Cerebrovascular Anatomy

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Introduction

Neuroanatomy poses an immense educational challenge. Surgical trainees require an intricate knowledge of neuroanatomy from an early stage in training to meet academic and clinical demands. Prior attempts for neuro-anatomic education have a gold standard of cadaveric dissection which can be cost prohibitive and time consuming. Alternative resources include two-dimensional (2D) representations of anatomical dissections and illustrations to provide a more rapid review. The surgeon must be able to recall anatomical detail in the 3D space to provide a meaningful reference intraoperatively. To augment the 3D learning modality to meet the needs of an increasingly technology-based trainee, a need exists for anatomically accurate computer-based 3D representations of the intricate operative anatomy.

The models developed by the authors attempt to provide an immersive 3D educational and virtual reality referential environment to augment the other available learning resources.

Cerebrovascular Anatomy

The cerebrovascular anatomy has an endocranial and exocranial component that can be further divided into the anterior and posterior circulation based on the contribution of blood flow through the internal carotid arteries and vertebral arteries, respectively. These structures are illustrated in the following models.

[Click here](#) to view related content for this model.

Model 1a

Model 1b

Model 1: Complete Cranial Cerebrovascular Anatomy with Neck Vasculature (1a) as well as Arterial (1b) Anatomy Alone.These models provide an overview rendition of the complete 3D venous and arterial cerebrovascular tree. All soft tissue, bony, and neural elements have been removed.The structures of the arterial and venous systems have been labelled in their own dedicated models below.(The instructions for use of these and the other following models are as follows:Please use the full screen function for optimal visualization (by clicking on the arrows on the right lower corner of the model). To move the model in 3D space, use your mouse's left click and drag; to enlarge the object, use the mouse's wheel. The right click and drag function moves the model across the plane.)

Model 2a

Model 2b

Model 2c

Model 2: Complete Cranial Vascular Anatomy with the Deep Brain Structures (2a) and Arterial System Alone (2b). The brain is slightly more opaque (2c) to demonstrate cerebral landmarks in relation to vasculature.

All other soft tissues, bony, venous, and superficial cortical structures have been removed.

Anterior (Carotid) Arterial Circulation

The anterior arterial circulation is the distal distribution of blood flow through the carotid system. This relevant cerebrovascular anatomy includes segmental divisions of the internal carotid arteries (ICAs), middle cerebral arteries (MCAs), and anterior cerebral arteries (ACAs), and subsequent branching arteries with corresponding perfusion zones.[1] Multiple perforator arteries emanating from the terminal ICAs, MCAs, and ACAs have a large perfusion zone along the basal nuclei and basal forebrain.[2]

The segmental division of the major anterior circulation vessels provides important insight into the associated branches and pathologies that arise along these distributions. The ACAs and MCAs have been divided into segments (A1 to A5 and M1 to M4, respectively). These annotations are demonstrated on Model 3. The ICAs has been divided into seven segments (C1-7) from proximal to distal within the most recent classification system, see Model 3.[1]

The segmental divisions of the ICAs are visualized from an endoscopic perspective within Model 4. The divisions include parapharyngeal, petrous, paraclival, parasellar, paraclinoid, and intradural segments.[3] This segmentation schematic provides an endoscopically relevant division of the ICA.

> 3D [Click here](#) to view related content for this model.

Model 3: Cerebral Anterior Circulation. This model provides a rendition of the 3D anterior circulation with bony, venous, and neural elements removed.Please click on "Select an annotation" link at the bottom of the window and "hide annotations" so that the anatomical labels become invisible.

Annotated structures include: Anterior Communicating Artery, A1 (Precommunicating Segment), A2 (Postcommunicating Segment), A3 (Precallosal Segment), Pericallosal Artery, Callosomarginal Artery, Orbitofrontal Artery, Frontopolar Artery, A4 (Supracallosal Segment), A5 (Postcallosal Segment), Anteromedial Frontal Branch, Intermediomedial Frontal Branch, Posteromedial Frontal Branch, Cingular Branch, Paracentral Branch, Superior Internal Parietal Artery, Inferior Internal Parietal Artery, C1 (Cervical Segment), C2 (Petrous Segment), C3 (Lacerum Segment), C4 (Cavernous Segment), C5 (Clinoid Segment), C6 (Ophthalmic Segment), Ophthalmic Artery, Lacrimal Artery, Ciliary Arteries, Supratrochlear Artery, Supraorbital Artery, C7 (Communicating Segment), Superior Hypophyseal Artery, Inferior Hypophyseal Artery, Anterior Choroidal Artery, Recurrent Artery of Heubner, Medial Lenticulostriate Arteries, Lateral Lenticulostriate Arteries, M1 (Sphenoidal Segment), M2 (Insular Segment), M3 (Opercular Segment), M4 (Cortical Segment), Angular Artery, Posterior Temporal Artery, Posterior Parietal Artery, Middle Temporal Artery, Central Artery, Anterior Temporal Artery, Ascending Frontal Artery, and Lateral Orbitofrontal Artery.

3D [Click here](#) to view related content for this model.

Model 4: Endonasal Vascular Correlates. This model provides an endoscopic endonasal perspective to the skull base with selective bone removal to permit visualization of the anterior circulation arterial anatomy and cavernous venous system. Annotated structures include the Pituitary Gland, Parapharyngeal ICA Segment, Petrous ICA Segment, Trigeminal Nerve (V3), Paraclival ICA Segment, Trigeminal Nerve (V2), Trigeminal Nerve (V1), Parasellar ICA Segment, Paraclinoidal ICA Segment, Intradural ICA Segment, Ophthalmic Artery, Optic Nerve (CN II), Oculomotor Nerve (CN III), Trochlear Nerve (CN IV), Cavernous Sinus, and Opticocarotid Recess.

Model 5: Internal Carotid Artery (ICA) Segments: The ICA has been labeled based on the Cincinnati criteria for the ICA division, which include 7 segments: cervical, petrous, lacerum, cavernous, clinoid, ophthalmic, and communicating segment. We have included a thorough 3D rendition of this schematic via partial temporal bone transparency. Annotated structures include the cervical, petrous, lacerum, cavernous, clinoid, ophthalmic, and communicating segments of the ICA.

Posterior (Vertebrobasilar) Arterial Circulation

The posterior arterial circulation is the distal distribution of blood flow through the vertebrobasilar system and demonstrates intricate relationship between the vascular and neural structures within the posterior fossa and deep brainstem nuclei. The posterior fossa contains three sets of neurovascular complexes: upper, middle, and inferior.[4]

These complexes correspond to the superior cerebellar artery (SCA), anterior inferior cerebellar artery (AICA), and posterior inferior cerebellar artery (PICA).[4] Similarly these complexes encompass a corresponding perfusion zone along the midbrain, cerebellar peduncle, and cerebellum.[1] The SCA, AICA, and PICA are divided into segments (s1 to s4, a1 to a4, and p1 to p5, respectively). This anatomy is illustrated within Model 6. This segmental division of the individual arteries permits detailed anatomical descriptions of vascular lesions arising along these arteries.

The supratentorial extent of the posterior circulation includes anastomoses with the anterior circulation via the posterior communicating arteries (PCoAs) bilaterally, to varying degrees dependent on dominance and/or atresia of these vessels.[1] The posterior cerebral arteries (PCAs) project posteriorly, segmented into P1 to P4 running proximal to distal, and provide watershed perfusion along the ACA and MCA distributions.[1]

Model 6: Posterior Fossa Arterial Circulation. This model provides a rendition of the 3D posterior circulation with bony, venous, and neural elements removed. Annotated structures include: V3, V4, Anterior Spinal Artery, Posterior Spinal Artery, Vertebrobasilar Junction, Basilar Artery, Posterior Communicating Artery (PCoA), P1 (Peduncular Segment), P2 (Ambient Segment), P3 (Quadrigeminal Segment), Medial Posterior Choroidal Artery, Lateral Posterior Choroidal Artery, P4 (Cortical Segment), Thalamoperforating Arteries, Anterior Temporal Artery, Posterior Temporal Artery, Parietooccipital Artery, Calcarine Artery, s1 (Anterior Pontomesencephalic), s2 (Lateral Pontomesencephalic), s3 (Cerebellomesencephalic), s4 (Cortical Segment), a1 (Anterior Pontine Segment), a2 (Lateral Pontine Segment), a3 (Flocculopeduncular Segment), a4 (Cortical Segment), p1 (Anterior Medullary), p2 (Lateral Medullary Segment), p3 (Tonsillomedullary Segment), p4 (telovelotonsillar Segment), and p5 (Cortical Segment).

Model 7: Complete Posterior Fossa Neurovascular Anatomy. This model provides a rendition of the 3D posterior fossa contents including all neurovascular elements. Select bony elements are removed to permit visualization.

Model 8: Posterior Circulation Arterial Anatomy with Neural Elements. This model provides a rendition of the arterial anatomy of the posterior circulation relative to the neural elements within the posterior fossa. The bony and venous elements were removed. Annotated structures include:V4, Anterior Spinal Artery, Posterior Spinal Artery, Vertebrobasilar Junction, Basilar Artery, P1 (Peduncular Segment), P2

(Ambient Segment), P3 (Quadrigeminal Segment), P4 (Cortical Segment), s1 (Anterior Pontomesencephalic), s2 (Lateral Pontomesencephalic), s3 (Cerebellomesencephalic), s4 (Cortical Segment), a1 (Anterior Pontine Segment), a2 (Lateral Pontine Segment), a3 (Flocculopeduncular Segment), a4 (Cortical Segment), p1 (Anterior Medullary), p2 (Lateral Medullary Segment), p3 (Tonsillomedullary Segment), p4 (telovelotonsillar Segment), p5 (Cortical Segment), optic nerve (CN II), oculomotor nerve (CN III), trochlear nerve (CN IV), trigeminal nerve (CN V), abducens nerve (CN VI), facial nerve (CN VII), vestibulocochlear nerve (CN VIII), glossopharyngeal nerve (CN IX), vagus nerve (CN X), spinal accessory nerve (CN XI), and hypoglossal nerve (CN XII).

Venous System

Cerebral venous anatomy can be divided into the cerebral and posterior fossa anatomical compartments, both illustrated in Model 9. The cerebral venous configuration can be subdivided into a deep (subependymal) and superficial group. The superficial division, as Rhoton[5] described, is a series of draining veins that can be grouped into four groups of bridging veins: a superior sagittal group, sphenoidal group, tentorial group, and falcine group. The high variation in location and dominance of the veins within these anatomical regions demonstrates the need for a region-based division.

The deep veins include those that drain the walls of the ventricles, choroid plexi, and basal cisterns. These structures include the basal venous system, internal cerebral venous system, and the vein of Galen.[5] These structures can be visualized with associated venous anatomy in Model 9.

The deep and superficial cerebral venous groups then converge on the major draining sinuses, which include the superior sagittal sinus, inferior sagittal sinus, straight sinus, transverse sinuses, tentorial sinuses, cavernous sinuses, superior petrosal sinuses, sphenoparietal sinuses, sphenobasal sinuses, and sphenopetrosal sinuses.[1,5,6] The majority of the drainage from the major draining sinuses converges on the internal jugular veins, which serve as the major outflow from the cranial vault.

The posterior fossa venous structures can be divided into four divisions: superficial, deep, brainstem, and bridging veins.[7] Rhoton further subdivided the superficial draining veins into tentorial, suboccipital, and petrosal draining surfaces.[7] The three superficial surfaces, deep posterior fossa veins along the cerebellar fissures, and plexi along the brainstem drain into one of the three groups of bridging veins: galenic, petrosal, or tentorial. The galenic group drains to the vein of Galen. The petrosal group drains into the inferior or superior petrosal sinuses. The tentorial group drains into the tentorial sinuses that ultimately drain onto the superior petrosal, straight, or transverse sinuses.[7]

> 3D [Click here](#) to view related content for this model.

Model 9: Cranial Venous System. This model provides a rendition of the 3D cerebral venous anatomy with bony, arterial, and neural elements removed. Annotated structures include: Internal Jugular Vein, Inferior Petrosal Sinus, Sigmoid Sinus, Superior Petrosal Sinus, Inferior Anastomotic Vein (of Labbé), Transverse Sinus, Confluence of Sinuses, Straight Sinus, Superior Sagittal Sinus, Superior Anastomotic Vein (of Trolard), Superficial Middle Cerebral Vein, Occipital Sinus, Inferior Sagittal Sinus, Great Cerebral Vein (of Galen), Basal Cerebral vein (of Rosenthal), Internal Cerebral Vein, Superior Choroidal Vein, Thalamostriate Vein, Venous Angle, Anterior Septal Vein, Anterior Caudate Vein, Cavernous Sinus, Basilar Venous Plexus, Posterior Intercavernous Sinus, Anterior Intercavernous Sinus, Superior Ophthalmic Vein, Inferior Ophthalmic Vein, Anterior Cerebral Vein, and Inferior Choroidal Vein.

> 3D [Click here](#) to view related content for this model.

Model 10a

Model 10b

Model 10: Complete (10a) and deep (10b) Cerebral Venous System with Deep Cerebral Structures. This model provides anatomical perspective of the venous vascular tree relative to deep brain structures. All soft tissue, bony, arterial, and superficial cortical structures have been removed.

Model 11: Posterior Fossa Venous System with Neural Elements. Annotated structures include: Median Anterior Medullary vein, Vein of the Pontomedullary Sulcus, Median Anterior Pontomesencephalic Vein, Transverse Pontine Vein, Lateral Anterior Pontomesenecephalic Vein, Peduncle Vein, Superior Petrosal Vein, Basal Vein of Rosenthal, Pontine Trigeminal Vein, Vein of the Cerebellopontine Fissure, Vein of the Middle Cerebellar Peduncle, Anterior Hemispheric Veins, Superior Petrosal Sinus, Vein of the Cerebellomesencephalic Fissure, and Vein of Galen.

Cerebrovascular Pathology

Cerebrovascular pathologies involve some of the most demanding operative interventions and an intricate understanding of the relevant neurovascular anatomy is critical to the success of the procedure. An example of an arteriovenous malformation (AVM) is presented in Model 12.

Model 12: A Callosal/Periatrial AVM. This model provides a rendition of the feeding vessels from the choroidal vessels in relation to the adjacent neural parenchyma and vascular structures. Neural elements have been selectively removed to allow for appropriate visualization of the lesion.

Conclusions

The cerebrovasculature anatomy possesses an unparalleled complexity. We have attempted to represent the anatomy in an understandable manner using 3D virtual models for the purposes of furthering education, research, and clinical applications.

The above material has also been previously published in the *Operative Neurosurgery* Journal: Volume 15, Issue 6, 1 December 2018, Pages 613–623

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