses to carotid or vertebral arteries can also be considered

"dangerous anastomoses" when attempting to embolize vascular lesions in the head and neck via external carotid branches. See below for discussion of individual ECA branch anastomoses and Tables 1.1, 1.2, 1.3, and 1.4.

3. Variants:
   (a) The most frequent branching pattern seen at the common carotid bifurcation (in 48.5%) is the external carotid arising anteromedially while the internal carotid arises posterolaterally. The most frequent branching pattern seen at the common carotid bifurcation finds the external carotid arising anteromedially. Occasionally, the ECA arises posterolaterally or directly laterally [8, 9].

Table 1.1 Anastomoses to anterior circulation

Anastomosis from	Anastomosis to	Comments/reference
Ascending pharyngeal, neuromeningeal trunk	Cavernous carotid via meningohypophyseal trunk	[14]
Ascending pharyngeal, inferior tympanic branch	Petrous carotid via caroticotympanic	[14]
Ascending pharyngeal, superior pharyngeal	Cavernous carotid via inferolateral trunk	[14]
Ascending pharyngeal, superior pharyngeal	Petrous carotid via mandibular branch	[14]
Accessory meningeal (cavernous branch)	Cavernous carotid via inferolateral trunk, posterior branch	[14]
Middle meningeal (cavernous branch)	Cavernous carotid via inferolateral trunk, posterior branch	[14]
Middle meningeal (cavernous branch)	Cavernous carotid via meningohypophyseal trunk	[14]
Distal maxillary (artery of foramen rotundum)	Cavernous carotid via inferolateral trunk, anterolateral branch	[14]

Table 1.2 Common anastomoses to ophthalmic artery

Anastomosis from	Anastomosis to	Comments/reference
Middle meningeal, sphenoidal branch	Ophthalmic	[14]
Middle meningeal, frontal branch	Ophthalmic via anterior falx artery	[14]
Inferolateral trunk, anteromedial branch	Ophthalmic	[14]
Distal maxillary, anterior deep temporal	Ophthalmic	[14]
Distal maxillary, infraorbital	Ophthalmic	[14]
Distal maxillary, sphenopalatine	Ophthalmic via ethmoidal branches	[14]
Distal facial	Ophthalmic	[14]
Transverse facial	Ophthalmic	[14]
Superficial temporal, frontal branch	Ophthalmic	[14]
Cavernous carotid, inferolateral trunk	Ophthalmic via recurrent meningeal branch	[14]

Table 1.3 Common anastomoses to posterior circulation

Anastomosis from	Anastomosis to	Comments/reference
Ascending cervical	Vertebral segmental branches	[14]
Deep cervical	Vertebral segmental branches	[14]
Occipital, muscular branches	Vertebral segmental branches	[14]
Ascending pharyngeal, muscular branches	Vertebral segmental branches	[14]
Ascending pharyngeal, neuromeningeal trunk	C3 segmental vertebral via odontoid arch	Odontoid arch connects side-to-side [14]

Table 1.4 More trouble: cranial nerve blood supply

Cranial nerve	Arterial supply	References
I: Olfactory	Anterior cerebral	[14]
II: Optic	Supraclinoid carotid, ophthalmic	[14]
III: Oculomotor	Basilar, superior cerebellar, posterior cerebral, inferolateral trunk, ophthalmic	[14, 70]
IV: Trochlear	Inferolateral trunk, meningohypophyseal trunk	[14, 70]
V: Trigeminal	Inferolateral trunk, meningohypophyseal trunk, middle meningeal, accessory meningeal, artery of foramen rotundum, infraorbital	[14, 70]
VI: Abducens	Inferolateral trunk, meningohypophyseal trunk, middle meningeal, accessory meningeal, ascending pharyngeal (jugular branch)	[14, 19, 70]
VII: Facial	Stylomastoid (from post auricular or occipital), middle meningeal (petrous branch), ascending pharyngeal (inferior tympanic and odontoid arcade)	[14, 71]
VIII: Auditory	Basilar, AICA, ascending pharyngeal jugular branch	[14, 72]
IX: Glossopharyngeal	Ascending pharyngeal jugular branch	[14, 19]
X: Vagus	Ascending pharyngeal jugular branch, superior and inferior thyroid, laryngeal branches	[14, 19]
XI: Spinal accessory	Ascending pharyngeal (jugular, inferior tympanic and musculospinal branches)	[14, 19]
XII: Hypoglossal	Ascending pharyngeal, hypoglossal branch and proximal trunk, occipital, directly from external carotid, lingual	[14, 73]

(b) The ECA and ICA may rarely arise as separate branches of the aortic arch [7, 10].
   (i) Some ECA branches, especially the superior thyroid artery, may arise from the CCA.
   (ii) Some branches (especially the ascending pharyngeal or occipital arteries) may originate from the ICA.
   (iii) A common origin of superior thyroid, occipital, and ascending pharyngeal arteries from the ICA has been reported [11].
   (iv) Rarely, all external carotid branches may arise from the ICA [12].
   (v) External carotid branches may arise as common trunks with other branches including linguofacial trunk (20% of cases), thyrolingual trunk (2.5% of cases), thyrolinguofacial trunk (2.5% of cases), and occipitoauricular trunk (12.5% of cases) [13].

1.4 Superior Thyroid Artery

Whether it arises above or below the common carotid bifurcation, the superior thyroid artery originates from the anterior surface of the parent artery and immediately turns caudally to supply the anterior soft-tissue structures of the neck.

1. Branches
   (a) Infrahyoid (hyoid) artery travels medially from its origin, and then follows along the lower hyoid bone. It can anastomose with the submental artery, providing a collateral pathway to the facial artery [14].
   (b) Superior laryngeal artery travels alongside the internal laryngeal nerve inferomedially from its origin and pierces the thyrohyoid membrane to supply the mucosa of the larynx superior to the vocal cords and taste buds of the epiglottis [15].
      (i) Branches
         - The superior thyroid artery has two major branches and a small epiglottic branch. Its ventral branch anastomoses with the both the cricothyroid artery and superior laryngeal arcade. The dorsal branch anastomoses with the longitudinal laryngeal arcade [14].

(ii) Territory
- The superior laryngeal artery supplies the pharyngeal and laryngeal structures as well as the internal laryngeal nerve. It anastomoses with its contralateral partner and with the inferior laryngeal artery from the inferior thyroid artery.

(iii) Variants
- May arise as a separate branch from the ECA or ascending pharyngeal artery [14].
- In 6 of 22 anatomic specimens, the superior laryngeal artery does not pierce the thyrohyoid membrane but instead passes through a foramen in the thyroid cartilage to supply the soft tissues of the larynx [16].

(c) Sternocleidomastoid artery
(i) The sternocleidomastoid artery feeds the middle part of the sternocleidomastoid muscle. It anastomoses superiorly with the muscular branches of the occipital and posterior auricular and inferiorly with the thyrocervical trunk and suprascapular. It can also connect with the glandular branches of the superior thyroid artery.

(d) Cricothyroid artery
(i) Anastomoses with the superior laryngeal artery and feeds the upper trachea.

(e) Glandular branches
(i) These are a continuation of the superior thyroid trunk with superior, medial, and lateral arcades to supply the thyroid gland. They freely anastomose with their contralateral counterparts.

2. Territories
(a) The superior thyroid artery supplies the majority of the blood to the larynx, its associated musculature, and the upper pole of the thyroid gland [7]. In a minority of cases the superior thyroid provides blood flow to the parathyroid glands [17]. The superior laryngeal branch accompanies and can supply the internal laryngeal nerve. The superior thyroid branches freely anastomose with their contralateral counterparts and the inferior thyroid artery (from the thyrocervical trunk).

3. Variants
(a) The superior thyroid artery arises from the ECA in 46% of cases and more commonly from the CCA in 52% of cases [18].
(b) The superior thyroid artery may arise in a common trunk with the lingual as a thyrolingual trunk.
(c) Rarely, the superior thyroid artery may arise from the ICA [11].

1.5 Ascending Pharyngeal Artery

The ascending pharyngeal artery is a thin, slender branch that arises from the very proximal posterior aspect of the ECA or in the crotch of the CCA (Fig. 1.7). It travels cephalad parallel to the ICA. Its termination in the superior pharynx creates a forward and medial right-angle turn.

1. Branches
(a) Inferior pharyngeal artery
(i) A relatively small vessel arising from the proximal ascending pharyngeal and the inferior pharyngeal travels anteriorly in a zigzag fashion. It supplies the pharyngeal muscles and mucosa. It anastomoses with its contralateral counterpart.

(b) Musculospinal artery
(i) The vessel may arise from the ascending pharyngeal itself or from the neuromeningeal trunk. It extends posteriorly and superiorly for a short distance before curving inferiorly.

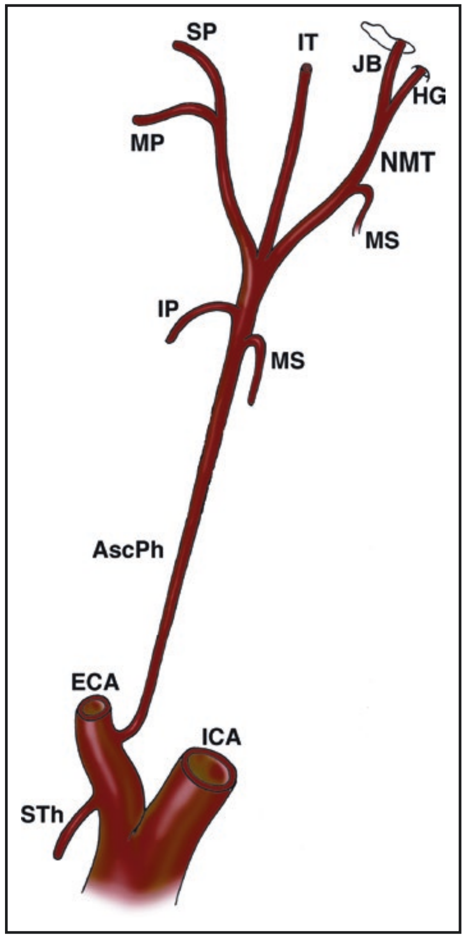

Fig. 1.7 Ascending pharyngeal artery. A common branching pattern of the ascending pharyngeal artery is shown. Note: *ICA* internal carotid, *ECA* external carotid, *STh* superior thyroid, *AscPh* ascending pharyngeal, *IP* inferior pharyngeal, *MP* middle pharyngeal, *SP* superior pharyngeal, *IT* inferior tympanic, *MS* musculospinal branches, *NMT* neuromeningeal trunk, jugular branch (*JB*) entering the jugular foramen, hypoglossal branch (*HG*) entering the hypoglossal foramen, and prevertebral (*not shown*)

It primarily supplies muscles, but also may supply the ipsilateral upper spinal nerve roots, the eleventh cranial nerve, and superior sympathetic ganglion. In addition, it may anastomose with the ascending and deep cervical and vertebral arteries [14, 19].

(c) Neuromeningeal trunk
  (i) This is a major branch of the ascending pharyngeal artery that continues cephalad but angles gently to the posterior. It has several important branches that pass through foramina in the skull base.
  (ii) Branches
    - *Musculospinal artery*
      – This branch may variably arise from the neuromeningeal trunk instead of originating from the ascending pharyngeal artery.
    - *Jugular artery*
      – Often the largest branch of the neuromeningeal trunk, this vessel heads straight cephalad to the jugular foramen. It supplies the 9th through the 11th cranial nerves and their ganglia. A medial branch ascends on the clivus to supply the eleventh cranial nerve. Its lateral branch travels along the dura around the sigmoid sinus. It

can be a major contributor to the dura of the posterior fossa. Anastomoses with the lateral clival branch of the meningohypophyseal trunk and dural branches of the vertebral artery are possible [14].

- *Hypoglossal artery*
  - This branch enters the hypoglossal canal and supplies the 12th cranial nerve. It also supplies the dura in the posterior cranial fossa and anastomoses with the jugular branch, medial clival branches of the meningohypophyseal trunk, the contralateral hypoglossal artery, and the odontoid arcade [14, 20].
- *Prevertebral artery*
  - It often arises from the neuromeningeal trunk and contributes to the odontoid arcade. It anastomoses with its contralateral counterpart, the anterior meningeal branch of the vertebral and hypoglossal artery branches [20].

(iii) Territories

- The very important neuromeningeal trunk of the ascending pharyngeal artery supplies cranial nerves VI, IX, X, XI, and XII, and potentially collateralizes to the upper three spinal nerves and the superior sympathetic ganglion. Its meningeal territory includes a large portion of the posterior fossa meninges. Anastomotic channels exist to its contralateral counterpart and meningeal branches of the vertebral artery and the meningohypophyseal trunk [19].

(iv) Variants

- All branches of the neuromeningeal trunk are in vascular equilibrium with each other and with their anastomotic connecting vessels. Hypoplasia or absence of one or more vessels is accompanied by hypertrophy of the existing branches.

(d) Prevertebral artery

(i) Occasionally, this artery arises directly from the ascending pharyngeal artery and contributes to the odontoid arcade [20].

(e) Inferior tympanic artery

(i) Branches [14]

- Ascending branch connects to petrosal branch of middle meningeal artery
- Anterior branch connects to the caroticotympanic branch
- Posterior branch connects to the stylomastoid artery, a branch of the posterior auricular artery

(ii) Territories

- Supplies the middle-ear cavity and associated nerves, including the 12th nerve and tympanic branch of the 9th cranial nerve (aka *Jacobson's nerve*).

(iii) Variants

- May arise from the neuromeningeal branch, the ascending pharyngeal artery, or it may appear as a trifurcation with the inferior tympanic artery arising in between neuromeningeal and pharyngeal divisions [14].

(f) Middle pharyngeal artery

(i) Branches

- No named branches.

(ii) Territories

- Supplies mucosa and muscles of the naso- and oropharynx as well as the soft palate [21]. Anastomoses with contralateral middle pharyngeal artery, ipsilateral ascending palatine artery, greater palatine artery, and branches of the accessory meningeal artery.