Arterial Anatomy

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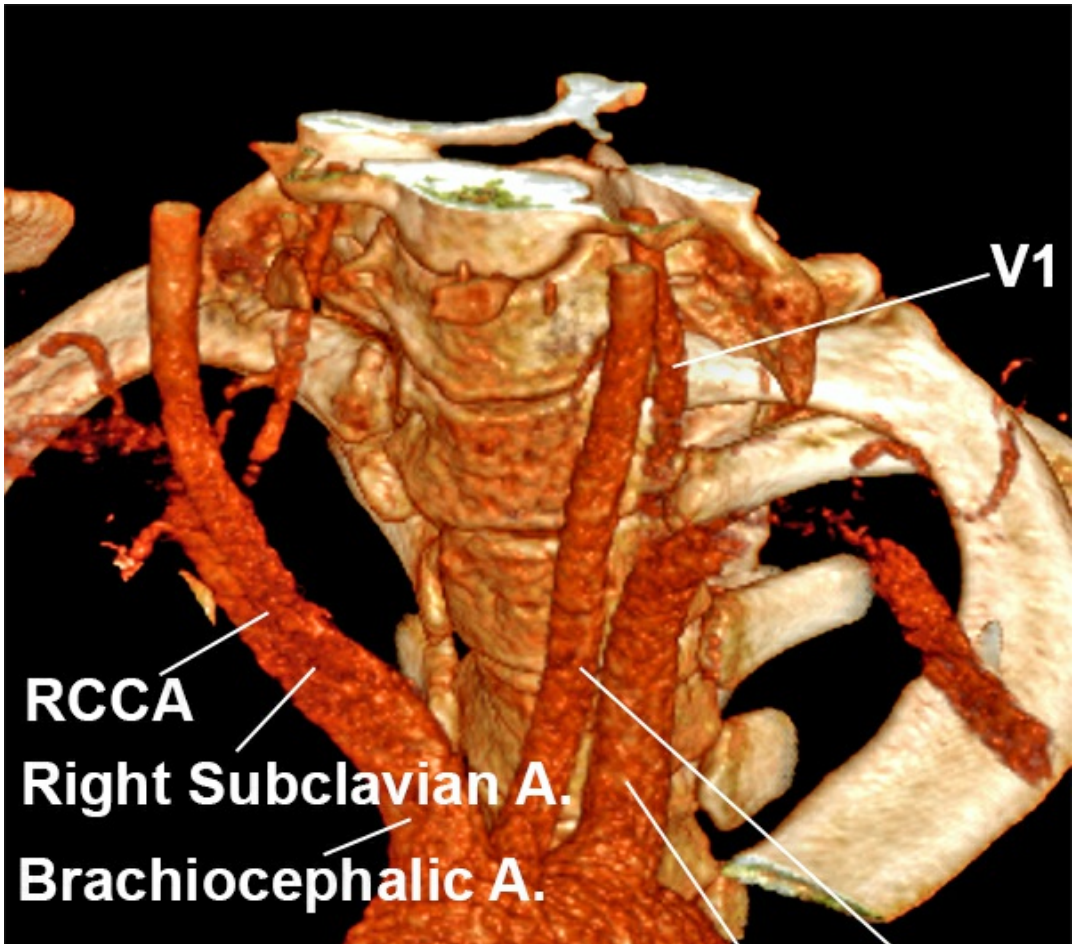
Aortic Arch and Proximal Great Vessels

Overview

Understanding of aortic arch (AA) anatomy is important in neuroangiography for complete radiographic evaluation of the craniocervical vasculature and in vessel selection during angiography procedures. In the majority of individuals, the thoracic aorta courses right to left and anterior to posterior in 4 segments, the ascending aorta, AA, aortic isthmus, and descending aorta. The AA has 3 proximal great vessels in the majority (~80%) of cases (from right to left), the brachiocephalic artery (BCA), left common carotid artery (LCCA), and left subclavian artery (LSCA).



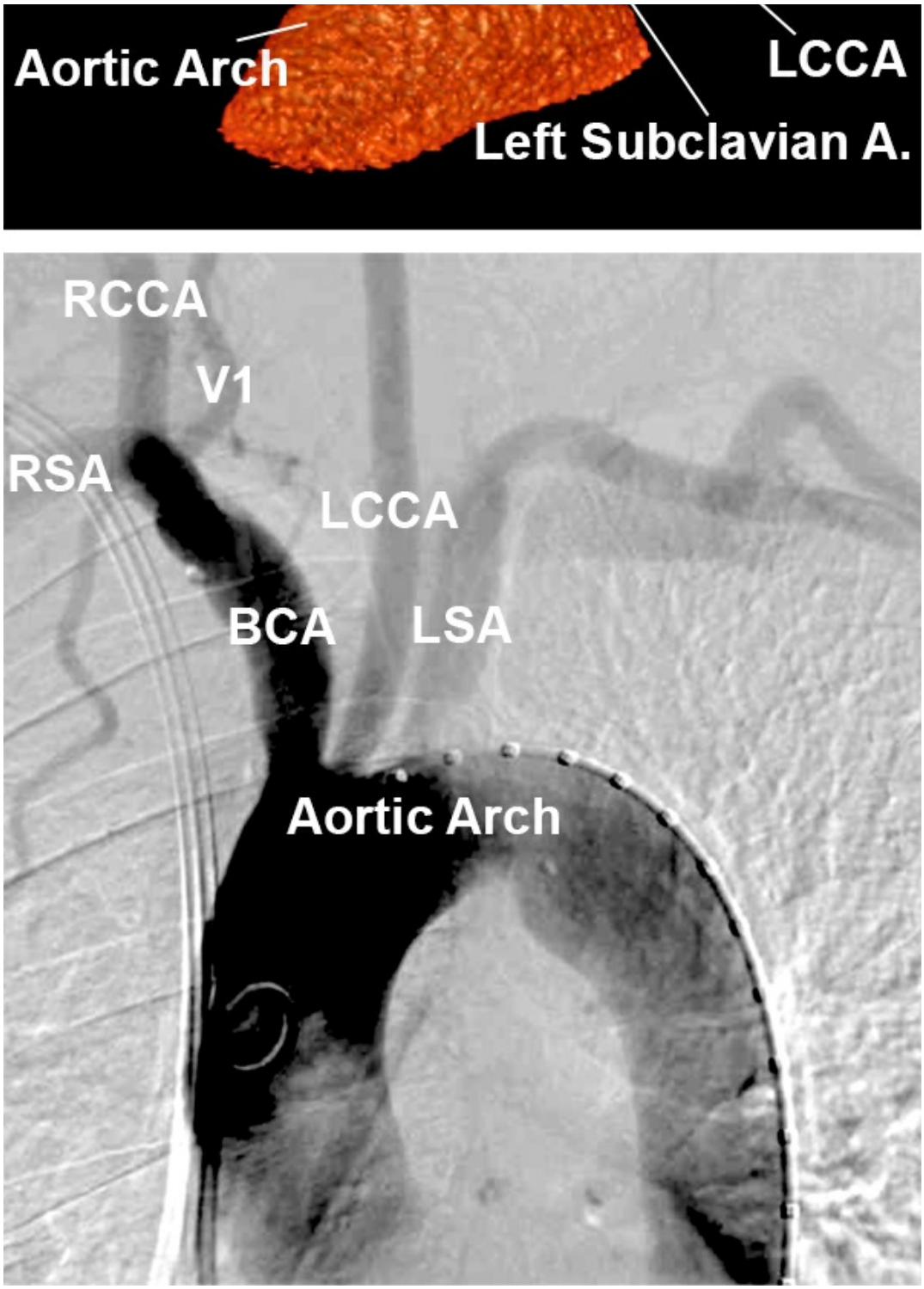


Figure 1: (Left) Computed tomography (CT) angiographic reconstruction of the AA. (Right) Digital subtraction angiography (DSA) of the AA and its large branch vessels.

Proximal Great Vessels

- BCA (brachiocephalic artery or innominate artery)
    - First AA branch, ascends anterior to the trachea and bifurcates into the right subclavian artery (RSCA) and right common carotid artery (RCCA)

    - RSCA
        - Right vertebral artery (VA)
        - Thyrocervical trunk
            - Inferior thyroid artery
            - Ascending cervical, laryngeal, and pharyngeal branches
            - Suprascapular artery
        - Costocervical trunk
            - Gives off superior intercostal, deep cervical arteries
    - RCCA
        - Bifurcates into the right internal and external carotid arteries (RICA and RECA)
- LCCA
    - Arises from the AA distal to the BCT, courses anteromedial to the internal jugular vein
    - Bifurcates into the internal and external carotid arteries (ICA and ECA)
- LSCA
    - Arises from the AA just distal to the LCCA
    - Left VA
    - Left thyrocervical trunk
    - Left costocervical trunk

Important Variants and Anomalies of the Aortic Arch

- Important to recognize for vessel selection during endovascular procedures
    - **Common variants**
        - Common origin of the BCT, LCCA, or “Bovine Arch” (10%–25%)
        - LCCA origin from BCT in (5%–7%)
        - Common origin of the LCCA and LSCA (1%–2%)

        - Left VA origin from AA in (~1%)
    - **Anomalies**—arch configurations with lower incidence (<1%)
        - Left AA with aberrant RSCA
            - Most common congenital arch anomaly (0.5%–1%)
            - 70%: RCCA, LCCA, LSCA, RSCA
            - 25%: Common stem for RCCA/LCCA, LSCA, RSCA
            - 5%: Other variations with RSCA as last branch from AA
            - Aneurysmal dilation of RSCA—“ductus of Kommerell”
        - Right AA with mirror image branching
            - Left brachiocephalic trunk, RCCA, RSCA
            - High association with congenital heart anomalies
        - Right AA with aberrant LSCA
            - LCCA, RCCA, RSCA, LSCA
            - Lower association with congenital heart anomalies
        - Double AA and other anomalies (rare)

Imaging Pearls

- Digital subtraction angiography: use left anterior oblique (LAO) positioning for arch-vessel visualization (“opening" or "unfolding" the arch)

Intracranial Arteries

Overview

Internal Carotid Artery’s Relationship to the Dural Rings

The cervical segment of the internal carotid artery (ICA) extends from the carotid bifurcation to the skull base. It then courses anteromedially through the petrous temporal bone (petrous segment) and turns superiorly at the foramen lacerum. It passes under the petrolingual ligament and enters the cavernous sinus, where it forms the carotid

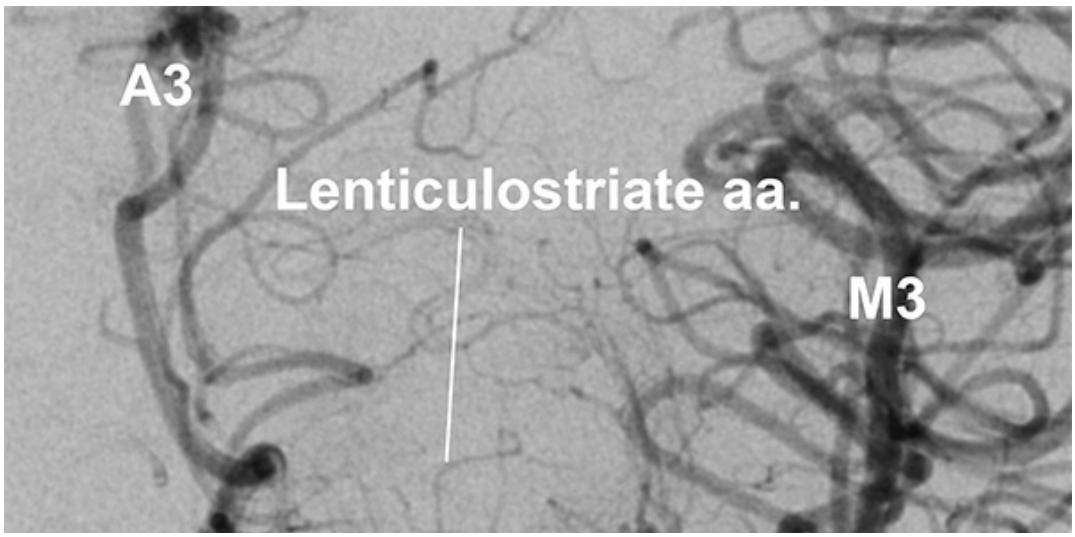
siphon. In the cavernous sinus, the artery is surrounded by the venous plexus.

After the anterior turn (genu), the ICA leaves the cavernous sinus, passing through the dural cover of the sinus that is called the “proximal dural ring.” The ICA then passes through the transitional segment region and outside the cavernous sinus, but not yet within the subarachnoid. After this short transitional segment, the ICA goes through another dural ring, called the “distal dural ring,” and then becomes intradural (subarachnoid). This transition is critical, because aneurysms past the distal dural ring are located in the subarachnoid space, and their rupture leads to subarachnoid hemorrhage.

ICA Segmental Anatomy (Origin to Terminus)

Multiple classification schemas with different nomenclature exist; the most widely accepted/used is the Bouthillier nomenclature[1]

- C1 cervical
- C2 petrous
- C3 lacerum
- C4 cavernous
- C5 clinoid
- C6 ophthalmic
- C7 communicating



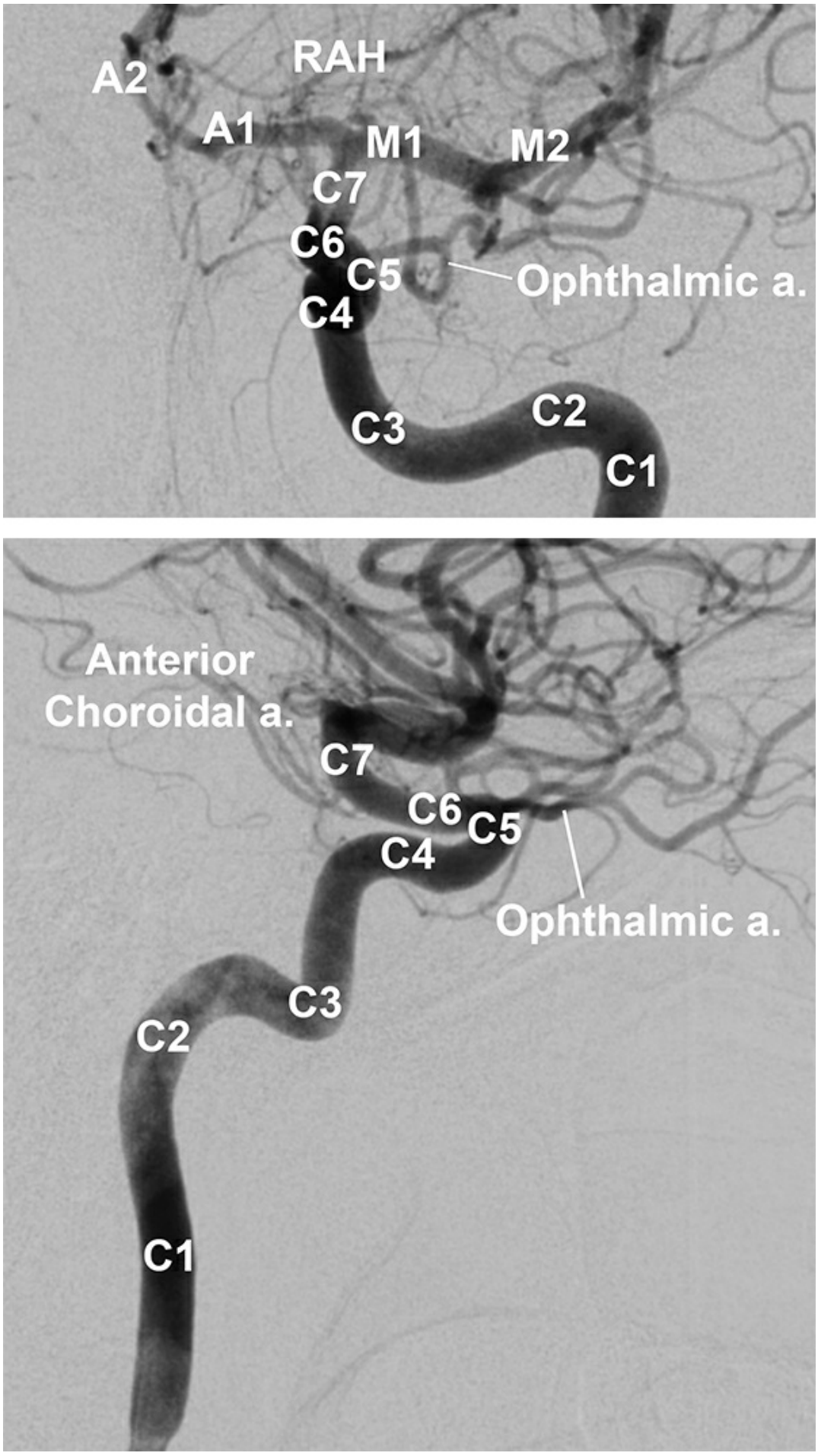


Figure 2: Segments of the right ICA in frontal (top) and lateral (bottom) views by DSA. Proximal anterior and MCA branches are more clearly

visible in the frontal view.

ICA Branches According to Segment

- **C1—cervical segment**
  - Typically no branches
- **C2—petrous segment**
  - Normal course
    - C2 and C3 segments of the ICA will traverse the vertical and horizontal segments of the carotid canal through the petrous bone
    - **Caroticotympanic artery branch**
      - The cochlear promontory will pick up arterial supply from the inferior tympanic artery via the inferior tympanic canaliculus and the caroticotympanic artery emerging from the carotid canal
    - **Vidian artery (artery of the pterygoid/vidian canal)**
      - Important anastomotic branch between the ICA and internal maxillary artery
      - The ascending pharyngeal artery can also collateralize with the vidian artery in the pterygopalatine fossa
    - **Mandibular artery**
  - Important variant: **aberrant ICA**
    - C1 segment of the carotid artery arrests in development, resulting in an enlarged inferior tympanic artery that anastamoses with the embryologic hyoid artery
    - The artery courses through the hypotympanum and inferior tympanic canaliculus entering the horizontal carotid canal through dehiscent bone, leaving the vertical portion of the canal absent
      - Symptomology
        - Otalgia, tinnitus, hearing loss, and vertigo
        - Seen as retrotympanic pulsatile mass

- Majority are right-sided, and 90% are discovered in females
  - Very rare

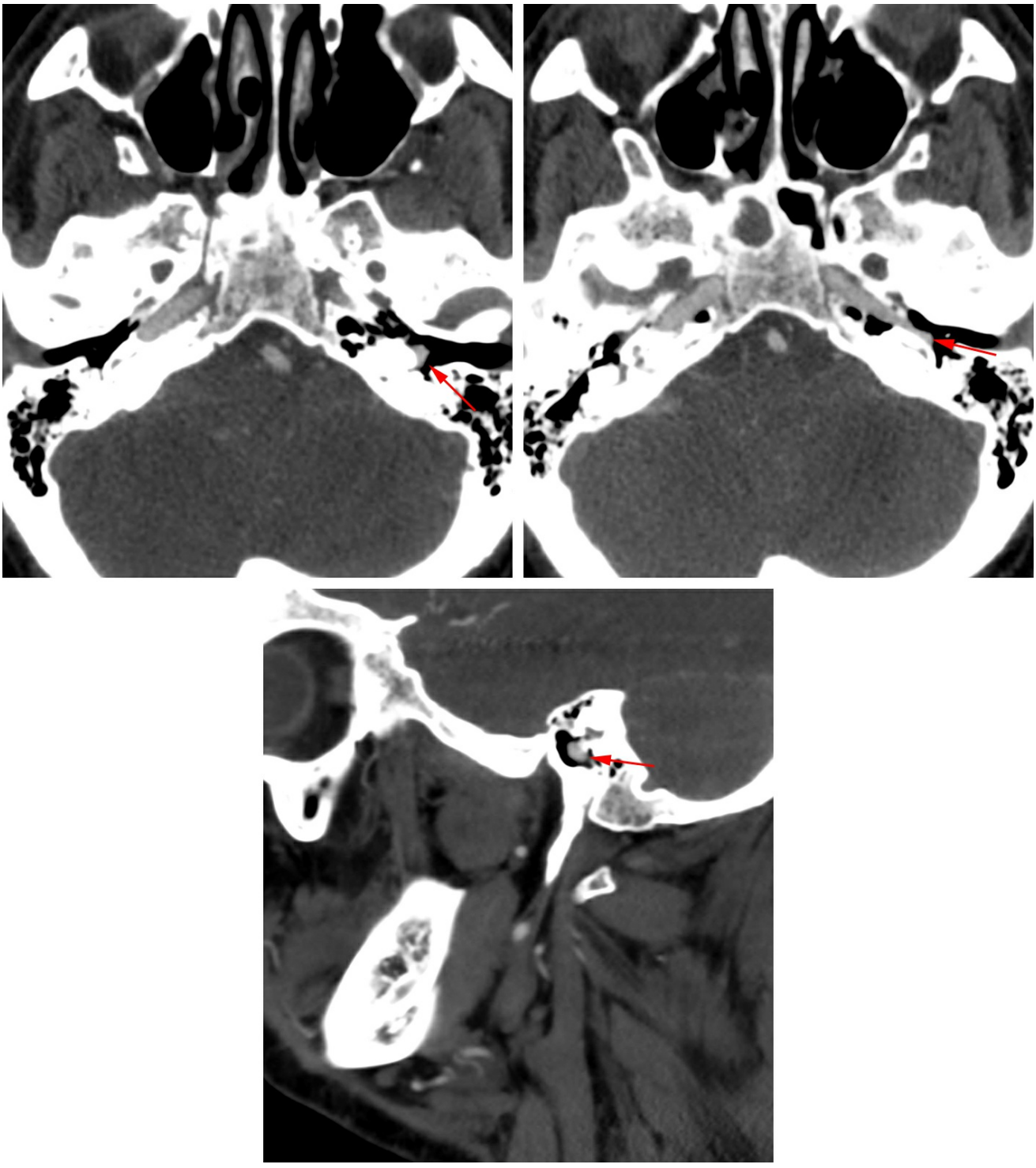


Figure 3: Axial (top) and sagittal (bottom) CT angiographic images of the head demonstrate an aberrant left ICA coursing through the temporal bone, superficial to the cochlear promontory. Patients with this variant anatomy occasionally present with pulsatile tinnitus. A pulsatile retrotympanic mass is commonly seen on otoscopy.

- **C3—lacerum segment**

    - Typically no branches
        - Note: the foramen lacerum, although largely filled with connective tissue, transmits small meningeal branches of the ascending pharyngeal artery and emissary veins from the cavernous sinus
- **C4—cavernous segment**
    - C4 segment within the cavernous sinus, where it forms the carotid siphon, surrounded by the venous plexus; after the anterior turn (genu), the ICA leaves the cavernous sinus, passing through the dural cover of the sinus, called the “proximal dural ring”
    - **Meningohypophyseal trunk (MHT)**
        - Inconstant branch of the cavernous segment of the ICA
        - Classically, the meningohypophyseal artery itself has 3 named branches
            - Dorsal meningeal artery
            - Inferior hypophyseal artery (can originate from the ICA)
            - Tentorial artery (artery of Bernasconi and Cassinari)
                - Tentorial basal branch (inconstant, variable origin)
                - Tentorial marginal branch (inconstant, variable origin)
    - **Inferolateral trunk (ILT)**
        - Originates as a single trunk (or a collection of smaller vessels) laterally
        - Supplies adjacent dura and cranial nerves (CNs)
        - Extensive anastomoses with the extracranial circulation,
        - Important anasmotic branch collateralizing the ICA with the internal maxillary artery, middle meningeal artery, and ophthalmic artery
    - **Artery of the foramen rotundum**

    - Additional small regional branches including
        - Meningeal branch—meninges of the anterior cranial fossa
        - Clival branches—supply the clivus
        - Capsular branches—supplies wall of cavernous sinus
        - Trigeminal ganglion branches—trigeminal ganglion
        - Small variable branches to CNs III, IV, and VI
- **C5—clinoid segment**
    - Typically no branches
- **C6—ophthalmic segment**
    - Ophthalmic artery
    - Superior hypophyseal artery
- **C7—communicating segment**
    - Posterior communicating artery (PCoA)
    - Anterior choroidal artery (AChA)
- **Carotid terminus**
    - Terminal bifurcation into anterior cerebral artery (ACA) and middle cerebral artery (MCA)

Anterior Cerebral Artery

3–5 Segments

- **A1—precommunicating segment**
    - Courses medially above the optic chiasm, joined by the anterior communicating artery (ACoA) to join the contralateral A1
    - Important perforating arteries arise from A1 and ACoA
    - **“Recurrent artery of Heubner”**
        - A dominant medial lenticulostriate perforator arising from distal A1 or proximal A2 near the ACoA
- **A2—postcommunicating segment**
    - Courses superiorly within interhemispheric fissure, around the genu of the corpus callosum

- **A3—pericallosal segment**
  - Marginal to the corpus callosum genu, divides into pericallosal, callosomarginal arteries
- **A4/A5—supracallosal/callosomarginal**
  - Variable terminal cortical branches
- **Cortical branches**
  - Orbitofrontal artery
    - Arises from proximal A2
    - Distributed over the inferior surface of the frontal lobe
- **Frontopolar artery**
  - Arises from mid-A2
  - Extends anteriorly to the frontal pole
- **Pericallosal artery**
  - Arises from A2 near the corpus callosum genu
  - Larger of 2 major distal ACA branches
  - Courses posterosuperiorly above the corpus callosum, below the cingulate gyrus
  - Gives off several callosal branches inferiorly
- **Callosomarginal artery**
  - Courses posterosuperiorly in the cingulate sulcus, above the cingulate gyrus

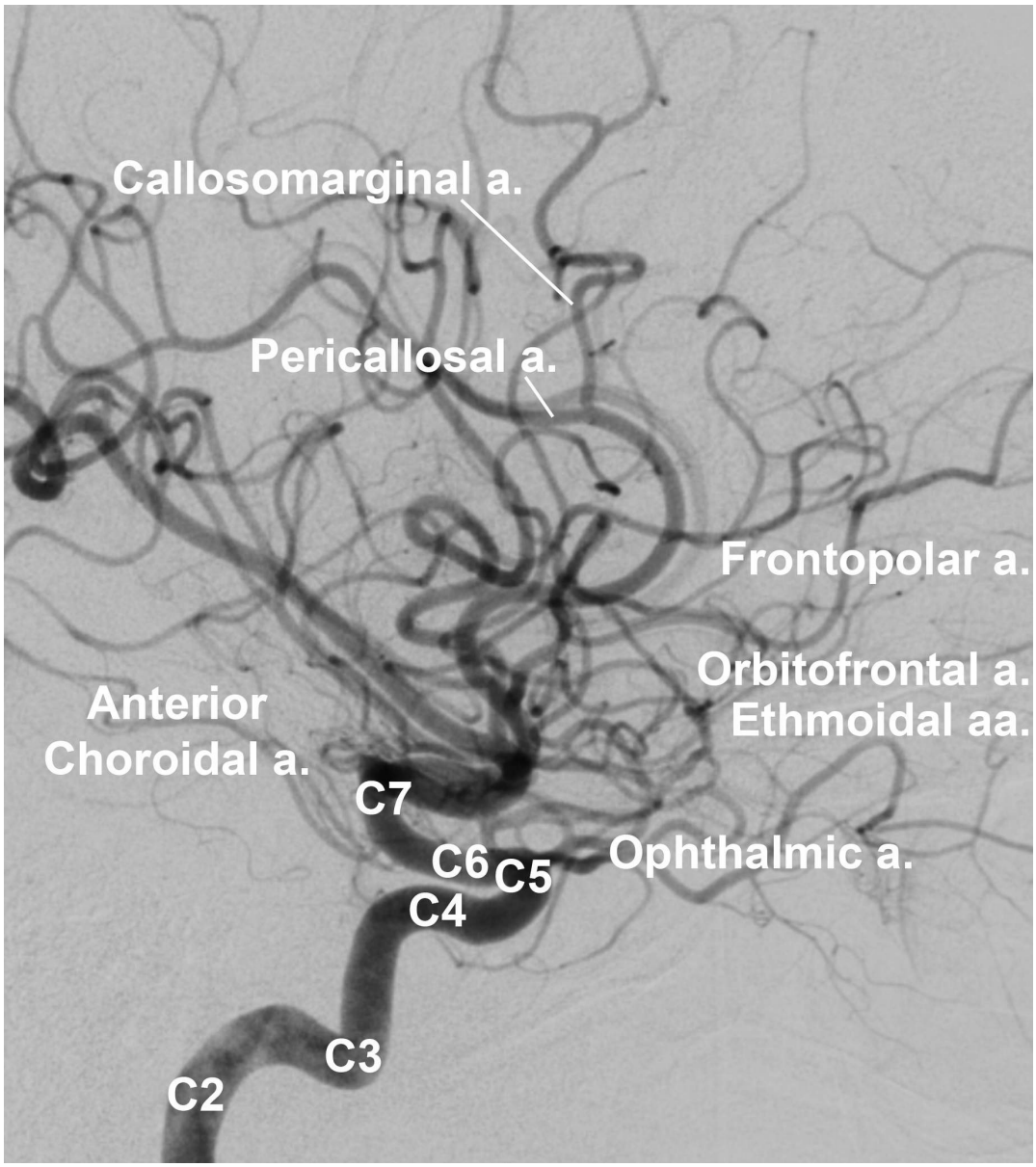


Figure 4: Lateral DSA view of the distal right ICA and its branches.

Normal Variants

- Unilateral hypoplastic or absent A1
- Bihemispheric ACA
    - Distal ACA supplies portions of contralateral hemisphere
- Absent, fenestrated, or duplicated ACoA
- Median artery of corpus callosum forms as branch from the developing ACoA and then regresses (may persist, appear as a third A2 segment)

Anomalies

- Azygous ACA

    - Associated with holoprosencephaly
    - Single ACA arises from junction of both A1s
- Infraoptic ACA
    - A1 passes under (not over) the optic nerve
    - Increased incidence of aneurysms

Territory Supplied by the ACA

- Corpus callosum (rostrum)
- Caudate head
- Anterior commissure
- Anteromedial portions of the putamen
- Globus pallidus
- Anterior limb internal capsule (variable depending on recurrent artery of Heubner anatomy)
- Cortical branches supply the gyrus recti and inferomedial frontal lobes, cingulate gyrus, and anterior two-thirds of the medial hemisphere surface

Imaging Pearls

- ACA displacement from midline by mass effect secondary to tumor, hemorrhage, and edema on CT, magnetic resonance imaging (MRI), and catheter angiography; rotation of the head off midline can cause ACA to appear displaced on frontal projection DSA
- May need to compress contralateral carotid artery during DSA to force contrast across ACoA
- Lack of ACA filling on ipsilateral ICA injection usually indicates absent or hypoplastic A1; both ACA territories fill from the contralateral ICA

Middle Cerebral Artery

Four Segments

- **M1—horizontal segment**
  - Courses laterally to the Sylvian fissure below the anterior perforated substance, bifurcates or trifurcates
  - Lenticulostriate perforators
  - Anterior temporal artery
  - Genu of MCA—posterosuperior turn toward the lateral cerebral (Sylvian) fissure
  - The M1 segment gives rise to the 2 or 3 main trunks of the M2 segment
    - Superior (frontal) division trunk
    - Inferior (temporal) division trunk
    - Intermediate trunk, variable
  - Variants
    - Duplication of the MCA at the ICA
    - Accessory MCA, which arises as a branch from the ACA
- **M2—insular segments**
  - Course within the lateral cerebral fissure
  - 6 to 8 small arterial branches usually arise from the M2 trunks, course within the Sylvian fissure, and supply the surface of the insula
- **M3—opercular segments**
  - Begin at the top of insula and turn laterally in the Sylvian fissure to supply the insular operculum (frontal, parietal, and temporal)
- **M4—cortical branches**
  - Emerge from the lateral cerebral fissure and course over the hemispheric surface

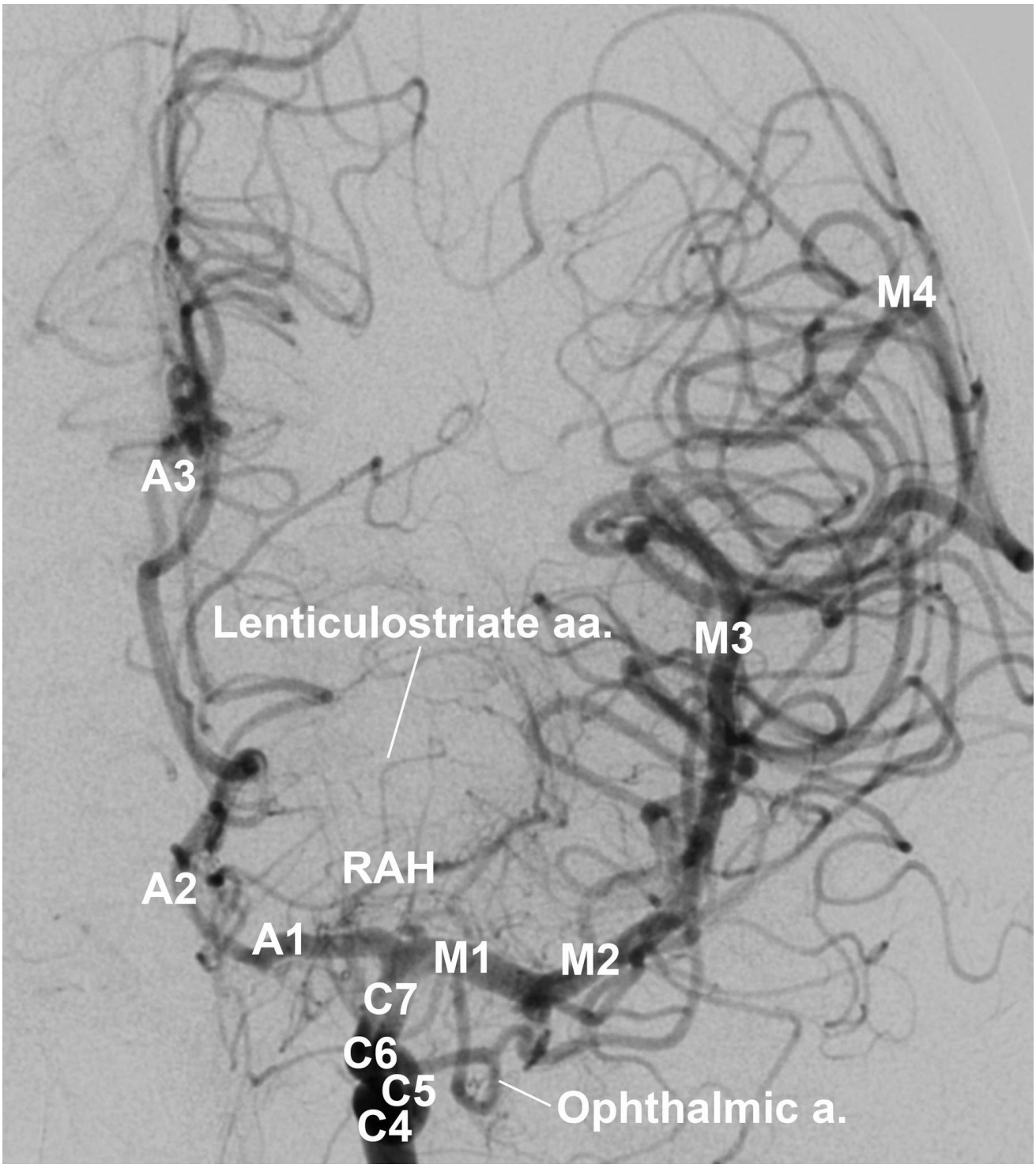


Figure 5: Frontal DSA view of the distal right ICA and its branches.

Cortical Branches

- Orbitofrontal (lateral frontobasal) artery and prefrontal arteries
- Precentral (prerolandic) artery
  - Runs between the precentral and central sulci
- Central sulcus (rolandic) artery
  - Runs within the central (rolandic) sulcus
- Postcentral sulcus (anterior parietal) artery

    - Runs in the postcentral and then the intraparietal sulcus
- Posterior parietal artery
    - Exits posterior end of the Sylvian fissure
    - Runs posterosuperiorly along the supramarginal gyrus
- Angular artery
    - Most posterior branch exiting the Sylvian fissure
    - Runs posterosuperiorly over the transverse temporal gyrus
- Temporo-occipital artery
    - Runs posteroinferiorly in the superior temporal sulcus
- Posterior temporal and medial temporal arteries
    - Extend inferiorly from the Sylvian fissure

Territory Supplied

- Putamen
- Globus pallidus
- Superior aspect of the internal capsule
- Caudate body
- Portions of the deep white matter
- Cortical branches (highly variable in territory of individual branches), majority of the lateral surface of the cerebral hemispheres, temporal pole

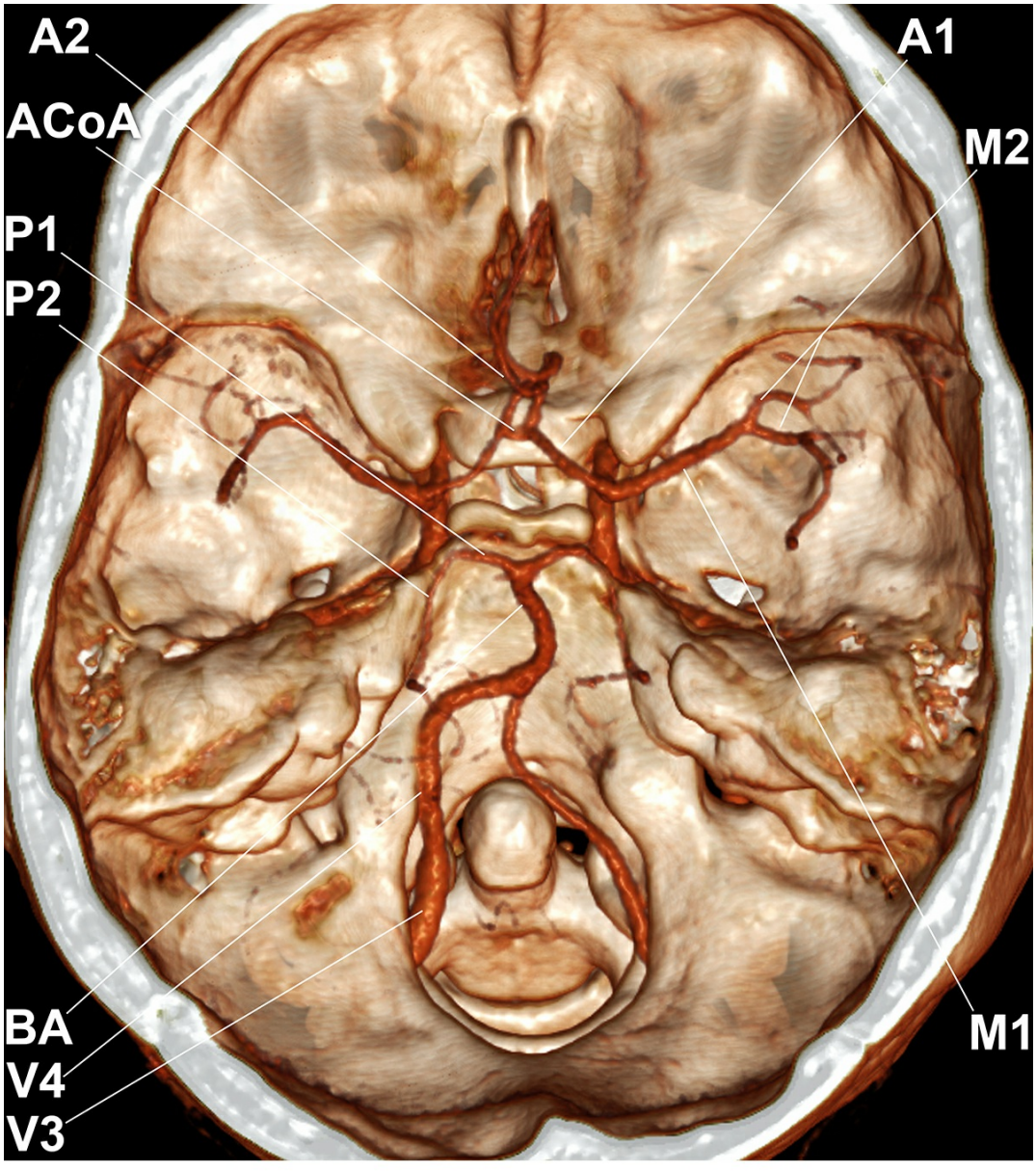
Normal Variants

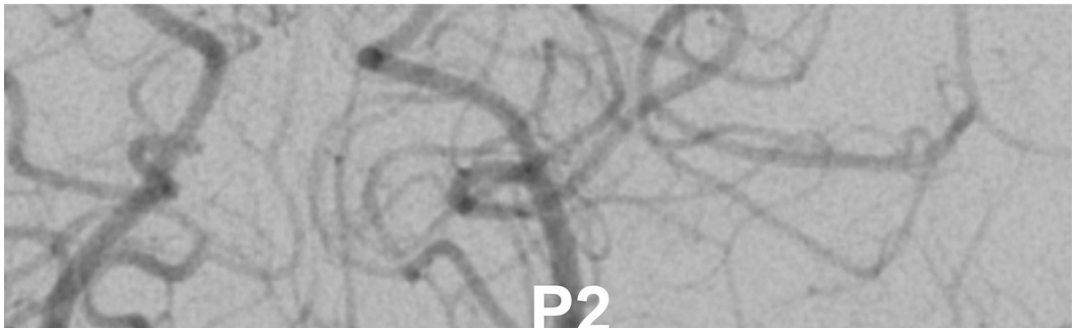
- High variability in branching patterns
- MCA duplication seen in 1% to 3% of cases
    - Large branch arises from the distal ICA just before the terminal bifurcation
    - Parallel to the main M1
- Accessory MCA (rare)
    - Arises from the ACA
    - High association with saccular aneurysm

- True anomalies (hypoplasia, aplasia) are rare

Vertebrobasilar System

Just before joining to form the basilar artery (BA), each of the VAs give off a branch that will become the anterior spinal artery, extending downward and medially to join in the midline with a corresponding branch from the other VA; the posterior spinal arteries can originate from the posterior inferior cerebellar arteries or from the intracranial portion of the VAs





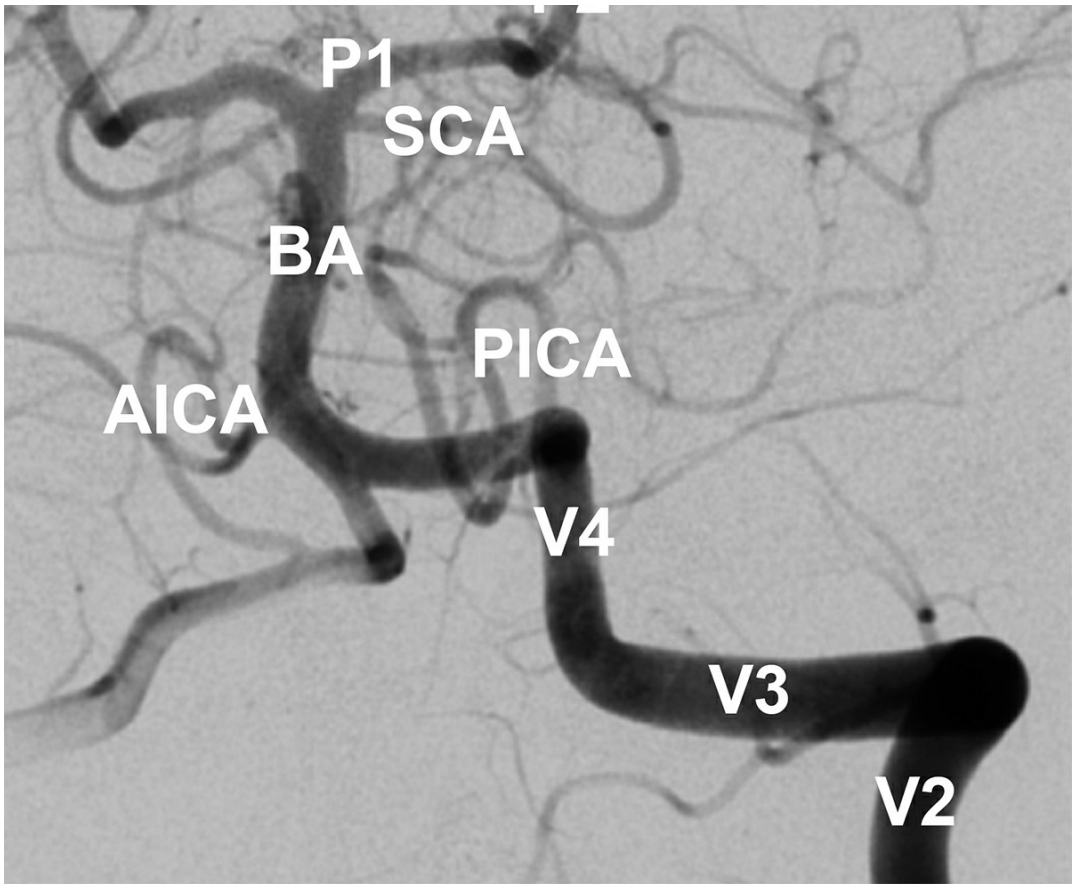


Figure 6: (Top) Reconstruction of CT angiogram demonstrating the circle of Willis and its more distal branches. (Bottom) The distal cervical and intracranial posterior circulation as seen with DSA.

Vertebral Arteries

Four Segments

- **V1—extraosseous segment**
  - Origin from each subclavian artery coursing superiorly to enter the C6 transverse foramen (80%–90%)
  - Variations
    - Origin of the left VA from the AA between the left common carotid artery and left subclavian artery has been described in 2% to 6% of cases
      - Enters the C5 transverse foramen in a majority of cases
    - Origins of the left VA from the left common carotid artery or external carotid artery (rare)
    - Origin of the right VA from the aorta, carotid arteries, or

brachiocephalic arteries (rare)
    - Important branch
        - Segmental cervical muscular branches
- **V2—foraminal segment**
    - Ascends from C6 to C2
    - Important branch
        - ***Anterior meningeal artery***
- **V3—extradural segment**
    - Exits top of the atlas (C1) transverse foramen, makes a wide extracervical loop between C2 and C1, courses superior to C1, curves posteromedially around atlantooccipital joint, turns sharply anterosuperiorly to enter the dura at the foramen magnum
        - Prone to dissection/pseudoaneurysm
    - Variations
        - Persistent first intersegmental artery; VA courses below the C1 arch after exiting the transverse foramen of C2 and enters the spinal canal without passing through the C1 transverse foramen (3%–4%)
    - Important branch
        - ***Posterior meningeal artery***
            - Supplies the falx cerebelli and the medial dura of the occipital posterior fossa
- **V4—intradural segment**
    - Enters the cranium via the foramen magnum
    - Important branches
        - Anterior spinal artery (1) and posterior spinal arteries (2) originate
        - Medullary perforators
        - Posterior inferior cerebellar arteries (PICAs)
            - Originate from this segment with variations
            - Variations
        - Nondominant VA commonly terminates in the PICA (does not join to form the BA)

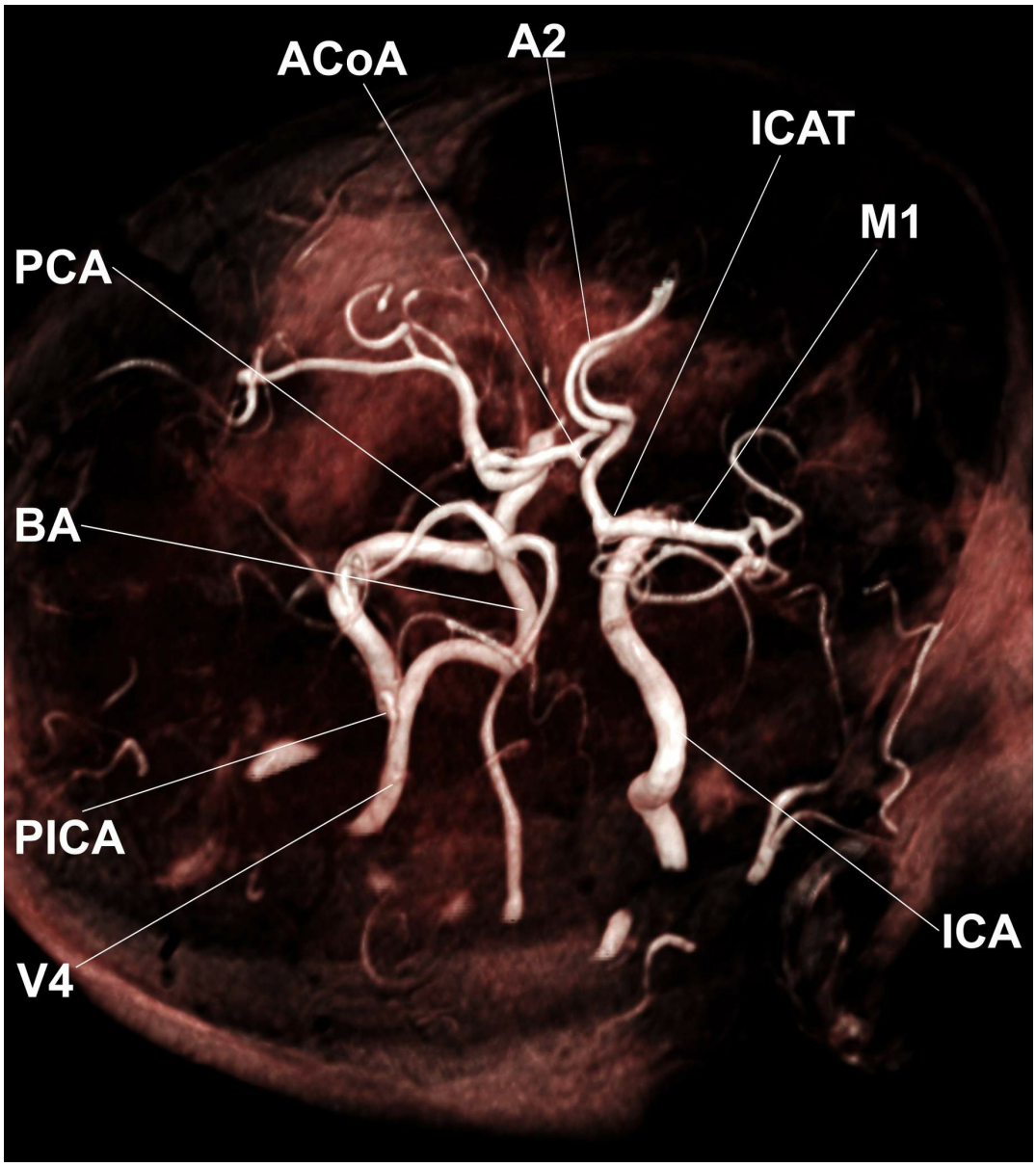


Figure 7: 3D reconstruction of the circle of Willis and its branches from an MR angiogram.

Basilar Artery

The 2 VAs fuse to form the BA, usually at the level of the pontomedullary junction within the prepontine cistern, ventral to the pons and midbrain. Variations are possible, including right or left dominant VA supply. A VA will occasionally terminate in the PICA and not join to form the basilar artery.

- Numerous pontine and midbrain perforators
- **Anterior Inferior cerebellar arteries (AICAs)**
    - Lie ventromedial to CN VII and VIII

    - Can loop into internal auditory meatus
- **Superior cerebellar arteries (SCAs)**
    - Originate near the basilar terminus before the PCA takeoff
    - Courses below CN III
- **Posterior Cerebral Arteries (PCAs)** at the terminal bifurcation

Territories supplied

- **VA**: PICA territory, medulla, cervicomedullary junction, cervical spine, cerebellar tonsils, inferior vermis/cerebellar hemispheres
- **BA**: PCA territory, most of the ventral pons, SCA and AICA territory, including the superior cerebellum/vermis

Normal variants

- BA/VA
    - Rifht/left variation in size, dominance common and slightly more commonly on the left
    - AA origin 1% to 5%
    - AICA/PICA may share common trunk off the BA
    - Fenestrations, duplications

Posterior Cerebral Arteries

- Originate at the basilar tip, bifurcation
- **4 segments**
    - **P1**—precommunicating segment, interpeduncular cistern
        - Thalamoperforators
        - **Artery of Percheron**—rare variant with dominant unilateral P1 perforator, supplies bilateral midbrain, thalami
    - **P2**—postcommunicating segment, ambient cistern; curves and courses posteriorly, stays above the tentorium
    - **P3**—quadrigeminal segment, quadrigeminal plate cistern

    - **P4**—cortical terminations, calcarine fissure

Cortical branches

- Anterior temporal artery
    - Arises from P2, courses anterolaterally under the parahippocampal gyrus of the inferior temporal lobe
- Posterior temporal artery
    - Arises from P2, courses posteriorly
- Distal PCA divides into 2 terminal trunks
    - Medial branches
        - Medial occipital artery
        - Parietooccipital artery
        - Calcarine artery
        - Posterior splenial arteries
    - Lateral branch
        - Lateral occipital artery

Territories supplied

- Diencephalon (thalamus, hypothalamus, portions of the midbrain)
- Portions of the choroid plexus
- Cortical branches: inferomedial temporal lobes and occipital poles

Normal variants

- "Fetal PCA"
    - Large PCoA gives direct origin to PCA
    - P1 (precommunicating) PCA segment hypoplastic or absent

Vascular territory

- Midbrain
- Thalami
- Posterior limb of the internal capsule

- Optic tract
- Ventricular and choroidal branches
    - Choroid plexus of third/lateral ventricles, parts of thalami, posterior commissure, cerebral peduncles; splenial branches: posterior body and splenium of the corpus callosum
- Cortical branch
    - Posterior one-third of the medial hemisphere surface; most of the inferior temporal lobe, most of the occipital lobe (including primary visual cortex)

Imaging pearls

- Absent PCA on vertebral angiography, usually due to hemodilution from "fetal" origin, not occlusion
    - Injection of ipsilateral carotid artery confirms presence of fetal PCA

Circle of Willis

- Central arterial anastomosis between the anterior and posterior circulation
- Critical for providing cross-flow and collateral support in large vessel occlusions and arterial injuries
- Located within the suprasellar cistern
- Prototypical configuration
    - Bilateral ICAs
    - Bilateral A1 segments of the ACA
    - Single ACoA
    - Bilateral posterior communicating arteries (PCoA)
    - BA
    - Bilateral proximal or horizontal (P1) PCA segments
- Normal variants, anomalies
    - Absent/hypoplastic components (55%–60%)

- Hypoplastic/absent PCoA (25%–30%)
- Hypoplastic/absent A1 segment of ACA (10%–20%)
- Fetal origin of the PCA from the ICA (15%–25%)
  - PCoA is same diameter as the ipsilateral P1 segment of PCA
  - P1 is hypoplastic or absent
- Infundibulum at the origin of the PCoA from the ICA in 5% to 15%
  - Should be <2 mm
  - PCoA arises from apex

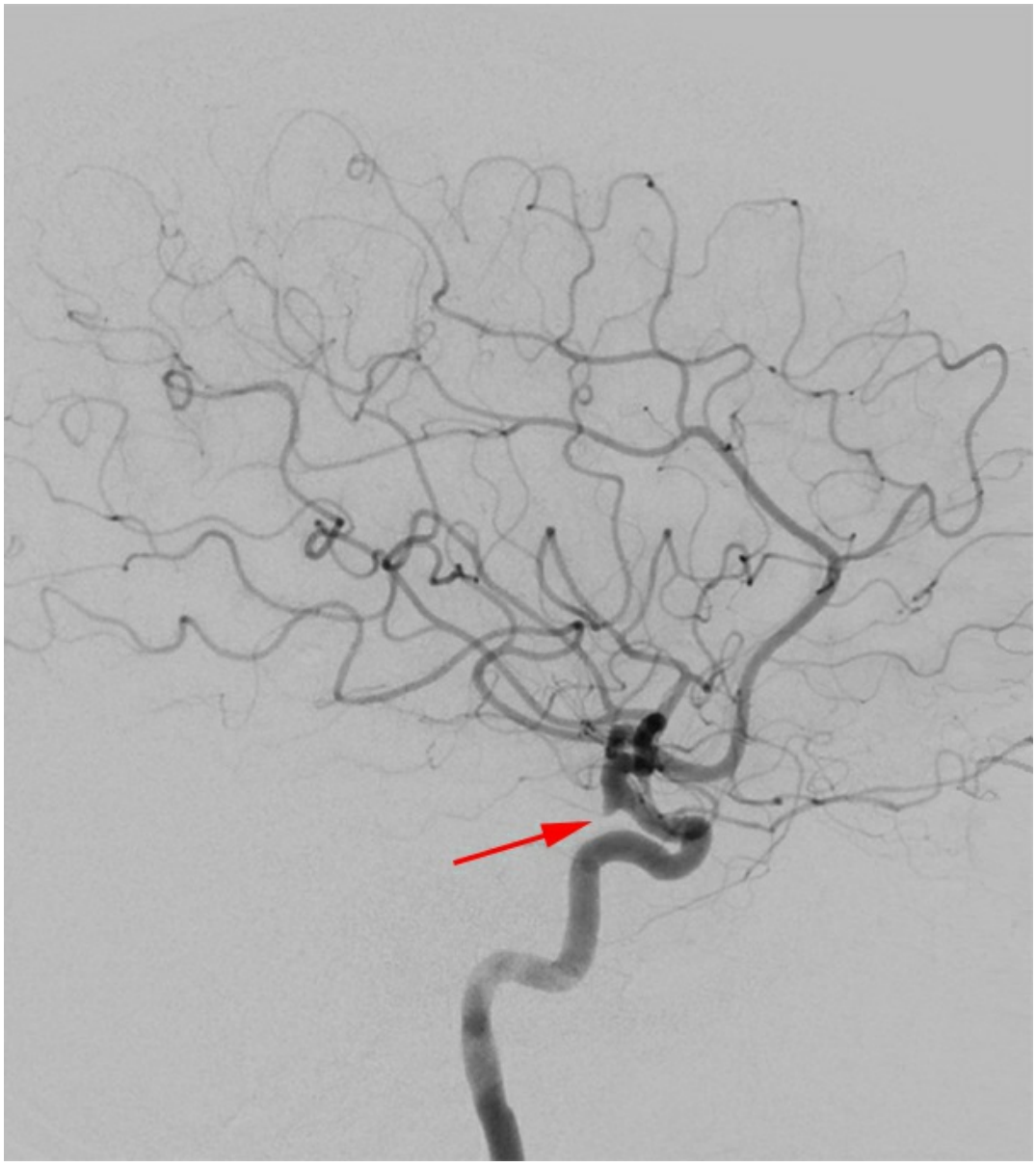


Figure 8: On this lateral DSA image, the small infundibulum is clearly visible at the origin of the PCoA from the distal ICA (arrow), but even

without the visible presence of the PCoA, small focal outpouching in this area implies an infundibulum rather than aneurysm.

Perfusion Border Zones ("Watersheds")

Cortical watershed zones are areas that receive dual supply at the distal confluences between the ACA, MCA, and PCA territories with variable subpial-leptomeningeal collateral support and are prone to hypoperfusion ischemia.

Internal watershed zones are areas that receive dual supply at the confluence of the cortical deep penetrating branches and perforating branches from the circle of Willis and lenticulostriates with variable subpial-leptomeningeal collateral support and are prone to hypoperfusion ischemia.

Persistent Carotid-Vertebrobasilar Anastomoses

Embryologic anastomotic connections between the anterior and posterior circulations that fail to regress in utero

- **Persistent trigeminal artery (PTA)**
  - Origin from the proximal cavernous ICA
  - Most common persistent carotid-vertebrobasilar anastomosis
  - Saltzman classification
    - Type I—PTA supplies the distal vertebrobasilar arteries; absent ipsilateral PCoA
    - Type II—PTA supplies the SCA; PCAs are supplied via the PCoA (fetal origin of ipsilateral PCoA)
  - "Neptune's trident sign" on angiography

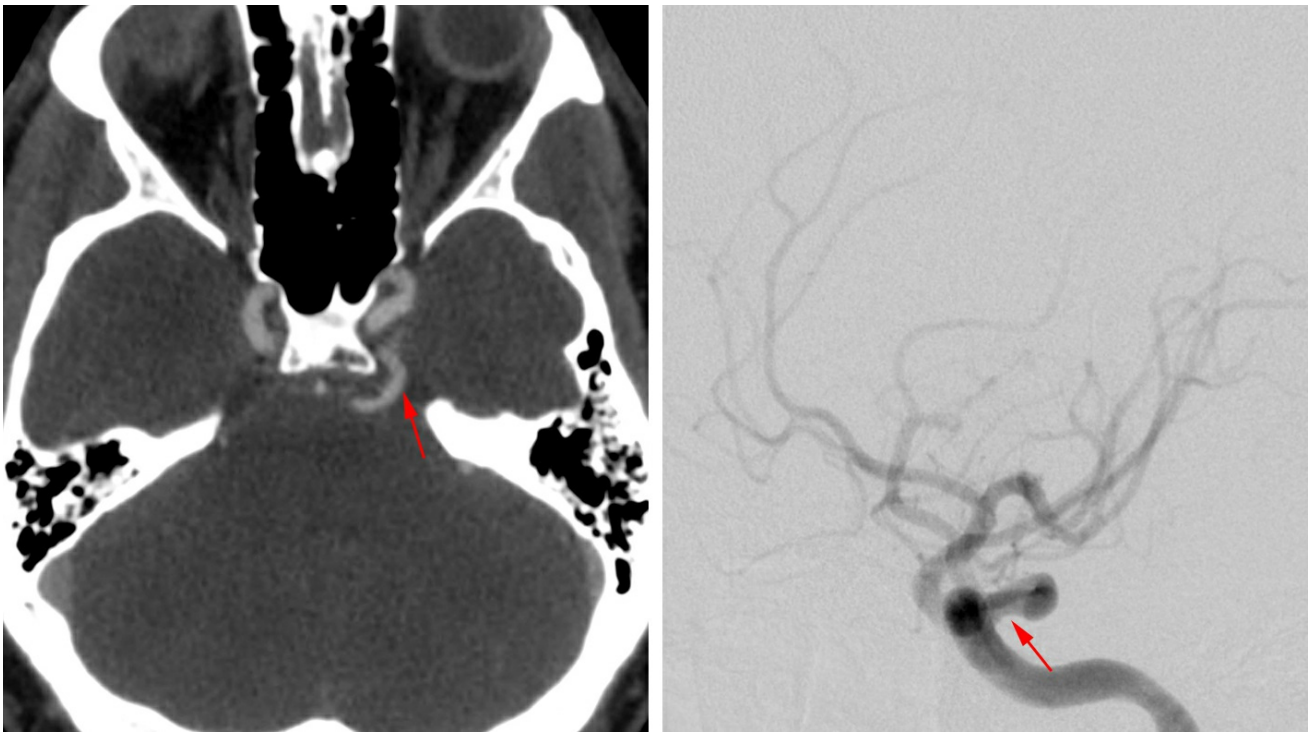


Figure 9: Axial CT angiography of the head (left) and lateral projection DSA (right) demonstrate a persistent left trigeminal artery coursing from the cavernous left ICA to the left superior cerebellar artery.

- **Persistent otic artery**
  - Controversial existence; very few confirmed cases in literature
  - Arises from the petrous ICA within the internal acoustic meatus along with CNs VII and/or VIII
- **Persistent hypoglossal artery (PHA)**
  - Origin from the cervical ICA at the level of C1-C2 or C2-C3, joins the BA via the hypoglossal canal
  - Parallels the hypoglossal nerve
  - Second most common persistent carotid-vertebrobasilar anastomosis
- **Persistent proatlantal intersegmental artery**
  - Most caudal of the persistent carotid-vertebrobasilar anastomosis
  - Types
    - Type I—cervical ICA at C2-C3 level (most common) to VA coursing between arch of C1 and the occiput
    - Type II—ECA origin (less common)

        - Other—CCA origin (very rare)
    - VAs may be absent or hypoplastic
    - Proatlantal intersegmental artery may be dominant or only supply to BA

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REFERENCES

1. Bouthillier A, van Loveren HR, Keller JT. Segments of the internal carotid artery: a new classification. *Neurosurgery* 1996;38:425–432. doi.org/10.1097/00006123-199603000-00001