4 Blood Supply, Meninges and Cerebrospinal Fluid Circulation

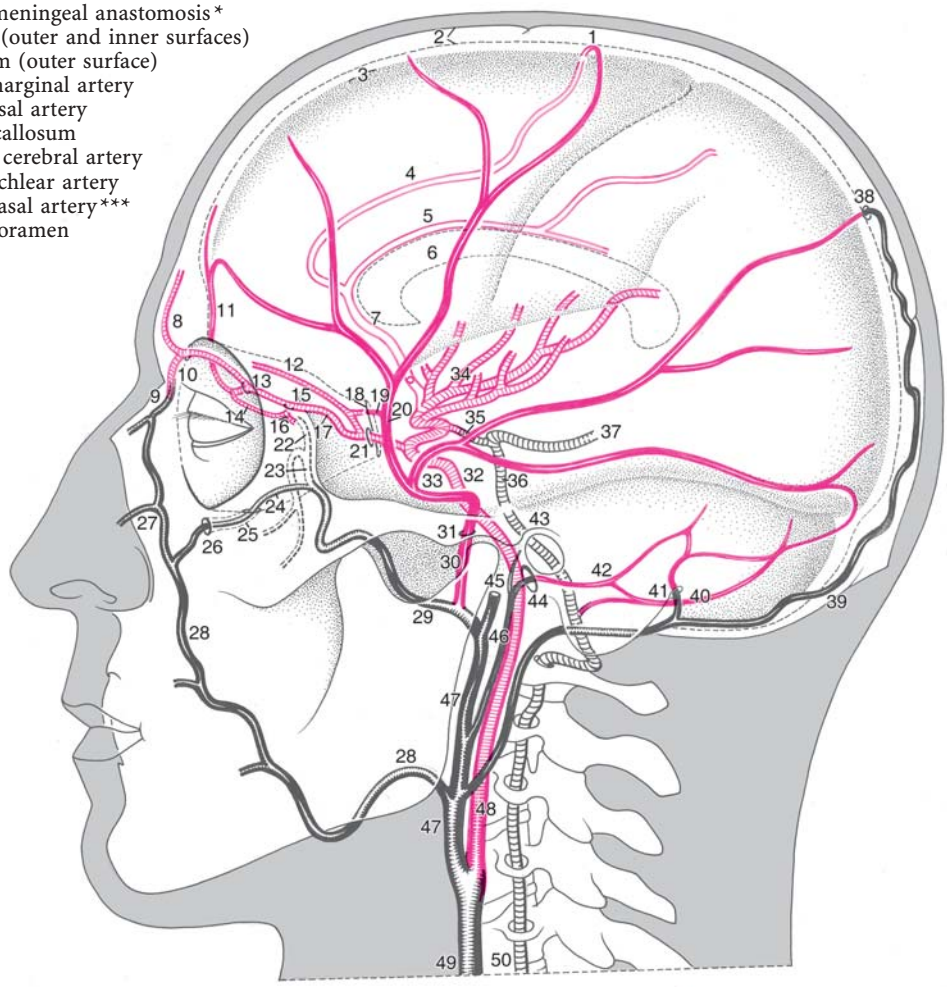
Introduction

The vascularization and the circulation of the cerebrospinal fluid (liquor cerebrospinalis, CSF) of the brain and the spinal cord are of great clinical importance. The main vascular syndromes are summarized in Table 4.1. In this chapter, the anatomy of blood vessels, meninges and circumventricular organs will be discussed. The central nervous system, which is of ectodermal origin (Chap. 2), is surrounded by mesodermal structures. A system of three connective tissue layers, the meninges, and a fluid compartment containing CSF are located between the bony skull and vertebral column and the nervous tissue of the brain and the spinal cord. Blood vessels, themselves of mesodermal origin, are surrounded by derivatives of the meninges over their full extent, until the interface between the capillary wall and the glial basal membrane makes exchange of substances possible. CSF is produced by the choroid plexus of the ventricles. It circulates from the interstitial spaces of the nervous tissue and the choroid plexus, through the ventricles and their apertures in the roof of the fourth ventricle, to the CSF compartment of the subarachnoid space and its exit through the arachnoid villi to the venous system. The nervous tissue of the central nervous system and the CSF spaces remain segregated from the rest of the body by barrier layers in the meninges (the barrier layer of the arachnoid), the choroid plexus (the blood-CSF barrier) and the capillaries (the blood-brain barrier). The circulation of the CSF plays an important role in maintaining the environment of the nervous tissue; moreover, the subarachnoidal space forms a bed that absorbs external shocks.

Arteries of the Brain

The arteries of the brain originate from two of the greater vessels in the neck: the paired internal carotid and vertebral arteries (Fig. 4.1). The *internal carotid artery* enters the skull through the petrosal bone in the carotid canal. It loops through the sinus cavernosus (carotis syphon), where it emits the *ophthalmic artery*. Immediately beyond the origin of the posterior communicating artery it splits into the middle and anterior cerebral arteries. The vertebral arteries enter the skull through the foramen magnum. After their passage through the dura, the arteries become located within connective tissue derived from the pia mater and the arachnoid.

The middle cerebral artery supplies the convexity of the hemisphere (Figs. 4.3, 4.4, 4.5) and the anterior cerebral artery vascularizes approximately the anterior and upper half of the medial aspect of the hemisphere, up to the precuneus (Fig. 4.2). The vertebral arteries unite into the basilar artery at the ventral aspect of the medulla oblongata. Its terminal

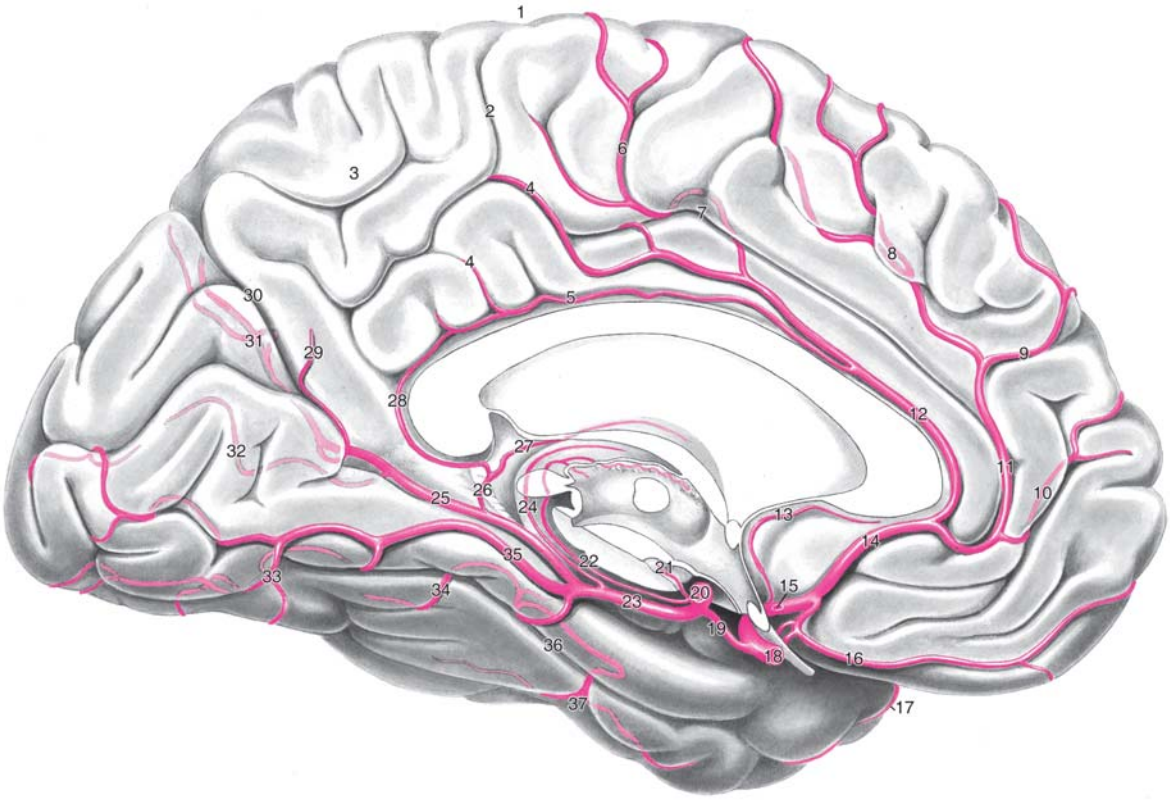


1 Cerebromeningeal anastomosis*
2 Calvaria (outer and inner surfaces)
3 Cerebrum (outer surface)
4 Callosomarginal artery
5 Pericallosal artery
6 Corpus callosum
7 Anterior cerebral artery
8 Supratrochlear artery
9 Dorsal nasal artery***
10 Frontal foramen
11 Anterior meningeal artery
12 Lacrimal artery
13 Anterior ethmoidal foramen
14 Anterior ethmoidal artery***
15 Posterior ethmoidal foramen
16 Posterior ethmoidal artery
17 Ophthalmic artery
18 Superior orbital fissure
19 Middle meningeal artery, anastomotic branch****
20 Middle meningeal artery, frontal branch
21 Optic canal
22 Superior conchal artery (anastomosis)***
23 Sphenopalatine artery
24 Infraorbital artery
25 Infraorbital canal
26 Infraorbital foramen***
27 Angular artery
28 Facial artery
29 Maxillary artery
30 Middle meningeal artery
31 Foramen spinosum
32 Internal carotid artery, petrous part
33 Middle meningeal artery, parietal branch
34 Middle cerebral artery, insular part
35 Posterior communicating artery
36 Basilar artery
37 Posterior cerebral artery
38 Parietal foramen**
39 Occipital artery
40 Occipital artery, mastoid branch**
41 Mastoid foramen
42 Posterior meningeal artery
43 Junction of the vertebral arteries
44 Jugular foramen
45 Superficial temporal artery
46 Ascending pharyngeal artery
47 External carotid artery
48 Internal carotid artery
49 Common carotid artery
50 Vertebral artery

Anastomoses

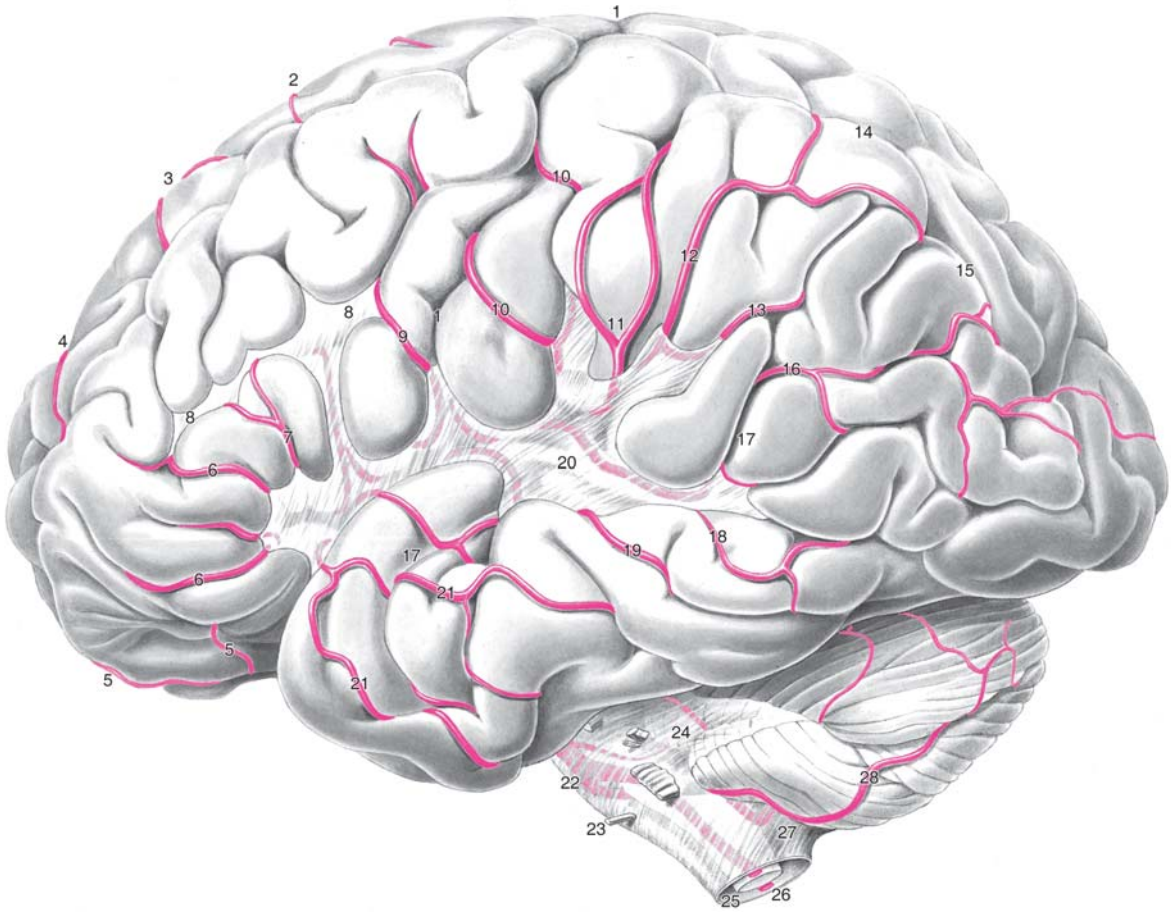
1	Cerebromeningeal	*
38+40	Extracraniomeningeal	**
9+22+26	Extracranial-orbital	***
14+19	Orbitomeningeal	****

Fig. 4.1. Collateral circulation in the arterial system of the head; semidiagrammatic lateral view (2/3x). *Black*: external carotid artery with extracranial branches; *black hatched*: system of the vertebral artery (main trunk); *solid red*: meningeal arteries; *red hatched*: internal carotid artery with orbital and lateral cortical branches; *open red*: medial cortical branches of internal carotid artery



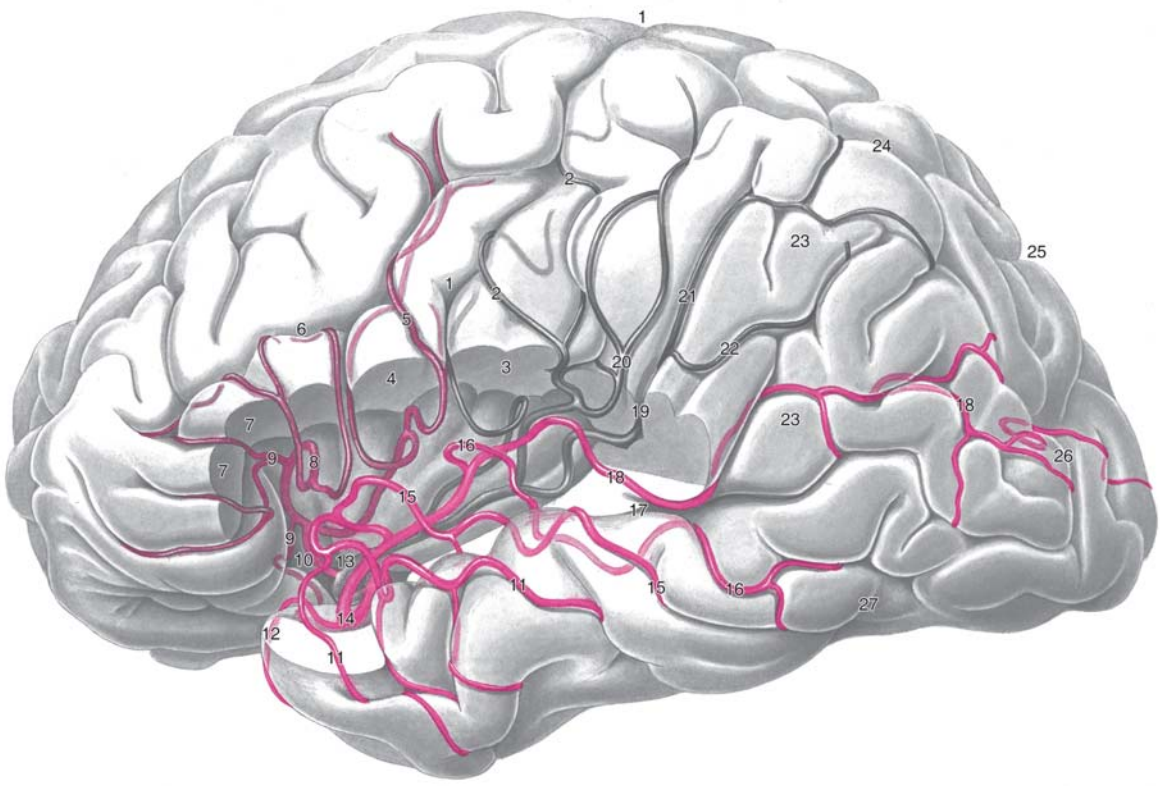
1 Central sulcus
2 Marginal branch of the cingulate sulcus
3 Precuneus
4 Artery of the precuneus
5 Pericallosal artery, posterior branch (anastomosis with 28)
6 Paracentral artery
7 Cingulate sulcus
8 Posteromedial frontal artery
9 Intermediomedial frontal artery
10 Anteromedial frontal artery
11 Callosomarginal artery
12 Pericallosal artery
13 Median artery of the corpus callosum
14 Anterior cerebral artery, postcommunicating part
15 Anterior communicating artery
16 Medial frontobasal artery
17 Temporopolar artery
18 Internal carotid artery
19 Posterior communicating artery
20 Posterior cerebral artery, precommunicating part
21 Posteromedial central arteries
22 Posterior medial choroidal branch
23 Posterior cerebral artery, postcommunicating branch
24 Posterior thalamic branches
25 Medial occipital artery
26 Cingulatethalamic artery
27 Superior thalamic branch
28 Dorsal branch of the corpus callosum (anastomosis with 5)
29 Parietal branch
30 Parieto-occipital sulcus
31 Parieto-occipital branch
32 Calcarine branch (in calcarine sulcus)
33 Posterior temporal branches
34 Medial intermediate temporal branch
35 Lateral occipital artery
36 Collateral sulcus
37 Anterior temporal branches

Fig. 4.2. The arteries of the medial hemisphere; the anterior and posterior cerebral arteries (1/1×). Some central branches of the posterior cerebral artery are also shown. End branches of the anterior cerebral artery that reach the lateral side of the superior frontal gyrus are illustrated in Fig. 4.3. Figures 4.2–4.6 are all derived from the same specimen



1 Central sulcus
2 Posteromedial frontal branch
3 Intermediomedial frontal branch
4 Anteromedial frontal branch
5 Medial frontobasal artery
6 Lateral frontobasal artery
7 Prefrontal artery
8 Inferior frontal sulcus
9 Artery of the precentral sulcus
10 Artery of the central sulcus
11 Artery of the postcentral sulcus (anterior parietal artery)
12 Posterior parietal artery
13 Artery of the angular gyrus
14 Intraparietal sulcus
15 Transverse occipital sulcus
16 Temporo-occipital artery
17 Superior temporal sulcus
18 Posterior temporal artery
19 Middle temporal artery
20 Cistern of the lateral cerebral fossa
21 Anterior temporal artery
22 Pontine cistern
23 Abducens nerve
24 Pontocerebellar cistern
25 Medullary cistern
26 Vertebral artery
27 Cerebellomedullary cistern (cisterna magna)
28 Posterior inferior cerebellar artery, lateral branch

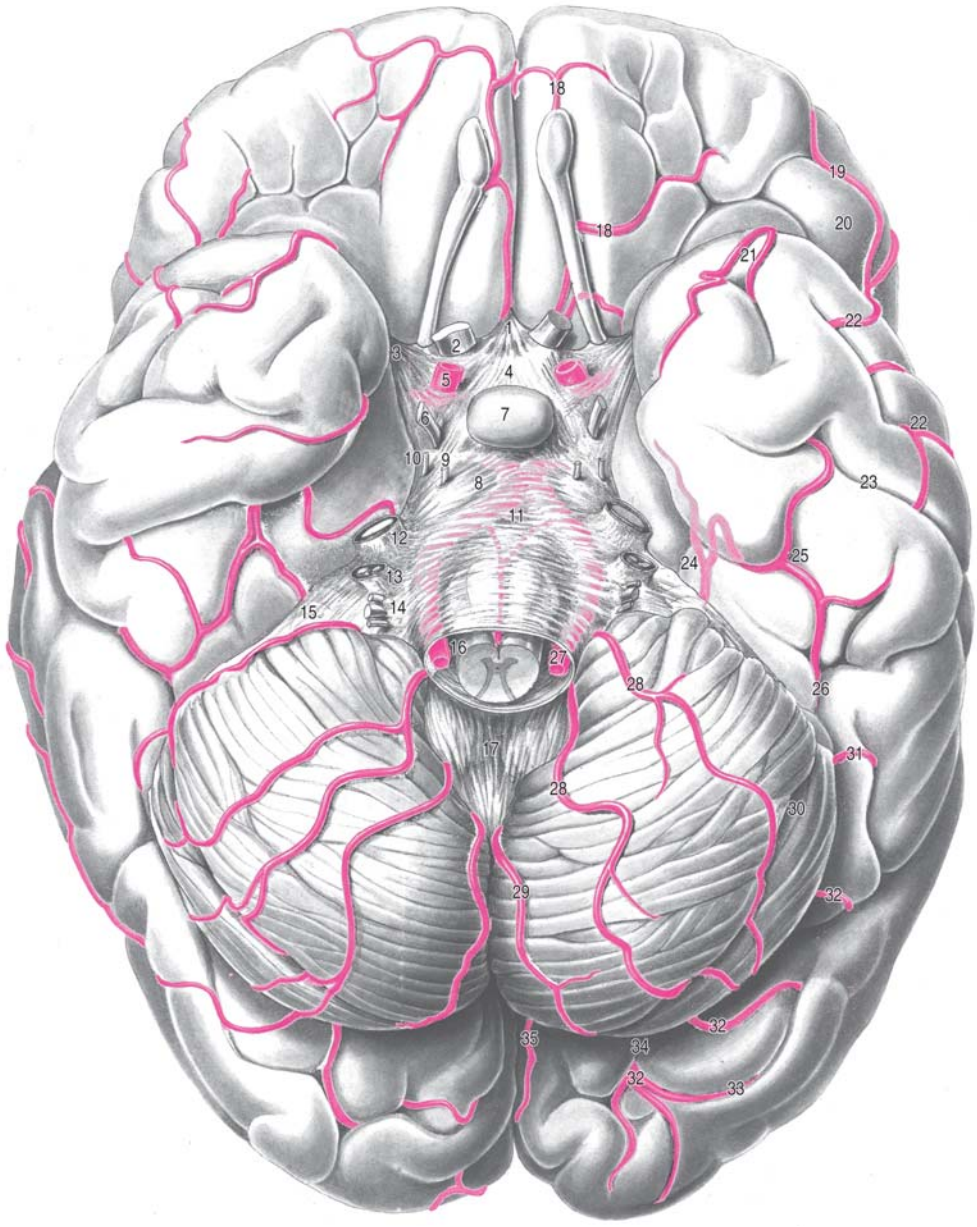
Fig. 4.3. The arteries of the lateral cerebral cortex: the middle cerebral artery (1/1×). In this figure the lateral and medullary cisterns are left intact. On the lateral surface of the cerebellum one inferior and two superior cerebellar branches are illustrated (see Fig. 4.11). On the superior frontal gyrus some end branches of the anterior cerebral artery can be seen



1 Central sulcus
2 Artery of the central sulcus (branches)
3 Postcentral gyrus
4 Precentral gyrus
5 Artery of the precentral sulcus
6 Inferior frontal sulcus
7 Inferior frontal gyrus, triangular part
8 Prefrontal artery (candelabrum artery)
9 Lateral frontobasal artery (branched)
10 Anterior trunk of the middle cerebral artery (ascending frontal artery)
11 Anterior temporal artery (branches)
12 Temporopolar artery
13 Middle trunk of the middle cerebral artery
14 Posterior trunk of the middle cerebral artery
15 Middle temporal artery
16 Posterior temporal artery
17 Superior temporal sulcus
18 Temporo-occipital artery
19 Lateral sulcus, posterior branch
20 Artery of the postcentral sulcus (anterior parietal artery)
21 Posterior parietal artery
22 Artery of the angular gyrus
23 Angular gyrus
24 Intraparietal sulcus
25 Parieto-occipital sulcus
26 Lunate sulcus
27 Anterior occipital sulcus

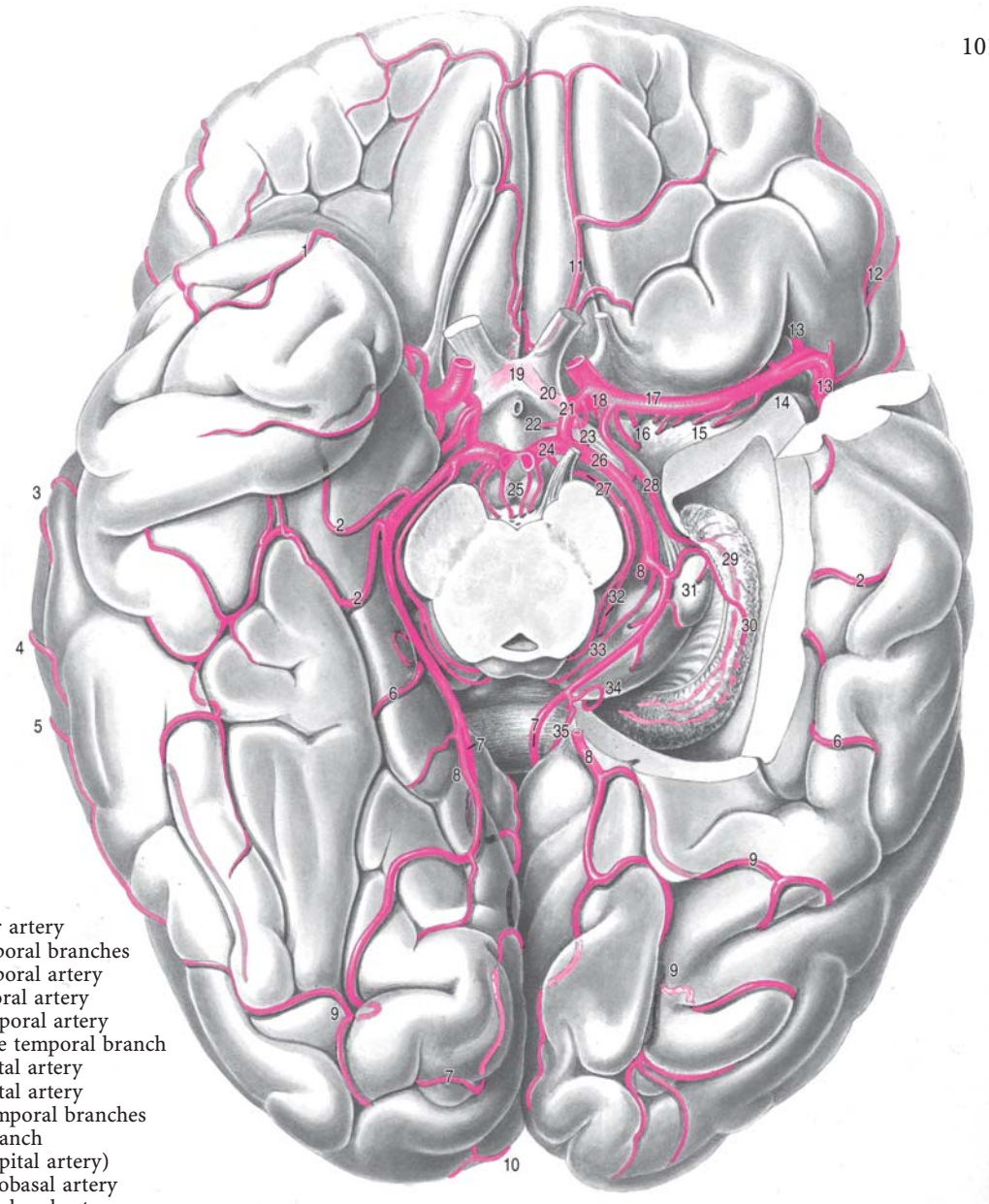
Alternative subdivision
11+15 Anterior temporal artery
16 Middle temporal artery
18 Posterior temporal artery
20 Parietal artery
21+22 Artery of the angular gyrus

Fig. 4.4. The branches of the middle cerebral artery seen at their full extent: lateral view (1/1×). In this specimen, as in most cases, a trifurcation can be seen of the artery. The branches of the anterior (frontal) trunk are shown in *black* and *red*; the branches of the middle (parietal) trunk are in *black* only; the branches of the posterior (temporal) trunk are in *red*. The candelabrum-like branching, especially of the anterior trunk, is a common phenomenon



1 Cistern of the lamina terminalis
2 Optic nerve
3 Cistern of the vallevula cerebri
4 Cistern of the chiasm
5 Internal carotid artery (cerebral part)
6 Oculomotor nerve
7 Hypophysis
8 Interpeduncular cistern
9 Abducens nerve
10 Trochlear nerve
11 Pontine cistern
12 Trigeminal cistern
13 Cistern of the internal acoustic meatus with facial and vestibulocochlear nerves
14 Glossopharyngeal, vagal and accessory nerves
15 Pontocerebellar cistern
16 Medullary cistern
17 Cerebellomedullary cistern
18 Medial frontobasal artery (branch of the anterior cerebral artery)
19 Lateral frontobasal artery (branch of the middle cerebral artery)
20 Inferior frontal gyrus, orbital part
21 Temporopolar artery
22 Anterior temporal artery
23 Inferior temporal sulcus
24 Collateral sulcus with lateral occipital artery
25 Anterior temporal branches
26 Occipitotemporal sulcus
27 Vertebral artery
28 Posterior inferior cerebellar artery, lateral branches
29 Posterior inferior cerebellar artery, medial branches
30 Horizontal fissure of the cerebellum
31 Medial middle temporal branch
32 Posterior temporal branches
33 Occipitotemporal sulcus
34 Collateral sulcus
35 Lateral occipital artery

Fig. 4.5. The arteries of the brain viewed from the basal side (1/1×). In this figure the basal, cerebellar and medullary cisterns are left intact



1 Temporopolar artery
2 Anterior temporal branches
3 Anterior temporal artery
4 Middle temporal artery
5 Posterior temporal artery
6 Medial middle temporal branch
7 Medial occipital artery
8 Lateral occipital artery
9 Posterior temporal branches
10 Calcarine branch (medial occipital artery)
11 Medial frontobasal artery
12 Lateral frontobasal artery
13 Middle cerebral artery, insular part
14 Limen insulae
15 Anterolateral central arteries, lateral branches
16 Anterolateral central arteries, medial branches
17 Middle cerebral artery, sphenoid part
18 Anteromedial central arteries
19 Anterior communicating artery
20 Anterior cerebral artery, precommunicating part
21 Posterior communicating artery
22 Hypothalamic artery
23 Thalamic branch (anteroinferior)
24 Posterior cerebral artery, precommunicating part
25 Posteromedial central arteries
26 Posterior cerebral artery, postcommunicating part
27 Medial posterior choroidal branch
28 Anterior choroidal artery
29 Choroidal branches of the anterior choroidal artery
30 Lateral posterior choroidal branch
31 Lateral geniculate body
32 Thalamic branch (inferior)
33 Thalamic branch (posterior)
34 Thalamic branch (superior)
35 Dorsal branch of the corpus callosum

19 + 20 + 21 + 24 Arterial circle (left half)

Fig. 4.6. The cerebral arteries viewed from the basal side (1/1×). Part of the left temporal lobe has been removed to show the sphenoid part of the middle cerebral artery and the arterial supply of the choroid plexus of the lateral ventricle. The lateral occipital artery has been interrupted to gain a clear view of the diencephalic, mesencephalic and retrosplenial branches of the posterior cerebral artery

branches are the left and right posterior cerebral arteries, which supply the posterior, medial and basal aspects of the cerebral hemisphere. The vertebro-basilar arteries also supply the brain stem and the cerebellum. It gives rise to the inferior, middle and superior cerebellar arteries (Fig. 4.11). Frontal and lateral projections of the arterial system are shown in Figs. 4.9 and 4.10.

A system of communicating arteries, known as the *circle of Willis* [18, 36], interconnects the anterior and middle cerebral arteries of both sides with the vertebro-basilar system (Figs. 4.6 and 4.14). It is located at the base of the brain and surrounds the infundibulum and the optic chiasm. It includes the *anterior communicating artery*, which interconnects the anterior cerebral arteries, immediately in front of the optic chiasm, and the two *posterior communicating arteries*, which form an anastomosis between the most distal part of the internal carotic and the posterior cerebral artery near their origin from the basilar artery.

The initial segments of the middle and anterior cerebral arteries give rise to *central arteries* (Figs. 4.6, 4.8, 4.12), which enter the brain in the anterior perforated substance (Fig. 3.4). Together with branches from the posterior communicating artery, they supply the basal ganglia, the internal capsule and the thalamus. The *middle cerebral artery* enters the sulcus lateralis. Just before this point it emits the anterior choroidal artery, which also supplies a branch to the globus pallidus (Fig. 4.8). At the surface of the insula the middle cerebral artery branches into anterior, middle and posterior trunks. The branches of the middle cerebral artery loop over the opercula and ramify over the surface of the cerebral hemisphere to supply the cerebral cortex and the adjacent white matter (Figs. 4.3, 4.4). The *anterior cerebral artery* enters the longitudinal fissure to branch on the medial aspect of the hemisphere. The anterior communicating artery, which connects the two anterior cerebral arteries, is located immediately rostral to the optic chiasm (Fig. 4.2).

The *vertebral arteries* enter the skull through the foramen magnum. They give rise to the *anterior spinal artery*, which descends in the anterior median fissure of the cord, and emit the *posterior inferior cerebellar arteries*. The vertebral arteries unite into the *basilar artery* at the ventral aspect of the brain stem. The basilar artery gives origin to the *anterior inferior* and *superior cerebellar arteries* and splits into the posterior cerebral arteries. The oculomotor nerve emerges between the superior cerebellar and the posterior cerebral arteries and thus marks the bifurcation of the basilar artery (Fig. 4.11). The posterior cerebellar artery makes a characteristic, caudally directed curve before it reaches the cerebellum. Both the posterior inferior and superior cerebellar arteries contribute branches to the dorsolateral brain stem.

The *posterior cerebral artery* supplies the medial aspect of the temporal and occipital lobes. The border region of the vascularization territories of the posterior and middle cerebral arteries include the temporal and occipital poles. The latter contains the posterior portion of the primary visual (striate) cortex with the representation of the fovea. Occlusion of the posterior cerebral artery thus leads to loss of peripheral vision, with maintained central vision ("tunnel vision") (Table 4.1). The borders of the arterial territories of the cerebral hemisphere do not correspond to the borders of the the four major lobes distinguished in the gross anatomy of the cerebral hemipheres (Fig. 4.7). Asymmetries of the brain's arterial system are frequently observed, most often in the calibre of the vertebral, the posterior cerebral and the posterior communicating arteries.

The vertebral, basilar and posterior cerebral arteries also give rise to smaller branches, which enter the brain stem in the median sulcus and more laterally (Fig. 4.11). Branches from the basilar and posterior cerebral arteries (Fig. 4.18) enter the mesencephalon in the posterior perforated substance, located in the floor of the interpeduncular fossa (Fig. 3.12). The vascularization territories of these arteries have been thoroughly studied by Duvernoy [12]. These territories are illustrated in a number of transverse sections in which both arterial supply and venous drainage are visualized (Figs. 4.18–4.20). These figures also document the important contributions of the cerebellar arteries to the vascularization of the brain stem.

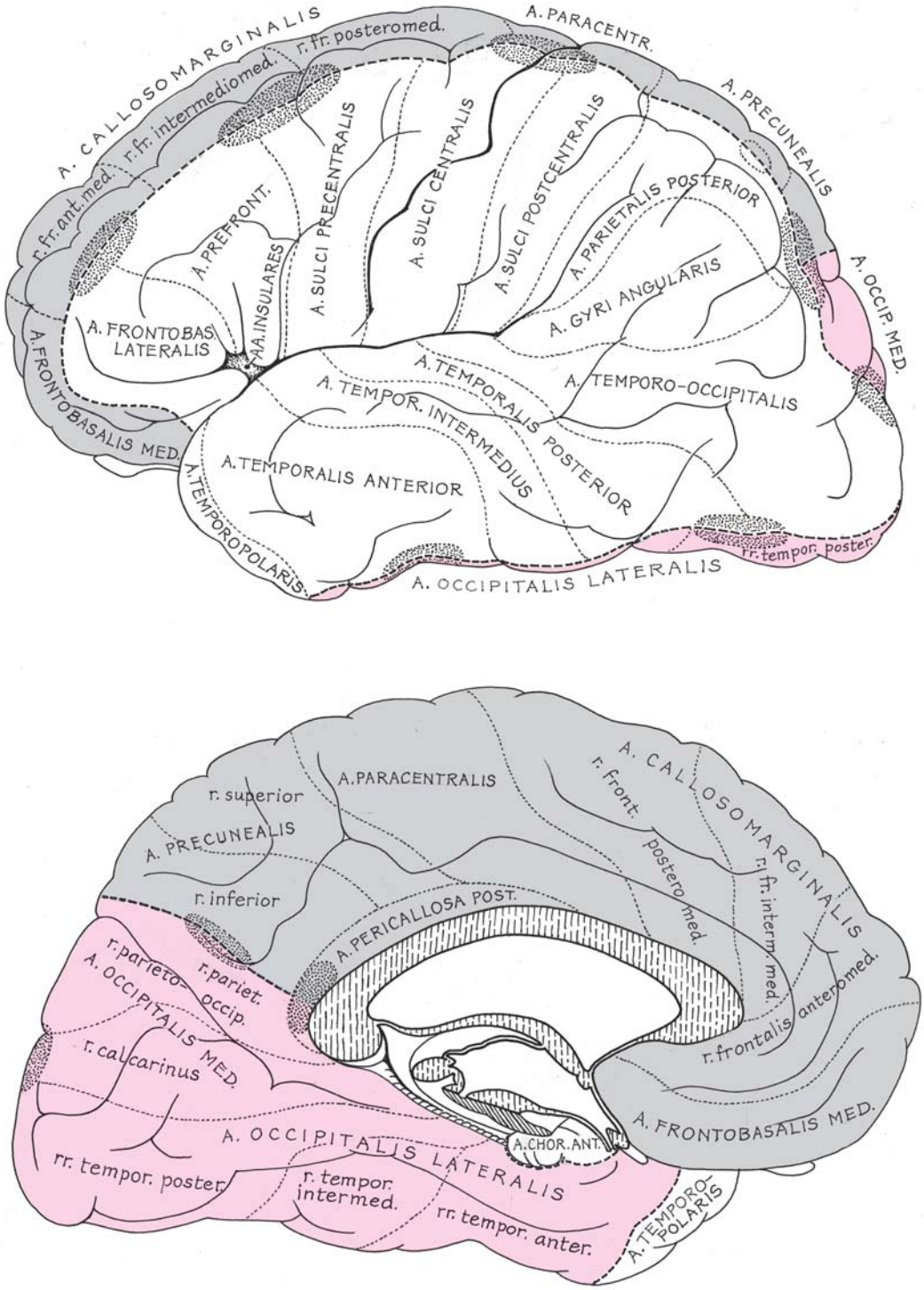
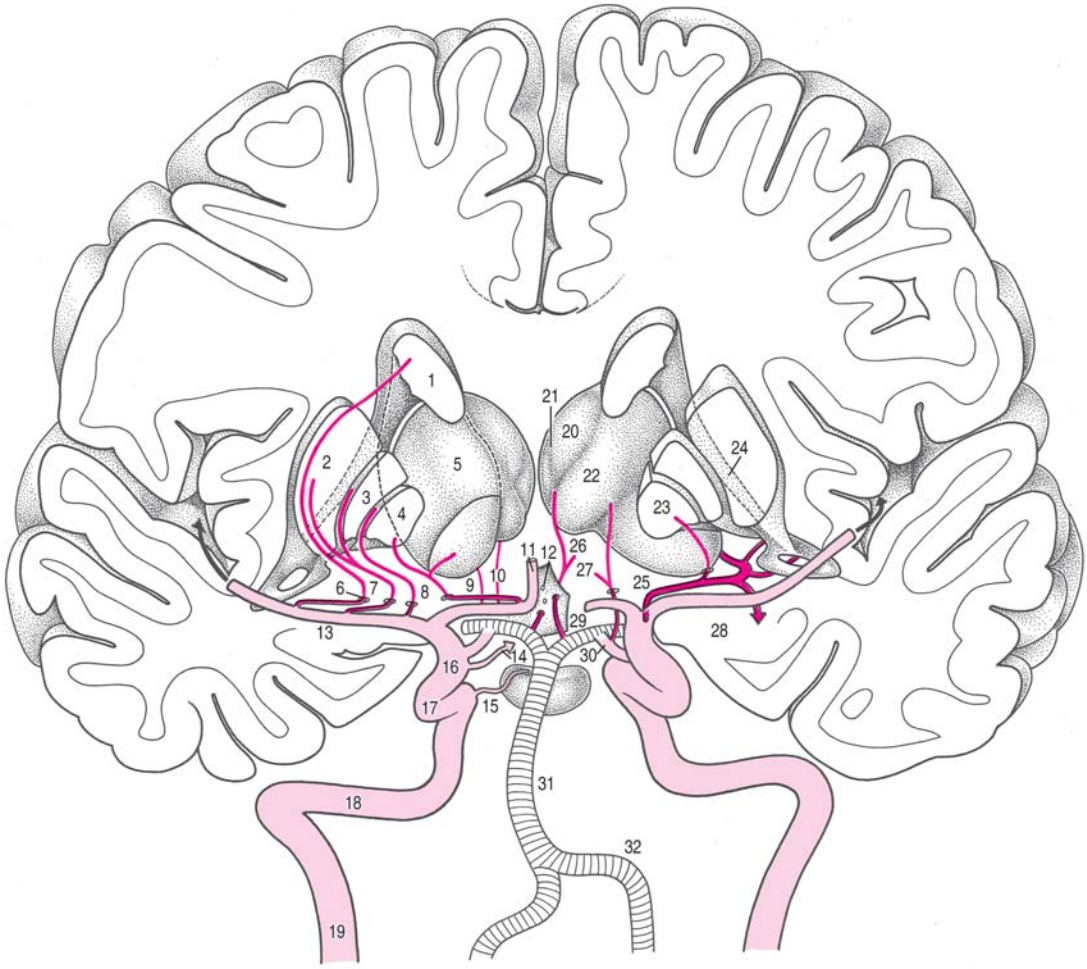
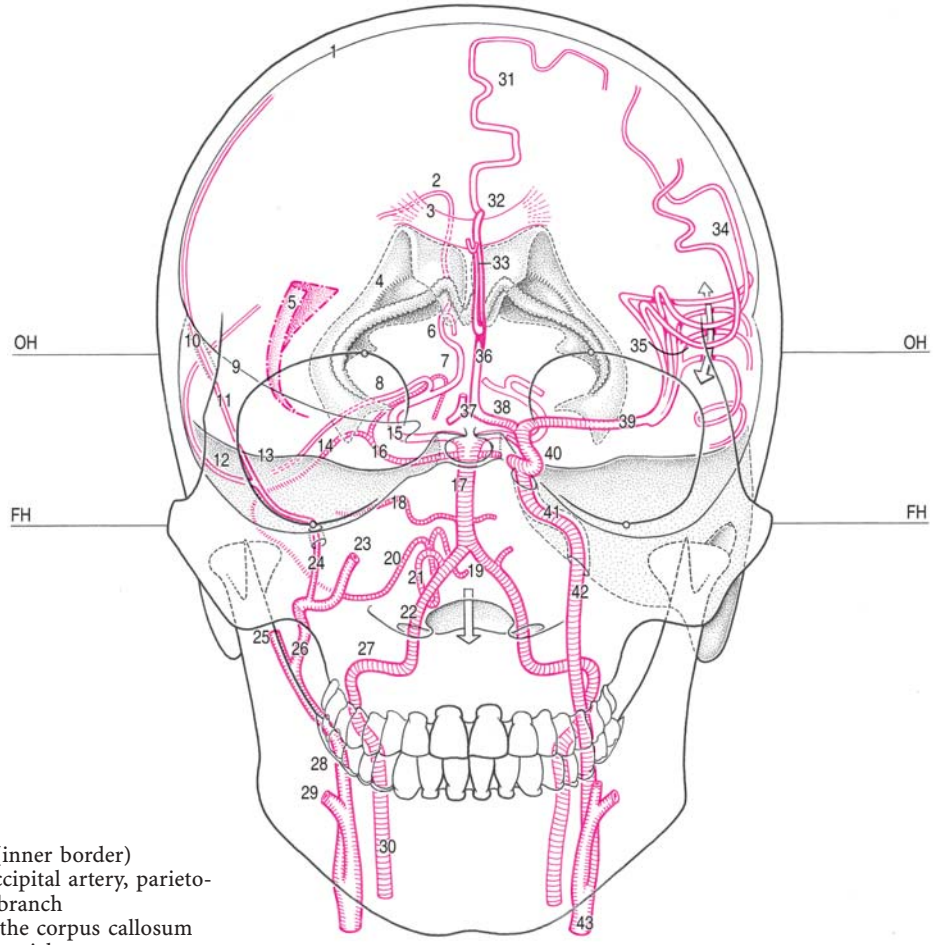


Fig. 4.7. Cortical territories of the three cerebral arteries; semidiagrammatic lateral and medial views of the left cerebral hemisphere (2/3×). The territories correspond to the vascularization pattern illustrated in Figs. 4.2–4.4. *Stippled areas*: sites of possible cerebrocerebral arterial anastomoses, mostly according to Gillilan [13]



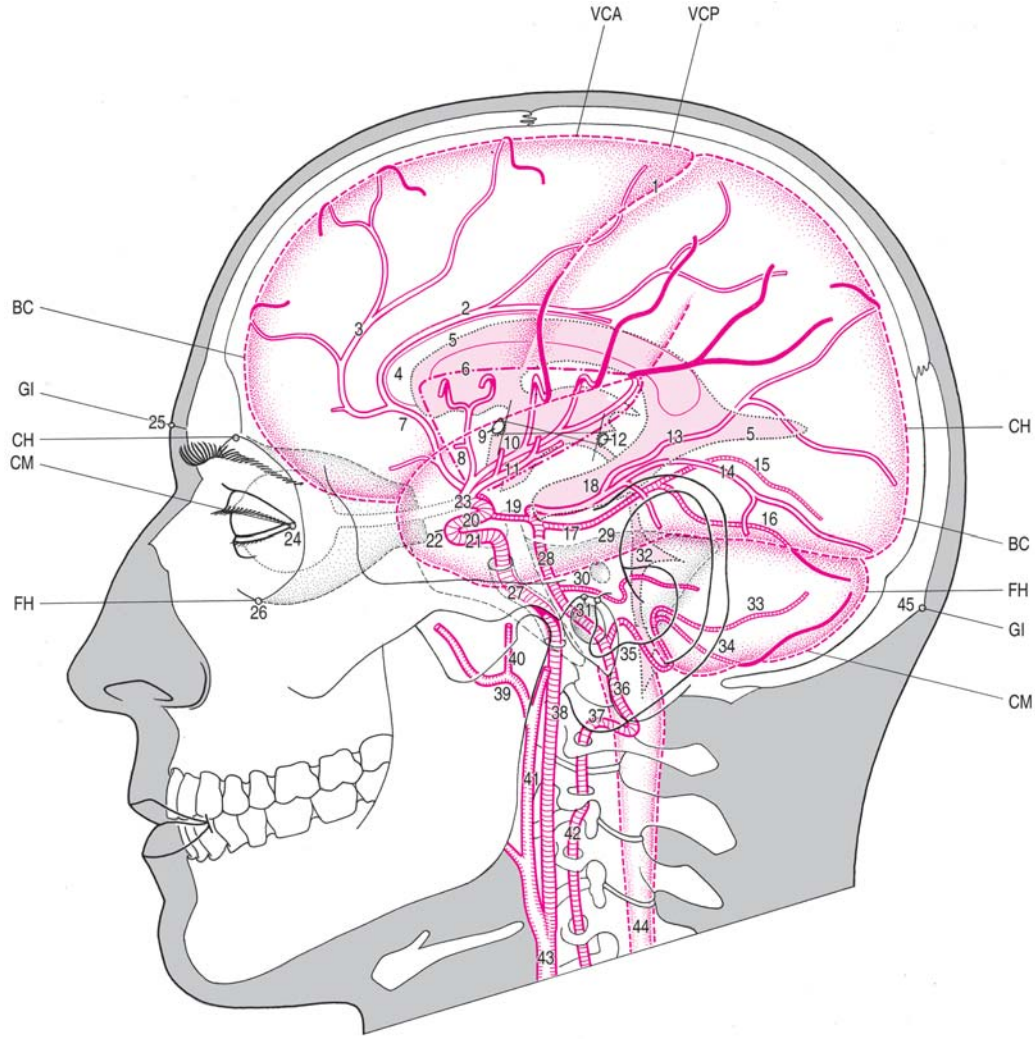
1 Caudate nucleus
2 Putamen
3 Globus pallidus, external segment
4 Globus pallidus, internal segment
5 Thalamus
6 Anterior perforated substance
7 Anterolateral central arteries, lateral branches
8 Anterolateral central arteries, medial branches
9 Long central artery (Heubner [16])
10 Anteromedial central arteries
11 Anterior cerebral artery
12 Posterior perforated substance
13 Middle cerebral artery, sphenoid part
14 Superior hypophyseal artery
15 Inferior hypophyseal artery
16 Internal carotid artery, cerebral part
17 Internal carotid artery, cavernous part
18 Internal carotid artery, petrous part
19 Internal carotid artery, cervical part
20 Medial nucleus of the thalamus
21 Midline nuclei of the thalamus
22 Anterior nucleus of the thalamus
23 Globus pallidus, internal segment
24 Tail of the caudate nucleus
25 Anterior choroidal artery
26 Subthalamus with posteromedial central arteries
27 Hypothalamus with hypothalamic branch
28 Amygdaloid nucleus
29 Posterior cerebral artery
30 Posterior communicating artery
31 Basilar artery
32 Vertebral artery

Fig. 4.8. The central arteries from the carotid and vertebral system in a frontal view (1/1×). Substrate based on a reconstruction. The frontal section is perpendicular to the horizontal plane of Frankfurt, passing through the centre of the insula. The central arteries have been derived from different sources



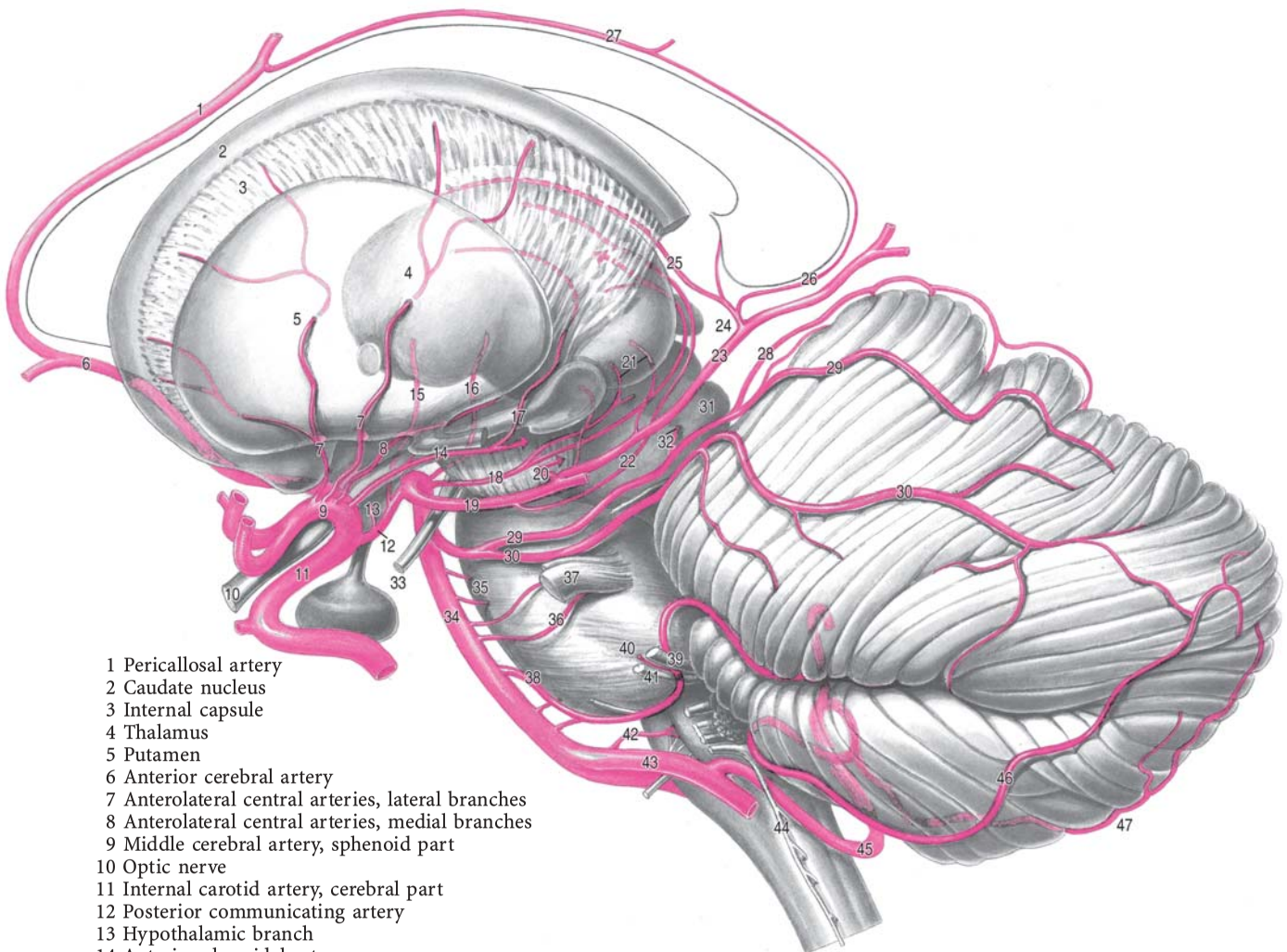
1 Calvaria (inner border)
2 Medial occipital artery, parieto-occipital branch
3 Trunk of the corpus callosum
4 Lateral ventricle
5 Insula
6 Medial occipital artery
7 Superior cerebellar artery, medial branch
8 Lateral occipital artery
9 Free margin of the lesser wing of the sphenoid bone
10 Middle meningeal artery, intraosseous part (inconstant)
11 Middle meningeal artery, frontal branch
12 Middle meningeal artery, parietal branch
13 Superior margin of petrous part of the temporal bone
14 Superior cerebellar artery, lateral branch
15 Posterior cerebral artery
16 Superior cerebellar artery
17 Basilar artery
18 Anterior inferior cerebellar artery
19 Posterior inferior cerebellar artery, medial branch
20 Posterior inferior cerebellar artery, lateral branch
21 Posterior inferior cerebellar artery
22 Vertebral artery, intracranial part
23 Maxillary artery, pterygoid part
24 Middle meningeal artery
25 Superficial temporal artery
26 Maxillary artery, mandibular part
27 Vertebral artery, atlantal part
28 External carotid artery
29 Facial artery
30 Vertebral artery, cervical part
31 Paracentral artery
32 Pericallosal artery
33 Callosomarginal artery
34 Middle cerebral artery, terminal part
35 Middle cerebral artery, insular part
36 Anterior cerebral artery, postcommunicating part
37 Anterior communicating artery
38 Anterior cerebral artery, precommunicating part
39 Middle cerebral artery, sphenoid part
40 Internal carotid artery, cavernous part
41 Internal carotid artery, petrous part
42 Internal carotid artery, cervical part
43 Common carotid artery

Fig. 4.9. Orthogonal frontal projection of the cerebral and cerebellar arteries in situ, together with some bony landmarks and the lateral ventricles (2/3×). The projection was made parallel to the horizontal plane of Frankfurt by using a graphical reconstruction from the frontal slices of one specimen, and by cross-reference with Fig. 4.10. In this figure and the next, ample use has been made of indications by Thijssen [29]. Most vessels are illustrated only in one half of the skull; the vertebral artery is shown bilaterally. *OH*, Upper horizontal plane (Krönlein): tangential to supraorbital margin; *FH*, Horizontal plane of Frankfurt (Reid): tangential to infraorbital margin; *double arrow,* sulcus lateralis; *single arrow:* foramen magnum



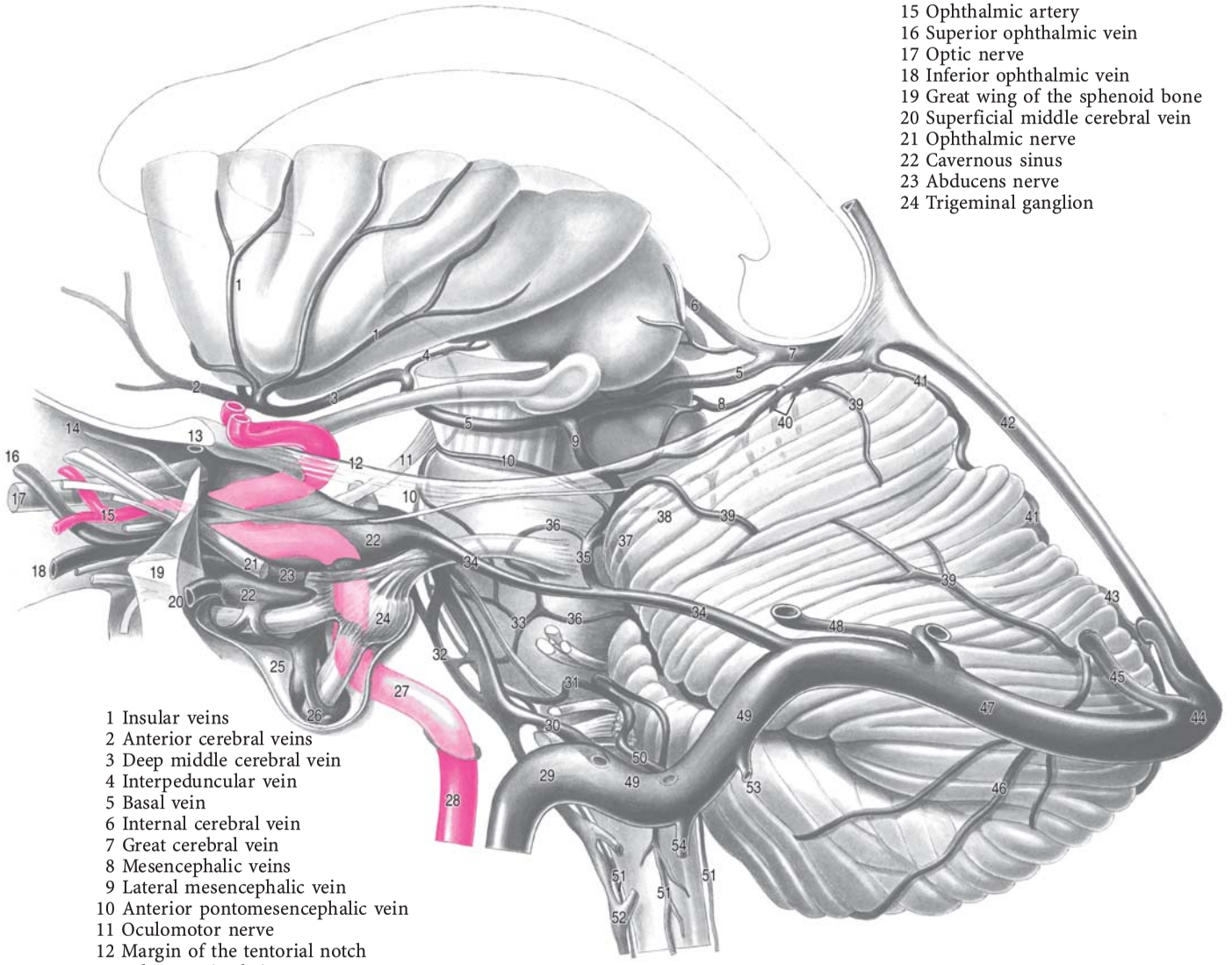
1 Central sulcus
2 Pericallosal artery
3 Callosomarginal artery
4 Corpus callosum
5 Outline of ventricles
6 Outline of insula
7 Anterior cerebral artery
8 Middle cerebral artery, frontal trunk
9 Anterior commissure
10 Middle cerebral artery, parietal trunk
11 Middle cerebral artery, temporal trunk
12 Posterior commissure
13 Medial occipital artery
14 Lateral occipital artery
15 Superior cerebellar artery, medial branch
16 Superior cerebellar artery, lateral branch
17 Superior cerebellar artery
18 Posterior cerebral artery
19 Posterior communicating artery
20 Internal carotid artery, cerebral part
21 Internal carotid artery, cavernous part
22 Siphon point
23 Middle cerebral artery, sphenoid part
24 Ektocanthion (Canthus externus)
25 Glabella
26 Orbital (on infraorbital margin)
27 Internal carotid artery, petrous part
28 Basilar artery
29 Superior margin of petrous part of the temporal bone
30 Anterior inferior cerebellar artery
31 Porion (on suprameatal margin)
32 Fourth ventricle
33 Posterior inferior cerebellar artery, medial branch
34 Posterior inferior cerebellar artery, lateral branch
35 Posterior inferior cerebellar artery
36 Vertebral artery, intracranial part
37 Vertebral artery, atlantal part
38 Internal carotid artery, cervical part
39 Maxillary artery
40 Middle meningeal artery
41 External carotid artery
42 Vertebral artery, cervical part
43 Common carotid artery
44 Spinal cord
45 Inion (external occipital protuberance)

Fig. 4.10. Orthogonal lateral projection of the cerebral and cerebellar arteries, together with external and bony landmarks, in a schematized composition of data from different specimens and publications (2/3×). Some neural structures are also illustrated in their outlines: the left hemisphere, cerebellum, left insula, corpus callosum and ventricular system. Within the outlines of the orbita the bulbus oculi and the optic nerve are indicated. On the outer side of the figure a number of reference lines are added. In the centre, two lines tangential to the anterior (AC) and posterior (PC) commissures can be seen: the one passing above the AC and beneath the PC is part of the bicommissural line of Talairach [27] (*BC*); the other tangent is part of the upper horizontal line of Krönlein (*OH*); *CM,* canthus-meatus line; *FH*, horizontal line or plane of Frankfurt (Reid); *GI*, glabella–inion line; *VCA*, vertical tangential to anterior commissure; *VCP*, vertical tangential to posterior commissure



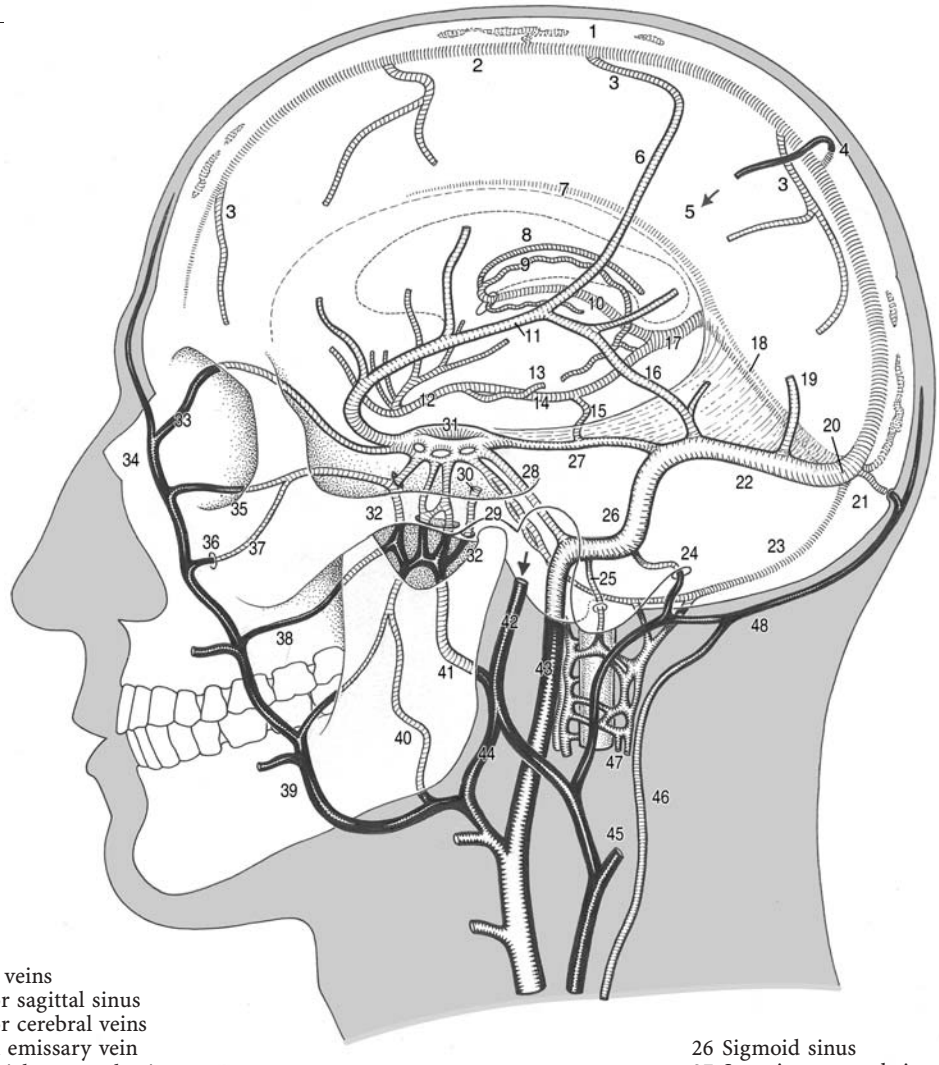
1 Pericallosal artery
2 Caudate nucleus
3 Internal capsule
4 Thalamus
5 Putamen
6 Anterior cerebral artery
7 Anterolateral central arteries, lateral branches
8 Anterolateral central arteries, medial branches
9 Middle cerebral artery, sphenoid part
10 Optic nerve
11 Internal carotid artery, cerebral part
12 Posterior communicating artery
13 Hypothalamic branch
14 Anterior choroidal artery
15 Anteroinferior thalamic branch
16 Posteromedial central arteries
17 Branch of the internal capsule (lateroinferior thalamic branch)
18 Posteromedial choroidal branch
19 Posterior cerebral artery, postcommunicating branch
20 Lateral posterior choroidal branch
21 Posteroinferior thalamic branches
22 Posterior thalamic branch
23 Medial occipital artery
24 Cingulothalamic artery
25 Superior thalamic branch
26 Dorsal branch of the corpus callosum (anastomosis with 27)
27 Pericallosal artery: posterior branch
28 Superior vermian artery
29 Medial branch of the superior cerebellar artery
30 Lateral branch of the superior cerebellar artery
31 Inferior colliculus
32 Mesencephalic branch
33 Oculomotor nerve
34 Basilar artery
35 Medial pontine arteries
36 Lateral pontine arteries
37 Trigeminal nerve
38 Anterior inferior cerebellar artery
39 Vestibulo-cochlear nerve
40 Labyrinthine artery
41 Facial nerve
42 Medullary branches
43 Vertebral artery
44 Spinal root of the accessory nerve
45 Posterior inferior cerebellar artery
46 Posterior inferior cerebellar artery, lateral branch
47 Posterior inferior cerebellar artery, medial branch

Fig. 4.11. The arteries of cerebellum, brain stem, thalamus and the corpus striatum in a lateral view (3/2×). Some arteries are slightly simplified in order to show their course and relations more clearly. The three *arrow points* indicate the choroidal branches of the three choroidal arteries. The same specimen as in Figs. 4.2–4.6, with some slight simplifications



1 Insular veins
2 Anterior cerebral veins
3 Deep middle cerebral vein
4 Interpeduncular vein
5 Basal vein
6 Internal cerebral vein
7 Great cerebral vein
8 Mesencephalic veins
9 Lateral mesencephalic vein
10 Anterior pontomesencephalic vein
11 Oculomotor nerve
12 Margin of the tentorial notch
13 Sphenoparietal sinus
14 Trochlear nerve
15 Ophthalmic artery
16 Superior ophthalmic vein
17 Optic nerve
18 Inferior ophthalmic vein
19 Great wing of the sphenoid bone
20 Superficial middle cerebral vein
21 Ophthalmic nerve
22 Cavernous sinus
23 Abducens nerve
24 Trigeminal ganglion
25 Trigeminal space
26 Venous plexus of the foramen ovale
27 Internal carotid artery, petrous part
28 Internal carotid artery, cervical part
29 Bulbus of the superior jugular vein
30 Inferior petrosal sinus
31 Vein of the pontomedullary sulcus
32 Basilar plexus
33 Pontine veins
34 Superior petrosal sinus
35 Petrosal vein
36 Superior and inferior transverse pontine veins
37 Lateral pontine vein
38 Vein of the superior cerebellar peduncle
39 Superior veins of the cerebellar hemisphere
40 Precentral cerebellar vein
41 Superior vein of the cerebellar vermis
42 Straight sinus
43 Inferior vein of the cerebellar vermis
44 Confluence of sinuses
45 Sinus of the tentorium (collecting infratentorial veins)
46 Inferior veins of the cerebellar hemisphere
47 Transverse sinus
48 Sinus of the tentorium (collecting supratentorial veins)
49 Sigmoid sinus
50 Inferior petrosal vein (inconstant)
51 Anterior, lateral and posterior spinal veins
52 Anterior internal vertebral venous plexus
53 Mastoid emissary vein
54 Condylar emissary vein

Fig. 4.12. Sinuses and veins of the diencephalon, brain stem and cerebellum in a lateral view (3/2×). Composite drawing from two specimens with additions from other sources. The cortical origins of the basal vein have been added, i.e. the insular veins, the deep middle cerebral vein and the anterior cerebral veins. The tentorium has been made fully transparent and the cavernous sinus has been deprived of its lateral dural wall. The inner lateral wall of the trigeminal space has also been removed. The orbit has been opened by a sagittal cut through its centre



1 Diploic veins
2 Superior sagittal sinus
3 Superior cerebral veins
4 Parietal emissary vein
5 Superficial temporal veins (parietal branch)
6 Superior anastomotic vein (Trolard [30])
7 Inferior sagittal sinus
8 Superior thalamostriate vein
9 Superior choroidal vein
10 Internal cerebral vein
11 Superficial middle cerebral vein
12 Deep middle cerebral vein
13 Inferior choroidal vein
14 Basal vein
15 Lateral mesencephalic vein and petrosal vein
16 Inferior anastomotic vein (Labbé [4])
17 Great cerebral vein
18 Straight sinus (sinus rectus)
19 Inferior cerebral veins
20 Confluens of the sinuses
21 Occipital emissary vein
22 Transverse sinus
23 Occipital sinus
24 Mastoid emissary vein
25 Condylar emissary vein
26 Sigmoid sinus
27 Superior petrosal sinus
28 Inferior petrosal sinus
29 Basilar plexus
30 Middle meningeal veins
31 Cavernous sinus
32 Pterygoid plexus
33 Superior ophthalmic vein
34 Angular vein
35 Inferior ophthalmic vein
36 Infraorbital foramen
37 Infraorbital vein
38 Deep facial vein
39 Facial vein
40 Palatine vein
41 Maxillary veins
42 Superficial temporal veins (see no. 5)
43 Internal jugular vein
44 Retromandibular vein
45 External jugular vein
46 Deep cervical vein
47 Internal vertebral venous plexus
48 Occipital vein

Fig. 4.13. Collateral circulation in the venous system of the head; semidiagrammatic lateral view (2/3×). Unpaired sinuses in the median plane are drawn *without outlines;* the extracranial veins draining into the internal and external jugular veins are in *black;* between the intravertebral venous plexuses a fragment of the spinal medulla can be seen. The *arrows* indicate the continuity of the superficial temporal veins

The existence of a collateral circulation is of great significance for the vascularization of the CNS. There are different types and different sites of anastomoses; moreover, the diameter of these anastomoses may differ considerably. Anastomoses between arteries can be found in relation to three arterial systems, i.e. between the two main arterial systems of the carotid and vertebral arteries and between the arterial systems of the brain and the external carotid artery.

Apart from the main arterial anastomosis between the systems of the internal carotid and the vertebral-basilar arterial system in the arterial circle of Willis, cerebro-cerebral anastomoses are present between the branches of the middle cerebral artery (Figs. 4.2, 4.14). Anastomoses between the cerebellar arteries are documented in Figs. 4.9 and 4.11.

Anastomoses with the external carotid artery occur both with meningeal and extracranial branches of this artery. Four types of anastomoses with branches of the external carotid artery are indicated with asterisks in Fig. 4.1. Orbital anastomoses with branches of the ophthalmic artery are enumerated as two special categories.

Meninges, Cisterns and Cerebrospinal Fluid Circulation

The brain is completely enclosed by three connective tissue layers: the meninges. These are, starting from the brain's surface, the *pia mater*, the *arachnoid* and the *dura mater*. The dura is also known as the pachymeninx, due to its strength and thickness, which is imparted by multiple layers of collagen tissue. The thin and loose tissue of the pia mater and the arachnoid is collectively known as the leptomeninx.

The cranial dura is merged with the periosteum of the inner table of the skull. As a consequence, the dura is firmly attached to the skull, especially at the sites of the sutures. Dural septa are located between the main divisions of the brain. In the midline, the *falx cerebri* is located between the cerebral hemispheres and the tentorium cerebelli extends between the occipital and temporal lobes of the hemisphere and the cerebellum. Venous sinuses occupy the inner and outer margins of the falx (superior and inferior sagittal sinus), the junction of the falx and the tentorium (straight sinus, or sinus rectus), and the attachment of the tentorium to the skull transverse sinus and superior petrosal sinus (Figs. 4.14–4.16). The *pia mater* closely covers the surface of the brain and intrudes into its sulci and depressions. The *arachnoid* covers the brain at a variable distance, thus creating a subarachnoidal space between the pia and the arachnoid. This space is bridged by many trabeculae. It contains the CSF. Widenings of the subarachnoid space are known as the cisterns.

For the understanding of the production, circulation and drainage of CSF, the fine structure of the interface of the CSF compartments, the nervous tissue and the mesenchymal tissue of the meninges is important. The central nervous system is isolated from the rest of the body by a series of cellular barriers, which limit the flux of hydrophilic molecules between these cells. These barriers generally consist of extensive tight junctions between the cells, where the outer leaflets of the plasma membranes of two opposing cells are fused. These barriers are found in the epithelium of the choroid plexus (blood-CSF barrier), the outer (barrier) layer of the arachnoid and in the endothelium of capillaries located within arachnoid and the pia mater and nervous tissue (blood-brain barrier).