# Overview of Pertinent Cerebral Vascular Anatomy

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Performing and interpreting cerebrovascular ultrasound studies requires a basic understanding of the anatomy of the vessels involved. You should make yourself familiar with the normal course and appearance of both arteries and veins.

From the heart, two pairs of arteries supply the brain: 1- internal carotid arteries (anterior circulation) and 2- vertebral arteries (posterior circulation). Anterior and posterior circulations ultimately anastomose with each other at the base of the brain forming a circle of arteries known as the circle of Willis.

The common carotid arteries (CCAs) branch from the aortic arch and ascend on both sides of the neck. The CCA bifurcates into an internal and an external branch. The internal carotid artery (ICA) enters the skull at the level of the petrous bone and gives off the ophthalmic artery as its first intracranial branch. The ICA terminates into anterior cerebral artery (ACA) and middle cerebral artery (MCA) on both sides. Right before terminating to ACA and MCA, the ICA gives off two branches: 1- anterior choroidal artery and 2- posterior communicating artery.

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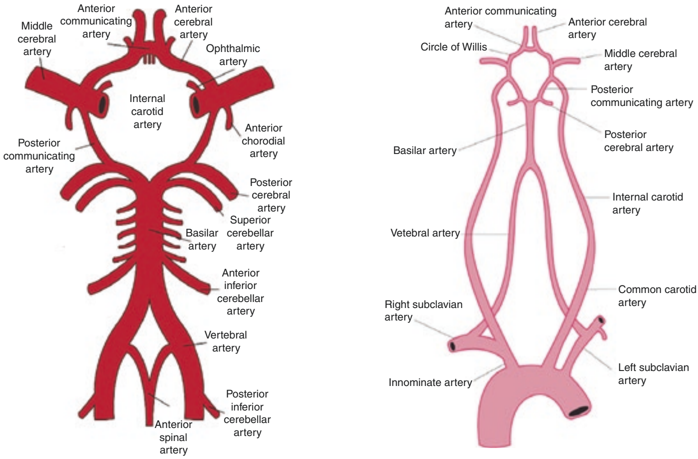


**Fig. 1** Intracranial arteries and their origination from the heart. Note the anastomosis of blood between the anterior and posterior intracranial circulations by way of the circle of Willis (picture on the left) and the origination of the internal carotid arteries and vertebral arteries from the aortic arch (picture on the right)

The vertebral arteries (VA) originate from the right and left subclavian arteries (from the aortic arch) [1]. The vertebral arteries ascend through the cervical vertebrae and join each other to form the basilar artery which later terminates into the posterior cerebral arteries (PCA) (Fig. 1).

## Anatomical Variations

Fewer than half of the normal population have a complete circle of Willis. There are many anatomical variations to this circle [2] however, some are relevant to cerebrovascular studies (Fig. 2). The most common anatomical variation is hypoplasia of one of the components of the circle of Willis which is present in up to 25% of patients.

Of all the anomalies, hypoplasia of the posterior communication artery is the most common followed by hypoplasia of the P1 segment of PCA, A1 segment of ACA and the anterior communicating artery.

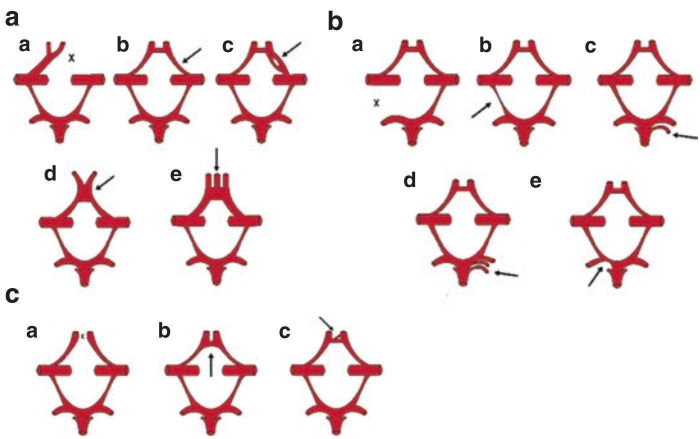


**Fig. 2** (**a**) Anterior cerebral artery common anatomical variations. (a) absent ACA; (b) hypoplastic ACA; (c) splitting ACA; (d) joint ACA; (e) triple ACA. (**b**) (a, b): Posterior communicating artery variations. (a) absent PcomA; (b) hypoplastic PcomA; (c–e): PCA anatomical variations, (c) duplicate PCA; (d) triple PCA; (e) hypoplastic PCA. (**c**) Anterior communicating artery common anatomical variations. (a) Absent AcomA; (b) Joint/absent variation; (c) Duplicate AcomA

The other less common anatomical variations are; presence of accessory vessels, anomalous origin and absent vessels [3].

## **Internal Carotid Artery Segments** [4] (Fig. 3)

- Cervical (C1): begins at the level of CCA bifurcation and ends where it enters the petrous bone via carotid canal.
- Petrous (C2): this segment refers to the part of ICA that runs through the carotid canal within the petrous bone. The ICA is considered intracranial at this level.
- Lacerum (C3): this segment of ICA is between the petrous segment and the cavernous segment. The ICA passes superior to the foramen lacerum, but doesn't pass through the foramen.
- Cavernous (C4): this segment is surrounded by the cavernous sinus and usually has a vertical segment, a posterior bend (medial loop of the ICA), a horizontal segment and an anterior

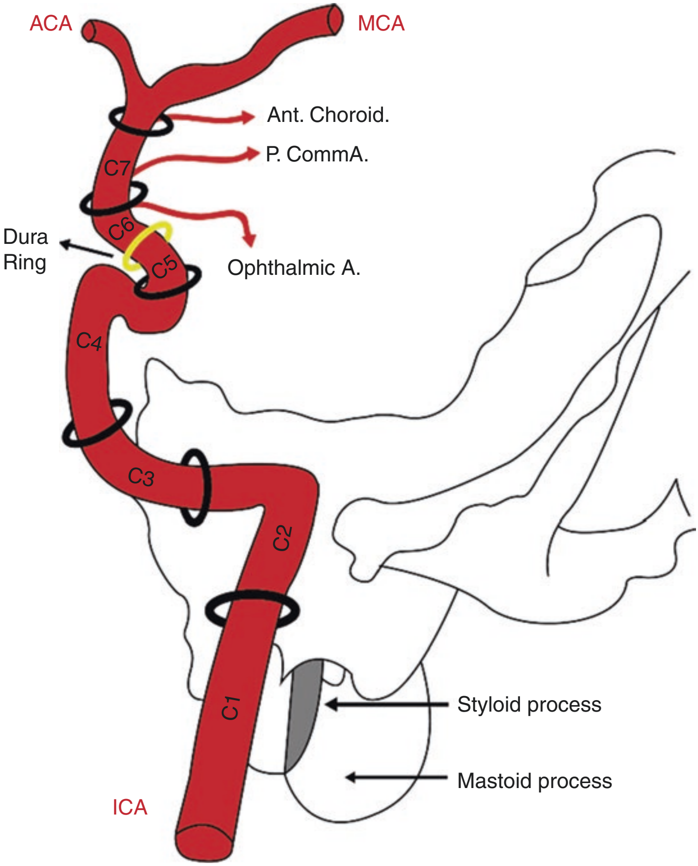


**Fig. 3** Internal carotid artery segments. C1: cervical, C2: Petrous, C3: Lacerum, C4: Cavernous, C5: Clinoid, C6: Ophthalmic, C7: Communicating

bend (anterior loop of the ICA) which together give the siphon shape to this segment of the ICA (carotid siphon).

- Clinoid (C5): this short segment is the continuation of the anterior loop of the cavernous segment.
- Ophthalmic (C6): this segment begins when the anterior loop of the ICA becomes intradural. The ophthalmic artery which is the first intracranial branch of the ICA arises from this segment in most people.

- Communicating (C7): this segment begins proximal to the area where the posterior communicating artery joins the ICA and ends where ICA bifurcates into MCA and ACA.

## Middle Cerebral Artery

MCA is the largest terminal branch of the ICA. The MCA divides into four main segments, denominated M1 to M4.

1. M1 segment originates at the carotid bifurcation and terminates as the middle cerebral artery.
2. M2 segment bifurcates or occasionally trifurcates. It travels laterally to the Sylvian fissure, and its branches end in the cerebral cortex.
3. M3 segment travels externally through the insula into the cortex.
4. M4 segments are thin and extend from the Sylvian fissure to the cortex [5].

M1 segment is the main segment of the MCA that is insonated in TCD through the temporal window. The blood is flowing towards the transducer (Fig. 4).

## Anterior Cerebral Artery (Proximal Segments)

As mentioned above, the ACA is part of the circle of Willis and perfuses the medial parts of the frontal lobe and medial superior parts of the parietal lobes.

ACA consist of five segments however, only the first two segments are relevant to TCD studies (Fig. 5)

1. A1 segment: originates from the ending of internal carotid artery and extends to the anterior communicating artery
2. A2 segment: originates at the anterior communicating artery and extends anterior to the lamina terminalis and along the rostrum of the corpus callosum, terminating either at the genu of the corpus callosum or at the origin of the callosomarginal artery [6]

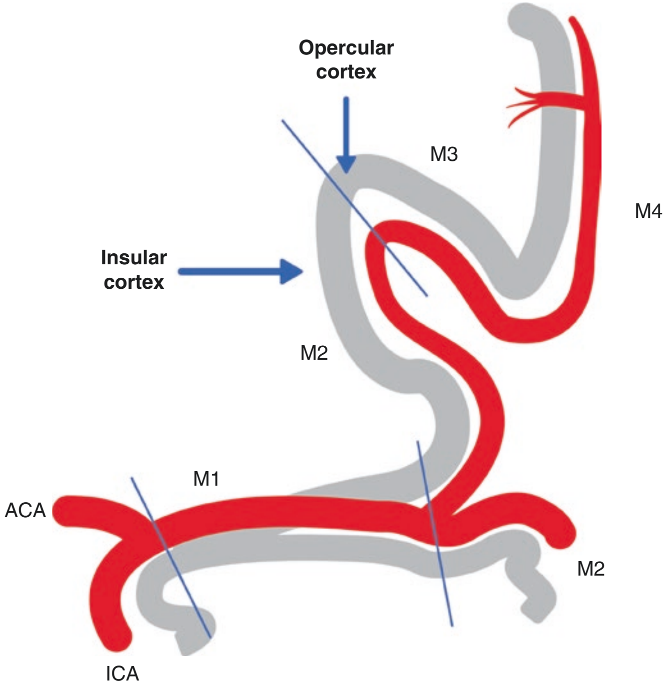


**Fig. 4** Schematic illustration of the Middle Cerebral Artery (MCA) segments

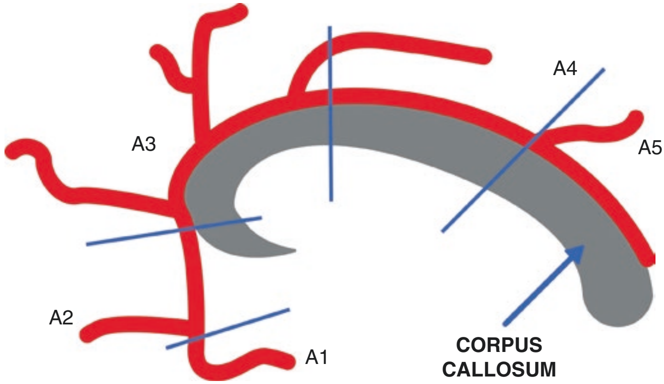


**Fig. 5** Schematic illustration of the Anterior Cerebral Artery (ACA) segments

## Basilar Artery

As mentioned above posterior circulation to the brain consist of the two vertebral arteries joining together to form the basilar artery. Basilar artery terminates into two posterior cerebral arteries (PCAs).

## Posterior Cerebral Artery [7]

PCAs curve around the midbrain and supply the midbrain, inferior portions of the temporal lobes, occipital lobes and the thalamus. This artery is divided into 5 segments, however only the P1 and P2 segments can be insonated by TCD (Fig. 8).

- P1: The P1 segment is located within the interpeduncular cistern and starts from the termination of the basilar artery to the posterior communicating artery, passing over the oculomotor nerve (CN III).
- P2: The P2 segment begins at the posterior communicating artery and curves around the ambient cistern of the midbrain, and courses above the tentorium cerebelli. The main branch of this segment is the posterior choroidal artery.
- P3: The P3 segment of the PCA refers to the part of the artery that runs through the quadrigeminal cistern.
- P4: The P4 segment is the last segment of the PCA as it ends in the calcarine sulcus.
- P5: The terminal branches of the parieto-occipital and the calcarine arteries are included as the P5 segment.

## Venous System

The venous drainage back to the heart is through the internal jugular veins. Cerebral veins can be divided to 1- superficial and 2-deep veins.

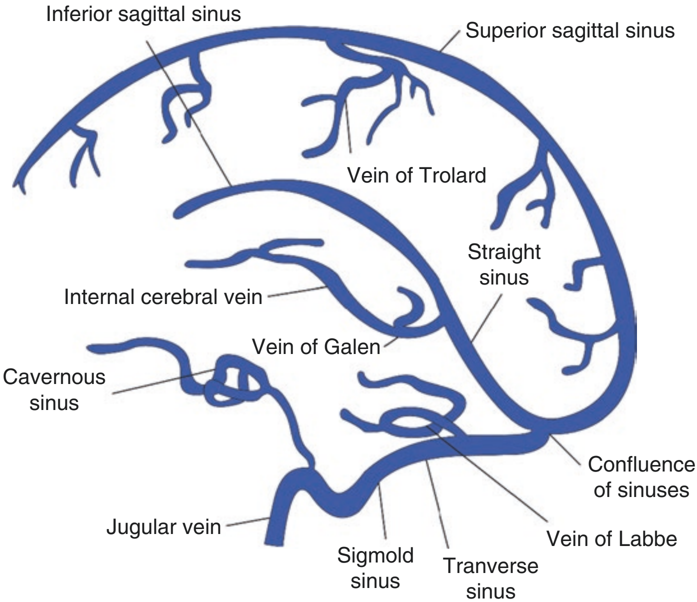


**Fig. 6** Schematic illustration of the intracranial venous system

In normal individuals the deep cerebral veins, especially the basal vein of Rosenthal and vein of Galen can be visualized with ultrasound. Unfortunately, ultrasound is not sensitive enough to be used for screening of venous sinus thrombosis (Fig. 6).

Vein of Galen is a deep vein that is formed by two internal cerebral veins (Fig. 6). A vein of Galen malformation is the most frequent arteriovenous malformation (AVM) in neonates and can be diagnosed with TCD.

## Locations for Transcranial Doppler Probes

The ultrasound frequencies are not able to penetrate through the bones of the skull sufficiently and therefore, areas with soft tissue or thinner bone are typically used to place the probe (Fig. 7).

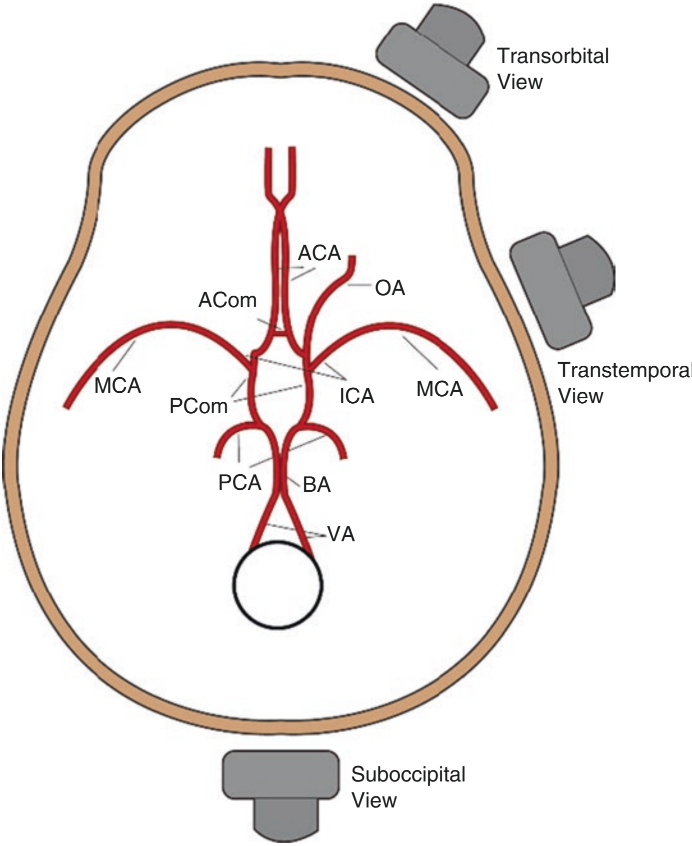


**Fig. 7** Schematic illustration of intracranial arteries in respect to various locations of transcranial Doppler probes

These areas are:

1. **Temporal window:** located right above the zygomatic arch. The temporal window can be used to insonate MCAs, proximal ACAs, ICA bifurcations and the PCAs.
2. **Orbital window:** used to insonate the ophthalmic arteries as well as the siphon of the ICAs.
3. **Suboccipital window:** used to insonate intracranial portions of the vertebral arteries and the basilar artery.

## Identifying Intracranial Vessels

Now that you are familiar with the cerebrovascular anatomy of the vessels. It is useful to know how to identify different vessels based on the window and the depth that you are insonating with the probe based on previous studies in adult patients aged between 18 to 80 years [8, 9] (Table 1 and Fig. 8).

## Evaluating Collateral Circulations

When an artery is blocked or severely narrowed an alternate route of circulation will be formed through the nearby smaller vessels; this is called collateral circulation formation. Usually these collateral pathways are dormant in healthy individuals however, when there is an occlusion or severe stenosis, the pressure gradient between the anastomosed vessels changes and a new collateral circulation is formed. As mentioned above, anterior and posterior communicating arteries are the main collateral systems in the brain.

**Table 1** Identifying the arteries based on the depth of insonation

| Artery | Window | Direction | Depth (mm) | Mean Flow Velocity |
|---|---|---|---|---|
| MCA | Temporal | Towards probe | 30–60 mm | 55 ± 12 cm/s |
| OA | Orbital | Towards probe | 40–60 mm | 20 ± 10 cm/s |
| Terminal ICA | Temporal | Towards probe | 55–65 mm | 39 ± 09 cm/s |
| ACA | Temporal | Away | 60–85 mm | 50 ± 11 cm/s |
| PCA | Temporal | Bidirectional | 60–70 mm | 40 ± 10 cm/s |
| ICA | Orbital | Bidirectional | 60–80 mm | 45 ± 15 cm/s |
| VA | Occipital | Away | 60–80 mm | 38 ± 10 cm/s |
| BA | Occipital | Away | 80–110 mm | 41 ± 10 cm/s |

*MCA* middle cerebral artery, *OA* ophthalmic artery, *ICA* internal carotid artery, *ACA* anterior cerebral artery, *PCA* posterior cerebral artery, *VA* vertebral artery, *BA* basilar artery

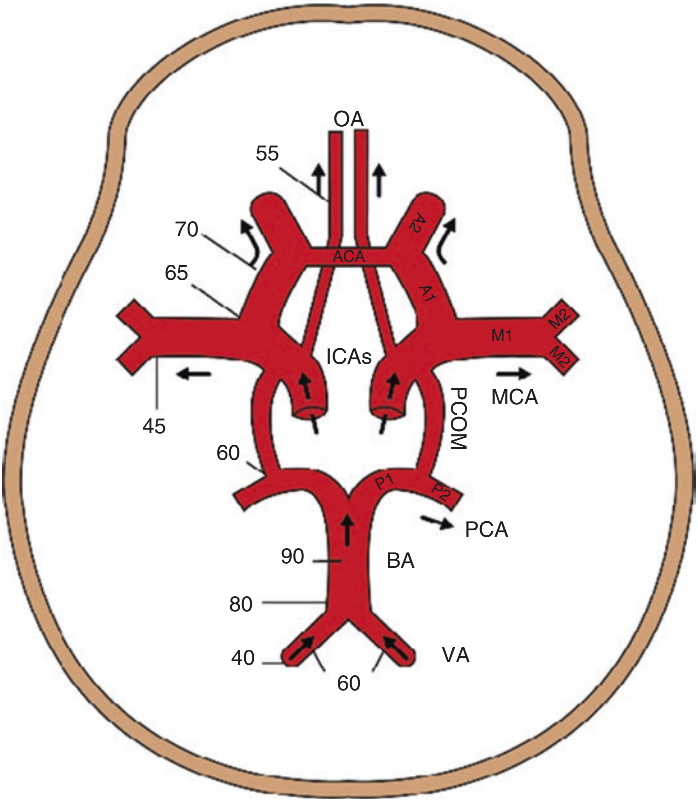


**Fig. 8** Flow directions of the intracranial arteries with depths of insonation (in mm) for an average human skull are shown. Please note that the direction of the flow may change in the setting of active collateral circulations. MCA middle cerebral artery, OA ophthalmic artery, ICA internal carotid artery, ACA anterior cerebral artery, PCA posterior cerebral artery, VA vertebral artery, BA basilar artery

TCD is very useful for evaluation of these collateral circulations. It can assess collateral flow with good sensitivity via the (1) circle of Willis and reversed ophthalmic artery flow in the case of proximal internal carotid artery occlusion/severe stenosis; (2) flow to leptomeningeal collaterals anastomosing ACA or PCA with the distal MCA branches in middle cerebral artery occlusion.

This flow diversion has been defined by an increase of 30% in velocities in the ACA or PCA (in comparison to the contralateral same vessels) and was associated with good leptomeningeal vessels on angiography in 88% of cases in a study of 51 patients with MCA occlusion [10]; (3) reversed basilar artery flow in proximal basilar occlusion and; (4) reversed vertebral artery flow in proximal subclavian or innominate artery occlusion (Fig. 8).

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