1 Anatomical Basics

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1.1 Classification of Supraaortic Arteries

In neuroradiology, a division into segments has become established (Fig. 1.1, Table 1.1), which has also found its way into ultrasound diagnostics. In addition, Table 1.2 provides an overview of the most important jargon terms used in neurovascular diagnostics.

1.2 Aortic Arch Branches

1.2.1 Normal Anatomy

The first and most powerful branch of the aortic arch is the brachiocephalic trunk, the second is the left common carotid artery, the third is the left subclavian artery (Fig. 1.2). The right common carotid artery does not have a direct outflow from the aortic arch, but originates from the brachiocephalic trunk, which itself flows into the right subclavian artery. This asymmetry is of clinical significance, as occlusive processes near the aorta can have a different effect on the right than on the left.

Note
Since the first vascular branches of the aortic arch lead to the brain, emboli coming from the cardiac system spread preferably cranially.

Another sonographically noteworthy feature is the fact that the **thyrocervical trunk** emerges from the subclavian artery few millimeters distal to the vertebral artery. Its main branch, the inferior thyroid artery, can be quite large in caliber (Table 1.3) and initially runs over a distance of usually 3–4 cm next to the vertebral artery in a cranial direction until it runs in an arc in a caudal direction to the lower pole of the thyroid gland. The other vessels of the thyrocervical trunk and the costocervical trunk, which also originates from the subclavian artery, are so thin, at least normally, that they cannot be followed sonographically over a longer distance.

Practical Tips
In the case of a extended vessel diameter, the initial section of the inferior thyroid artery can be sonographically confused with the terminal section of the vertebral artery. Decisive for the differentiation is the traceability of the vertebral artery further cranially to the sonographically well recognizable transverse processes.

1.2.2 Anatomical Variations

Variants of Aortic Arch Branches
Anatomical variations in the area of the aortic arch branches are relatively rare compared to the intracranially located vessel sections and are found "only" in 25–30% of all cases (Lang 1991; Lippert 1969). The most important are (Fig. 1.3):

- Origin of the left common carotid artery from the brachiocephalic trunk (25%)
- Origin of the left common carotid artery from the left subclavian artery(7%)
- Origin of the left vertebral artery from the aorta (5%)
- Origin of the vertebral artery from the thyrocervical trunk (1–2%).

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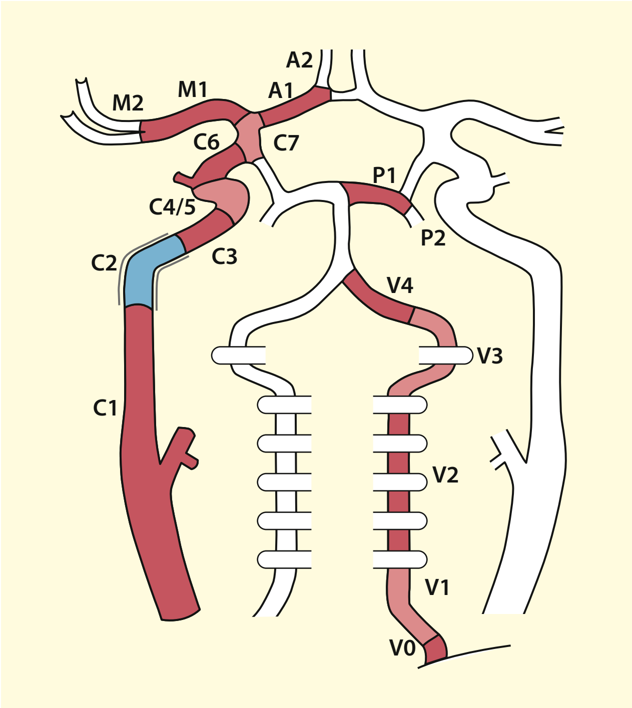


Fig. 1.1 Segmentation of the brain-supplying arteries (further details Table 1.1)

Other varieties, such as a bicarotic trunk or the direct exit of the right common carotid artery from the aortic arch, are in the range of less than 1%.

> **Note**
> **The frequency of anatomical variations in the arteries supplying the brain increases from caudal to cranial.**

Kinkings and Coilings

Stronger elongations of the common carotid artery are among the rarities and are usually noticed by the affected persons themselves with increasing age, when a pulsating "tumor" – preferably on the right side of the neck – slowly develops. The cause of the development of such vascular changes, which according to clinical experience are coincidentally often the result of colds with persistent coughing, is not known. In contrast, kinkings and coilings at the origin of the vertebral artery occur in about 50% of all normal persons and thus do not represent a fundamentally pathological finding (Trattnig et al. 1993). Information on the diameter varieties of the vertebral artery can be found in Sect. 20.3.

Summary
The first vascular outlets from the aorta lead to the brain. They are usually asymmetrically arranged (on the right side in upstream position the brachiocephalic trunk). Anatomical variants of the aortic arch branches are found in 20–30% of cases.

1.3 Extracranial Course of the Carotid Arteries

1.3.1 Normal Anatomy

The common carotid artery runs cranially to the side of the trachea and divides into the internal carotid artery and the external carotid artery approximately at the level of the thyroid cartilage. The localization of the bifurcation is subject to considerable individual variations in each case. In young people in particular, there is a bifurcation which is still located far cranially and can hardly be detected sonographically below the jaw angle, whereas in older people it is usually located much more caudally. In relation to the cervical spine, the point of division is at the level of the vertebral body C4 in almost 70% of all cases, C3 in 20% and C5 in about 10% (Lang 1991). The origin of the internal carotid artery, usually referred to as **carotid bulb** or **carotid sinus**, regularly shows a dilatation of the vascular lumen (Fig. 1.4).

> **Practical Tips**
> The location of the carotid bifurcation – usually in the middle of the fourth cervical vertebra – can serve as a rough "guide" for the assignment of the cervical transverse processes when examining the vertebral artery.

Normally, the internal carotid artery is largely straight until the base of the skull, without significant branches, while the external carotid artery branches out into various branches shortly after its origin. The first branch is regularly the superior thyroid artery, which, on its way to the thyroid gland, usually runs ventral of the common carotid artery, a short distance against the direction of flow (Fig. 1.5, Table 1.4).

Other important branches are the occipital artery, the facial artery, and the superficial temporal artery, all three of which supply the scalp and muscles with blood, the maxillary artery, which gives off branches to the upper and lower jaw

Table 1.1 Segmentation of the brain-supplying arteries

Vessel	Segment	Segment description	Ultrasound
Internal carotid artery	C1	Cervical section from the carotid bifurcation to the skull base	To be recorded by Doppler or duplex sonography between the carotid bifurcation and the jaw angle
	C2	Petrous section through the petrous bone	**Not detectable by sonography**
	C3	Lacerous section with the passage through the foramen lacerum	To be recorded in coronary section by transcranial duplex sonography at the exit from foramen lacerum
	C4	Cavernous section through the cavernous sinus ("**carotid siphon**"), S-shaped course	To be recorded transorbital with transcranial Doppler and duplex sonography
	C5	Clinoidal section between the proximal and the distal dural ring	**Not detectable by sonography**
	C6	Ophthalmic segment from distal dural ring up to the origin of the posterior communicating artery	To be recorded with transcranial duplex sonography
	C7	Distal section between the origin of the posterior communicating artery and the carotid T	To be recorded with extra cranial Doppler- and duplex sonography
Vertebral artery	V0	Origin of vessel	To be recorded with extracranial duplex sonography
	V1	Course up to the entry in the transversal foramina	To be recorded with extracranial duplex sonography
	V2	Course between the transversal foramina to HWK2	To be recorded with extracranial duplex sonography between the foramina
	V3	"**Atlas loop**"	To be recorded with extracranial duplex sonography
	V4	Intracranial section with origin of the posterior inferior cerebellar artery	To be recorded with transcranial duplex sonography
Middle cerebral artery	M1	Main trunk with origin of the lenticulostriatal vessels	To be recorded with transcranial duplex sonography
	M2	Main branches	**Not detectable by sonography**
Anterior cerebral artery	A1	Precommunical section proximal to the anterior communicating artery	To be recorded with transcranial duplex sonography
	A2	Post-communical cranial section	**Not detectable by sonography**
Posterior cerebral artery	P1	Precommunical section proximal to the posterior communicating artery	To be recorded with transcranial duplex sonography
	P2	Post-communical course at the cerebral peduncle	To be recorded with transcranial duplex sonography

According to Runge (2017)

Table 1.2 Important jargon terms of supraaortic vascular anatomy

Term	Meaning
Carotid bulb	Dilatation of the internal carotid artery at the exit from the common carotid artery
Carotid siphon	Convex arch of the internal carotid artery after passing through the skull base including the exit of the ophthalmic artery
Carotid T	Branching of the internal carotid artery into the middle and anterior cerebral artery
Atlas loop	Suboccipital elongation of the vertebral artery to allow for pitching and rotating movements
Basilaris head	Branching of the basilar artery into the posterior cerebral arteries

and the meninges, and the ascending pharyngeal artery. The diameter of the large branches of the external carotid artery is normally 1.5–2 mm, but can also be up to approximately 3 mm (Lang 1991). A smaller branch is the posterior auricular artery, which supplies the base of the skull in the area of the mastoid and can be considerably hyperperfused in dural arteriovenous malformations.

1.3.2 Anatomical Variations

Internal Carotid Artery

In the area of carotid bifurcation as well as in the course of the internal carotid artery there are numerous anatomical variations which can lead to uncertainties in the sonographic assessment. Due to the essential importance of the internal

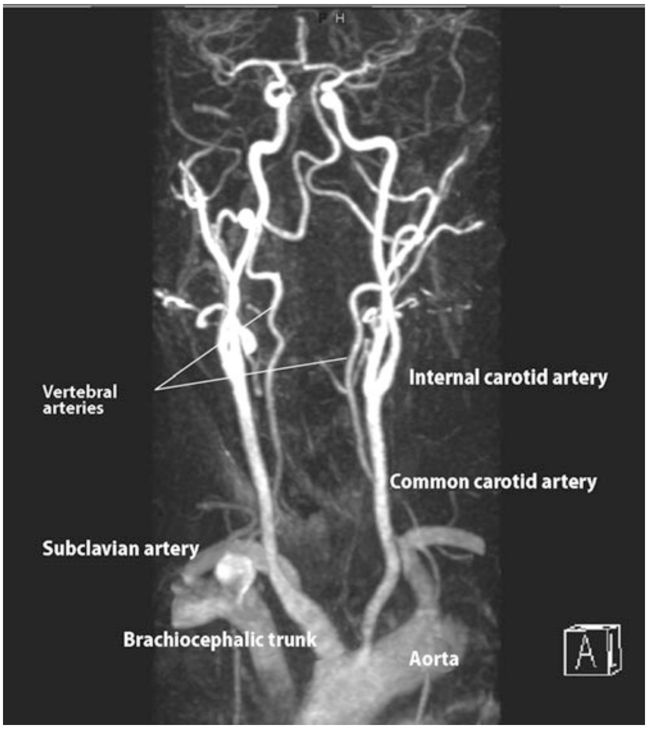


Fig. 1.2 Aortic arch and cervical arteries in MRA

carotid artery in vascular diagnostics, these should be familiar to the examiner.

Bifurcation Variants

In almost 90% of all cases (Prendes et al. 1980) the internal carotid artery is located dorsally to the external carotid artery, but in almost 20% of these cases the external carotid artery is located laterally to the internal carotid artery (Fig. 1.6). In almost 10% of cases, the internal and external carotid arteries are completely superimposed in lateral view, whereby both the internal and external carotid arteries can be the more superficial vessel. In rare cases, a rostral exit of the internal carotid artery can also be found. ◄

Variants of the Carotid Bulb

In duplex sonographic differentiation of the carotid branches, variants of the carotid sinus can cause confusion in individual cases. Although in the majority of cases the typical dilatation at the exit of the internal carotid artery is evident, there may also be an isolated dilatation at the origin of the external carotid artery or a completely missing "bulb" (Fig. 1.7, Table 1.5). ◄

Practical Tips
A missing carotid bulb or sinus is mainly found in connection with elongations and kinking of the internal carotid artery, which usually can be found 1–3 cm distal to the bifurcation.

Kinkings and Coilings

In 2/3 of all cases, the internal carotid artery runs in direct extension of the common carotid artery, in the remaining third there are more or less strongly kinked courses. Bends toward the skin surface ("lateral") and inward ("medial") occur with about the same frequency (Fig. 1.8). In about 15% of the cases the angle is 30° and more. In connection with, but also independently of a kinking at the origin of the internal carotid artery, further kinking and looping can occur in the course of the vessel up to the base of the skull. These are relatively rare in young people, but increase significantly with age (Fig. 1.9). In most cases, such vascular processes are then visible on both sides. Elongations, kinkings, and coilings can be distinguished by their shape (Sect. 20.1). ◄

Background Information
Two factors can be assumed to be the cause of elongations and kinkings that occur more frequently at an advanced age: On the one hand, there is a reduction in body size with "too long" vessels in the course of life, mainly due to the reduction in height of the intervertebral discs, on the other hand, there may be a hypertension-associated cranial displacement of the aortic arch.

Table 1.3 Standard values (mean value and range of variation) of diameter and length of the proximal cervical arteries in the anatomical preparation

	Diameter in mm	Length in mm
Brachiocephalic trunk	15 (10–22)	45 (20–74)
Subclavian artery (until vertebral outflow)	10.5 (7–15)	Right 20 (0–48) Left 35 (16–50)
Common carotid artery	9 (6–12)	Right 100 Left 120
Inferior thyroid artery	3.5 (2.0–4.7)	32 (10–58)

According to Lang (1991)

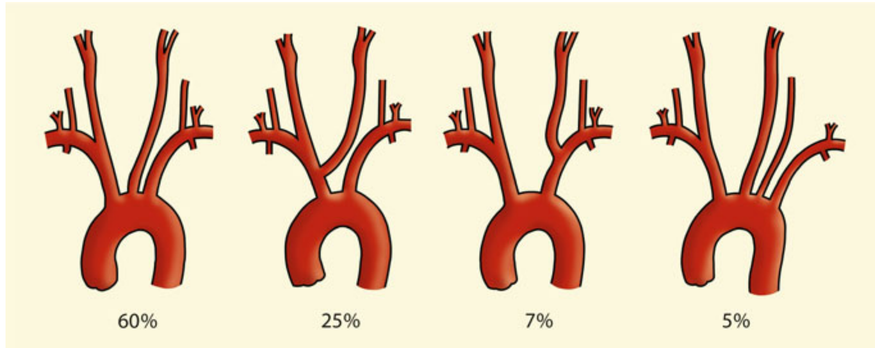


Fig. 1.3 Anatomical variations of the aortic arch

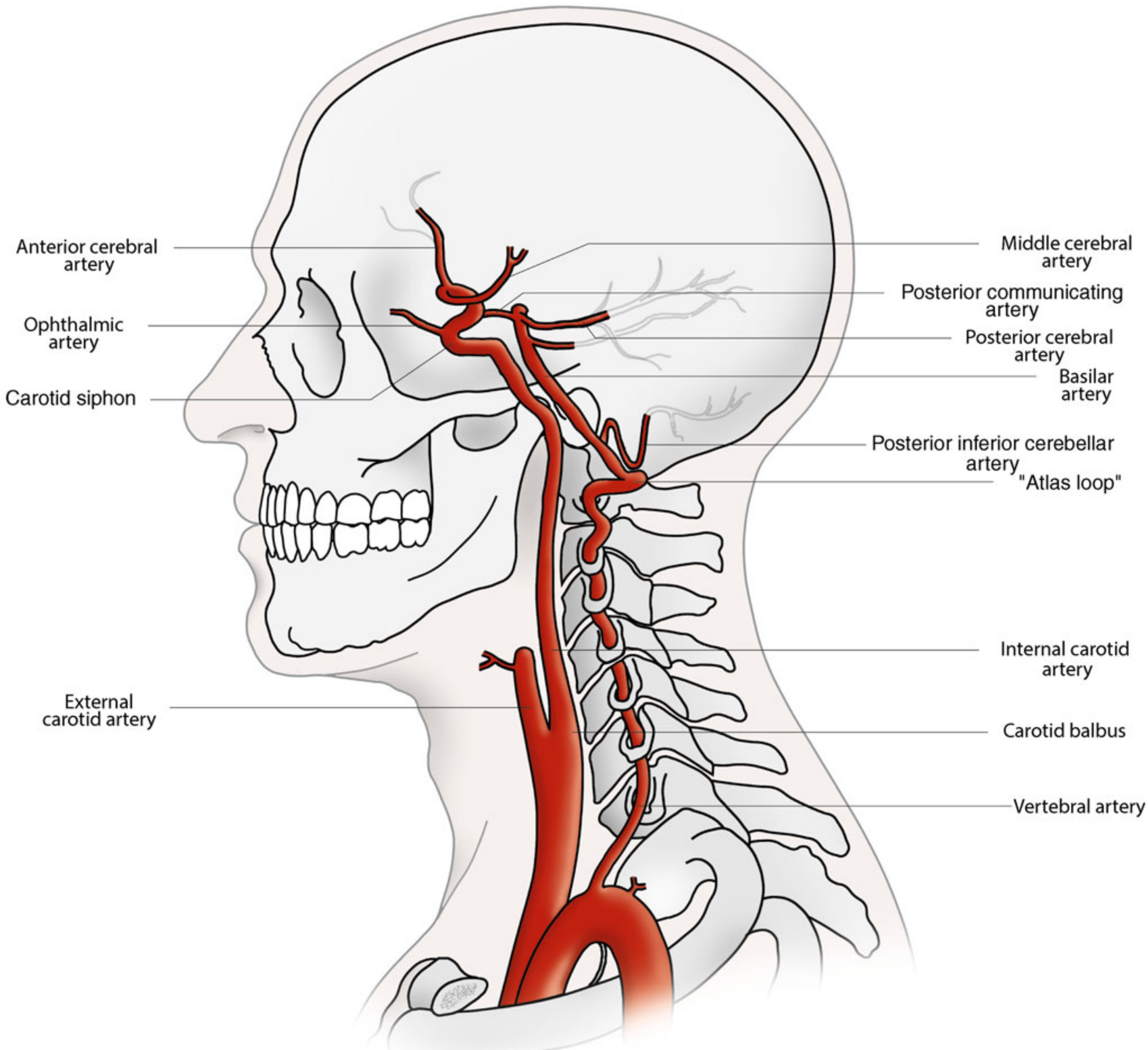


Fig. 1.4 Course of the large brain-supplying arteries in the area of the neck and the skull base in lateral view

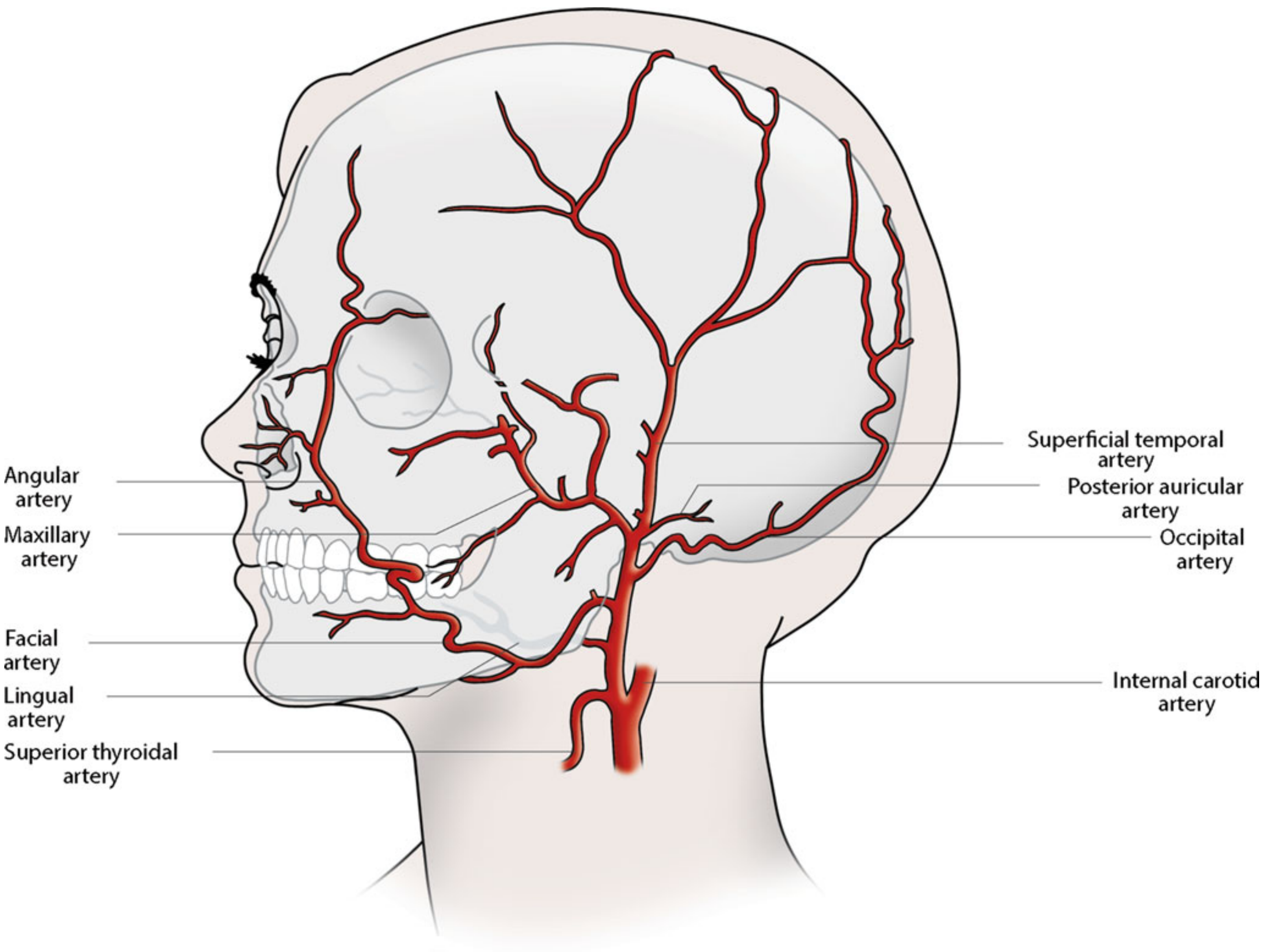


Fig. 1.5 Branches of the external carotid artery in lateral view

Table 1.4 Branches of the external carotid artery

	Course	Special features
Superior thyroid artery	In front of the common carotid artery pulling caudally to the upper pole of the thyroid gland	Origin frequently from the common carotid artery, but on the side of the external carotid artery
Ascending pharyngeal artery	Between internal carotid artery and pharynx pulling toward the base of the skull	Originates in 5% of cases from the internal carotid artery or directly from the carotid bifurcation
Lingual artery	With a strongly tortuous course under the lower jaw with cranialmedial course to the tongue	**Cannot be detected sonographically**
Occipital artery	Craniodorsal course behind the mastoid, crossing the internal carotid artery in the area of the jaw angle together with the hypoglossal nerve	Hyperperfusion can be confused by Doppler sonography with a stenosis of the internal carotid artery, e.g., as a result of an AV fistula
Posterior auricular artery	Pulling behind the mastoid at the jaw angle	Sonographically normally not detectable, but may be hyperperfused due to an AV fistula
Facial artery	Wraps around the lower jaw bone cranially to the cheek muscles	Can be sonographically displayed on the cover around the lower jaw
Maxillary artery	From the parotid gland forward into the deep facial region	**Cannot be detected sonographically**
Superficial temporal artery	Pulling cranially from the jaw angle	In front of the ear on a distance of 1–2 cm sonographically representable

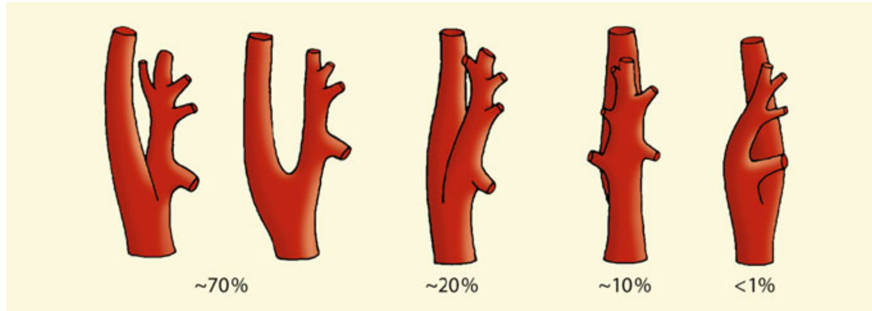


Fig. 1.6 Positional variants of the internal carotid artery (ICA) when looking laterally at the right carotid bifurcation. (according to Prendes et al. 1980)

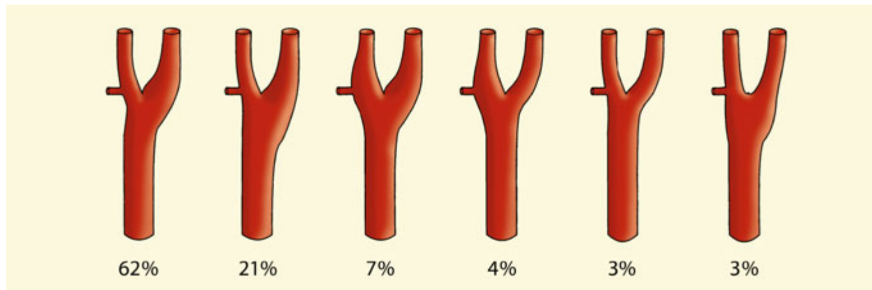


Fig. 1.7 Frequency of the different types of carotid sinus/ Carotid bulb at the carotid bifurcation

Table 1.5 Standard values (mean value and range of variation) of the diameter of the large cervical arteries in the anatomical preparation (Lang 1991)

	Diameter in mm
Common carotid artery	9 (6–12)
Internal carotid artery (carotid bulb)	9 (4–11)
Internal carotid artery (course)	5 (3.5–7)
External carotid artery	5 (3–7)
Vertebral artery	3.5 (0–5.5)

Practical Tips
When using the simple Doppler probe without B-mode image control, kinkings can cause false results due to the increased or decreased Doppler frequencies compared to standard values (Fig. 5.2).

Additional Carotid Artery Branches

In about 5% of the cases, the cervical section of the internal carotid artery shows further arterial branches. These include above all the ascending pharyngeal artery, but also the occipital artery. Furthermore, "primitive" connections between the internal carotid artery and the vertebrobasilar vascular system can persist from the embryonic period (Fig. 1.10). There is also evidence of an origin of the anterior inferior cerebellar artery from the internal carotid artery (Bykowski et al. 2011). ◀

Practical Tips
Cervical vessel outlets can, in the case of an intracranially located occlusion of the internal carotid artery, produce the image of a partially recanalized dissection with apparently typical string sign (Sect. 18.1), if a thin vessel runs cranially with an open initial section of the internal carotid artery.

Variations of the Vessel Diameter

The width of the carotid artery is physiologically subject to considerable fluctuations (Table 1.5) and depends on the body size, but also on the general constitution. A clear distinction from pathological phenomena such as dilated arteriopathy on the one hand, or narrowing of the vessels in long-term smoking or vascular dysplasia on the other hand, is therefore only possible if the measured values clearly fall below or exceed normal values. ◀

External Carotid Artery

The branches of the external carotid artery show a high degree of variety. For example, vessels that are not attached or duplicated, as well as vessels originating from another artery, are the rule rather than the exception. Sonographically, it should be noted that the superior thyroid

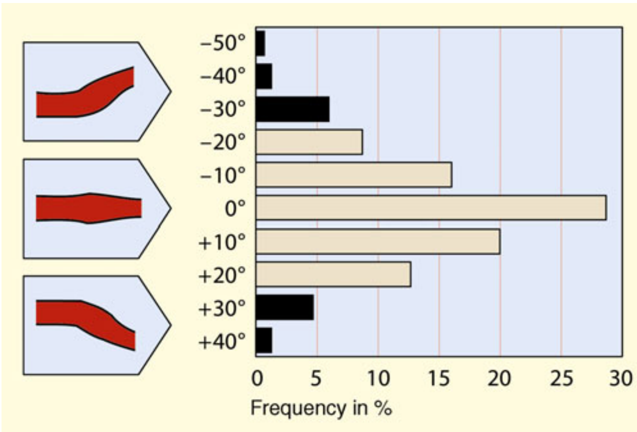
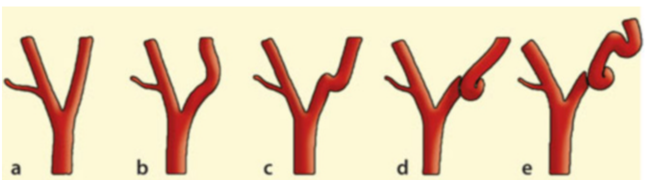


Fig. 1.8 Frequency of "lateral" (top) and "medial" (bottom) deflections of the internal carotid artery at its exit from the common carotid artery



	0 – 20 Years	21 – 50 Years	51 – 74 Years
Straightforward **a**	86%	72%	34%
Crooked **b**	8%	12%	29%
Buckled **c**	4%	10%	22%
Loop **d**	2%	5%	13%
Double loop **e**	–	1%	2%

Fig. 1.9 Frequency of kinkings and coilings of the internal carotid artery. (Huber et al. 1982)

artery only emerges from the external carotid artery in slightly more than half of all cases, otherwise it emerges at the carotid bifurcation – but then almost always on the side of the external carotid artery.

Summary
The common carotid artery is usually divided into the internal carotid artery and the external carotid artery at the level of HWK4. The internal carotid artery rarely gives off cervical branches, while the external carotid artery usually divides into eight branches. Elongations and kinkings of the internal carotid artery are more frequent with increasing age.

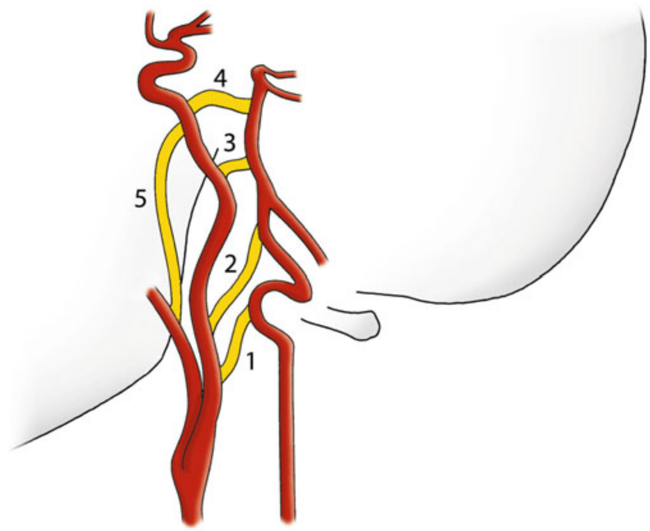


Fig. 1.10 Persistent primitive connections of the internal carotid artery with the vertebrobasilar vascular system and the external carotid artery. 1 proatlantal artery, 2 primitive hypoglossal artery, 3 Primitive auditory artery, 4 primitive trigeminal artery, 5 ascending pharyngeal artery. (According to Siqueira et al. 1993)

1.4 Cervical Course of the Vertebral Artery

1.4.1 Normal Anatomy

Coming from its origin, the vertebral artery usually enters the transverse processes at the sixth cervical vertebra and then runs largely stretched together with the vertebral vein – more precisely a network of several veins – through the foramina of the transverse processes in a cranial direction. In order to ensure head rotation between axis and atlas, a loop formation dorsolateral is found in the cervical segment HWK 1/2. After passing through the atlas, the vertebral artery initially bends back almost at right angles and runs almost horizontally dorsally for approximately 1 cm, then bends medially toward the foramen magnum. This so-called **atlas loop** enables above all the pitching movement of the head in the atlantooccipital joint (Fig. 1.11).

Practical Tips
Sonographically, the loop of the vertebral artery is usually derived in the segment HWK 1/2. Although formally not quite correct, it has also become common practice here to derive from atlas loop to speak.

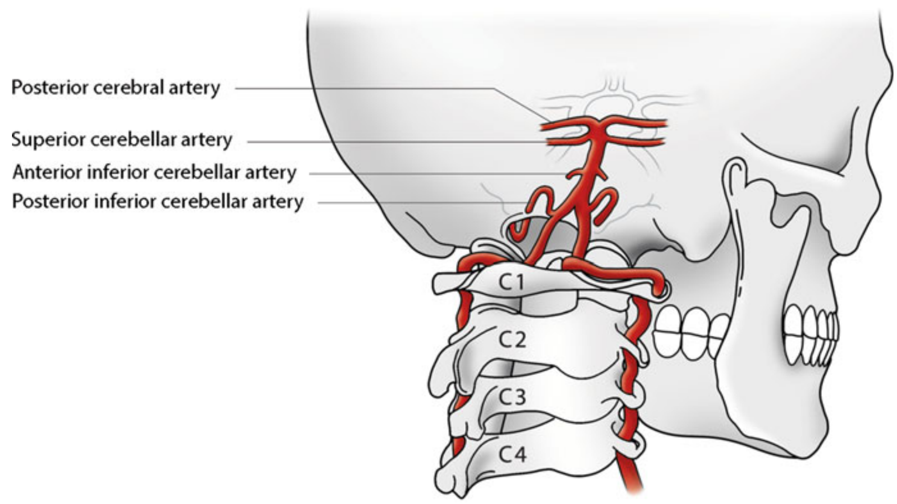


Fig. 1.11 Vertebrobasilar transition area when viewed from the rear

1.4.2 Anatomical Variations

In the area of the vertebral artery, three anatomical variants are of sonographic importance.

Variants of Origin

The exit of the vertebral artery from the subclavian artery shows a more or less distinct elongation (Fig. 1.12). It is also not uncommon for the vertebral artery to form kinkings and coilings, which – comparable to the internal carotid artery – increase with age.

Entry Variants in the Transverse Foramina

In 12% of all people the vertebral artery does not enter the transverse foramina at HWK 6, in individual cases an extraforaminal course up to HWK 4 is even possible (Table 1.6).

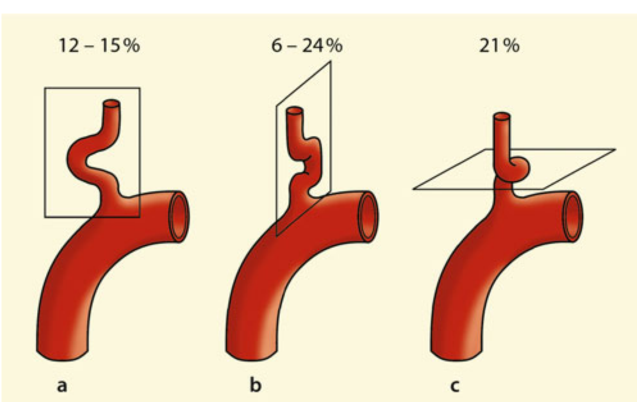


Fig. 1.12 (**a–c**) Frequency of kinkings and coilings at the exit of the vertebral artery. (**a**) lateral elongation, (**b**) sagittal elongation, (**c**) horizontal kinking. (According to Trattnig et al. 1993)

Variations of the Vessel Diameter

Caliber asymmetries of the vertebral artery are the rule rather than the exception, and even more pronounced hypoplasia is to be expected in as many as 9% of cases (Sect. 20.3). In most cases, however, compensatory hyperplasia of the contralateral vertebral artery is present. Heavily hypoplastic vertebral arteries often show no or only insufficient connection to the basilar artery and end in the posterior inferior cerebellar artery (PICA) or possibly only in a branch leading to the neck muscles. If both vertebral arteries are hypoplastic (2%), the supply of the posterior cerebral artery (and the distal basilar artery) is via the circle of Willis from the anterior cerebral circulation, in individual cases also via an postoccipital artery originating from the external carotid artery or a primitive hypoglossal artery (Lang 1991).

Summary

The vertebral artery usually begins its course through the transverse foramina at HWK 6. In HWK 1/2, elongations of the vessel are found, which are called “atlas loop.” Caliber asymmetries of the vertebral artery are frequent, in individual cases hypoplasia can also occur on both sides.

1.5 Intracranial Course of the Internal Carotid Artery

1.5.1 Normal Anatomy

After entry into the skull base, the internal carotid artery runs in the 25–35 mm long carotid canal of the petrous bone in medioventral direction **(petrous section).** The vessel then enters the cavernosus sinus **(cavernous section)** and shows,

Table 1.6 Entry of the vertebral artery into the transverse foramina of the cervical spine

HWK 4	5%
HWK 5	7%
HWK 6	88%
HWK 7	5%

According to Huber et al. (1982)

close to the sphenoid bone, a sharp forward convex arch. This bow is also called **carotid siphon** (Fig. 1.14). The diameter of the vessel in this area averages about 3 mm (Table 1.7).

On entering the cavernous section, several small vascular branches come off, which lead mainly to the tentorium and to the neighboring cranial nerves. The first larger branch in the anterior section of the carotid siphon is the ophthalmic artery (diameter 1–1.5 mm), which supplies the eye, the largest part of the orbital cavity and the medial, supraorbital part of the forehead skin with blood via its end branches.

After exiting the cavernosus sine, the internal carotid artery turns over 10–20 mm craniolaterally. This part is called the **subarachnoid** or **cerebral part** and is directly assessable by sonography. Here, the second larger vascular outlet of the internal carotid artery is the posterior communicating artery. Immediately above it (2–4 mm), the third major vascular branch is the anterior choroidal artery, which supplies parts of the visual pathway and the dorsal leg of the internal capsula (Fig. 1.15). On average 5 mm further cranially, the internal carotid artery divides into its two main branches, the middle cerebral artery and the anterior cerebral artery, which are responsible for the blood supply to the largest part of the brain. The site of division is usually referred to as **carotid T**.

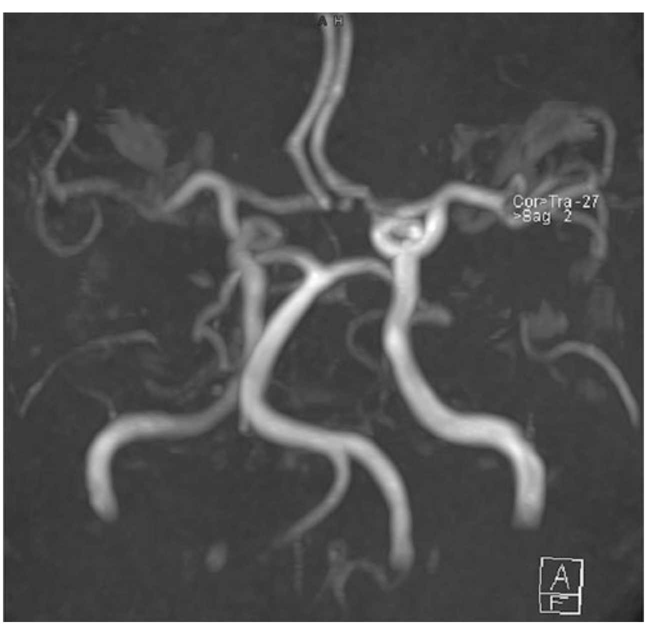


Fig. 1.13 MR angiography for hypoplasia of the right vertebral artery. Typical is the deflection of the basilar artery in an arc to the hypoplastic side

Practical Tips

Since short-stretch embolic occlusions can only affect the segment between two vessel outlets, knowledge of the sequence of vessel outlets and their anatomical variants is of great clinical importance.

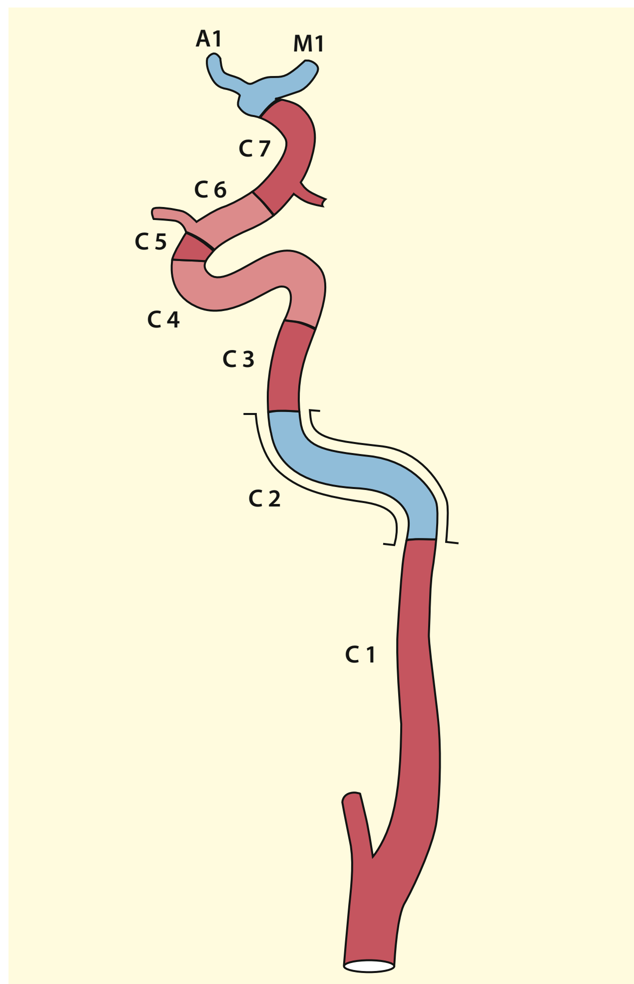


Fig. 1.14 Course of the internal carotid artery with segmentation in lateral view

Table 1.7 Standard values (mean value and range of variation) of the diameter of the main intracranial arteries in the anatomical preparation

	Diameter in mm	Length in mm
Distal internal carotid artery	3 (1.6–3.8)	13 (8–18)
Ophthalmic artery	1–1.5	–
Anterior choroidal artery	Approx. 0.5	–
Middle cerebral artery (M1)	2.7 (1.5–3.5)	16 (5–24)
Anterior cerebral artery (A1)	2.1 (0.5–4)	13 (8–18)
Posterior cerebral artery (P1)	2.1 (0.7–3)	6 (3–9)
Anterior communicating artery	2–2.5 (often as plexus)	2.5 (0.3–7)
Posterior communicating artery	1.2 (0.5–3)	14 (8–18)
Basilar artery	3 (2–4)	32 (15–40)

According to Lanz and Wachsmuth 1955; Riggs and Rupp 1963)

1.5.2 Anatomical Variations

Similar to the extracranial internal carotid artery, elongations are also found in the carotid siphon of older people. However, pronounced kinkings are relatively rare at about 4% (Huber et al. 1982). Sonographically significant is the fact that in about 4% of cases it must be expected that the ophthalmic artery does not originate from the carotid siphon but from the middle meningeal artery. Among the numerous varieties of posterior communicating artery, see Sect. 1.7.2.

Practical Tips
Indirect Doppler sonography of the supratrochlear artery fails in the case of an ophthalmic artery originating from the middle meningeal artery (branch of the external carotid artery), which is based on the evaluation of the pressure equilibrium between the internal carotid artery and external carotid artery.

Summary
After passing through the bony skull, the carotid artery runs in a forward convex arc, the "carotid siphon." It can be sonographically detected cranially from this arc over a short distance and here it gives off the posterior communicating artery and the anterior choroidal artery. Anatomical variations are rarely found here.

1.6 Vertebrobasilar Arteries

1.6.1 Normal Anatomy

The vertebral artery together with the brainstem passes through the foramen magnum into the interior of the skull, where usually the posterior inferior cerebral artery (known as the **PICA** abbreviated) origins, who supplies the dorsolateral medulla oblongata and caudal cerebellum with blood (Fig. 1.15). The posterior inferior cerebellar artery shows a pronounced caudal loop in its course, which facilitates its sonographic identification. In addition, the anterior spinal artery, although very thin and generally not detectable by sonography, is detached medially a few millimeters before it joins the basilar artery.

At the lower edge of the pons the two vertebral arteries meet to form the unpaired basilar artery. The basilar artery releases numerous small, paramedian vessels and, as larger branches, the anterior inferior cerebellar artery, the labyrinthine artery, and the superior cerebellar artery. At the upper edge of the pons, the basilar artery divides into its two end branches, the posterior cerebral arteries (neuroradiologically known as **basilaris head**). These normally supply the dorsal, mediobasal part of the brain.

1.6.2 Anatomical Variations

The intracranial section of the vertebral and basilar arteries regularly shows numerous anatomical variations that can lead to uncertainties during sonographic examination.

Vertebral Artery
While young people predominantly demonstrate a "textbook-like", stretched course of the vertebral artery, older people show "normal" conditions in less than 20% of cases (Lanz and Wachsmuth 1955). In about half of the cases there are elongations of both vertebral arteries of different kinds. In about 1/3 of cases only one vertebral artery shows a more or less strong elongation, while the other vessel is stretched. The basilar artery lies at its beginning regularly laterally shifted toward the vertebral artery with a smaller caliber (Fig. 1.13).

The most important branch of the vertebral artery, the posterior inferior cerebellar artery, is not build in about 20% of all people (Huber et al. 1982). In about 10% of cases it emerges from the basilar artery. In individual cases, it already originates from the vertebral artery in the area of the

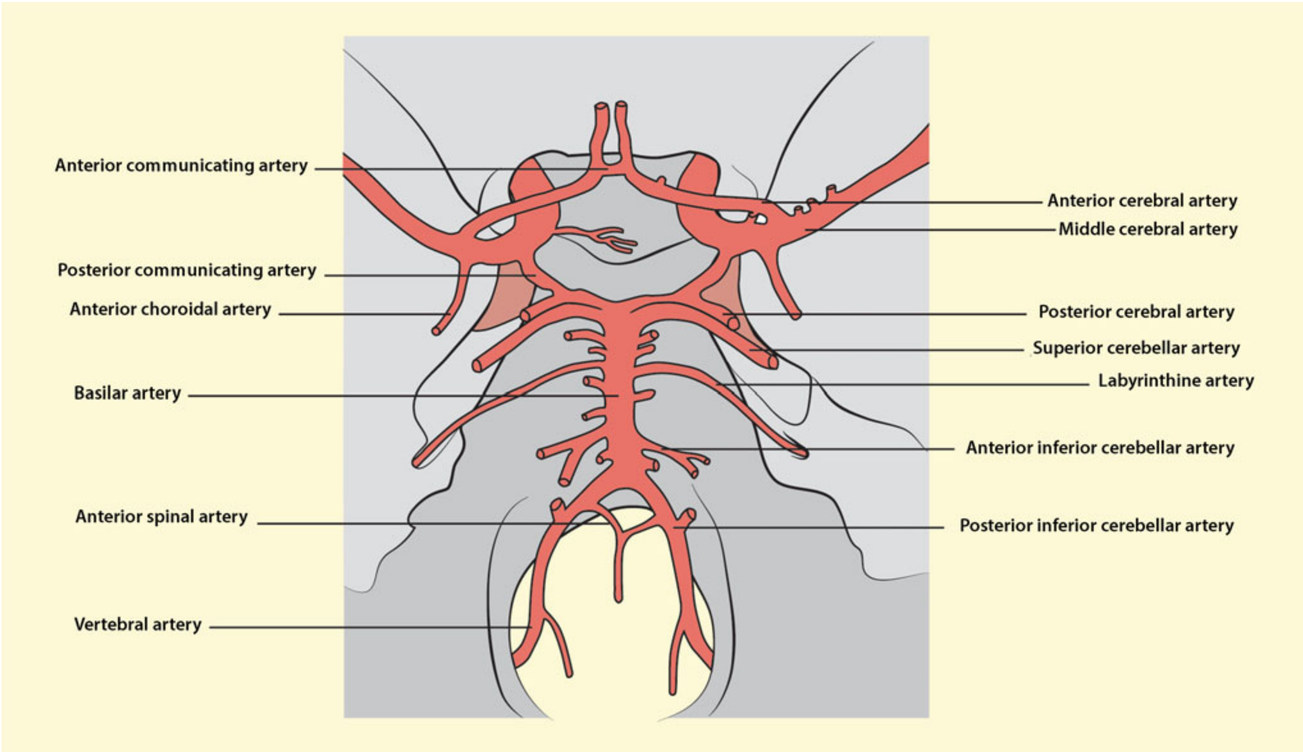


Fig. 1.15 View from above to the arteries at the skull base

atlas loop. Its diameter is usually 1–1.5 mm, which is just sufficient for duplex sonographic imaging.

Basilar Artery
Figure 1.16 gives an overview of the most common varieties in the area of the basilar artery. These range from aneurysmatic dilatation ("ectasia") to pronounced hypoplasia, in rare cases also to a complete or almost complete absence of the basilar artery with vertebral arteries separated up to cranially. Fenestrations (short-distance double-branched basilar artery) are also frequent, especially in the area of the proximal basilar artery (Fig. 1.17).

Summary
The vertebral artery passes together with the brainstem through the foramen magnum, then the paired vessels meet at variable locations to form the basilar artery. The most important branch of the vertebral artery is the posterior inferior cerebellar artery (PICA). In elderly people the vertebral artery frequently show an elongated course. Anatomical variations in the vertebrobasilar transition area are very common.

1.7 Intracerebral Arteries

1.7.1 Normal Anatomy

Middle Cerebral Artery
The middle cerebral artery is the largest intracranial vascular branch with an average diameter of 2.5–3 mm. According to its origin from the distal internal carotid artery in the area of the **carotid T** it initially continues the course of this vessel at its origin, which underlines its importance as the cerebral main vessel (Fig. 1.18). The first segment called the main stem ("**M1 segment**") is 10–20 mm long on average and runs in the subarachnoid space of the skull base largely horizontally outward. The only vascular outlets here are the lenticulostriatal branches which run vertically to the cranial side and are not recognizable by sonography.

After their division into usually 2–5 so-called main branches, the **M2 segment** begins. Here the vascular branches initially run further in the direction of the M1 segment, which is why they can usually be visualized sonographically. In the insula area they bend almost at right angles to cranial and supply the predominant part of the cerebral cortex.

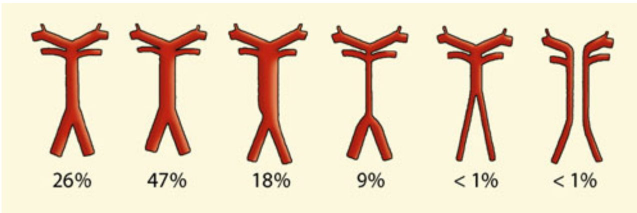


Fig. 1.16 Anatomical variants of basilar artery. (According to Huber et al. 1982)

Anterior Cerebral Artery
The anterior cerebral artery also originates in the area of the **Carotid T** in a short medial arc and then runs initially almost horizontally for an average of 10–15 mm medially (A1). The A2 segment begins after the anterior communicating artery has left, and the vessel moves cranially in the interhemispheric gap, where it supplies medial and frontal brain structures.

Posterior Cerebral Artery
The posterior cerebral artery continues in the area of the **basilar head** from the basilar artery and winds in an arc just above the pons around the cerebral peduncle. The first section (P1) extends to the posterior communicating artery, which is usually reached after 5–10 mm. The posterior cerebral artery supplies parts of the brain base including the base of the temporal lobe as well as the occipital region.

Anterior Communicating Artery
In the midline above the optic chiasma, the anterior communicating artery connects the two anterior cerebral arteries. The anterior communicating artery represents the anterior part of the circle of Willis and is the most important anastomosis in unilateral internal carotid artery occlusions. Its average length is 2.5 mm, its diameter is comparable to that of the large cerebral arteries (Table 1.7).

Fig. 1.17 MR angiography for fenestration of the basilar artery

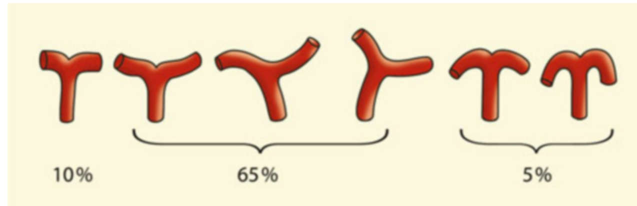


Fig. 1.18 Anatomical variants of the carotid T with the origins of the middle and anterior cerebral artery – seen from the front (a.p. view), corresponding to the sonographic view in the coronary section. (According to Huber et al. 1982)

Posterior Communicating Artery
The posterior communicating artery connects the distal internal carotid artery and the proximal posterior cerebral artery and forms the posterior part of the circle of Willis. Compared to the anterior communicating artery, it is considerably longer (14 mm in diameter) and usually has a smaller caliber, which is why it is often of only minor hemodynamic importance in the case of vascular occlusion.

1.7.2 Anatomical Variations

Middle Cerebral Artery
The main stem of the middle cerebral artery is the only intracranial vessel that is almost always "textbook-like." According to the literature, a non-existent middle cerebral artery is found in only 0.3% of all investigated cases (Table 1.8). However, in 0.2–3% of the cases it is duplicated, which can lead to confusion during ultrasound examination (Lanz and Wachsmuth 1955). While in younger people the main stem of the middle cerebral artery runs largely horizontally, in older people the vessel regularly runs downward at an angle of up to approximately 30°. The distance to the division into its branches is relatively constant. Only in 2% of cases is there branching less than 10 mm after its origin (Fig. 1.19).

Anterior Cerebral Artery
In contrast, this vessel shows a considerable number of anatomical variations. Only in about 2/3 of all cases is there a symmetrical formation of the initial section. In all other cases, hypoplasia of varying degrees must be expected (Fig. 1.20). In rare cases (1–2%) there is a complete aplasia of the proximal A1 section and a complete restoration of the distal anterior cerebral artery via the contralateral side.

Table 1.8 Hypo- and aplasia of the large cerebral arteries

	Hypoplasia	Aplasia
Middle cerebral artery (M1)	0.3%	–
Anterior cerebral artery (A1)	1–9%	1–2%
Posterior cerebral artery (P1)	9–22%	"Fetal supply type" in 17% (10–36%)
Anterior communicating artery	9% (1–40%)	1%
Posterior communicating artery	22% (16–40%)	2–12%

According to Hoksbergen et al. (2000); Lanz and Wachsmuth (1955); Riggs and Rupp (1963)

Posterior Cerebral Artery

The most intracranial varieties can be found for the posterior cerebral artery. This is due to the fact that the vessel initially emerges from the internal carotid artery during the fetal period. Only with the later "degeneration" of this vascular connection the posterior cerebral arteries are connected to the basilar artery. This results in two clinically important supply variants:

- **Fetal supply type** in 10–36% of cases with (almost) exclusive supply of the posterior cerebral artery via the internal carotid artery. In this constellation, hypoplastic vertebral arteries are often found (Sect. 20.3). This situation can occur on one or both sides.
- **Mixed supply type** in 8–15% of the cases with supply of the posterior cerebral artery via both the internal carotid artery and the basilar artery

Practical Tips

Due to the frequent supply of the posterior cerebral artery via the anterior cerebral circulation, a possible cause of occipital cerebral infarction by carotid artery embolization must be considered.

Anterior Communicating Artery

The anterior communicating artery as the anterior part of the circle of Willis is "textbook-like" in about 3/4 of all cases. More pronounced hypoplasia is present in only about 10% of cases. However, it should be taken into account that the anterior communicating artery is not always a single vessel, but a collection of several small vessels or even a network of vessels (Huber et al. 1982).

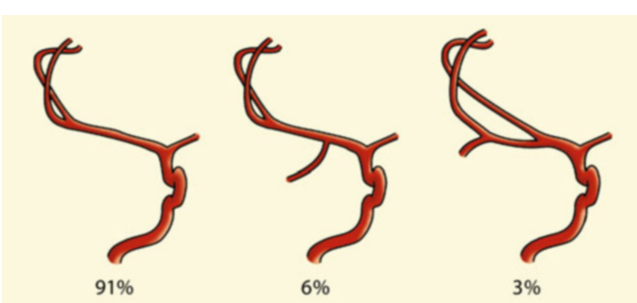


Fig. 1.19 Variants of middle cerebral artery. (According to Huber et al. 1982)

Posterior Communicating Artery

The numerous varieties of the posterior communicating artery are due to its embryonic development. For details see above.

Summary

The three large cerebral arteries middle, anterior, and posterior cerebral artery are interconnected via the anterior communicating artery and the two posterior communicating arteries (circle of Willis). While the anterior communicating artery is relatively rarely hypoplastic or not created, the posterior communicating artery shows numerous variants. In about 1/4 of the cases, the posterior cerebral artery is even supplied exclusively by the anterior circulation ("fetal supply type").

1.8 Collateral Connections

1.8.1 Extracranial Collaterals to the Anterior Cerebral Circulation

The most important anastomoses between the internal and external carotid artery run through the ophthalmic artery, which is in contact with both vessels. However, due to the larger diameter of the internal carotid artery, the intracranial perfusion pressure is higher, so that the ophthalmic artery is

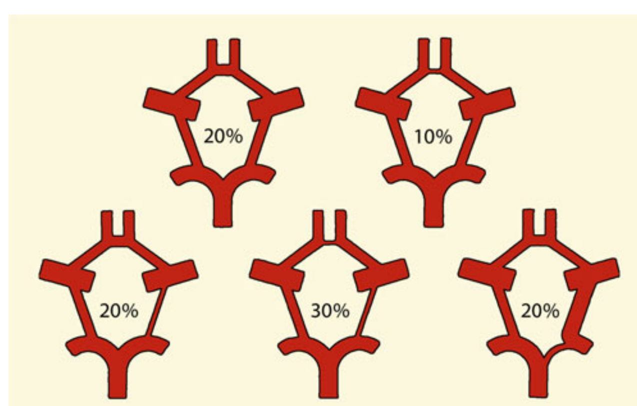


Fig. 1.20 Overview of the most important anatomical variations of the circle of Willis (according to Riggs and Rupp 1963)

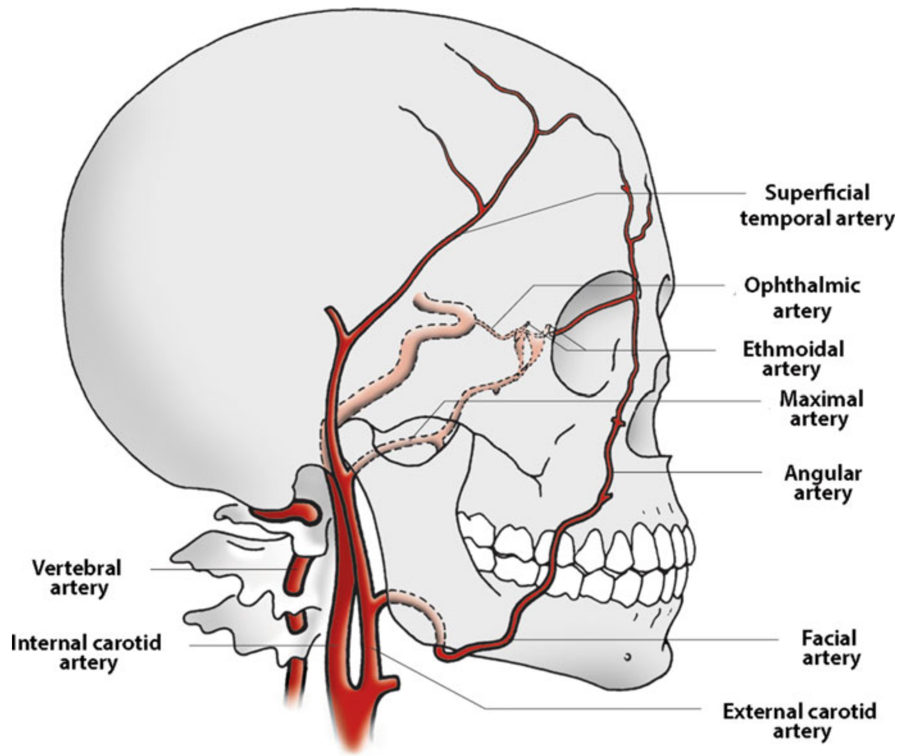


Fig. 1.21 Important collateral connections between the external carotid artery and internal

normally perfused from the inside to the outside. However, in occlusive disease of the internal carotid artery, the flow in the ophthalmic artery can be reversed and the collaterals via the external carotid artery can contribute to the blood flow in the anterior cerebral region. To be mentioned are three so-called **ophthalmic collaterals** between the internal carotid artery and the external carotid artery (Fig. 1.21):

- Facial artery → Angular artery → Supratrochlear artery → Ophthalmic artery,
- Superficial temporal artery → Supratrochlear artery (and orbital) → Ophthalmic artery,
- Maxillary artery → Ethmoidal arteries → Ophthalmic artery.

Practical Tips

It is important for the ultrasound examination that both the facial and the superficial temporal arteries run in significant sections outside the skull bone and are therefore both palpable and compressible, whereas this is not possible with the maxillary artery inside the maxillary sinus.

Background Information

When the common carotid artery is occluded, it is not uncommon for the internal carotid artery to remain open, with the vessel being filled via the external carotid artery, which in turn is supplied retrogradely from the opposite side or from the ipsilateral thyrocervical trunk. A relatively rare collateral is an ascending pharyngeal artery which opens into the distal internal carotid artery (Fig. 1.10). This can cause confusion during the sonographic examination if it is mistaken for an non-occluded internal carotid artery. Since in such a case the distal internal carotid artery may still be slightly perfused, thrombi may form in it and lead in particular to ophthalmic ischemia. Other external branches such as the occipital artery or the middle meningeal artery can also form anastomoses to the internal carotid artery. Finally, there are also collaterals between the two ophthalmic arteries via the dorsal nasal arteries, which can "jump in" in hypoplasia of the anterior communicating artery.

1.8.2 Extracranial Collaterals to the Posterior Cerebral Circulation

In occlusive disease of the proximal vertebral artery (V0/V1 segment), three collateral connections are particularly relevant, which can guarantee perfusion of the vessel in the V2 or V3 segment (Fig. 1.22):

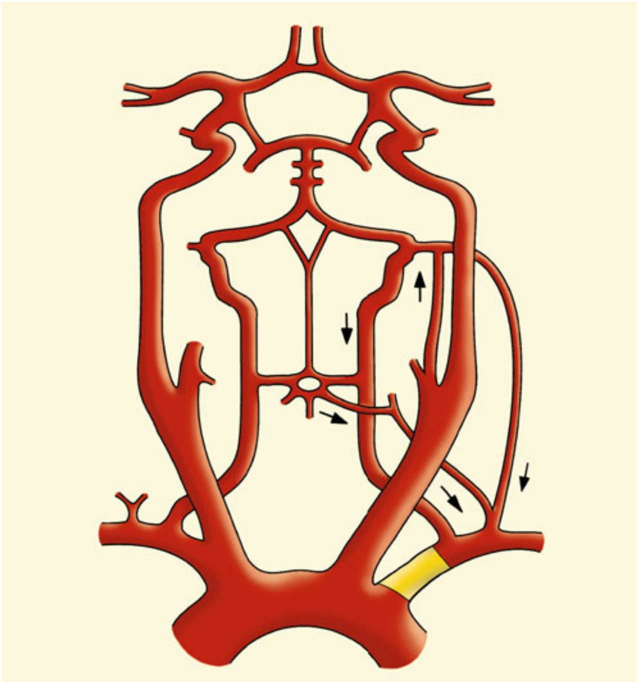


Fig. 1.22 Collaterals in occlusions of the proximal subclavian artery

- Thyrocervical trunk → Ascending cervical artery → Vertebral artery,
- Contralateral vertebral artery → Spinal arteries → Ipsilateral vertebral artery,
- External carotid artery → Occipital artery → Vertebral artery.

Of particular importance are also the spinal arteries, which are often very large in caliber but rarely present in all segments and are then usually impressively visible in color coded duplex sonography.

Background Information

Collaterals between the proximal internal carotid artery and the vertebrobasilar system are very rare (<1%), but can lead to considerable confusion (Gasecki et al. 1994; Siqueira et al. 1993). These are persistent primitive vessels of the embryonic period, which connect the internal carotid artery with the distal vertebral artery and basilar artery at different localizations (Fig. 1.10). In stenoses of the internal carotid artery, paradoxical embolisms can thus occur in the vertebrobasilar vascular system.

1.8.3 Intracranial Collateral Connections

Circle of Willis

The most important intracranial collateral connection is the **circle of Willis**, located at the base of the skull. It connects both hemispheres with each other via the anterior communicating artery and the hemispheres with the vertebrobasilar circulation via posterior communicating arteries. It should be noted, however, that the circle of Willis is only "textbook" in about 1/5 of all people. In all other cases there are more or less pronounced hypoplasias and/or the afore mentioned "fetal" origin of the posterior cerebral artery from the anterior cerebral circulation (Fig. 1.20).

Leptomeningeal Anastomoses

The second most important collateral connection is the network via the vessels of the cerebral convexity (Fig. 11.1). However, in acute vascular occlusions, these anastomoses are generally insufficient to ensure sufficient collateral supply.

Practical Tips

A sonographic evaluation of leptomeningeal anastomoses is only indirectly possible by means of the increase in flow in the other large cerebral arteries.

Rare Anastomoses

For the ultrasound examiner, in individual cases also rare collateral compounds are of importance, since they can develop relevant vessel diameters >1 mm, especially in slowly developing occlusive diseases, and thus – at least under good examination conditions – can be detected with transcranial color coded duplex sonography.

The three most important ones are:

- The so-called **Heubner's artery** (recurrent artery of Heubner) originates from the A1 segment of the anterior cerebral artery and runs "backward" from there to the middle cerebral artery. If the middle cerebral artery is occluded, it can contribute to collateral supply and, if the lumen is wide enough, can simulate an open vessel.
- **Choroidal anastomoses** run between the distal internal carotid artery and the posterior cerebral artery at the skull base, in individual cases also transversely from one side to the other, which can lead to confusing images in the ultrasound image.
- In slowly developing (or already existing) occlusive disease in the carotid T-region, small vascular anastomoses are often found, which are angiographically described as **moyamoya network** and in individual cases can also be detected by duplex sonography (Sect. 19.2).

1.8.4 Collaterals in Subclavian Artery Occlusions

When the proximal subclavian artery is occluded, the vertebral artery is often retrogradely perfused and contributes to the blood supply of the affected arm (Fig. 1.22). This situation is called **subclavian steal effect.** Another connection to the subclavian artery is via the thyrocervical trunk, which anastomoses with thyroid branches and via the skin vessels of the neck with the external carotid artery.

Summary
Collateral connections play an essential role in cerebral vascular disorders. The most important extracranial collateral to the anterior cerebral circulation runs from branches of the external carotid artery via the ophthalmic artery (ophthalmic collateral). Almost all dorsal cervical vessels lead to the posterior circulation. The circle of Willis and leptomeningeal anastomoses are mainly responsible for the intracranial collateral supply.

1.9 Cerebrovascular Territories

Since sonographic examinations should never be performed isolated, but always in the context of the clinical picture, the following section will briefly discuss the brain areas supplied by the described arteries and their variants, as they are of importance in daily routine.

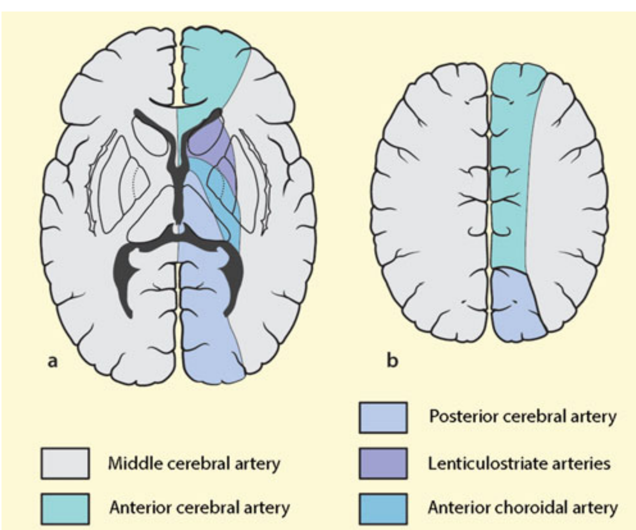


Fig. 1.23 (**a, b**) Topographical assignment of the supply areas of the major cerebral arteries on two characteristic axial sections through the brain. (**a**) Section at the level of the internal capsula, here both the anterior and posterior horn of the lateral ventricles are shown. (**b**) Section a few centimeters below the vertex (Centrum semi-ovale). Note in particular the paramedian borderline running from front to back between the middle cerebral artery and the other two major cerebral arteries

1.9.1 Normal Anatomy

The reference for the differentiation of the supply areas of the three major cerebral arteries is the ventricular system. As a rule, the borderline between the middle and anterior cerebral artery as well as between the middle and posterior cerebral artery is in extension of the anterior or posterior horn

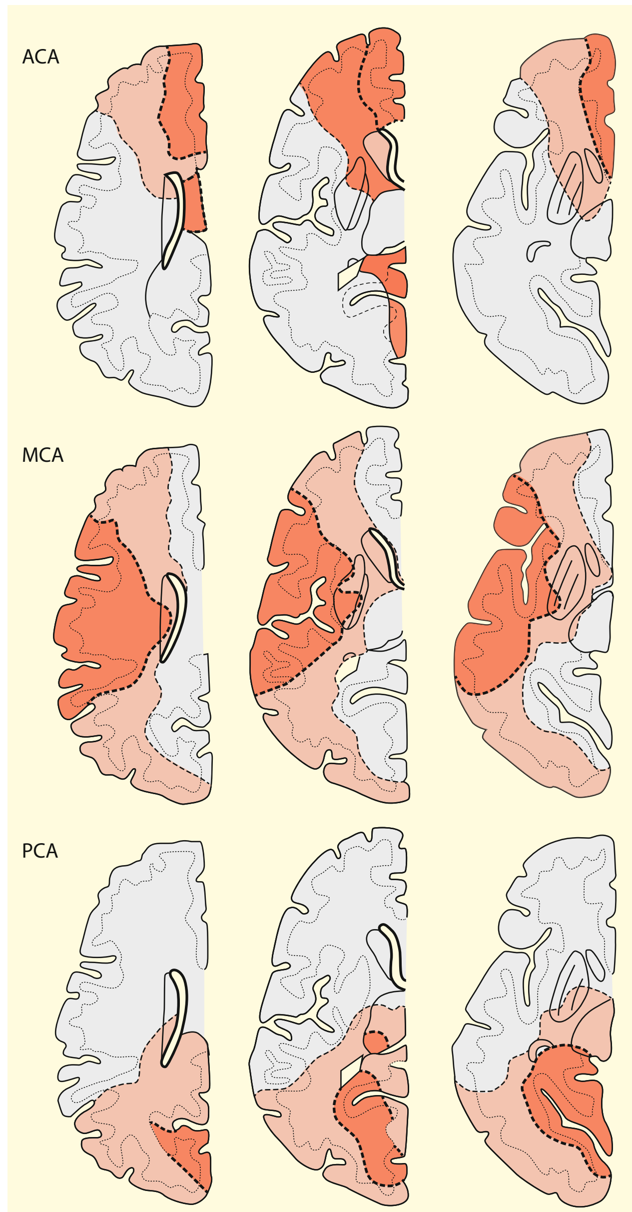


Fig. 1.24 Most important varieties of the cerebral vascular supply areas. Dark red minimum supply area, light red maximum possible supply area; ACA anterior cerebral artery, MCA middle cerebral artery, PCA posterior cerebral artery. (According to van der Zwan et al. 1992)

(Fig. 1.23). On the higher layers, there is an paramedian boundary line, with the majority of the midline structures being supplied by the anterior cerebral artery.

The supply area of the anterior choroidal artery is of special importance, since it is normally the only larger cerebral vessel that emerges directly from the internal carotid artery before the intracranial vessel bifurcation. Lesions in this area therefore give important indications of an occlusive disease in the upper section of the internal carotid artery. In contrast, lesions involving the area supplied by the lenticulostriate arteries indicate a process in the main stem of the middle cerebral artery.

1.9.2 Anatomical Variations

Not least due to the above mentioned "fetal supply patterns," there are relatively frequent deviations in supply pattern. Figure 1.24 gives an overview of this.

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