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Handbook of Cerebrovascular Disease and Neurointerventional Technique

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ABBREVIATIONS

A-comm	Anterior communicating artery
ACAS	Asymptomatic Carotid Atherosclerosis Study
ACCP	American College of Chest Physicians
ACE	Angiotensin converting enzyme
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 aka	Anterior inferior cerebellar artery 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); Anterior spinal artery
ASAN	Atrial septal aneurysm
ASITN	American Society of Interventional and Therapeutic Neuroradiology
ASNR	American Society of Neuroradiology
atm	Atmosphere
AV	Arterio-venous
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
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
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
CNS	Central nervous system
COSS	Carotid Occlusion Surgery Study
CPK	Creatine phosphokinase
CPP	Cerebral perfusion pressure

Cr	Creatinine
CREATE	Carotid Revascularization With ev3 Arterial Technology Evolution
CREST	Calcinosis, Raynaud 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
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
EC-IC	Extracranial to intracranial
EC-TRICKS	Elliptical centric time-resolved imaging of contrast kinetics
ECA	External carotid artery
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
ICH	Intracranial hemorrhage
ICP	Intracranial pressure
ICSS	International Carotid Stenting Study
ICU	Intensive care unit
IEL	Internal elastic lamina
IEP	Intracranial embolization procedure
II	Image intensifier
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
KSS	Kearns-Sayre Syndrome
LAC	Lacunar stroke
LDL	Low density lipoprotein
LINAC	Linear accelerator
LMWH	Low molecular weight heparin
LOC	Level of consciousness; loss of consciousness
LV	Left ventricle
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, and stroke-like episodes
MERRF	Myoclonic epilepsy and ragged red fibers
MI	Myocardial infarction
mm	Millimeter
MRA	Magnetic resonance angiography
MRI	Magnetic resonance imaging
mRS	Modified Rankin score
MTT	Mean transit time
MVP	Mitral valve prolapse
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
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
NPO	Nil per os (no feeding)
NS	Not significant
NSAID	Nonsteroidal antiinflammatory drug
OA-MCA	Occipital artery to middle cerebral artery
OA-PCA	Occipital artery to posterior cerebral artery
OCP	Oral contraceptive
OEF	Oxygen extraction fraction
OSA	Obstructive sleep apnea
OTW	Over the wire
P-comm	Posterior communicating artery
PA	Postero-anterior
PAC	Partial anterior circulation stroke
PAN	Polyarteritis nodosa
PASCAL	Performance And Safety of the Medtronic AVE Self-Expandable Stent in Treatment of Carotid Artery Lesions
PCA	Posterior cerebral artery
PCR	Polymerase chain reaction
PCWP	Pulmonary capillary wedge pressure
PCXR	Portable chest xray
PEEP	Positive end-expiratory pressure
PET	Positron emission tomography
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
Pro-UK	Prourokinase
PROACT	Prolyse in Acute Cerebral Thromboembolism
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
RHV	Rotating hemostatic valve (aka Y-adapter, aka Touey-Borst Valve)
RIND	Reversible ischemic neurologic deficit
RPR	Rapid plasma reagin
RR	Risk reduction
RRR	Relative risk reductiion
RX	Rapid exchange
SBP	Systolic blood pressure
SCA	Superior cerebellar artery
SCD	Sickle cell disease
SDH	Subdural hematoma
SECURITY	Study to Evaluate the Neuroshield Bare Wire Cerebral Protection System and X-Act Stent in Patients at High Risk for Carotid Endarterectomy
SIADH	Syndrome of inappropriate ADH secretion
SIM	Simmons
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
TAC	Total anterior circulation stroke
TASS	Ticlopindine Aspirin Stroke Study
TCD	Transcranial Doppler
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
UOP	Urinary output
VACS	Veterans Affairs Cooperative Study on Symptomatic Stenosis
VBI	Vertebrobasilar insufficiency
VDRL	Venereal Disease Research Laboratory
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

Introduction

In recent years, neurointerventional radiology has evolved into 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 have resulted in a need for a practical, unified handbook of techniques and essential literature. The purpose of this book is to serve as a practical guide to endovascular methods and as a reference work for neurovascular anatomy and published data about cerebrovascular disease from a neurointerventionalist's perspective.

We have attempted to enhance the accessibility and ease use of this handbook by arranging it in a semioutline 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:
      - Essential neurovascular anatomy and basic angiographic techniques provide the foundation of the first section.
        - The focus of Chap. 1 (*Essential Neurovascular Anatomy*) is on vascular anatomy that is pertinent to day-to-day clinical practice. Embryology and discussions of angiographic shift, which are less pertinent these days because of widely available noninvasive intracranial imaging, are left out. Discussions of anatomic variants include both normal variants and anomalies.
        - Chapters 2 and 3 cover diagnostic angiographic techniques.
        - Chapter 4 (*Neuroendovascular Suite*) is primarily intended for newcomers to the angio suite and for experienced interventionalists planning a new suite.

   (b) Techniques:
      - Endovascular methods, device information, and tips and tricks are detailed.

   (c) Specific disease states:
      - Essential, useful information about each commonly encountered condition is presented.
        1. Significant clinical studies are summarized and placed into context.
        2. Interesting and novel facts (and *factlets*) are included here and there.
      - 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.
      - For readers with extra time on their hands, *A Brief History of…* sections describe the background and evolution of various techniques.
      - Chapter 17 (*Acute Ischemic Stroke*) contains a comprehensive discussion of the medical management of patients with stroke. The topics are arranged alphabetically to permit ease of use.

2. Core philosophy: Within the practical infor mation 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 sensible 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, because of 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. Overlap and redundancy: Discussion of some topics may appear to be repetetive and redundant; for instance, guide catheters are discussed in both Chap. 5 (*Intracranial Aneurysm Treatment*), and in Chap. 7 (*Intracranial Embolization*). This is intentional, as we hoped to avoid frequent cross-referencing between sections of the book, which can be annoying for a busy reader looking for quick advice. In addition, some overlap can actually be beneficial, as some topics can be discussed from different perspectives. For example, the evaluation of a stroke patient in the emergency room is discussed in Chap. 9 (*Thrombolysis for Acute Ischemic Stroke*), from the perspective of an interventionalist seeing a patient with a firm diagnosis of acute ischemic stroke, whereas a discussion of the same topic appears in Chap. 17 (*Acute Ischemic Stroke*) from the perspective of the *Code Stroke* team answering a call from the ER.
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.

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1. Essential Neurovascular Anatomy

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 artery (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 share a common origin (up to 27% of cases), or the left common carotid artery arises from the innominate artery (7% of cases).[1]
   (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 the way to the right upper extremity. Most common congenital arch anomaly; incidence: 0.9%.2 Associated with Down syndrome.
   (c) Origin of the left vertebral artery from the arch, is seen in 0.5% of cases.[1]

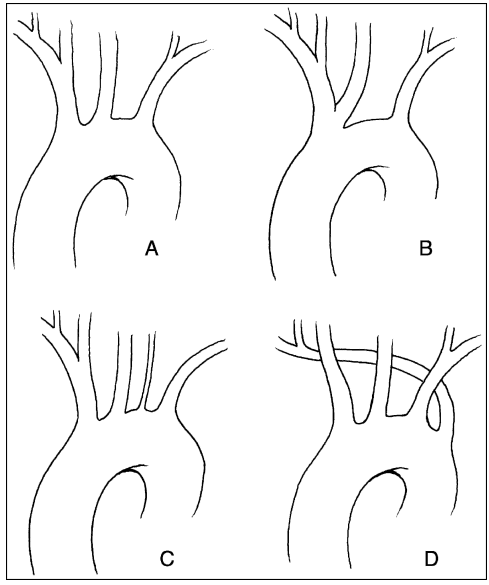

Fig. 1.1 Common aortic arch configurations. *Clockwise from upper left*: Normal arch; Bovine arch, Aberrant right sublclavian artery, origin of the left vertebral artery from the arch.

(d) Less common variants (Fig. 1.3). Some of these rare anomalies can lead to the formation of a vascular ring, in which the trachea and esophagus are encircled by connected 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 may undergo *metaplastic transformation*, in which elastic and muscular tissue in the artery wall is replaced by loose connective tissue.[3]

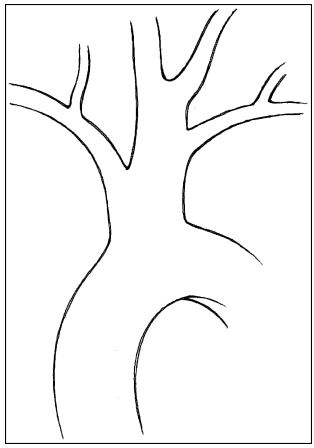

Fig. 1.2 What exactly is a "Bovine Arch?" Drawing of an arch from a cow.

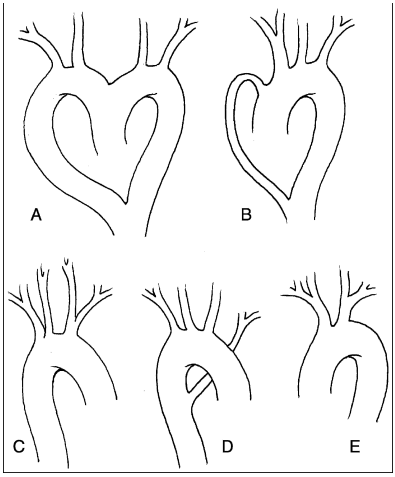

Fig. 1.3 Selected aortic arch anomalies. (A) Double aortic arch. The arches encircle the trachea and esophagus to form the descending aorta, which is usually on the left. The *right arch* is larger than the left in up to 75% of cases.[1] (B) Double aortic arch with left arch atresia. (C) Right aortic 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.[4] (E) Bi-innominate artery.

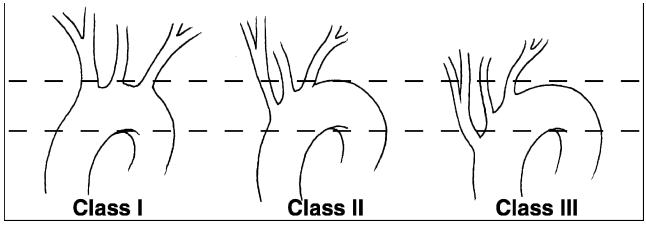

Fig. 1.4 Aortic arch elongation classification scheme.

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

- Vertebral artery (1)
- Thyrocervical trunk
  - Inferior thyroid artery (2)
  - Ascending cervical artery (most commonly a branch of transverse cervical) (3)
  - Transverse cervical artery (4)
  - Suprascapular artery (5)
- Costocervical trunk
  - Deep cervical artery (6)
  - Superior or supreme intercostal artery (7)
- Dorsal scapular artery (8)
- Internal thoracic (mammary) artery (9)

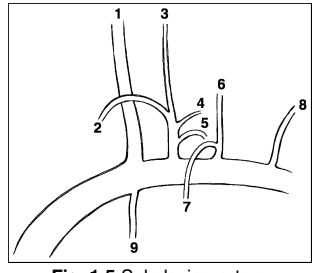

Fig. 1.5 Subclavian artery.

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.[5] 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 originates at the common carotid bifurcation. From its origin, the external carotid usually curves forward medial to the internal carotid, then immediately begins a cephalad ascent, curving laterally and slightly posteriorly until it ends behind the mandible in its terminal bifurcation `into the internal maxillary and superficial temporal arteries.[6] 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.

External Carotid Branches (Fig. 1.6)

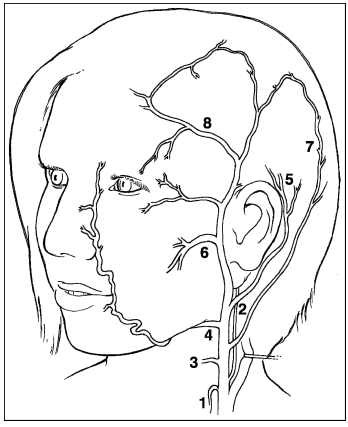

Fig. 1.6 External carotid artery. (1) Superior thyroid artery; (2) Ascending pharyngeal artery; (3) Lingual artery; (4) Facial artery; (5) Posterior auricular artery; (6) Internal maxillary artery; (7) Occipital artery; (8) Superficial temporal artery.

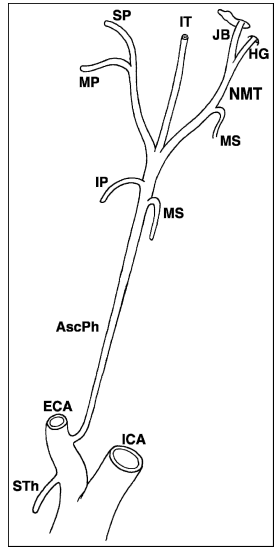

Fig. 1.7 Ascending pharyngeal artery. A common branching pattern of the ascending pharyngeal artery is shown. Note internal carotid (ICA), external carotid (ECA), superior thyroid (STh), ascending pharyngeal (Asc Ph), inferior pharyngeal (IP), middle pharyngeal (MP), superior pharyngeal (SP), inferior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

Mnemonic for the External Carotid Branches
After reading this book…
Some **A**ngry **L**inguists **F**ind **O**ur **P**aragraphs **S**omewhat **I**rritating.
Superior thyroid
Ascending pharyngeal
Lingual
Facial
Occipital
Posterior auricular
Superficial temporal
Internal maxillary
One can also construct more amusing and off-color mnemonics 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.

There are eight major branches of the external carotid. A common order of listing the branches is related to the frequent origin of the vessels from proximal to distal (Figs. 1.7, 1.8, and 1.9):
(a) Superior thyroid
(b) Ascending pharyngeal
(c) Lingual
(d) Facial
(e) Occipital
(f) Posterior auricular
(g) Superficial temporal
(h) Internal maxillary
These various branches can sometimes arise variably from the external carotid trunk. Therefore, a more useful way to consider the external carotid branches regards grouping them into the ventral group which arises anteriorly from the

external carotid and the dorsal group of branches, which arises posteriorly from that vessel. These tend to be more constant than the proximal to distal order.

- Ventral external carotid branches:
  - Superior thyroid
  - Lingual
  - Facial
  - Internal maxillary
- Dorsal external carotid branches
  - Ascending pharyngeal
  - Occipital
  - Posterior auricular
  - Superficial temporal

4. Territories
   The external carotid 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 anastamoses are present between external carotid branches and the branches of the internal carotid and vertebral arteries. These anastamoses provide collateral flow to the vascular

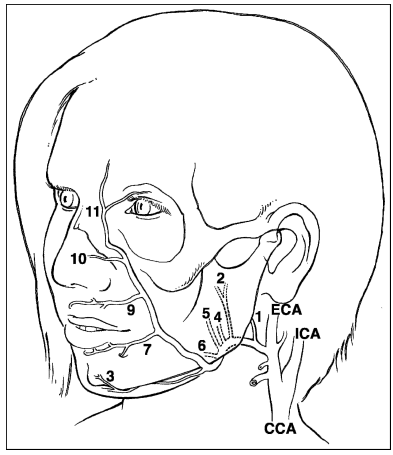

Fig. 1.8 Facial artery. (1) Ascending palatine artery; (2) Tonsilar artery; (3) Submental artery; (4) Inferior masseteric artery; (5) Jugal trunk; (6) Middle mental artery; (7) Inferior labial artery; (8) Anterior jugal artery (not shown); (9) Superior labial artery; (10) Lateral nasal artery; (11) Angular artery.

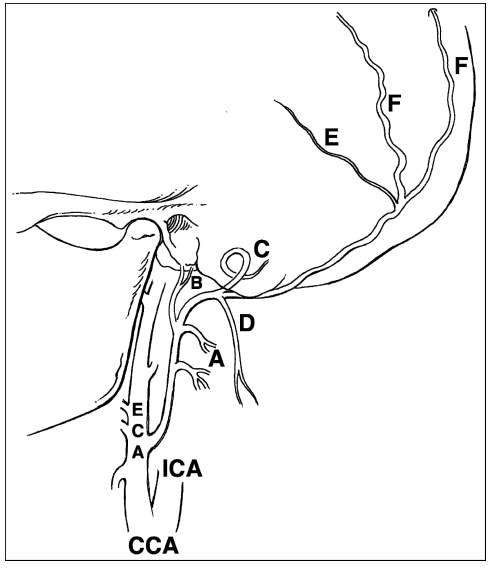

Fig. 1.9 Occipital artery. (A) Sternocleidomastoid branches; (B) Stylomastoid artery; (C) Mastoid branch; (D) Descending branch; (E) Lateral meningeal branch; (F) Occipital branches.

territories distal to a proximal occlusion. Anastamoses to carotid or vertebral arteries can also be considered "dangerous anastamoses," when attempting to embolize vascular lesions in the head and neck via external carotid branches. See below for discussion of individual external carotid branch anastamoses and Tables 1.1, 1.2, 1.3, and 1.4.

5. Variants:
   (a) The most common branching pattern at the common carotid bifurcation (in 48.5%) is the external carotid arises anteromedially while the internal carotid arises posterolaterally,[7] but occasionally one can see the external carotid arising posterolaterally or directly laterally.[8, 9]
   (b) The external and internal carotid may rarely arise as separate branches of the aortic arch.[6, 10]

Table 1.1 Danger zones: Common anastamoses: Anterior circulation

Territory at risk	Anastamosis from	Anastamosis to	Comments/ reference
Brain: Anterior circulation	Ascending pharyngeal, neuromeningeal trunk	Cavernous carotid via meningo-hypophyseal trunk	19
	Ascending pharyngeal, inferior tympanic branch	Petrous carotid via caroticotympanic	19
	Ascending pharyngeal, superior pharyngeal	Cavernous carotid via inferolateral trunk	19
	Ascending pharyngeal, superior pharyngeal	Petrous carotid via mandibular branch	19
	Accessory meningeal (cavernous branch)	Cavernous carotid via inferolateral trunk, posterior branch	19
	Middle meningeal (cavernous branch)	Cavernous carotid via inferolateral trunk, posterior branch	19
	Middle meningeal (cavernous branch)	Cavernous carotid via meningo-hypophyseal trunk	19
	Distal internal maxillary (artery of foramen rotundum)	Cavernous carotid via inferolateral trunk, anterolateral branch	19

Table 1.2 Danger zones: Common anastamoses: Ophthalmic artery

Territory at risk	Anastamosis from	Anastamosis to	Reference
Eye (and secondarily brain)	Middle meningeal, sphenoidal branch	Ophthalmic	19
	Middle meningeal, frontal branch	Ophthalmic via anterior falx artery	19
	Inferolateral trunk, anteromedial branch	Ophthalmic	19
	Distal internal maxillary, anterior deep temporal	Ophthalmic	19
	Distal internal maxillary, infraorbital	Ophthalmic	19
	Distal internal maxillary, sphenopalatine	Ophthalmic via ethmoidal branches	19
	Distal facial	Ophthalmic	19
	Transverse facial	Ophthalmic	19
	Superficial temporal, frontal branch	Ophthalmic	19
	Cavernous carotid, inferolateral trunk	Ophthalmic via recurrent meningeal branch	19

Table 1.3 Danger zones: Common anastamoses: Posterior circulation

Territory at risk	Anastamosis from	Anastamosis to	Comments/ reference
Brain: Posterior circulation	Ascending cervical	Vertebral segmental branches	19
	Deep cervical	Vertebral segmental branches	19
	Occipital, muscular branches	Vertebral segmental branches	19
	Ascending pharyngeal, muscular branches	Vertebral segmental branches	19
	Ascending pharyngeal, neuromeningeal trunk	C3 segmental vertebral via odontoid arch	Odontoid arch connects side-to-side[19]

Table 1.4 More trouble: Cranial nerve blood supply

Cranial nerve	Arterial supply	References
I: Olfactory	Anterior cerebral	19
II: Optic	Supraclinoid carotid, ophthalmic	19
III: Occulomotor	Basilar, superior cerebellar, posterior cerebral, inferolateral trunk, ophthalmic	19, 73
IV: Trochlear	Inferolateral trunk, meningohypophyseal trunk	19, 73
V: Trigeminal	Inferolateral trunk, meningohypophyseal trunk, middle meningeal, accessory meningeal, artery of foramen rotundum, infraorbital	19, 73
VI: Abducens	Inferolateral trunk, meningohypophyseal trunk, middle meningeal, accessory meningeal, ascending pharyngeal(jugular branch)	19, 24, 73
VII: Facial	Stylomastoid (from post auricular or occipital), middle meningeal (petrous branch), ascending pharyngeal (inferior tympanic and odontoid arcade)	19, 74
VIII: Auditory	Basilar, AICA, ascending pharyngeal jugular branch	19, 75
IX: Glossopharyngeal	Ascending pharyngeal jugular branch	19, 24
X: Vagus	Ascending pharyngeal jugular branch, superior and inferior thyroid, laryngeal branches	19, 24
XI: Spinal Accessory	Ascending pharyngeal (jugular, inferior tympanic and musculospinal branches)	19, 24
XII: Hypoglossal	Ascending pharyngeal, hypoglossal branch and proximal trunk, occipital, directly from external carotid, lingual	19, 76

(c) Some external carotid branches, especially the superior thyroid, may arise from the common carotid.
(d) Some branches (especially ascending pharyngeal or occipital) may originate from the internal carotid.
(e) A common origin of superior thyroid, occipital, and ascending pharyngeal from the internal carotid has been reported.[11]
(f) Rarely, even all external carotid branches may arise from the internal carotid.[12]
(g) 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]

(h) Persistent stapedial artery,[14] or, for the anatomic purist, the persistent hyoido-stapedial artery[15] arises from the petrous internal carotid, passes through the middle ear, and forms the middle meningeal. The prevalence of persistent stapedial arteries in 100 temporal bones that were studied was 0.48%.[16] This anomaly can be associated with the so-called aberrant course of the internal carotid in the middle ear, which probably really represents a collateral pathway involving the inferior tympanic branch of the ascending pharyngeal bypassing a segmental agenesis of the true internal carotid.[17, 18]

1.3.1. Superior thyroid artery

Whether it arises above or below the common carotid bifurcation, the superior thyroid 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 artery
   The infrahyoid (a.k.a. hyoid) artery travels medially from its origin, and then follows along the lower hyoid bone. It can anastamose with the submental artery, providing a collateral pathway to the facial artery.[19]
   (b) Superior laryngeal artery
   The superior laryngeal artery traveling inferomedially from its origin, follows along with the internal laryngeal nerve, and pierces the thyrohyoid membrane to supply the mucosa of the larynx superior to the vocal cords and taste buds of the epiglottis.[20]
      i. Branches
      There are two major branches consisting of a ventral branch that anastamoses with the cricothyroid artery and superior laryngeal arcade and a dorsal branch that anastamoses with the longitudinal laryngeal arcade. There is also a small epiglottic branch.[19]
      ii. Territory
      The superior laryngeal supplies the pharyngeal and laryngeal structures, as well as the internal laryngeal nerve. It anastamoses 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 external carotid or ascending pharyngeal.[19]
         – In 6 of 22 anatomic specimens, the superior laryngeal does not pierce the thyrohyoid membrane but instead passes through a thyroid foramen in the thyroid cartilage to supply the soft tissues of the larynx.[21]
   (c) Sternocleidomastoid artery
   Feeds the middle part of the sternocleidomastoid muscle and can anastamose with the muscular branches of the posterior auricular and occipital superiorly, and thyrocervical trunk and suprascapular inferiorly. The sternocleidomastoid branch can also connect with the glandular branches of the superior thyroid.
   (d) Cricothyroid artery
   Anastamoses with the superior laryngeal and feeds the upper trachea.
   (e) Glandular branches
   This is the continuation of the superior thyroid trunk. There are superior, medial and lateral arcades to supply the thyroid gland and freely anastamose with their contralateral counterparts.
2. Territories
   (a) The superior thyroid artery supplies the majority of the blood to the larynx with its associated musculature and upper pole of the thyroid gland.[6] Only in a small minority of cases does the superior thyroid provide blood flow to the parathyroid glands.[22] The superior laryngeal branch accompanies and can supply the internal laryngeal nerve. The superior thyroid branches freely anastamose with their contralateral counterparts and with the inferior thyroid artery (from the thyrocervical trunk).

3. Variants
   (a) The superior thyroid arises from the external carotid in 46% of cases and more commonly, from the common carotid in 52% of cases.[23]
   (b) Superior thyroid may arise in a common trunk with the lingual as a thyrolingual trunk.
   (c) Very rarely, the superior thyroid may arise from the internal carotid.[11]

1.3.2. Ascending pharyngeal artery

A thin, slender branch arising at the very proximal posterior aspect of the external carotid, or in the crotch of the common carotid travels cephalad and parallels the internal carotid. Its termination in the superior pharynx creates a forward and medial right angle turn (Fig. 1.7).

1. Branches
   (a) Inferior pharyngeal
   A relatively small vessel arising from the proximal ascending pharyngeal and traveling anteriorly in a zigzag fashion. It supplies pharyngeal muscles and mucosa. It anastamoses with its contralateral counterpart.
   (b) Musculospinal
   The vessel may arise from the ascending pharyngeal itself or from the neuromeningeal trunk. It takes a typical course extending posteriorly and superiorly for a short distance before curving inferiorly. It supplies primarily muscles, but also potentially the ipsilateral upper spinal nerve roots, the XIth cranial nerve and superior sympathetic ganglion with potential anastamoses with the ascending and deep cervical and vertebral arteries.[19, 24]
   (c) Neuromeningeal trunk
   It is a major branch of the ascending pharyngeal that continues cephalad, but angling gently to the posterior. It has several important branches that pass through foramina in the skull base.
      i. Branches
         – *Musculospinal*.
         This branch may variably arise from the neuromeningeal trunk instead of originating from the ascending pharyngeal itself.
         – *Jugular*.
         Often the largest branch of the neuromeningeal trunk, this vessel heads straight cephalad to the jugular foramen. It supplies the IXth through XIth cranial nerves and their ganglia. A medial branch then ascends on the clivus supplying the VIth cranial nerve and a lateral branch travels along the dura around the sigmoid sinus. It can be a major contributor to the dura of the posterior fossa. Anastamoses with the lateral clival branch of the meningohypohyseal trunk and dural branches of the vertebral are possible.[19]
         – *Hypoglossal*.
         This branch enters the hypoglossal canal and supplies the XIIth cranial nerve. It also supplies the dura in the posterior cranial fossa and anastamoses with the jugular branch, medial clival branches of the meningohypohyseal trunk, the contralateral hypoglossal artery, and the odontoid arcade.[19, 25]
         – *Prevertebral*.
         It often arises from the neuromeningeal trunk and contributes to the odontoid arcade. It anastamoses with its contralateral counterpart and the anterior meningeal branch of the vertebral, as well as the hypoglossal branch.[25]
      ii. Territories
      The very important neuromeningeal trunk of the ascending pharyngeal supplies cranial nerves VI, IX, X, XI, and XII, and potentially collateralizes to the upper three spinal nerves and the superior sympathetic ganglion. The meningeal component of its territory includes much of the meninges of the posterior fossa. Anastamotic channels exist to its contralateral counterpart, meningeal branches of the vertebral and the meningohypophyseal trunk.[24]

iii. Variants
All the branches of the neuromeningeal trunk are in vascular equilibrium with each other, and with their anastamotic connecting vessels. Hypoplasia or occlusion of one or more vessels leads to hypertrophy of the existing branches.

(d) Prevertebral
Occasionally, this vessel arises directly from the ascending pharyngeal, but still contributes to the odontoid arcade.[25]

(e) Inferior tympanic
i. Branches
There are three common branches of the inferior tympanic.[19]
– Ascending branch connects to petrosal branch of middle meningeal
– Anterior branch connects to the caroticotympanic branch
– Posterior branch connects to the stylomastoid artery, a branch of the posterior auricular artery
ii. Territories
Supplies middle ear cavity and associated nerves, including VIIth nerve and tympanic branch of the IXth cranial nerve (aka Jacobson's nerve).
iii. Variants
May arise from the neuromeningeal branch, the ascending pharyngeal distal to the origin of the latter, or it may appear as a trifurcation with a neuromeningeal division and pharyngeal division with the inferior tympanic arising in between.[19]

(f) Middle pharyngeal
i. Branches
No named branches.
ii. Territories
Supplies mucosa and muscles of the naso- and oropharynxas well as the soft palate.[26] Anastamoses with contralateral middle pharyngeal, ipsilateral ascending palatine, greater palatine, and branches of the accessory meningeal.
iii. Variants
May arise from ascending pharyngeal proximal or occasionally distal to the origin of neuromeningeal trunk.

(g) Superior pharyngeal
As the most cephalad anterior branch of the ascending pharyngeal, this tends to be a small vessel. The pharyngeal branches take an abrupt anterior and medial angulation from the vertical ascending pharyngeal.
i. Branches
There are several common branches of the superior pharyngeal, but only one is named.
– Carotid branch actually traverses the cartilage filling the foramen lacerum and connects to the cavernous carotid artery via the inferolateral trunk.
– Anterior un-named branches to the upper nasopharynx and adjacent tissues.
ii. Territories
Supplies upper nasopharynx including the orifice of the Eustachian tube as well as associated muscles, including superior constrictor. Has many potential anastamoses, including accessory meningeal, pterygovaginal, contralateral superior pharyngeal with dangerous anastamoses to cavernous carotid via the carotid branch and petrous carotid via its Vidian branch, if present.
iii. Variants
Pharyngeal territories of the superior pharyngeal may be primarily supplied by the accessory meningeal, Vidian, or other nasopharyngeal feeders.

2. Territories
Ascending pharyngeal supplies the mucosa and adjacent muscles of the pharynx, soft palate, odontoid process, bones, muscles and nerve roots at C1 and C2, lower cranial nerves (IX–XII and potentially VI and VII), lower clivus and medial skull base, middle ear, and meninges of the posterior fossa and portions of the middle cranial fossa. There are extensive anastamoses with its contralateral counterpart as well as the occipital, middle and accessory meningeal, and distal internal maxillary arteries as well as particularly dangerous anas-

tamoses with the internal carotid and vertebral arteries.[24] This is a *very busy* little artery.

3. Variants
   (a) Ascending pharyngeal may arise from the internal carotid.
   (b) Often arises as a common trunk with the occipital artery.
   (c) Ascending cervical artery may supply the territory of the ascending pharyngeal.[19]
   (d) Can contribute to the persistent hypoglossal artery variant.
   (e) Can reconstitute the vertebral artery when it is aplastic.
   (f) The so-called "aberrant internal carotid" in the middle ear cavity is probably more appropriately termed the ascending pharyngeal artery, providing a collateral pathway for the territory of a segmentally occluded internal carotid.[17, 18]

1.3.3. Lingual artery

Arises from the ventral aspect of the external carotid and takes a gentle anterior-inferior path to create a "U" shaped curve on both frontal and lateral angiographic projections. It then curves upward to form an arc through the tongue as the dorsal lingual branch with its characteristic radiating branches to the tongue:

1. Branches
   (a) Suprahyoid
   A small branch runs along the superior aspect of the hyoid bone and anastamoses with the contralateral suprahyoid.[6]
   (b) Dorsal lingual
   May consist of two or three upwardly arcing branches that curve up over the tongue and gives radiating branches, that follow the pattern of the radiating intrinsic lingual muscle. The dorsal lingual anastamoses with its contralateral counterpart.[6]
   (c) Sublingual
   This branch angles anteriorly to supply the sublingual gland and floor of the mouth, and anastamoses with the submental branch of the facial and with its contralateral counterpart. A small branch pierces the lingual foramen of the mandible, and supplies the adjacent bone.[6]
   (d) Deep lingual
   A small terminal branch to the frenulum of the tongue.[6]
2. Territories
   The lingual artery provides generous arterial supply to the tongue and floor of the mouth. There are anastamoses with the contralateral lingual and ipsilateral facial via the submental branch. However, it should be remembered that the branches to the tip of the tongue are effectively end arteries, and distal embolization with small particles or liquid agents can produce ischemic necrosis of the tip of the tongue, especially if the emboli are forced across the midline via the side-to-side anastamosis, or if bilateral embolization is intentionally done.
3. Variants
   (a) Often arises from a common facial-lingual trunk with the facial artery (20% of cases).[13]
   (b) Occasionally, can arise as a common thyrolingual trunk with the superior thyroid artery (2.5% of cases), or thyrolinguofacial trunk (2.5% of cases).[13]
   (c) Rarely can arise from the common carotid.
   (d) Lingual artery can supply variable amounts of the submental artery's supply to the floor of the mouth.

1.3.4. Facial artery

The facial artery is usually one of the larger external carotid branches and arises from the anterior aspect of the external carotid. It then curves in a slightly redundant fashion through the submandibular gland and under and around the angle of the mandible, then angling forward and cephalad, as well as medially to extend up along the angle of the nose as the angular artery. The facial artery has a number of named and un-named branches that anastamose freely from one to the other, and with other vessels in the face (Fig. 1.8).

1. Branches
   (a) Ascending palatine

This vessel ascends for a few centimeters from its origin, and then takes a right angle forward to the soft palate, by taking a small loop-de-loop as it curves around the tonsils. Consequently, this vessel can be a casualty of tonsillectomy or palatal surgery,[26] and can be the source of post-op bleeding, along with the smaller tonsilar arteries.

i. Branches
Three fairly constant and several less constant branches were found on a cadaveric study of palatine blood supply.[27]
   - *Glossal*. Arises at the level of the upper border of the tongue and supplies the palatoglossus muscle.
   - *Tonsillar*. Arises at the level of the oropharyngeal tonsil, supplying the tonsil and palatopharyngeus and sometimes palatoglossal muscles.
   - *Hamular*. Arises adjacent to the hamulus of the medial pterygoid plate and mucosa and palatoglossus.
   - Variable branches to uvula, levator palatini, palatoglossus, and palatopharyngeus muscles.

ii. Territories
Supplies mucosa and muscles of the lateral opropharynx and soft palate. Anastamoses with contralateral ascending palatine and ipsilateral middle pharyngeal, greater palatine, and the branches of accessory meningeal.

iii. Variants
Usually arises from the proximal facial artery, but may arise directly from the external carotid, from a common trunk with the submandibular branch, occasionally from the middle pharyngeal artery (from the ascending pharyngeal) or even from the accessory meningeal artery.[19]

(b) Tonsillar artery
One or more small proximal facial branches to the tonsils. This is the dominant supply to the palatine (oropharyngeal) tonsil along with the ascending palatine artery, pharyngeal branches of the ascending pharyngeal, dorsal lingual branch of the lingual, and greater palatine branch of the internal maxillary.[6] The tonsilar artery must, therefore, be considered as a culprit in the case of postoperative bleeding after tonsillectomy, along with the ascending palatine. The tonsilar branches of the facial can also contribute to the nasopharyngeal tonsils, but most of the blood supply to that tonsil comes from the superior pharyngeal, ascending palatine, pterygo-vaginal, and occasionally the inferior hypophyseal branch of the meningohypohyseal trunk.[6]

(c) Submandibular branches
Small branch or branches to the submandibular gland region. May arise from the submental artery. It may anastamose to the lingual and superior thyroid branches.[28]

(d) Submental artery
This vessel is usually fairly large, traveling along the inferior margin of the mandible, and it shares the task of supplying the floor of the mouth with the lingual artery. The submental anastamoses to the lingual via its submandibular branch, and with the superior thyroid via its infrahyoid branch, and also has side-to-side anastamoses with its contralateral partner.[28] Its terminal branches curve up to the chin to anastamose with the middle mental and inferior labial arteries.[6]

(e) Inferior masseteric
Anterior-superior angling branch that follows along and can supply the lower masseter muscle. Can have a small amount of collateral flow to the superior masseteric branch of the internal maxillary.[28]

(f) Jugal trunk
Those who are familiar with Latin know that "jugal" concerns the cheek, and the jugal trunk is one of the three main superior-to-inferior anastamoses in the soft tissues of the cheek.

i. Branches
Two fairly constant and angiographically visible branches arise from the trunk.
   - *Bucco-masseteric. (aka buccal)*. Arises from the trunk at the level of the ramus of the heads cephalad, and deeply in the cheek. It gives a buccal branch that supplies the mucosa and deep parts of the cheek and a masseteric branch that feeds

that muscle. There are anastamoses from the buccal with the distal internal maxillary via the buccal branch of the latter and the superior masseteric. The masseteric branch anastamoses with the transverse facial and infraorbital. On lateral angiographic views it characteristically crosses the transverse facial at a right angle.[28]

– *Posterior jugal*. This branch travels obliquely anterior-superiorly and anastamoses with the infraorbital branch of the internal maxillary, superior alveolar and also the transverse facial.[28]

(g) Middle mental
A small horizontal branch along the body of the mandible supplying skin and adjacent subcutaneous tissues with anastamoses to adjacent facial branches and inferior alveolar branch of the internal maxillary.[28]

(h) Inferior labial
This anterior and medially directed branch is the major supply to the lower lip. It has anastamoses with the contralateral inferior labial, and also potentially with the ipsilateral superior labial and submental arteries.[28] There may be a common trunk with the superior labial in 10% of angiographic studies.[29]

(i) Middle jugal
An inconstant branch that parallels and potentially anastamoses with the anterior and posterior jugal trunks.[28]

(j) Superior labial
Anterior and medially directed branch to the upper lip, it parallels but is usually larger than the inferior labial. It usually has septal and alar branches to the nose. It freely anastamoses with the contralateral superior labial and has potential dangerous anastamoses with nasal branches of the ophthalmic.[6, 28]

(k) Anterior jugal
The anterior-most of the upward angulated branches in the cheek, it supplies the anterior cheek and lateral aspect of the upper lip and nose. It freely anastamoses with the infraorbital, the posterior and middle jugal arteries, the transverse facial, and superior alveolar artery.[28]

(l) Lateral nasal (aka alar)
This small branch extends anteriorly to supply the nostril and anastamose with the contralateral alar artery.[6]

(m) Nasal arcade
Anastamotic channels curving over and across the nose and collecting and connecting inputs from the facial and ophthalmic arteries bilaterally.[28]

(n) Angular
Lives up to its name and travels up along the angle lateral to the nose, supplying the cheek beside the nose and the lateral aspect of the nose, contributing to the nasal arcade. It has dangerous anastamoses with inferior palpebral and nasal branches of the ophthalmic.[28]

2. Territories
The major supply to the superficial soft tissues of the face, it also contributes to the masseter muscle, parotid gland, palate and tonsils, floor of the mouth, and portions of the buccal mucosa. It can give vasa nervora to distal facial artery branches in the face. There are numerous anastamoses between facial branches and to virtually every other artery in the facial region, including major connections to the internal maxillary, transverse facial, and important collaterals to distal ophthalmic branches.

3. Variants
Lasjaunias proposed a theory of hemodynamic balance at a number of collecting points in the face, to explain the variety of vascular configurations encountered in clinical practice.[19, 28] There is a buccal and masseteric balance in the posterolateral aspect of the face, an infraorbital and transverse facial balance in the mid-portion, and an ophthalmic balance in the anteromedial face. At six points in the face (termed jugal, infraorbital, and ophthalmic superiorly, and mandibular, labial and nasal inferiorly), dominance of blood flow to the region by one or the other potential inputs determines the course and size of the facial artery. Numerous variations are possible, but the common variants are listed below.

(a) The facial artery frequently may arise as a common trunk with the lingual (20% of cases).[13]

(b) The proximal facial may have a posterolateral "jugal" course through the jugal point.[19]

(c) It may also travel anteromedially through the labial point for a "labial course."[19]
(d) Left and right facial arteries are symmetrical in 68% of autopsy cases.[30]
(e) Sixty-eight percent of facial arteries appear to terminate in the angular artery.[30]
(f) Twenty-six percent end in the lateral nasal branch.[30]
(g) Four percent terminate in the superior labial.[30]

1.3.5. Occipital artery

This is a large branch of the posterior aspect of the external carotid that angles posteriorly and superiorly, first being fairly straight as it goes up through the upper neck, becoming more tortuous and redundant as it travels up the posterior scalp (Fig. 1.9).

1. Branches
   (a) Sternocleidomastoid branches (aka muscular branches)
   There may be multiple muscular branches. The hypoglossal nerve hooks around the lowest branch as it heads first inferiorly, then anteriorly toward the tongue.[6] Each muscular branch characteristically tends to curve cephalad for a short distance, before taking an abrupt turn posteroinferiorly. Each muscular branch corresponds to a vertebral level and provides segmental supply to the muscles, nerves and bone at these levels. The occipital artery shares the segmental vertebral blood supply with the vertebral artery, ascending pharyngeal and deep cervical artery, all of which the occipital muscular branches freely anastamose. The muscular branches normally supplied by the occipital may also arise from the posterior auricular or directly from the external carotid.[19]
   (b) Stylomastoid artery
   The stylomastoid artery arises from the occipital artery in 20–50% of cases.[19, 31] It is a common source of blood flow to the facial nerve and middle ear. It can form collateral anastamoses with the inferior tympanic, anterior tympanic, and superior tympanic arteries.
   (c) Mastoid branch
   This vessel angles cephalad and medially from the occipital artery giving some supply to the soft tissues in the adjacent scalp, before entering the skull via the occipital foramen.
      i. Branches
      After it enters the skull, the mastoid commonly gives three groups of branches.[19]
         – *Descending branches*.
         These approach the jugular foramen and anastamose with the jugular branch of the ascending pharyngeal.
         – *Ascending branches*.
         These approach the internal auditory canal and can anastamose with the subarcuate branch of the anterior-inferior cerebellar artery.
         – *Posteromedial branches*.
         These spread out into the lateral dura of the posterior fossa, potentially anastamosing with branches of the hypoglossal branch of the ascending pharyngeal or the posterior meningeal branch arising from the vertebral (or posterior-inferior cerebellar).[19]
      ii. Territories
      Supplies the superficial soft tissues, the bone and dura in the mastoid and temporal bone region. It may supply large areas of the dura in the posterior fossa.
      iii. Variants
      The mastoid artery may be absent or hypoplastic, and its territory supplied by middle meningeal, hypoglossal or jugular branches or the meningeal branches of the vertebral.
   (d) Descending branch
   The most cephalad muscular branch at the occipital–C1 junction tends to be quite prominent, usually with large anastamotic connections to the

vertebral artery and a descending branch connecting to the deep cervical artery.

(e) Lateral meningeal branches
Distal to the origin of the mastoid branch, there may be one or more branches that enter the skull via a small parietal foramen and supply supratentorial dura. There are usually anastamoses with middle meningeal branches.

(f) Occipital branches
Multiple scalp vessels with a redundant, zigzag configuration arise from the occipital to supply the scalp, muscles and pericranium. These anastamose with the contralateral occipital branches, and with scalp branches of the posterior auricular and superficial temporal arteries.[6]

2. Territories
The occipital artery travels 3 cm lateral to the inion and generally supplies the posterior third of the scalp, the occipital-frontalis, trapezius, and sternocleidomastoid muscles, portions of the occipital, mastoid and temporal bones, dura, the seventh and ninth cranial nerves and first few spinal nerves. There are numerous anastamoses to the contralateral occipital artery, the ipsilateral ascending pharyngeal artery, vertebral artery, middle meningeal artery, superficial temporal artery, posterior auricular artery, deep cervical artery and even anterior–inferior–cerebellar artery.

3. Variants
   (a) The ascending pharyngeal may arise from the occipital artery.
   (b) There can be a common origin of the occipital with the posterior auricular as an occipitoauricular trunk (12.5% of cases).[13]
   (c) The occipital may arise from the internal carotid artery.
   (d) The occipital can be involved with persistent carotid-vertebral anastamoses, such as a persistent proatlantal artery.
   (e) The occipital may originate from C1 or C2 segmental branches of the vertebral artery or from the ascending cervical artery.[19, 32]

1.3.6. Posterior auricular artery

This posterior branch of the distal external carotid is usually fairly small and can be identified angiographically by the tortuous scalp branch curving cephalad behind the ear.

1. Branches
   (a) Sternocleidomastoid branch (aka muscular)
   Proximal branch of the posterior auricular can assist the occipital in providing blood flow to the sternocleidomastoid, digastric and stylohyoid muscles.[6]

   (b) Parotid branches
   Small branches from the proximal posterior auricular to the parotid. Can supply portions of the facial nerve.

   (c) Stylomastoid branch
   The stylomastoid artery arises from the posterior auricular in 50–70% of cases.[31, 33] The next most common origin is from the occipital, followed by direct origin from the external carotid. It feeds the facial nerve and middle ear, mastoid air cells and portions of the inner ear.[6] It can anastamose with anterior tympanic (from middle meningeal) and inferior tympanic (from ascending pharyngeal).

   (d) Auricular branch
   A fairly constant branch seen in 65% of cases, this vessel supplies much of the posterior aspect of the pinna.[34] Its branches from a dense arterial network in the ear.

   (e) Occipital branch (aka retroauricular branch)
   Also a fairly constant branch seen in 65% of cases, this branch supplies the scalp behind the ear.

   (f) Parietal branch
   A fairly inconstant branch only seen when the superficial temporal does not have a dominant parietal branch. It has the typical ascending, tortuous appearance of a scalp vessel.

2. Territories
The posterior auricular artery supplies the auricle, entering the middle part of the ear posteriorly.[35] It is the major supplier of blood flow to the ear.[36] It can

supply portions of the parotid gland, facial nerve, sternocleidomastoid, digastric and stylohyoid muscles.[6] It has variable supply to the scalp posterior and superior to the ear, depending on the dominance of the superficial temporal and occipital arteries. It anastamoses with the superficial temporal, and occipital via the scalp and auricular branches and with anterior tympanic (from middle meningeal) and inferior tympanic (from ascending pharyngeal) via the stylomastoid artery.

3. Variants
   (a) May arise 12.5% of the time in common with the occipital artery as an occipito-auricular trunk.[13]
   (b) The scalp territories of the posterior auricular are in a hemodynamic balance with the superficial temporal and occipital arteries. If one is hypoplastic, the adjacent vessels are hypertrophic, and vice versa.

1.3.7. Superficial temporal artery

One of the two terminal branches of the external carotid (the other is the internal maxillary), this vessel continues the general vertical course of the external carotid. The superficial temporal arises behind the neck of the mandible within the parotid gland. It is easily palpable anterior to the ear at the tragus.[6] The superficial temporal provides typically two major branches that then angle cephalad in a wavy, redundant fashion that is typical for scalp vessels:

1. Branches
   (a) Transverse facial
   This vessel originates anteriorly from the superficial temporal artery within the parotid gland and travels anteriorly and slightly inferiorly between the parotid duct and zygomatic arch, to supply the structures in the face.[6] On lateral angiographic studies, it typically crosses the buccal artery at right angles.[19] With agenesis or diminution of the facial artery, this branch may take over as the dominant artery of the face.
      i. Branches
      Along its course, the transverse commonly has a number of branches, but only one (superior masseteric) has a well described formal name.
         – *Parotid branches*.
         These feed the parotid gland and duct and may contribute to facial nerve branches.
         – *Superior masseteric*.
         Prominent branch to the masseter muscle that anastamoses with the buccal artery (from the facial artery).[19]
         – *Jugal branches*.
         One or more descending branches to the cheek that may anastamose with the jugal branches of the facial artery.
         – *Zygomatic branches*.
         These spread out into the face, potentially anastamosing with branches of the zygomatico-orbital branch of the superficial temporal.[19] Distally these terminal branches may anastamose with the infraorbital and lacrimal arteries.[6]
      ii. Territories
      It supplies the superficial soft tissues of the upper face. It freely anastamoses with other superficial temporal and facial branches, as well as with potential collaterals to the infraorbital and ophthalmic arteries.
      iii. Variants
      The transverse facial artery may arise directly from the external carotid.
   (b) Anterior auricular
   It is a proximal branch of the superficial temporal, supplying blood primarily to the anterior aspect of the ear. It has three branches, the most superior of which curves up over the helix to anastamose with posterior auricular branches, but the lower two branches only provide limited supply to the anterior ear.[35]
   (c) Zygomatico-orbital
   A variably prominent, anteriorly directed branch of the superficial temporal runs just superior to the zygomatic arch towards the lateral aspect

of the orbit. It supplies the scalp and the orbicularis occuli muscles.[6] It can have numerous anastamoses with the frontal branch of the superficial temporal, transverse facial, and supraorbital, frontal, palpebral, and lacrimal branches of the ophthalmic.[19]

(d) Middle temporal
Also called the posterior deep temporal by some authors, this is a relatively small branch supplying the temporalis muscle, specifically the posterior aspect of this muscle.[37] It potentially anastamoses with the deep temporal branches of the internal maxillary.[6]

(e) Frontal branch
One of the two large terminal branches of the superficial temporal takes a tortuous course over the frontal scalp, supplying tissues from skin down to pericranium. It anastamoses with its contralateral counterpart across the midline, and with the ipsilateral zygomatico-orbital branch of the superficial temporal and supraorbital and supratrochear branches of the ophthalmic.[6] The distal frontal branch over the vertex can also provide branches that pass through foramina for emissary veins, to anastamose with middle meningeal branches.[19] This is why superficial temporal arteries sometimes supply intracranial lesions such as meningiomas.

(f) Parietal branch
The other, usually larger terminal branch of the superficial temporal angles more posteriorly to supply the parietal scalp. It anastamoses with the contralateral parietal branch, and ipsilateral frontal branch, as well as posterior auricular and occipital branches. It can also provide some trans-cranial anastamoses with the middle meningeal branches.

2. Territories
The superficial temporal is a major contributor of blood flow to the scalp, and is in a hemodynamic equilibrium with the occipital and posterior auricular arteries. There are extensive anastamoses between the superficial temporal branches and the branches of occipital, posterior auricular, middle meningeal, ophthalmic, and facial arteries.
3. Variants
There is considerable variability of the size and territory of the major superficial branches. The balance that exists between individual superficial temporal branches and between the superficial temporal and its competing scalp vessels, means that when one vessel is large and takes on a wide territory, the adjacent vessels may be small or absent.

1.3.8. Internal maxillary artery

The internal maxillary artery (IMA) is the larger of the two terminal branches of the external carotid. Inclusion of the word *internal* is superfluous, as there is no "external" maxillary artery; however, *internal maxillary artery* is the colloquial, and most widely used, version of the term for this vessel. The IMA arises at a right angle from the external carotid behind the neck of the mandible, and travels anteriorly. Anatomically, it can be divided into three segments (1) the proximal mandibular part traveling horizontally, first posterior, then medial to the mandible, (2) the middle pterygoid part travels in a slightly oblique fashion, anteriorly and cephalad, adjacent to the lateral pterygoid muscle (medial or lateral to it, depending on whether it is the superficial or deep variant as described below), and (3) the distal pterygopalatine part passes between the upper and lower heads of the lateral pterygoid, curves medially and travels through the pterygomaxillary fissure into the pterygopalatine fossa.[6]

1. Branches
The mandibular part of the IMA often gives rise to the deep auricular, anterior tympanic, middle meningeal, accessory meningeal, and inferior alveolar arteries (i.e., branches that traverse foramina or fissures). The pterygoid part usually has deep temporal, pterygoid, masseteric and buccal branches (i.e., muscular branches). The pterygopalatine part provides the posterior superior alveolar, infraorbital, artery of foramen rotundum, pterygovaginal, greater palatine, Vidian, and sphenopalatine arteries.[6]

(a) Deep auricular artery
Tiny branch of very proximal internal maxillary

i. Branches
No named branches.

ii. Territories
Supplies external auditory meatus, tympanic membrane, and temporomandibular joint.[6]
iii. Variants
– May arise in a common trunk with anterior tympanic

(b) Anterior tympanic
Very small branch of very proximal internal maxillary
i Branches
No named branches.
ii Territories
Supplies tympanic cavity and anastamoses with the stylomastoid artery, pterygovaginal branch of internal maxillary and caroticotympanic artery from petrous carotid.[6]
iii. Variants
Extremely variable anterior tympanic origins were found in a study of 104 cadaveric specimens.[38]
– May arise as a common trunk with deep auricular artery, middle meningeal, accessory meningeal, or posterior deep temporal.
– Seventy-eight percent of right and 45% of left arise from internal maxillary
– Next most common site of origin: superficial temporal
– 1–4% arise from external carotid itself
– Rarely, the anterior tympanic may be duplicated, triplicated, or absent.[38]

(c) Middle meningeal artery (Fig. 1.10)
The first substantial ascending branch of the internal maxillary enters the cranial cavity through foramen spinosum. It then takes a characteristic right-angle turn in both the sagittal plane in which it turns anteriorly and coronal plane, in which it turns laterally.

i. Branches
– *Accessory meningeal*.
This may be a major extracranial branch of the middle meningeal, or may arise separately from the internal maxillary. The accessory meningeal is discussed in detail below.
– *Petrous*.
The small, but important petrous branch first gives a medial cavernous branch to the cavernous sinus which can anastamose with the posterior branch of the inferolateral trunk, then gives a posterior basal tentorial branch, potentially anastamosing with basal tentorial branches of the petrosquamosal branch of the middle meningeal, and cavernous branches of the internal carotid.[19] It then follows along the greater petrosal nerve giving the superior tympanic branch to the facial nerve and geniculate ganglion. This portion anastamoses with the stylomastoid.[6]
– *Petrosquamosal*.
A posteriorly directed branch of the proximal intracranial middle meningeal supplies to the middle cranial fossa dura, and can have a basal tentorial branch that can contribute to the dura of the posterior fossa, and potentially anastamose with the jugular branch of the ascending pharyngeal.[19].
– *Sphenoidal*.
This branch supplies dura along the planum sphenoidale, and then enters the orbit via the superior orbital fissure to freely communicate with the ophthalmic.[39] The sphenoidal collateral to the ophthalmic was seen in 16% of cadaveric specimens.[40]
– *Meningolacrimal*.
This orbital branch is derived from the superior branch of the primitive stapedial artery, enters the orbit through a craniorbital foramen (of Hyrtl), and directly fills the lacrimal artery.[39] This type of orbital branch of the middle meningeal was found in 43% of the cadaveric specimens.[40]
– *Temporo-occipital (aka temporal)*.
It usually arises distal to the sphenoidal branch and curves posteriorly. It supplies skull and dura of the middle cranial

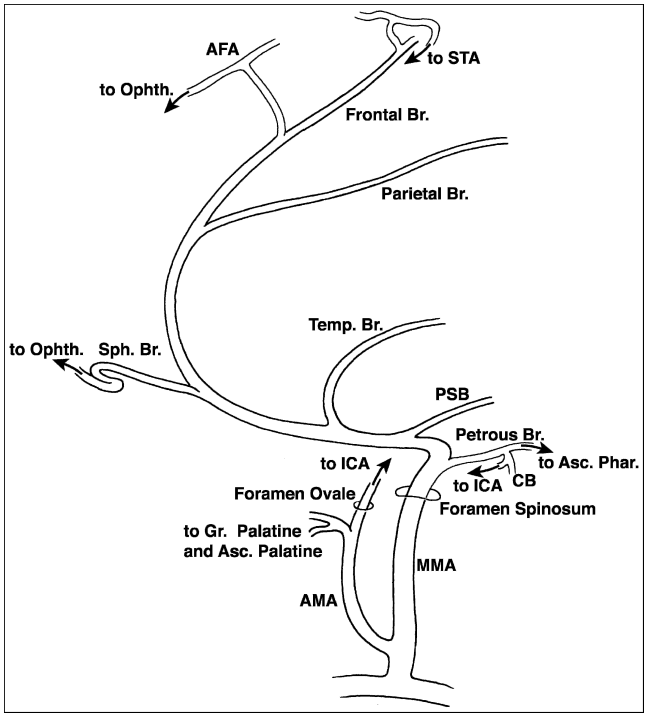

Fig. 1.10 Middle meningeal artery: Branches and anastamoses. The middle meningeal artery (MMA) often has a large extracranial branch, the accessory meningeal artery (AMA), which, in turn has anastamoses with the greater palatine (Gr. Palatine) and ascending palatine (Asc. Palatine) arteries before entering the skull via the foramen ovale and anastamosing with cavernous branches of the internal carotid (ICA). The middle meningeal artery continues into the skull via the foramen spinosum. The petrous branch (Petrous Br.) is the first intracranial branch and anastamoses with ascending pharyngeal branches in the temporal bone and with ICA branches via its cavernous branch (CB). Petrosquamosal (PSB), temporal, parietal, and frontal branches supply the dura over the middle and anterior fossa. Transcranial anastamoses rto the superficial temporal (STA) and midline anastamoses with the anterior falx (AFA) branch of the ophthalmic (Ophth.) are depicted. The sphenoidal branch (Sph. Br.) is a major collateral to the ophthalmic.

fossa and can extend all the way around the calvarium to the midline, sometimes contributing to the posterior falx and tentorium, but generally only in pathological states. It anastamoses with the petrosqamosal and parietal branches of the middle meningeal and potentially with scalp vessels via transcranial collaterals.

– *Parietal*.
One of the two terminal branches of the middle meningeal, this vessel contributes to the blood supply of anterior cranial fossa dura. It can be of a variable size and distribution, since it is in a hemodynamic balance with the frontal and temporo-occipital

branches, with which it can freely anastamose. The parietal branch reaches the vertex and can contribute to the walls of the superior sagittal sinus and falx. At the midline, it may anastamose with the contralateral middle meningeal artery. Transcranial anastamoses with scalp vessels (superficial temporal and occipital) are also seen, in virtually all 20 cadaver specimens studied.[41]

– *Frontal*.
Usually the last branch of the middle meningeal, this branch also is in hemodynamic balance with the parietal branch and can therefore be of a variable size and distribution. It is a major contributor to the blood supply of anterior cranial fossa dura. It can reach the midline and frequently anastamoses with the anterior falx branch of the ophthalmic. Other anastamoses include the ipsilateral parietal branch, the contralateral frontal branch, and transcranial collaterals from the scalp vessels, especially the frontal branch of the superficial temporal.

ii. Territories
The middle meningeal provides extensive flow to the calvarium and meninges of the anterior and middle fossae (Table 1.5). It

Table 1.5 Intracranial dural vascular supply

Dural structure/ region	Feeding arteries	…Which usually arise from:	Reference
Posterior fossa	Petrosquamosal	Middle meningeal	
	Petrous	Middle meningeal	
	Mastoid	Occipital	6
	Jugular	Ascending pharyngeal	6
	Hypoglossal	Ascending pharyngeal	6
	Posterior meningeal	Vertebral	6
	Anterior meningeal	Vertebral	
Tentorium	Artery of Bernasconi and Cassinari (marginal tentorial)	Cavernous carotid	19
	Basal tentorial	Cavernous carotid	19
	Petrosqamosal	Middle meningeal	19
	Mastoid	Occipital	19
	Artery of Davidoff and Schechter	Posterior cerebral	63
Falx cerebri	Anterior falx artery	Ophthalmic	
	Frontal and parietal branches	Middle meningeal	
	Artery of Davidoff and Schechter	Posterior cerebral	63
Anterior cranial fossa	Ethmoidals	Ophthalmic	6
	Recurrent meningeal	Ophthalmic	
	Anterior falx	Ophthalmic	
	Sphenoidal	Middle meningeal	
	Frontal and parietal branches	Middle meningeal	
Middle cranial fossa	Inferolateral trunk	Cavernous carotid	6
	Accessory meningeal	Middle meningeal	6
	Temporo-occipital	Middle meningeal	6
	Recurrent meningeal	Ophthalmic	6
	Carotid branch	Ascending pharyngeal	6

These vessels should be considered when evaluating vascular lesions in or around the dura