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Chapter 13

Anatomy of the circulation of the brain and spinal cord

LAURENT TATU [1,2]*, FABRICE VUILLIER [1,2], AND THIERRY MOULIN [2]

[1] *Laboratoire d'Anatomie, Faculté de Médecine, Université de Franche-Comté, Besançon, France*

[2] *Service de Neurologie, Centre Hospitalier Universitaire Jean Minjoz, Besançon, France*

13.1. Arterial circulation of the brain

13.1.1. General organization

13.1.1.1. Brainstem

Arterial trunks supplying the brainstem include the vertebral artery, basilar artery, anterior and posterior spinal arteries, posterior inferior cerebellar artery, anterior inferior cerebellar artery, superior cerebellar artery, posterior cerebral artery, collicular artery, and anterior choroidal artery (Fig. 13.1).

The collaterals of these arteries are divided into four groups (anteromedial, anterolateral, lateral, and posterior arteries) according to their point of penetration into the parenchyma. This classification was devised by Lazorthes (1976), who divided the superficial arteries into anterior, lateral, and posterior. For the arteries of the anterior group, the most accurate subdivision is that proposed by Duvernoy (1999) dividing anterior arteries into anteromedial and anterolateral arteries. Each of the anteromedial, anterolateral, lateral, and posterior arterial groups supplies the corresponding arterial territories in the brainstem. At each level of the brainstem, the arteries supplying each of the territories vary.

The arterial territories have a variable extension at different levels of the brainstem. For example, the posterior group no longer exists in the lower pons. Consequently, the nuclei and tracts that extend into the brainstem may be supplied by several arterial groups.

13.1.1.2. Cerebellum

The cerebellum is supplied by three pairs of long cerebellar arteries, namely the posterior inferior cerebellar artery, anterior inferior cerebellar artery, and superior cerebellar artery. The posterior inferior and superior cerebellar arteries give rise to medial and lateral branches that supply the cortex and the central nuclei of the cerebellum. The three long cerebellar arteries also participate in supplying blood to the particular lateral or posterior arterial groups of the brainstem. The branches of long cerebellar arteries develop a pial anastomotic network on the surface of the cerebellum.

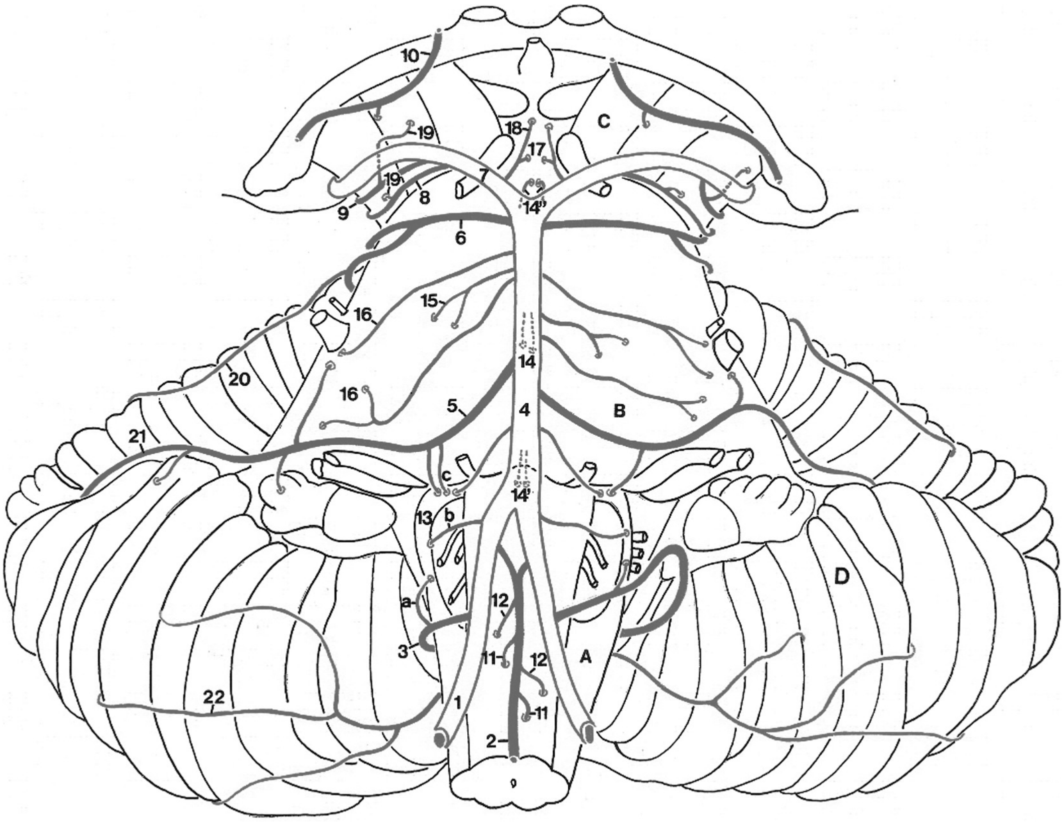
13.1.1.3. Cerebral hemispheres

The arterial circulation of the cerebral hemispheres is divided into two systems: the leptomeningeal arteries and the perforating arteries (Fig. 13.2). Nevertheless, perforating branches can arise from leptomeningeal arteries and some leptomeningeal branches can originate in the large perforating arteries.

The leptomeningeal arteries (also known as superficial or pial), consisting of the terminal branches of the anterior cerebral artery, middle cerebral artery, posterior cerebral artery, and anterior choroidal artery, form an anastomotic network on the surface of the hemispheres and yield branches that penetrate the cortex and subjacent white matter. The deepest ones form the medullary (or superficial perforating) arteries.

The perforating arteries (or deep perforating arteries) that spring from the arterial circle of Willis or from its immediate branches perforate the brain parenchyma as direct penetrators (Fig. 13.3). The perforating arteries arising from the internal carotid artery, anterior cerebral artery, middle cerebral artery, anterior communicating artery, and anterior choroidal artery pass through the anterior perforated substance. Some perforating arteries arising from the posterior cerebral artery enter the brain through the posterior perforated substance, forming the interpeduncular arteries. These latter arteries are classed in three rami;

*Correspondence to: Laurent Tatu, Laboratoire d'Anatomie, Faculté de Médecine, Université de Franche-Comté, 25 000 Besançon, France. E-mail: laurent.tatu@univ-fcomte.fr, Tel: +3-81-66-5619, Fax: +3-81-66-5676.



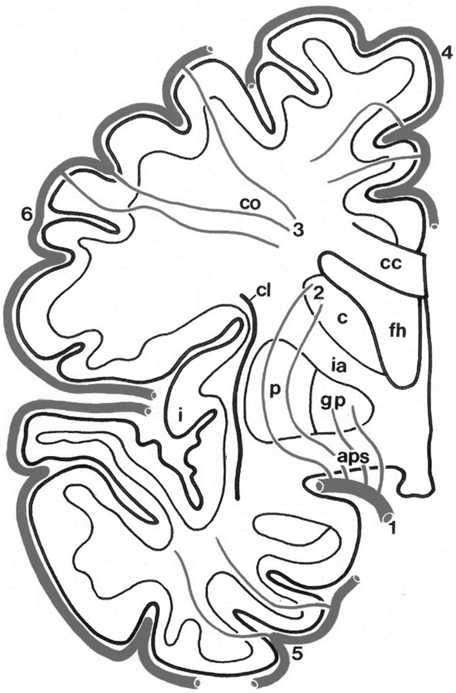
1. Vertebral artery
2. Anterior spinal artery
3. Posterior inferior cerebellar artery
4. Basilar artery
5. Anterior inferior cerebellar artery
6. Superior cerebellar artery
7. Posterior cerebral artery
8. Collicular artery
9. Posteromedial choroidal artery
10. Anterior choroidal artery
11. Anteromedial group of medullary arteries
12. Anterolateral group of medullary arteries
13. Lateral group of medullary arteries (a. inferior rami arising from the posterior inferior cerebellar artery; b. middle rami arising from the vertebral artery; c. superior rami arising from the anterior inferior cerebellar artery)
14. Anteromedial group of pontine arteries penetrating the basilar sulcus (14′ arteries penetrating the foramen coecum; 14′′ arteries penetrating the interpeduncular fossa, inferior rami of the interpeduncular fossa)
15. Anterolateral group of pontine arteries
16. Lateral group of pontine arteries
17. Anteromedial group of mesencephalic arteries (middle rami of the interpeduncular fossa)
18. Anterolateral group of mesencephalic arteries (superior rami of the interpeduncular fossa)
19. Lateral group of mesencephalic arteries
20. Branches of the superior cerebellar artery
21. Branches of the anterior inferior cerebellar artery
22. Branches of the posterior inferior cerebellar artery

Fig. 13.1. Anterior view showing the general arrangement of the brainstem and cerebellar arteries. (A) Medulla. (B) Pons. (C) Midbrain. (D) Cerebellum.

the superior rami participate in supplying blood to the thalamus (thalamoperforating arteries) whereas the inferior rami supply the pons and the middle rami supply the midbrain. The posterior cerebral artery also gives rise to the thalamogeniculate branches and the posterior choroidal arteries to supply blood to the thalamus and geniculate bodies. The posterior communicating artery gives rise to perforating branches, notably the premammillary artery, which passes through the lateral perforated substance.

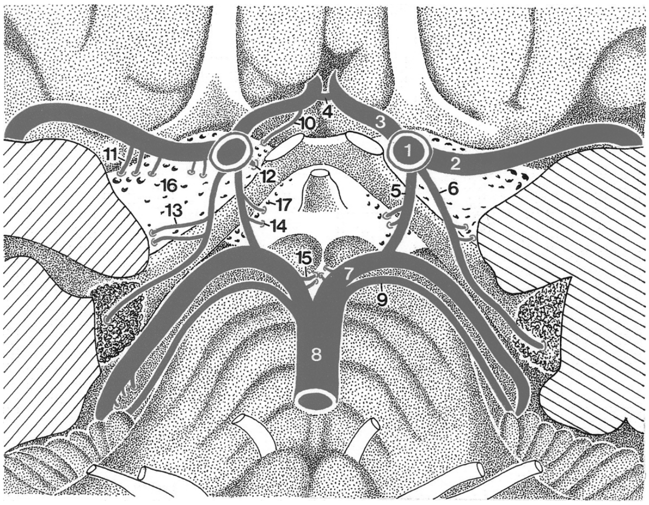
13.1.2. Maps of cerebral arterial territories

In order to discuss in more detail the arterial supply of blood to the brain we have chosen the medium of brain mapping defining the areas supplied by various arteries in the brain. Indeed, it is very important that a vascular neurologist understands the basic anatomy of cerebral arteries and is also able to apply this knowledge easily in the routine interpretation of neuroimaging studies.



1. Middle cerebral artery
2. Perforating arteries (deep perforating arteries)
3. Medullary arteries (superficial perforating arteries)
4. Leptomeningeal branches of the anterior cerebral artery
5. Leptomeningeal branches of the posterior cerebral artery
6. Leptomeningeal branches of the middle cerebral artery

Fig. 13.2. Coronal section of the brain showing the general arrangement of the hemispheric arteries. aps, anterior perforated substance; c, caudate nucleus; cc, corpus callosum; cl, claustrum; co, centrum ovale; fh, frontal horn of lateral ventricle; gp, globus pallidus; i, insula; ia, anterior limb of internal capsule; p, pallidum.



1. Internal carotid artery
2. Middle cerebral artery
3. Anterior cerebral artery
4. Anterior communicating artery
5. Posterior communicating artery
6. Anterior choroidal artery
7. Posterior cerebral artery
8. Basilar artery
9. Superior cerebellar artery
10. Recurrent artery of Heubner
11. Middle cerebral artery perforating branches
12. Internal carotid artery perforating branches
13. Anterior choroidal artery perforating branches
14. Posterior communicating artery perforating branches
15. Posterior cerebral artery perforating branches
16. Anterior perforated substance
17. Lateral perforated substance

Fig. 13.3. The arterial circle of Willis.

Charles Edward Beevor was the first to illustrate the vascular territories of the brain in 1907 (Beevor, 1908). Based on anatomical studies of brain injections, this map revealed the structures and main vascular territories of the brain in a series of horizontal, sagittal, and vertical sections. Obviously, this was of major practical interest in the field of anatomopathology in formulating anatomoclinical correlations post mortem. The emergence of the computed tomography (CT) scan at the beginning of the 1970s created a new need for morphological and vascular reading techniques. A series of maps thus appeared, for the most part not based on anatomical data and of questionable practical interest. Only the map of Hanna Damasio was to become a reference work because of its solid anatomical basis and its applicability to CT scan reference planes (Damasio, 1983). The advent of magnetic resonance imaging (MRI) technology created the need for more precise anatomical reading techniques and imposed a new reference plane for performing sections: the bicommissural plane. Once again, a series of unreliable, non-anatomical maps appeared that were of little practical use. The work of Michel Pullicino, carried out after an exhaustive summary of anatomical studies and with a view to being applicable to MRI, opened the way for designing new maps (Pullicino, 1993).

In the remainder of this chapter we present the morphological description of the arteries outlined in maps of areas of distribution that have already been published and updated elsewhere (Tatu et al., 1996, 1998, 2001). It fulfills two major requirements by, first, proposing templates produced in the centrobicommissural reference plane and, second, delimiting the areas of distribution of cerebral arteries solely based on anatomical sources.

This map is presented in 24 serial templates, based on a bicommissural plane passing through the center of the anterior and posterior commissures. The sections of the brainstem (Fig. 13.4) and cerebellum (Fig. 13.5) (sections I–XII) are 4 mm thick whereas those of the cerebral hemispheres (Fig. 13.6) (sections XIII–XXIV) are 8 mm thick. The right side of the sections shows the anatomical structures and Brodmann's areas for cerebral hemispheres. The arterial territories appear on the left side of the sections. Morphological data concerning the 24 sections is based on anatomical atlases by Duvernoy (Duvernoy, 1995; Duvernoy and Cabanis, 1999). The arterial territories were outlined based on an extensive overview of anatomical studies of cerebral blood supply. This overview included either vascular injection studies or microanatomical studies of the cerebral arteries and is developed in more detail below. The variability of the cortical territories of anterior, middle, and posterior arteries is presented, using the results of the study by van der Zwan et al. (1992) to designate the minimal and maximal cortical supply areas. Nevertheless, several aspects of hemispheric blood supply have purposely not been described in detail because of a lack of reliable anatomical studies in this area. Some of these aspects are also developed below.

13.1.3. Arterial supply of the brainstem

The brainstem arterial territories have been described and illustrated using the anatomical work of Duvernoy (1995, 1999) and Lazorthes (Lazorthes et al., 1958; Lazorthes, 1976) dividing supply into anteromedial, anterolateral, lateral, and posterior arterial groups.

The collaterals of the main arterial trunks form these four arterial groups (anteromedial, anterolateral, lateral, and posterior), which supply the brainstem structures. At each level of the brainstem, the origin of these groups varies.

13.1.4. Arterial supply to the medulla

The arterial supply of the medulla comes from the vertebral arteries, which form the middle rami of the lateral medullary fossa, the posterior inferior cerebellar artery, which creates the inferior rami of the lateral medullary fossa, and the anterior and posterior spinal arteries.

The *anteromedial group* arises from the anterior spinal artery (sections I, II, III) or the anterior spinal and vertebral arteries (section IV).

The *anterolateral group* arises from the anterior spinal and vertebral arteries (section I), anterior spinal and posterior inferior cerebellar arteries (sections II, III), or anterior spinal and vertebral arteries (section IV).

The *lateral group* derives from the posterior inferior cerebellar artery (inferior rami of the lateral medullary fossa; sections I, II, III) or the vertebral artery (middle rami of the lateral medullary fossa; section IV).

The *posterior group* stems from the posterior spinal artery (sections I, II) or the posterior inferior cerebellar artery (sections III, IV).

13.1.5. Arterial supply in the pons

Different arterial trunks supply blood to the pons, including the vertebral arteries, anterior inferior cerebellar artery, superior cerebellar artery, and basilar artery. The anterior inferior cerebellar artery enters the parenchyma in the pontomedullary sulcus and gives off the superior and posterior rami of the lateral medullary fossa. Different branches of the basilar artery enter the foramen cecum at the lower level (foramen cecum arteries), through the ventral part of the pons (anteromedial, anterolateral, and lateral pontine arteries) or the interpeduncular fossa in the upper level (inferior rami of the interpeduncular arteries; Fig. 13.7).

The *anteromedial group* arises from the foramen cecum arteries (section V, part a′ of sections VI and VII) or pontine arteries (section VIII, part a of sections VI, VII, IX, and X) or interpeduncular fossa arteries (part a′ of sections IX and X).

The *anterolateral group* arises from the pontine arteries (sections V, VI, VII, VIII, IX, X).

The *lateral group* arises from the vertebral and anterior inferior cerebellar arteries (superior and posterior rami of the lateral medullary fossa) (section

Table 13.1

Anatomical structures of the brainstem and cerebellum (sections I–XII)

1	Corticospinal tract	30	Medial geniculate body
2	Medial lemniscus	31	Pulvinar
2′	Medial longitudinal fasciculus	32	Mammillothalamic tract
3	Spinothalamic tract	33	Column of fornix
4	Spinal trigeminal tract and nuclei	34	Caudate nucleus
5	Gracile and cuneate nuclei	35	Putamen
6	Nucleus of the solitary tract	36	Anterior commissure
7	Dorsal motor vagal nucleus	37	Tonsil
8	Hypoglossal nucleus	38	Biventer lobule
9	Inferior olivary nucleus	39	Inferior semilunar lobule
10	Inferior cerebellar peduncle	40	Pyramid of vermis
11	Vestibular nucleus	41	Uvula
12	Nucleus prepositus	42	Superior semilunar lobule
13	Facial nucleus	43	Tuber of vermis
14	Superior olivary nucleus	44	Middle cerebellar peduncle
15	Abducens nucleus	45	Dentate nucleus
16	Pontine nuclei	46	Folium of vermis
17	Motor trigeminal nucleus	47	Nodulus
18	Principal sensory trigeminal nucleus	48	Flocculus
19	Nucleus ceruleus	49	Declive
20	Superior cerebellar peduncle	50	Simple lobule
21	Substantia nigra	51	Culmen
22	Inferior colliculus	52	Quadrangular lobule
23	Trochlear nucleus	53	Central lobule
24	Superior colliculus	54	Ala of the central lobule
25	Oculomotor nucleus	V	Trigeminal nerve
26	Red nucleus	VII	Facial nerve
27	Mammillary body	VIII	Vestibulocochlear nerve
28	Optic tract	IX	Glossopharyngeal nerve
29	Lateral geniculate body		

V), the pontine arteries (section IX, part b of sections VI and VII), the anterior inferior cerebellar artery (part b′ of sections VI and VII), the pontine arteries and anterior inferior cerebellar artery (section VIII), or the superior cerebellar artery (section X).

The *posterior group* only exists in the upper part of the pons and arises from the medial and lateral branches of the superior cerebellar artery (sections IX and X).

13.1.6. Arterial supply to the midbrain

Five arterial trunks supply the arterial midbrain groups, from bottom to top, the superior cerebellar artery (mainly the medial branch), the collicular artery, the posteromedial choroidal artery, the posterior cerebral artery (middle rami of the interpeduncular arteries), and the anterior choroidal artery.

The *anteromedial group* arises from the posterior cerebral artery (sections XI, XII).

The *anterolateral group* arises from the collicular and posteromedial choroidal arteries (section XI) or the collicular, posteromedial, and anterior choroidal arteries (section XII).

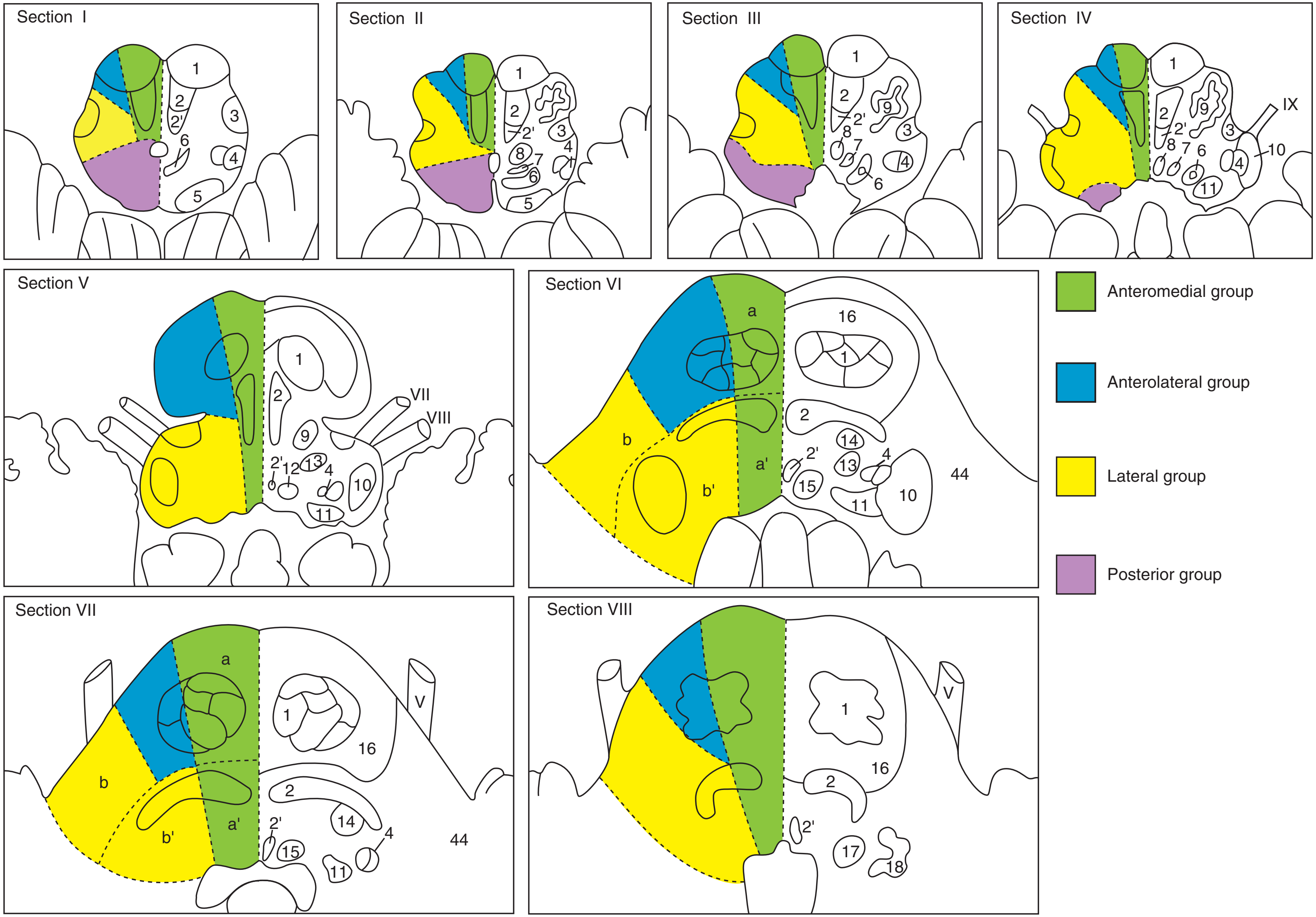
The *lateral group* arises from the collicular artery (section XI) or the collicular, posteromedial choroidal, and posterior cerebral arteries (section XII).

The *posterior group* arises from the superior cerebellar and collicular arteries (section XI) or the collicular and posteromedial choroidal arteries (section XII).

13.1.7. Arterial supply of the cerebellum

The brainstem arterial territories have been described and depicted using the anatomopathological work of Amarenco et al. (Amarenco and Hauw, 1989, 1990a, b; Amarenco et al., 1989; Amarenco, 1991) and the injection studies of Marinkovic et al. (1995).

The cerebellar arterial supply depends on three long arteries (Fig. 13.1). The posterior inferior cerebellar artery is the most variable of the cerebellar arteries and originates in the vertebral artery. It gives off medial and lateral branches and supplies the inferior



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VII
VIII
Section VI
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Section VIII
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Anteromedial group
Anterolateral group
Lateral group
Posterior group

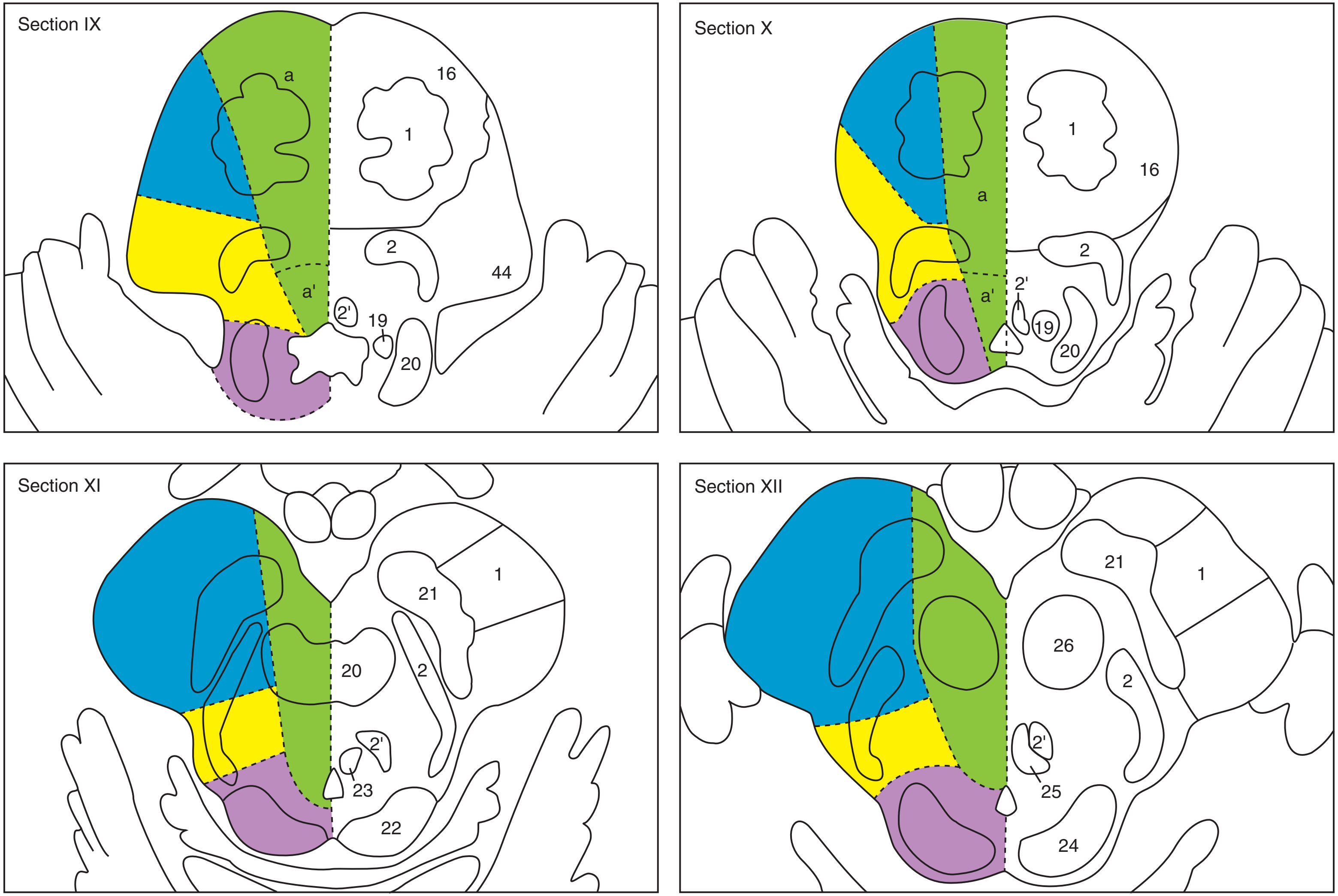


Fig. 13.4. Sections of the brain stem. See Table 13.1 for key to anatomical structures.

vermis and the inferior and posterior surfaces of the cerebellar hemispheres. The posterior inferior cerebellar artery also takes part in the lateral and posterior arterial groups of the medulla.

The anterior inferior cerebellar artery usually arises from the bottom third of the basilar artery or more rarely the posterior cerebral artery and supplies the anterior surface of the simple, superior, and inferior semilunar lobules as well as the flocculus and the middle cerebellar peduncle. The internal auditory artery, for the most part, originates from it. The anterior inferior cerebellar artery participates in supplying the middle cerebellar peduncle and often the lower part of the pontine tegmentum. The superior cerebellar artery—also known as the anterior superior cerebellar artery—divides into medial and lateral branches and supplies the superior half of the cerebellar hemisphere and vermis as well as the dentate nucleus. These two branches can arise independently from the basilar artery. The territory of the superior cerebellar artery often includes the upper part of the pontine tegmentum.

In cerebellum territories some variations are not uncommon, such as an anterior inferior cerebellar artery replacing a hypoplastic posterior inferior cerebellar artery and taking over most of the anterior and inferior part of the cerebellar hemisphere. There are also many individual variations in the relative importance of cerebellar arteries in supplying blood to the brainstem. These aspects need further anatomical studies. Some variations are less frequent, such as cerebellar arteries originating from the internal carotid artery (Siqueira et al., 1993).

13.1.8. Arterial supply of the cerebral hemispheres

We have chosen the classical description of the cerebral arteries divided into perforating and leptomeningeal arteries. Nevertheless, perforating branches may arise from leptomeningeal arteries and the large perforating arteries may be the origin of some leptomeningeal branches (Marinkovic et al., 1996). Because of the numerous variations in the branching patterns of the leptomeningeal arteries, we preferred not to itemize the arterial territory of each cortical branch of the anterior cerebral artery, middle cerebral artery, and posterior cerebral artery. Using the results of the study by van der Zwan et al. on cortical boundaries, we have chosen to explain in detail the variability of the cortical territories of the three main cerebral arteries (van der Zwan et al., 1992).

The anterior choroidal artery also has a superficial and deep distribution area. However, because of its course and how it divides into collateral branches, it does not really fit into a clear superficial branch/deep branch dichotomy. For our present purposes we will consider it as a deep artery.

13.1.9. Perforating branches of the cerebral arteries

For each type of perforating artery, we present only the main points of interest such as patterns of origin and vascular supply.

13.1.9.1. Internal carotid artery perforating branches

From the supraclinoid portion, the internal carotid artery gives off arteries that distribute to the hypophysis as well as to the adjacent hypothalamus and optic chiasm (Alicherif et al., 1977; Gibo et al., 1981; Willinsky et al., 1987; Marinkovic et al., 1989). Certain perforating branches, also arising from the supraclinoid portion, near the origin of the anterior choroidal artery or at the internal carotid artery bifurcation, pass through the anterior perforated substance to enter the brain (Alexander, 1942; Dunker and Harris, 1976; Saeki and Rhoton, 1977; Fujii et al., 1980; Gibo et al., 1981; Rosner et al., 1984; Marinkovic et al., 1990a; Erdem et al., 1993). These branches supply the genu of the internal capsule, the adjacent part of the globus pallidus, and the contiguous posterior limb of the internal capsule (Alexander, 1942; Dunker and Harris, 1976).

13.1.9.2. Anterior choroidal artery

The anterior choroidal artery usually arises from the supraclinoid portion of the internal carotid artery (Otomo, 1965; Saeki and Rhoton, 1977; Rhoton et al., 1979; Fujii et al., 1980; Gibo et al., 1981) but can arise from another artery such as the middle cerebral artery or more rarely the posterior communicating artery (Carpenter et al., 1954; Hussein et al., 1988;

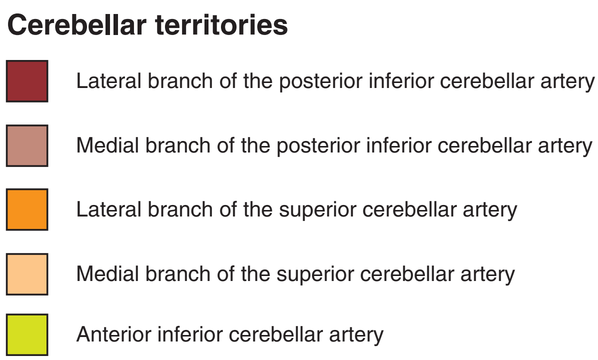


Fig. 13.5. (*facing and subsequent pages*). Structure of the cerebellum (sections I–XII). See Table 13.1 for key to anatomical structures.

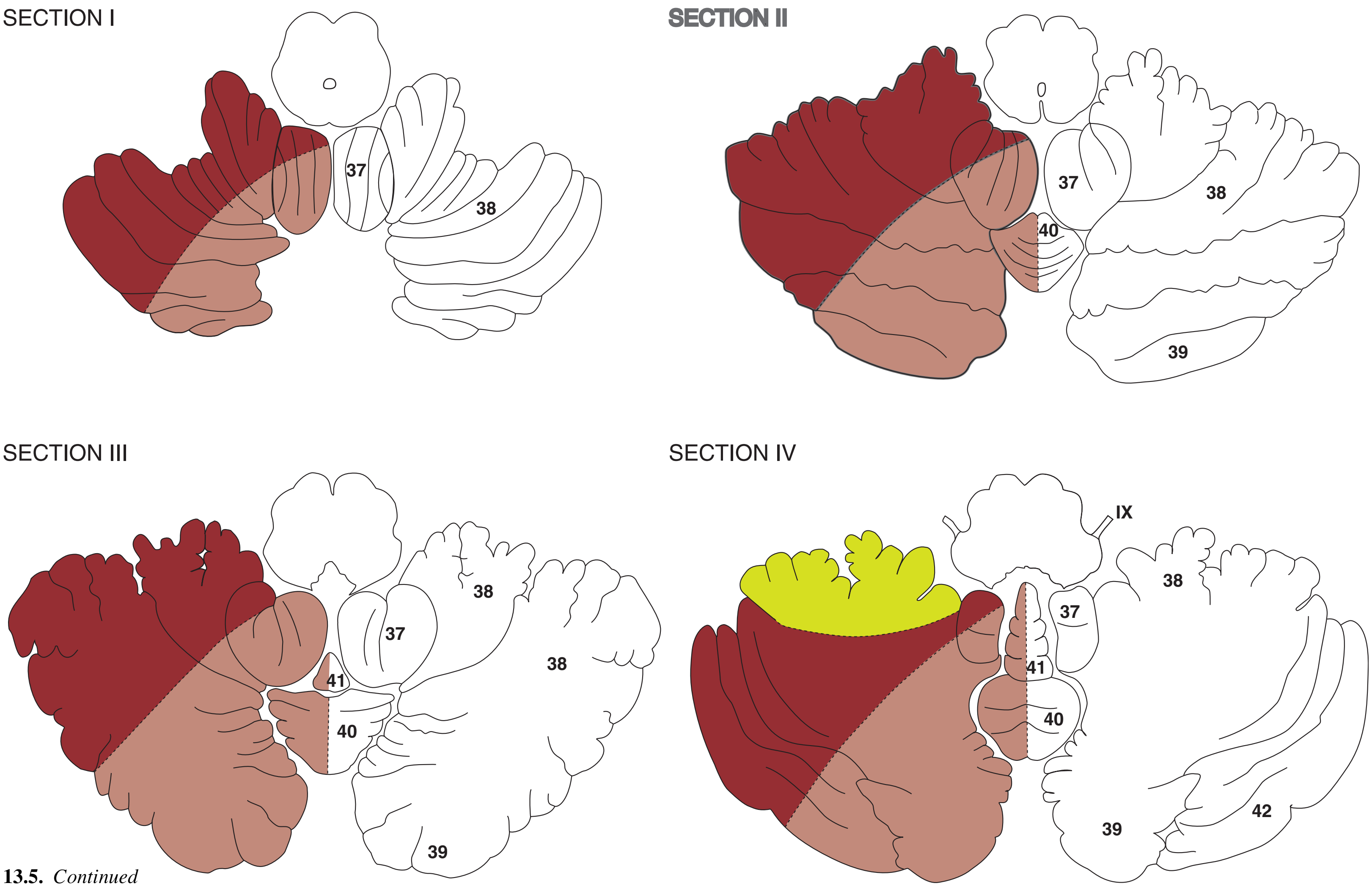


Fig. 13.5. *Continued*

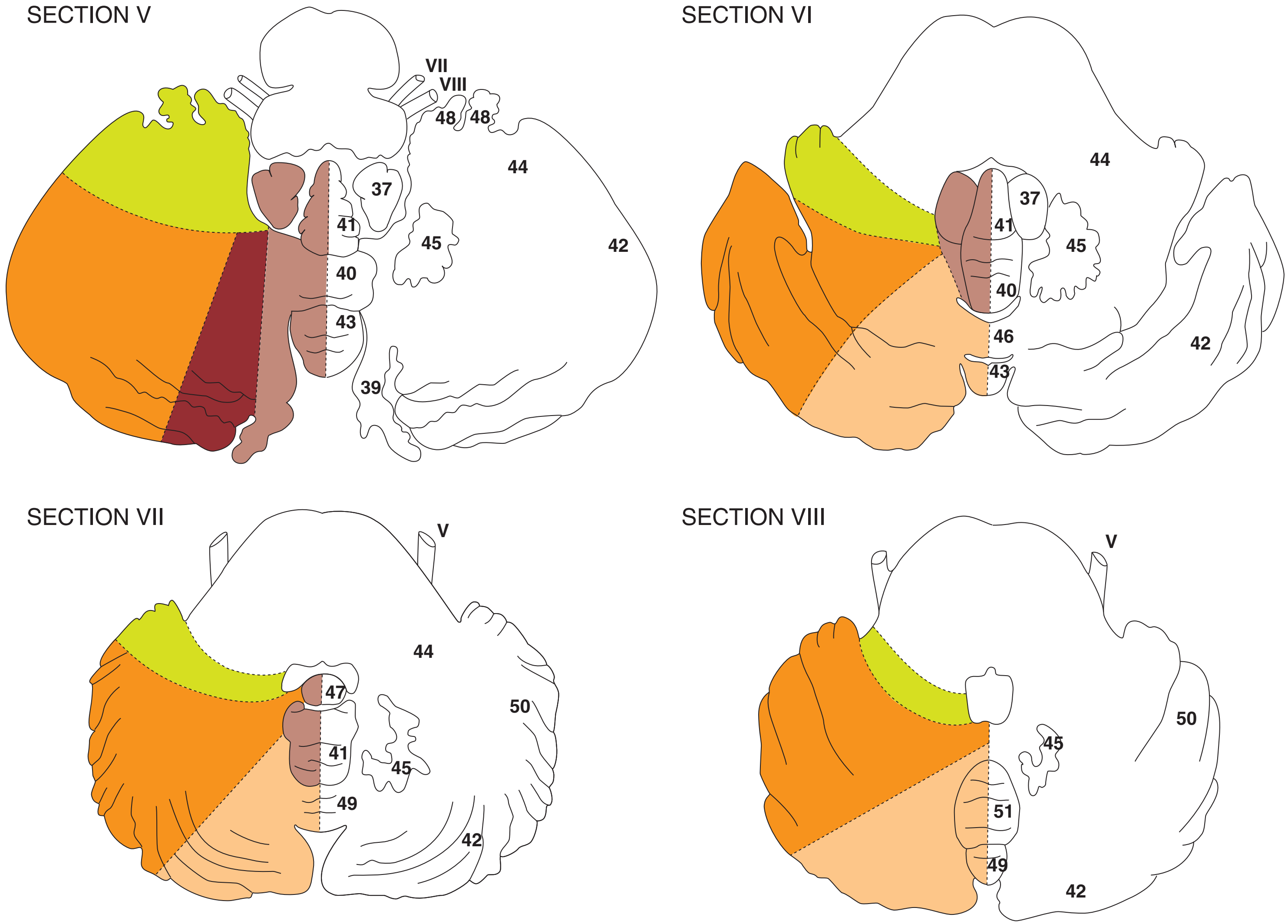


Fig. 13.5. *Continued*

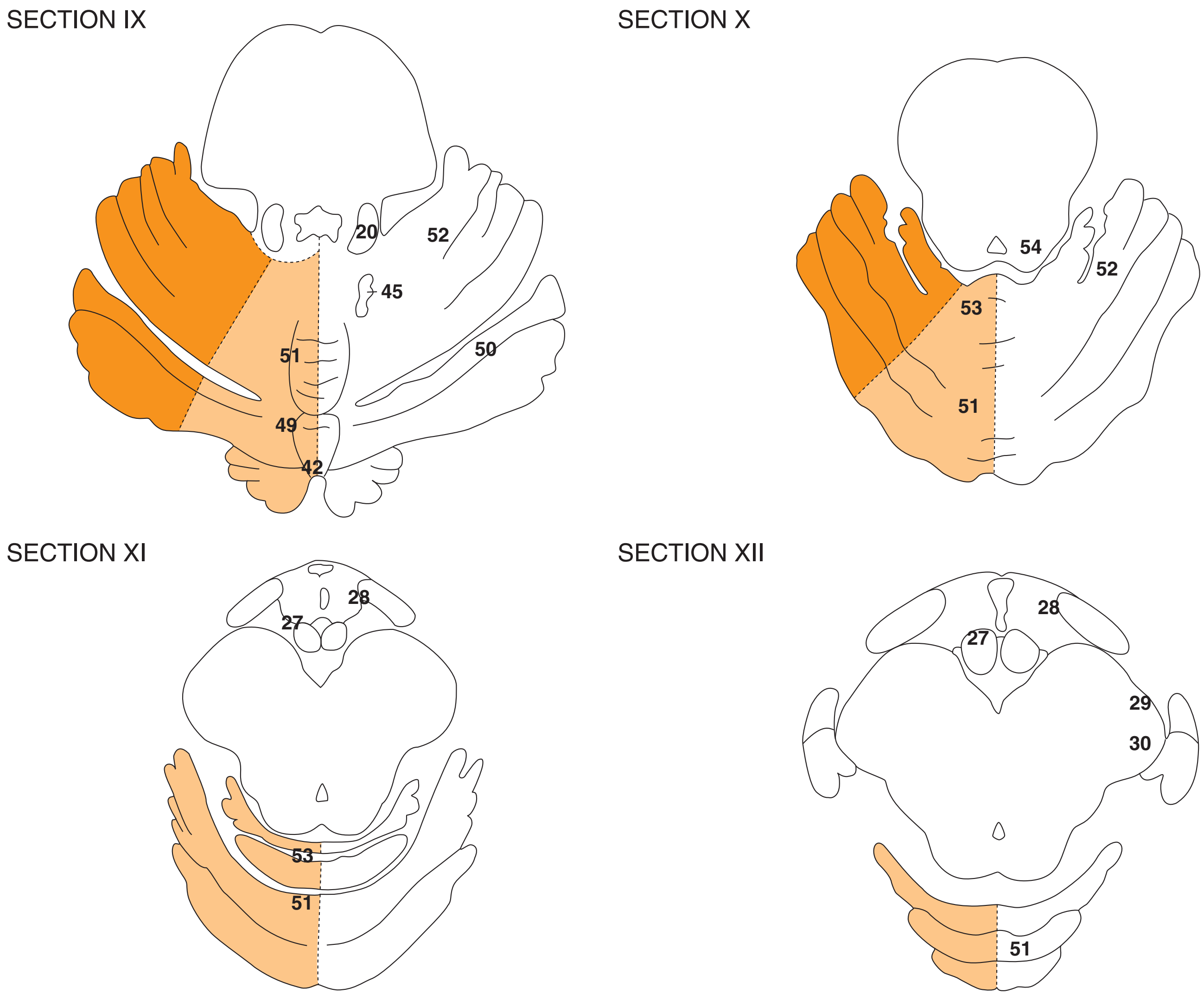


Fig. 13.5. *Continued*

Morandi et al., 1996). The superficial territory includes a part of the uncus (Fujii et al., 1980), a part of the head of the hippocampus (Marinkovic et al., 1992, 1994), a part of the amygdaloid nucleus (Abbie, 1933; DeReuck, 1971a) and the lateral part of the lateral geniculate body (Abbie, 1933; Alicherif et al., 1977; Fujii et al., 1980). The perforating territory includes the lower part of the posterior two-thirds and the retrolenticular part of the internal capsule (Beevor, 1908; Abbie, 1933; Alexander, 1942; Herman et al., 1966; Furlani, 1973), the adjacent optic radiations and acoustic radiations (Alexander, 1942; Herman et al., 1966; Alicherif et al., 1977), the medial globus pallidus (Beevor, 1908; Abbie, 1933; Alexander, 1942) and the tail of the caudate nucleus (Plets et al., 1970; Furlani, 1973; Alicherif et al., 1977).

13.1.9.3. Anterior communicating artery

The perforating branches of the anterior communicating artery are now described as having constant patterns (Rubinstein, 1944; Dunker and Harris, 1976; Crowell and Morawetz, 1977; Marinkovic et al., 1990c; Vincentelli et al., 1991). These branches originate directly from the anterior communicating artery or from the junctional site of the anterior communicating artery and anterior cerebral artery (Avci et al., 2003). The anterior communicating artery gives off perforating branches that divide into three groups: the hypothalamic arteries, the subcallosal artery, and the median callosal artery. The former two branches have never been found to arise together from the anterior communicating artery (Marinkovic et al., 1990c; Ture et al., 1996). The vascular territory of this artery includes the lamina terminalis, anterior hypothalamus, septum pellucidum, a part of the anterior commissure and of the fornix, the paraterminal gyrus including the septal nuclei (Duvernoy et al., 1969; Dunker and Harris, 1976; Vincentelli et al., 1991), and occasionally the subcallosal region, the anterior part of the corpus callosum, and the cingulate gyrus (Dunker and Harris, 1976; Wolfram-Gabel et al., 1989; Vincentelli et al., 1991).

13.1.9.4. Perforating branches of the anterior cerebral artery

The anterior cerebral artery perforating branches are divided into two groups. The anterior cerebral artery direct perforators usually arise from the proximal precommunicating segment (Rosner et al., 1984; Marinkovic et al., 1986a) and the recurrent artery of Heubner, from the proximal post-communicating segment (Perlmutter and Rhoton, 1976; Gomes et al., 1984, 1986). These arteries supply the anterior and inferior part of the head of the caudate nucleus, the anterior and inferior portion of the anterior limb of the internal capsule (Beevor, 1908; Ostrowski et al., 1960; DeReuck, 1971a; Dunker and Harris, 1976), the adjacent part of the putamen and globus pallidus (Ostrowski et al., 1960; Dunker and Harris, 1976), the caudal rectus gyrus, the subcallosal gyrus (Marinkovic et al., 1986a, 1996), and a medial part of the anterior commissure.

13.1.9.5. Perforating branches of the middle cerebral artery

The perforating branches of the middle cerebral artery, known as lenticulostriate arteries, usually arise from the basal segment (Gibo et al., 1981; Rosner et al., 1984; Marinkovic et al., 1985). However, the origin of these perforating branches can vary and in a considerable number of cases they emerge from the cortical or early branches of the middle cerebral artery, cortical arteries arising from the main trunk of the middle cerebral artery proximal to its bifurcation or trifurcation (Marinkovic et al., 1996; Tanriover et al., 2003). Many classifications for the perforating branches of the middle cerebral artery have been proposed that are based on the distribution of the lenticulostriate arteries in two (Lazorthes, 1976) or three groups (Rosner et al., 1984; Umansky et al., 1984; Marinkovic et al., 1985). Nevertheless, they are usually classified into two groups: the medial and the lateral arteries (Stephens and Stilwell, 1969; Umansky et al., 1985). However, this disposition is variable and a common stem may be present. These perforating branches supply the superior part of the head and the body of the caudate nucleus, the lateral segment of the globus pallidus, the putamen, the dorsal half of the internal capsule, and the lateral half of the anterior commissure (Herman et al., 1963; Stephens and Stilwell, 1969; DeReuck, 1971a; Umansky et al., 1984).

13.1.9.6. Perforating branches of the posterior communicating artery

The posterior communicating artery arises from the midportion of the supraclinoid segment of the internal carotid artery and passes posteromedially to join the posterior cerebral artery. Seven to ten branches arise from the posterior communicating artery. The largest branch is termed the premammillary artery (anterior thalamoperforating artery or tuberothalamic artery) (Stephens and Stilwell, 1969; Gibo et al., 1981; Pedroza et al., 1987). The posterior communicating artery perforators supply the posterior portion of the optic chiasm and optic tract (Vincentelli et al., 1990) as well as the posterior part of the hypothalamus and mammillary body (Plets et al., 1970; Pedroza et al., 1987). The thalamic territory of the posterior communicating

Table 13.2

Anatomical structures of the cerebral hemispheres (sections XIII–XXIV)

Gyri (purple)	
CG	Cingulate gyrus
F1	Superior frontal gyrus
F2	Middle frontal gyrus
F3	Inferior frontal gyrus
F3op	Inferior frontal gyrus pars opercularis
F3or	Inferior frontal gyrus pars orbitalis
F3t	Inferior frontal gyrus pars triangularis
FMG	Frontomarginal gyrus
GR	Gyrus rectus
LOG	Lateral orbital gyrus
MOG	Medial orbital gyrus
PCu	Precuneus
POG	Posterior orbital gyrus
SCG	Subcallosal gyrus
PCL	Paracentral lobule
PoCG	Postcentral gyrus
PrCG	Precentral gyrus
AG	Angular gyrus
P1	Superior parietal gyrus
P2	Inferior parietal gyrus
SMG	Supramarginalis gyrus
T1	Superior temporal gyrus
T2	Middle temporal gyrus
T3	Inferior temporal gyrus
T4	Fusiform gyrus
T5	Parahippocampal gyrus
TTG	Transverse temporal gyrus
O1	Superior occipital gyrus
O2	Middle occipital gyrus
O3	Inferior occipital gyrus
O4	Fusiform gyrus
O5	Lingual gyrus
O6	Cuneus
GD	Gyrus descendens (Ecker)
RSG	Retrosplenial gyrus
Sulci (brown)	
AOS	Anterior occipital sulcus
CaS	Calcarine sulcus
CiS	Cingulate sulcus
CoS	Collateral sulcus
CS	Central sulcus
IFS	Inferior frontal sulcus
IOS	Intra-occipital sulcus (superior occipital sulcus)
IPS	Intraparietal sulcus
LF	Lateral fissure
LS	Lingual sulcus
OS	Olfactory sulcus
PCS	Paracentral sulcus
PoCS	Postcentral sulcus
POF	Parieto-occipital fissure
PrCS	Precentral sulcus
RCS	Retrocalcarine sulcus
SFS	Superior frontal sulcus
SPS	Subparietal sulcus
STS	Superior temporal sulcus (parallel sulcus)
TOS	Transverse occipital sulcus
Internal structures (green)	
CN	Caudate nucleus
CNh	Caudate nucleus, head
CNt	Caudate nucleus, tail
IA	Internal capsule, anterior limb
IG	Internal capsule, genu
IP	Internal capsule, posterior limb
NA	Nucleus accumbens
P	Putamen
PL	Globus pallidus, pars lateralis
PM	Globus pallidus, pars medialis
SN	Septal nuclei
A	Anterior thalamic nucleus
CM	Centromedian thalamic nucleus
DM	Dorsomedial thalamic nucleus
LD	Lateral dorsal thalamic nucleus
LP	Lateral posterior thalamic nucleus
Pu	Pulvinar
VA	Ventral anterior thalamic nucleus
VL	Ventral lateral thalamic nucleus
VPL	Ventral posterolateral thalamic nucleus
C	Claustrum
CR	Corona radiata
IN	Insula
LI	Limen insulae
CC	Corpus callosum
F	Fornix
Hb	Hippocampus, body
Hh	Hippocampus, head
Ht	Hippocampus, tail
AC	Anterior commissure
Amg	Amygdala
APS	Anterior perforated substance
CrC	Crus cerebri
GA	Gyrus ambiens
H	Hypothalamus
LB	Lateral geniculate body
M	Mammillary body
MB	Medial geniculate body
MT	Mammillothalamic tract
OR	Optic radiations
OT	Olfactory tract
ST	Subthalamic nucleus
T	Tuber

Brodmann's areas (blue).
Colors refer to usual colors used in anatomy illustration.

artery includes the nucleus anterior and the polar part of the nucleus ventralis anterior and of the nucleus reticularis (Stephens and Stilwell, 1969; Plets et al., 1970; Percheron, 1976a).

13.1.9.7. Thalamoperforating branches

The thalamoperforating (or paramedian thalamic) arteries form a part of the interpeduncular arteries. The latter, which penetrate the posterior perforating substance, can be divided into three groups: the inferior, middle, and superior rami (Pedroza et al., 1986; Duvernoy, 1995, 1999). While the inferior rami originate from the basilar bifurcation or the P1 segment of the posterior cerebral artery, the middle and superior rami arise as single or common trunks from the P1. The inferior and middle rami supply the brainstem (pons and brain; Duvernoy, 1999). Only the superior rami corresponding to the thalamoperforating arteries contribute to the supply of the thalamus. Furthermore, they supply the medial nuclei, the intralaminar nuclei, a part of the dorsomedial nucleus, the posteromedial portion of the lateral nuclei, and the ventromedial pulvinar (Stephens and Stilwell, 1969; Plets et al., 1970; Percheron, 1976b).

13.1.9.8. Thalamogeniculate branches

The thalamogeniculate arteries (inferolateral thalamic arteries) usually arise as individual vessels from the posterior cerebral artery segment in proximity to the geniculate bodies (Saeki and Rhoton, 1977; Zeal and Rhoton, 1978; Yamamoto and Kageyama, 1980; Milisavljevic et al., 1991). These vessels are known to be part of the arterial anastomotic network of the geniculate bodies (Stephens and Stilwell, 1969; Alicherif et al., 1977). They supply the major part of the lateral side of the caudal thalamus, including the rostrolateral part of the pulvinar, the posterior part of the lateral nuclei and lateral dorsal nucleus, and the ventral posterior and ventral lateral nuclei (Stephens and Stilwell, 1969; Plets et al., 1970; Percheron, 1977).

13.1.9.9. Posterior choroidal arteries

The posterior choroidal group includes usually one or two medial and one to six lateral posterior choroidal arteries (Fujii et al., 1980; Vinas et al., 1995). The medial posterior choroidal artery usually arises from the proximal perimesencephalic segments of the posterior cerebral artery (Zeal and Rhoton, 1978; Fujii et al., 1980; Yamamoto and Kageyama, 1980). The lateral posterior choroidal artery arises directly from the posterior cerebral artery (distal perimesencephalic segments of the posterior cerebral artery) or from a branch of the posterior cerebral artery (Zeal and Rhoton, 1978; Fujii et al., 1980; Yamamoto and Kageyama, 1980; Erdem et al., 1993). The medial posterior choroidal artery supplies the medial geniculate body, as well as the posterior part of the medial nucleus and of the pulvinar. The lateral posterior choroidal artery supplies part of the lateral geniculate

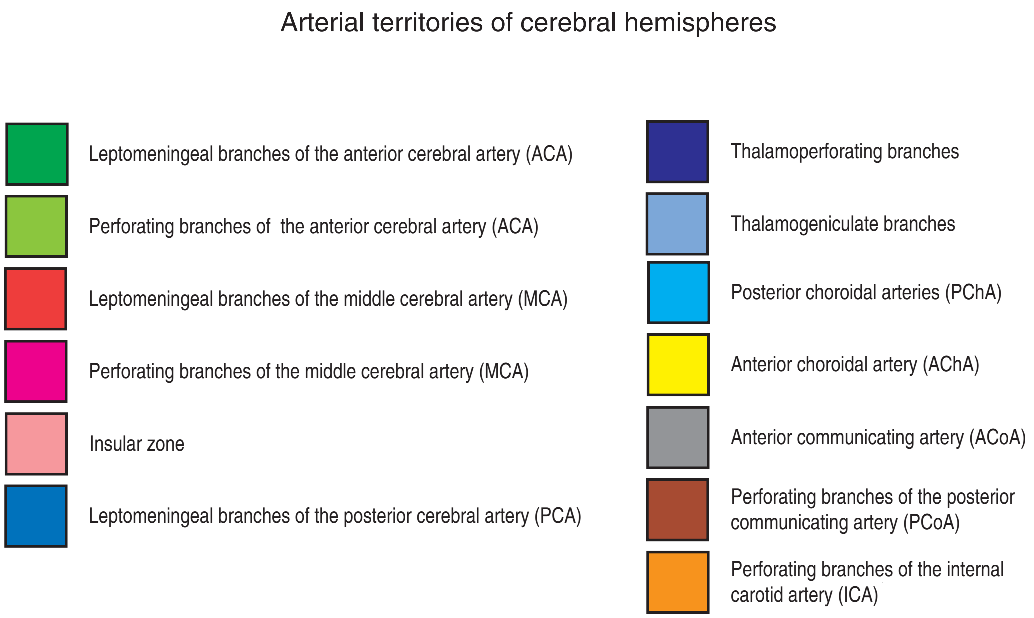


Fig. 13.6. (*facing and subsequent pages*). Structure of the cerebral hemispheres (sections XIII–XXIV). The key to anatomical structures is in Table 13.2.

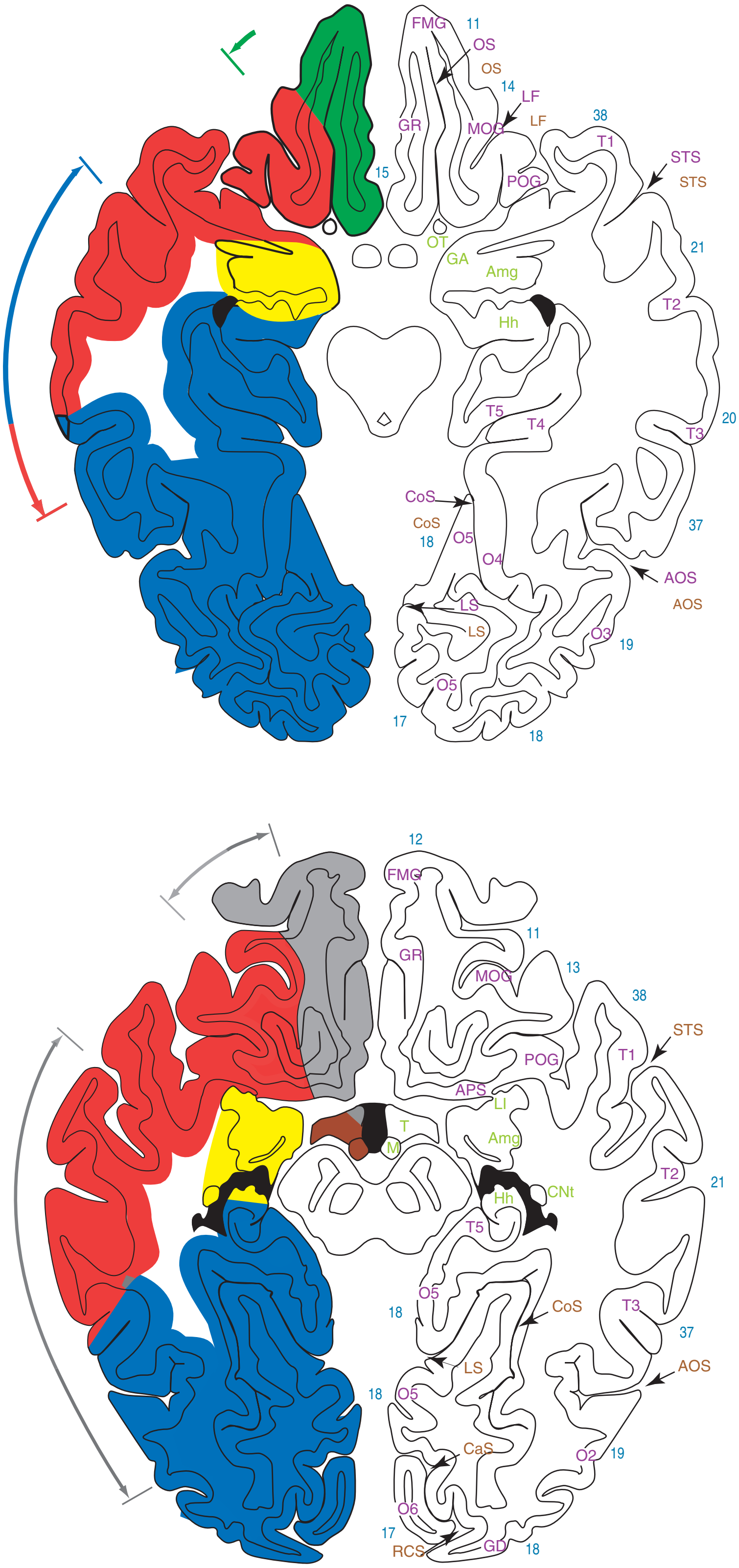
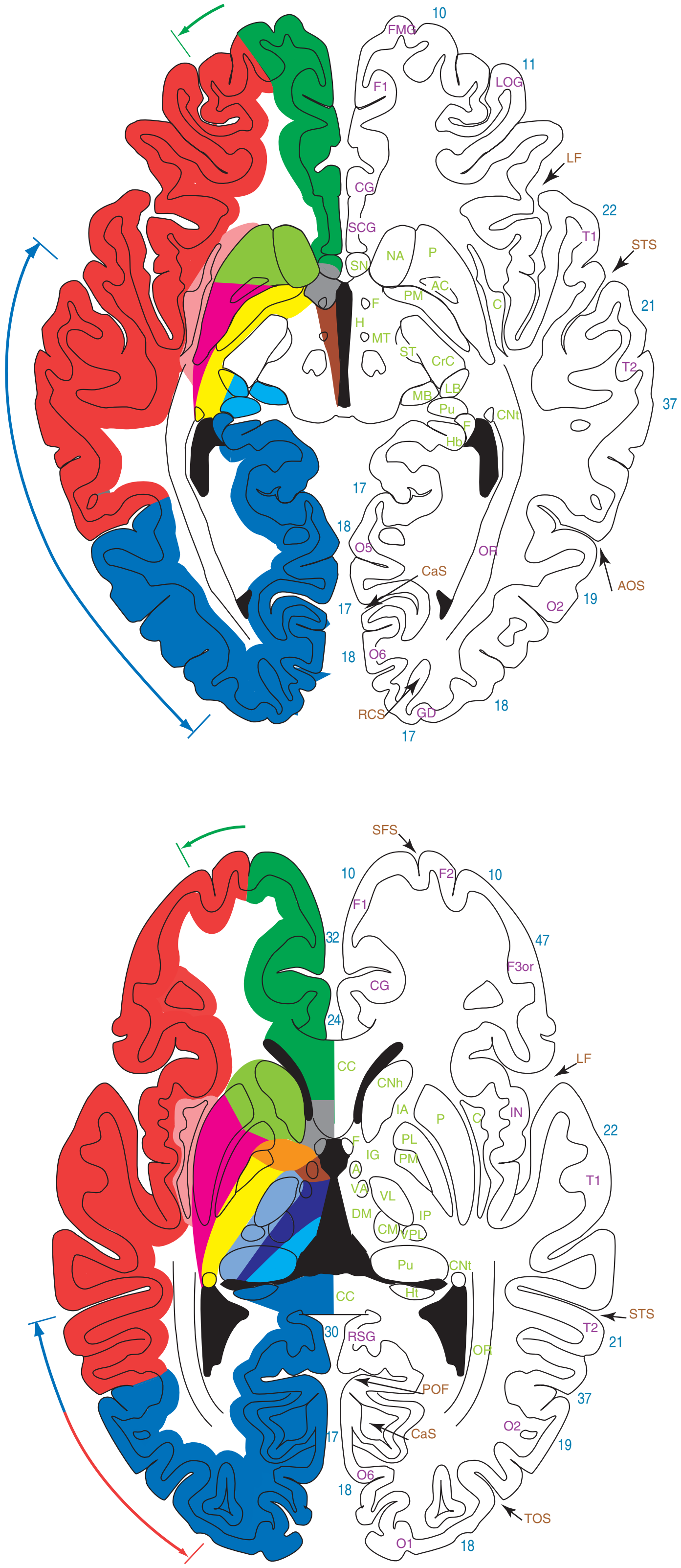


Fig. 13.6. *Continued*



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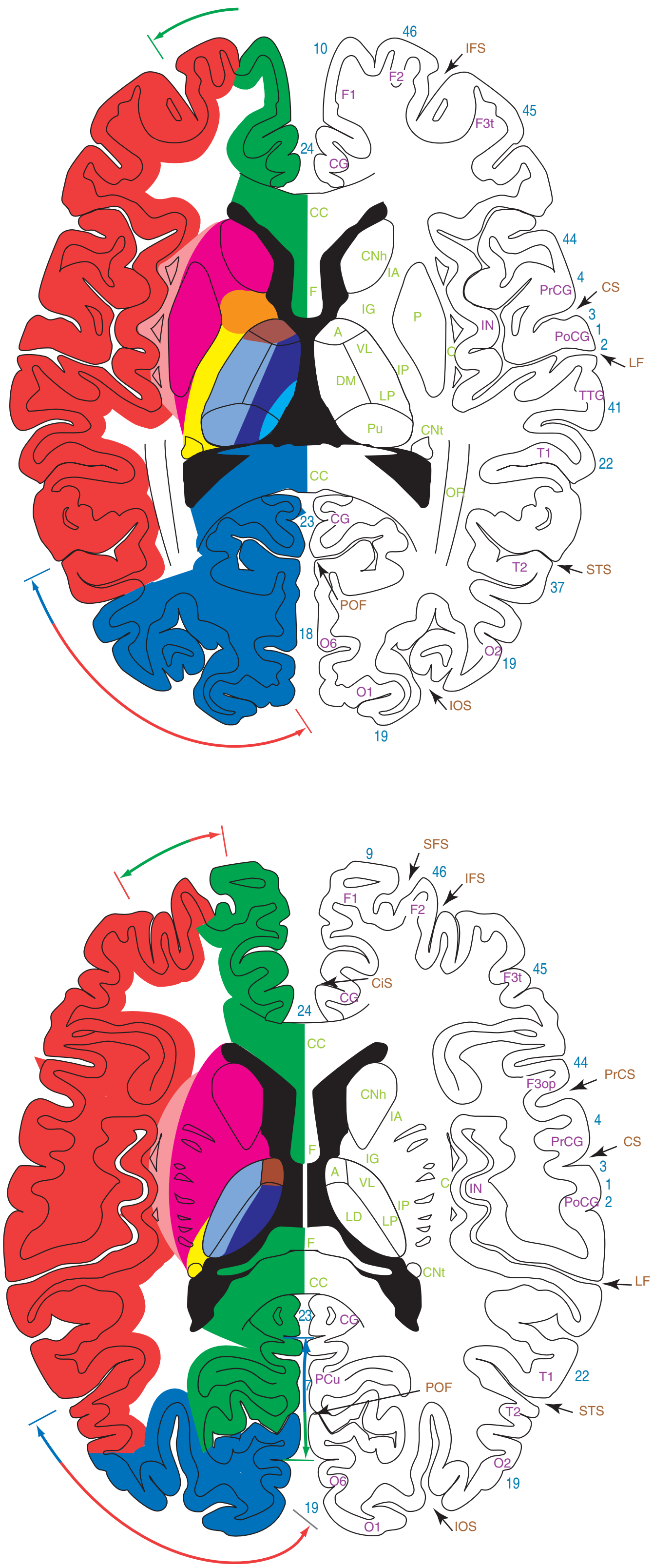

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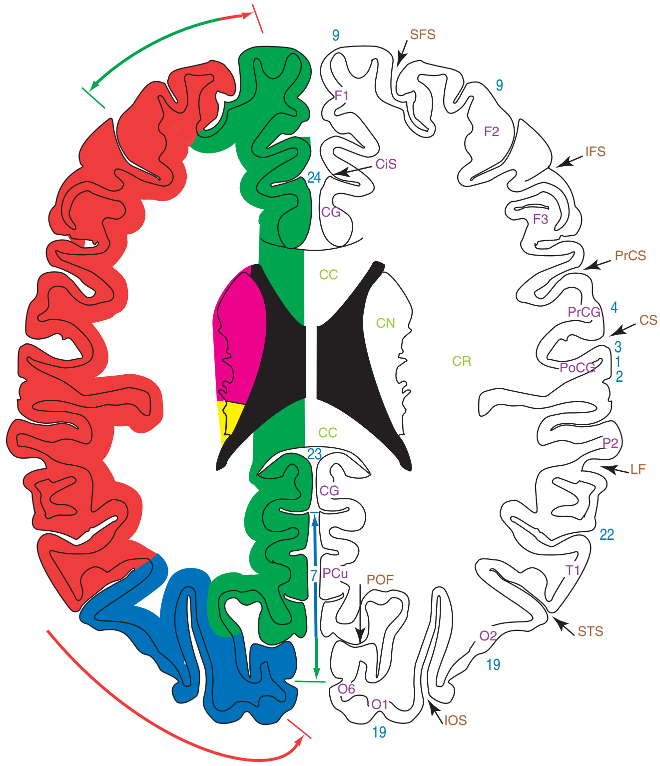

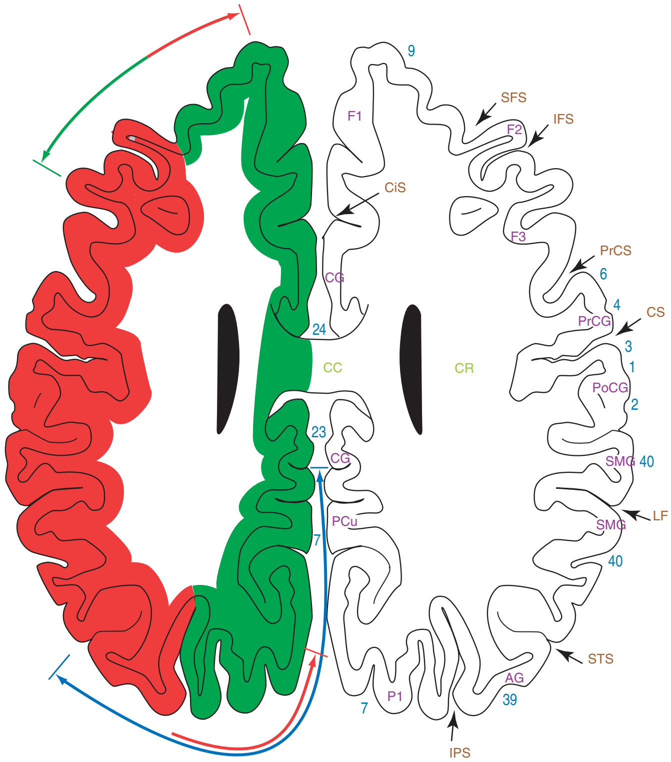

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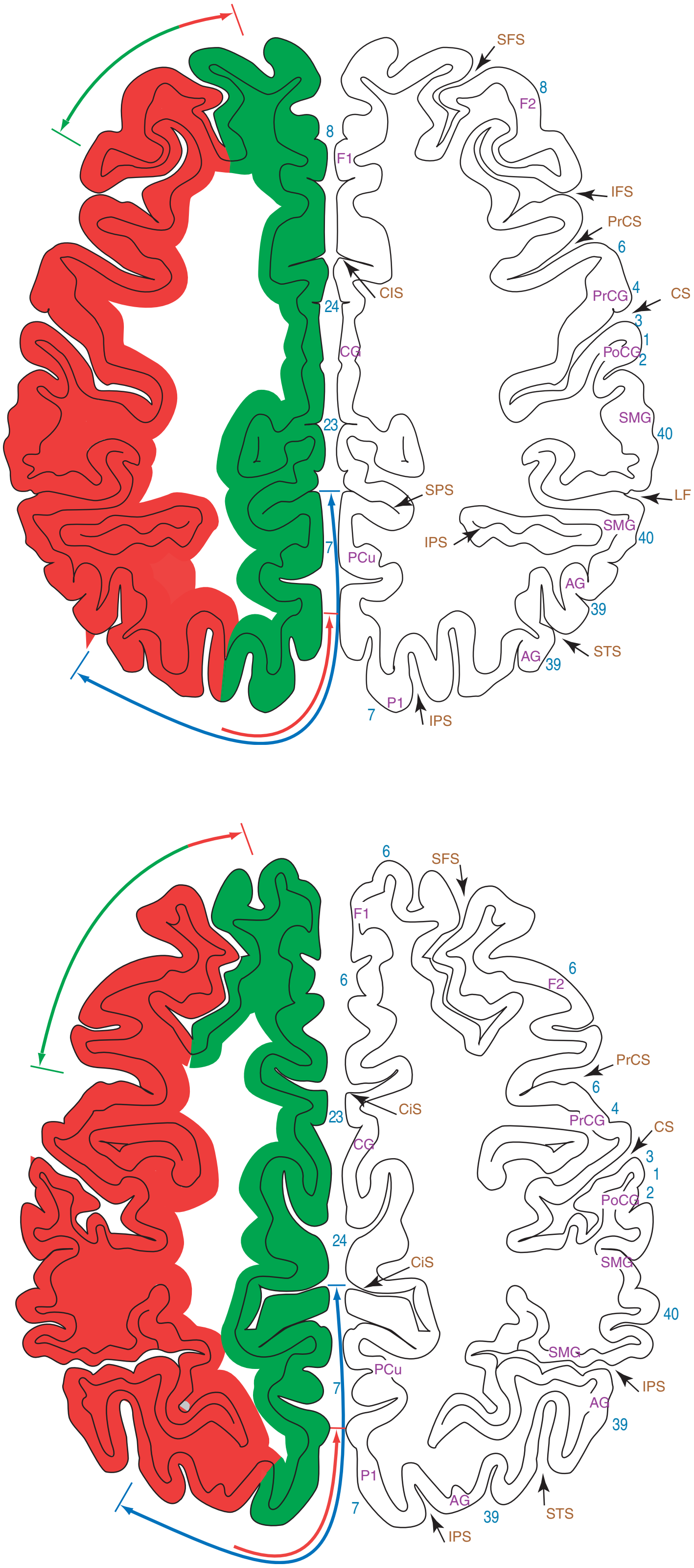

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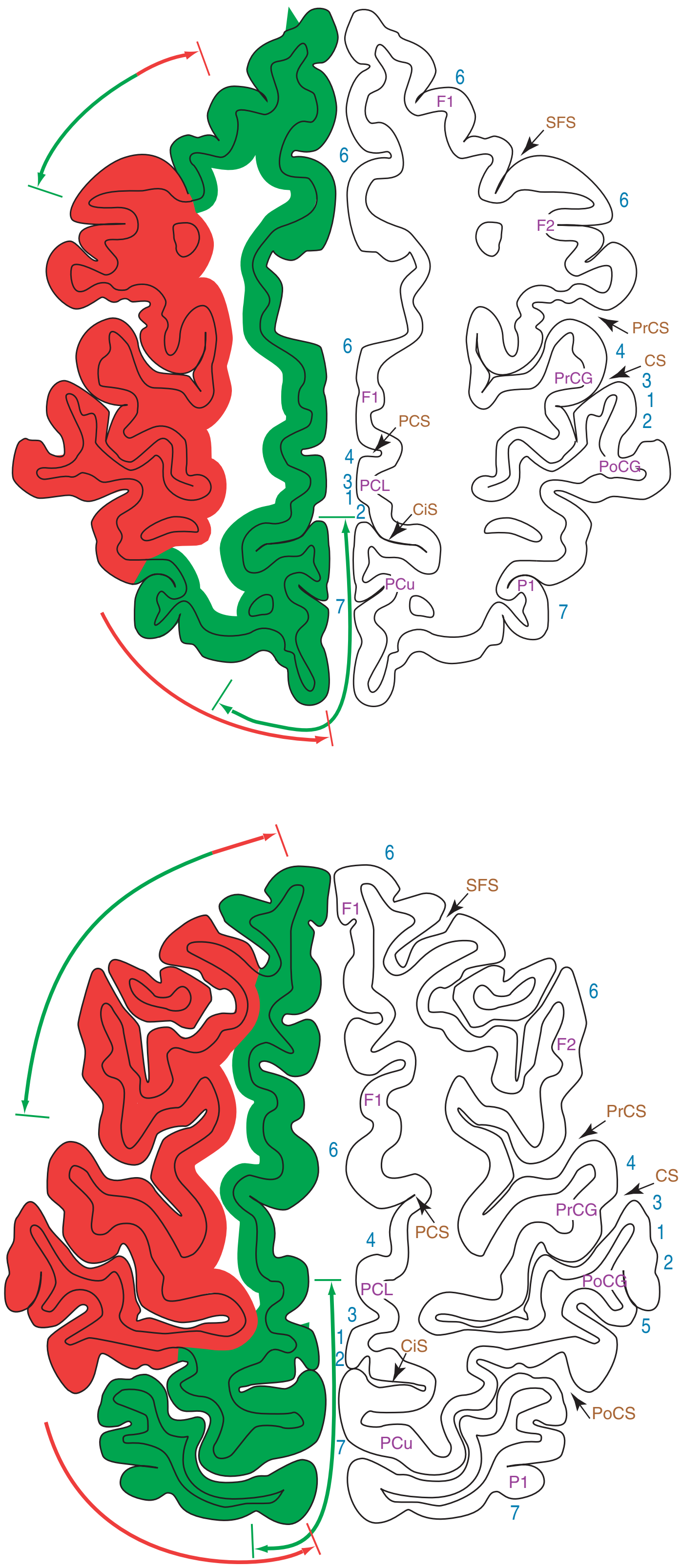

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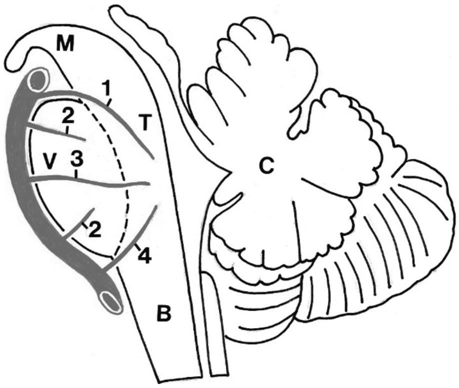


1. Descending arteries (inferior rami of the interpeduncular fossa) supplying the upper part of the pontine tegmentum
2. Arteries with a straight path supplying ventral part of the pons
3. Arteries with a straight path supplying the middle part of the pontine tegmentum
4. Ascending arteries penetrating the foramen cecum and supplying the lower part of the pontine tegmentum

Fig. 13.7. Sagittal section of the pons showing the paths of different pontine arteries arising from the basilar artery. B, medulla; C, cerebellum; M, midbrain; T, pontine tegmentum; V, ventral part of the pons.

body, part of the dorsomedial nucleus, and part of the pulvinar (Stephens and Stilwell, 1969; Plets et al., 1970; Alicherif et al., 1977; Percheron, 1977).

13.1.10. Leptomeningeal branches of the cerebral arteries

13.1.10.1. Leptomeningeal branches of the anterior cerebral artery

The distal segment of the anterior cerebral artery, the pericallosal artery, gives rise to the cortical and the callosal branches. The callosal branches supply the rostrum, genu, and body of the corpus callosum. These branches join together posterior to the splenial branches of the posterior cerebral artery. In the most frequent disposition, the anterior cerebral artery supplies the cortical area of the medial surface of the hemisphere extending to the superior frontal sulcus and the parieto-occipital sulcus. On the orbitofrontal surface, the arterial territory includes the medial orbital gyri. At its greatest the cortical anterior cerebral artery territory reaches the inferior frontal sulcus and at its smallest it includes only the anterior part of the frontal lobe.

13.1.10.2. Leptomeningeal branches of the middle cerebral artery

The middle cerebral artery begins its division into cortical arteries at the base of the sylvian fissure and extends over the surface of the hemisphere to form the M4 segment. The middle cerebral artery most frequently distributes to the area on the lateral surface of the hemisphere that extends to the superior frontal sulcus, the intraparietal sulcus, and the inferior temporal gyrus. On the orbitofrontal surface, the arterial territory includes the lateral orbital gyri. The maximum area supplied by the middle cerebral artery covers the whole lateral surface of the hemisphere, reaching the interhemispheric fissure, whereas the minimum area is confined to the territory between the inferior frontal and the superior temporal sulci.

13.1.10.3. Leptomeningeal branches of the posterior cerebral artery

As the posterior cerebral artery approaches the dorsal surface of the midbrain, it gives rise to cortical branches. These branches include the hippocampal arteries and the splenial artery, which anastomose with the distal part of the pericallosal artery to supply the splenium of the corpus callosum. The most frequent cortical distribution of the posterior cerebral artery includes the inferomedial surfaces of the temporal and the occipital lobe extended to the parieto-occipital fissure. At its greatest, the cortical supply can extend as far as the superior temporal sulcus and the upper part of the precentral sulcus and its smallest only as far as the medial face of the occipital lobe limited by the parieto-occipital fissure.

13.1.11. Some debated aspects of brain arterial supply

13.1.11.1. Supply to the centrum ovale and insular zone

The supply of blood to the centrum ovale is still under debate (DeReuck, 1971a; Moody et al., 1990). It includes transcortical arterioles having exclusive territory as well as terminal ramifications of some perforating branches. The lack of specific anatomical studies on the origin of the blood supply to the centrum ovale has meant that we do not take its supply into account on the brain maps.

The arterial supply of the external capsule/claustrum/extreme capsule area, which we have called the insular zone, is more complex than was first described by Shellshear (1920). According to Moody et al. (1990), this area has a triple blood supply: a double cortical supply, like the U-fibers, and lateral rami of the lateral striate arteries.

13.1.11.2. Participation of the anterior choroidal artery in thalamus blood supply

The participation of the anterior choroidal artery in supplying blood to the thalamus was initially suggested by Beevor (1908). This notion was subsequently reviewed in the studies of Abbie and more recent anatomical works and observations made in neurovascular pathology have fed the controversy (Abbie, 1933). Percheron (1977) affirmed the absence of 'a thalamic territory constituted by the anterior choroidal artery'. The existence of branches supplying the thalamus coming from the cisternal segment of the anterior choroidal artery and perforating the optic tract or the inferolateral part of the anterior perforated substance is frequently described. Plets et al. (1970) even proposed terming these branches that frequently reach the lateral thalamus the 'lateral ventral thalamic network'.

More recent anatomical studies have confirmed the participation of anterior choroidal artery branches in the laterodorsal thalamic supply in about 30% of cases (Morandi et al., 1996; Cosson et al., 2003). Two types of branch are described: cisternal perforating branches of the anterior choroidal artery running towards the lateral thalamus and other branches perforating the temporal horn of the lateral ventricle and running towards the pulvinar (Cosson et al., 2003).

13.2. Venous circulation of the brain

13.2.1. General organization

The cerebral venous system is far more variable than the arterial system. It is usually systematized in four broad units: cortical cerebral veins, deep cerebral veins, posterior fossa veins, and dural sinuses. The dural sinuses collect all the venous blood of the brain that eventually enters the internal jugular veins to join the general venous circulation.

The brain's return circulation is not an exact model of its arterial system. The notion of venous territories is of little value, as few significant correlations exist between the site of venous occlusion and the topography of the corresponding infarction (Bergui et al., 1999). We thus present the cerebral veins and their main variations in a more descriptive manner; as they may appear on a magnetic resonance angiogram without reference to a map of venous territories.

13.2.2. Cortical cerebral veins

Cortical cerebral veins drain the cerebral cortex and the subcortical white matter, in particular the U-fibers, by the superficial transcerebral (superficial medullary) venous system. The cortical venous system is extremely variable. Even if specific nomenclature for the cortical veins is sometimes proposed, it is of no practical value in neurology. The topographical groupings of these veins would appear to be more appropriate. Several types of grouping have been proposed (Stephens and Stilwell, 1969; Hacker, 1974; Lazorthes, 1976) but the classification most adapted to neurovascular practice is that of Lasjaunias and Berenstein (1990). They grouped these veins into three broad systems: (1) a dorsomedial system draining the high convexity and midline cortical veins mainly into the superior sagittal sinus, the inferior sagittal sinus, in the straight sinus or the great cerebral vein (of Galen); (2) a ventrolateral system draining temporo-occipital cortical veins into the lateral sinus; and (3) an anterior system draining the anterior temporal, parasylvian cortex, and anterior inferior frontal lobes into the cavernous sinus or the pterygoid venous plexus.

There are veins that anastomose in the cortical venous network. Apart from the random anastomoses that can occur between different cortical veins, two large-caliber anastomotic veins are usually described: the superior anastomotic vein (of Trolard) and the inferior anastomotic vein (of Labbé). The superior anastomotic vein (of Trolard) is the larger, crossing the cortical surface of the frontal and parietal lobes and joining the superior sagittal sinus with the superficial middle cerebral vein. It is most commonly located in the post-central area. The inferior anastomotic vein (of Labbé) is described as a complex of veins draining the posterior portion of the temporal lobe and forming an anastomosis between the superficial middle cerebral vein and the transverse sinus. This venous complex has a high degree of variability (Guppy et al., 1997).

13.2.3. Deep cerebral veins

The deep transcerebral (deep medullary) venous system drains the deep white matter into the subependymal vein of the ventricular wall and finally into the deep venous system. The deep cerebral veins are less variable than cortical veins. They drain the deep white matter, the periventricular regions, and the diencephalic structures (Chaynes, 2003; Kiliç et al., 2005).

13.2.3.1. Internal cerebral vein

Paired veins originate in the posterior aspect of the interventricular foramen (of Monro) by union of the anterior septal and thalamostriate veins. Both cerebral veins pass along the roof of the third ventricle and above the medullaris stria of the thalamus, between the two layers of the tela choroidea of the third ventricle. They run their course beneath the splenium of the corpus callosum and above the lateral aspect of the pineal body before joining to form the great cerebral vein (of Galen). The internal cerebral veins (Stephens and Stilwell, 1969; Stein and Rosenbaum, 1974; Lazorthes, 1976; Ono et al., 1984; Chaynes, 2003; Kiliç et al., 2005) receive the superior choroidal, septal, and thalamic veins (Fig. 13.8).

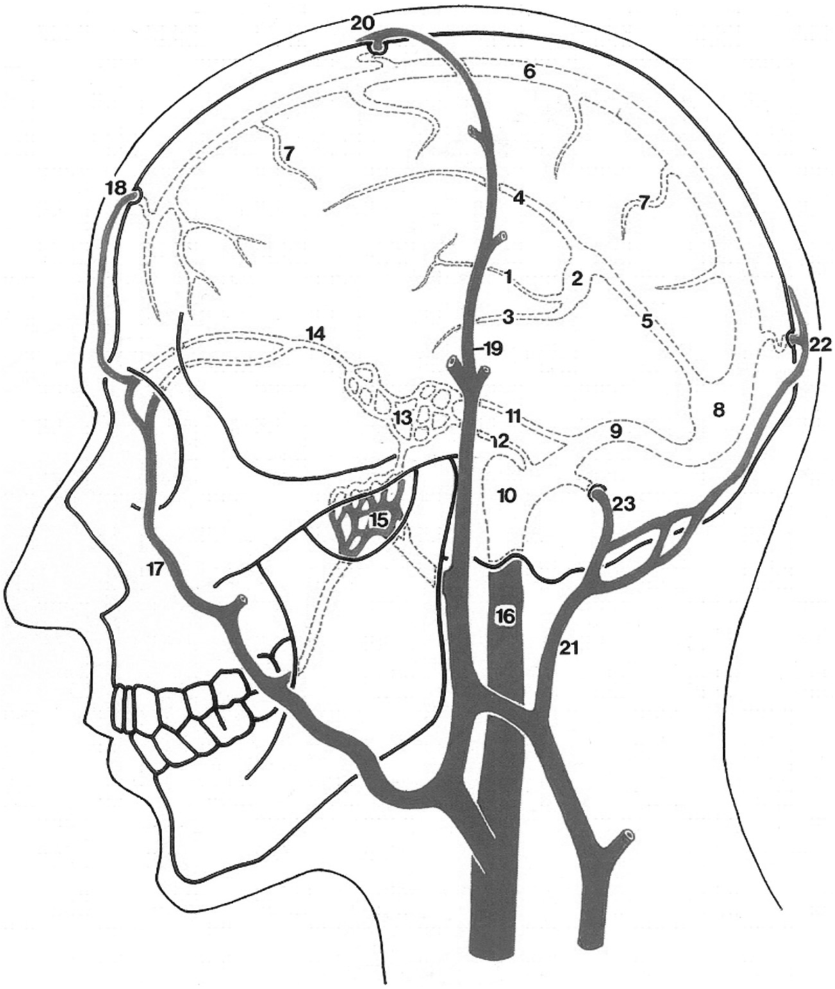
13.2.3.2. Great cerebral vein (of Galen)

The great cerebral vein (Stephens and Stilwell, 1969; Stein and Rosenbaum, 1974; Lazorthes, 1976; Ono et al., 1984; Chaynes, 2003; Kiliç et al., 2005) is a vessel that varies in length from 0.5 to 2 cm, originating under the splenium of the corpus callosum by the union of the two internal cerebral veins. The vein passes behind and above the splenium of the corpus callosum to terminate at the anterior junction of the falx cerebri and tentorium cerebelli. The inferior sagittal sinus joins the great cerebral vein to form the straight sinus (Fig. 13.8).

The most constant tributaries of the vein of Galen include: the internal cerebral veins, basal veins, superior cerebellar veins, superior vermian veins, precentral cerebellar vein, pineal veins, collicular veins, superior thalamic veins, internal occipital veins, and posterior pericallosal veins.

13.2.3.3. Basal vein (of Rosenthal)

The basal vein (Stephens and Stilwell, 1969; Huang and Wolf, 1974a; Lazorthes, 1976; Ono et al., 1984; Chaynes, 2003; Kiliç et al., 2005) represents, for the floor of the third ventricle, the equivalent of what the internal cerebral vein is to the roof of the third ventricle. Because of its size and anastomotic role with the superficial venous system, it occupies a special place in the deep venous system. The basal vein originates on the surface of the anterior perforated space by the union of the anterior cerebral, deep middle cerebral, and inferior striate veins. The basal vein circumvents



1. Internal cerebral vein
2. Great cerebral vein (of Galen)
3. Basal vein (of Rosenthal)
4. Inferior sagittal sinus
5. Straight sinus
6. Superior sagittal sinus
7. Cortical vein
8. Torcular herophili
9. Lateral sinus
10. Jugular foramen
11. Superior petrosal sinus
12. Inferior petrosal sinus
13. Cavernous sinus
14. Ophthalmic vein
15. Pterygoid plexus
16. Internal jugular vein
17. Facial vein
18. Frontal emissary vein
19. Superficial temporal vein
20. Parietal emissary vein
21. Occipital vein
22. Occipital emissary vein
23. Mastoidal emissary vein

Fig. 13.8. The venous circulation of the brain.

the cerebral peduncle at the uncus and pulvinar levels, where it flows into the great cerebral vein of Galen. Sometimes it terminates directly in an internal cerebral vein or in the sinus rectus. The principal veins flowing into the basal vein are the chiasmatic, hypothalamic, interpeduncular, and lateral mesencephalic veins, the veins of the temporal lobe and the lateral ventricle, and the inferior temporal veins (Fig. 13.9).

13.2.4. Dural venous sinuses

Dural venous sinuses (Stephens and Stilwell, 1969; Hacker, 1974; Lazorthes, 1976) are venous channels enclosed between the two layers of the dura mater. They drain blood from the brain, meninges, and skull. They communicate with the meningeal and diploic veins and with the extracranial venous system through emissary veins (Fig. 13.8).

The principal dural sinuses are the superior sagittal sinus, the inferior sagittal sinus, the straight sinus, the lateral sinus, the occipital sinus, the superior petrosal sinuses, the sphenoparietal sinuses, the sinuses of the tentorial venous, and the cavernous sinus. The superior sagittal, straight, lateral, and occipital sinuses converge at the posterior confluence of the sinuses opposite the internal occipital protuberance. The cavernous sinuses drain the superior and inferior petrosal sinuses and the sphenoparietal sinuses.

Some sinuses, such as the tentorial venous sinus, that are present in variable numbers and flow essentially into the lateral sinuses, have a more surgical than medical value (Muthukumar and Palaniappan, 1998).

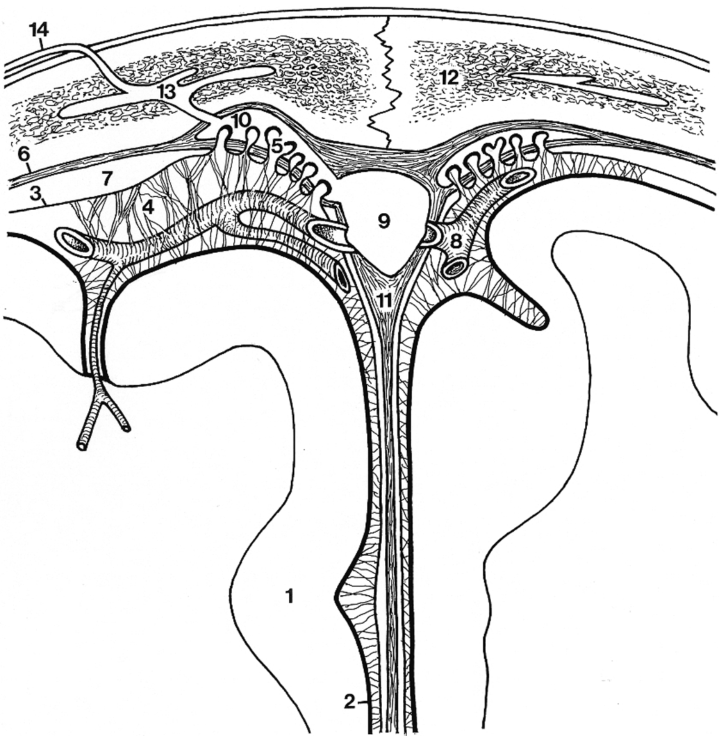
13.2.4.1. Superior sagittal sinus

The superior sagittal sinus is contained within the dura mater at the junction of the falx cerebri and the attachment of the falx to the cranial vault. The superior sagittal sinus extends anterior to the foramen cecum posterior to the torcular herophili, increasing gradually in size. It communicates with the nasal veins by the emissary vein of the foramen cecum and behind it flows into the confluence of sinuses. One frequent variation is the termination of the superior sagittal sinus in one of the transverse sinuses, especially the left one (Bisaria, 1985a).

The superior sagittal sinus communicates, by lateral expansions, with the arachnoid granulations of Pacchioni and constitutes one of the main sites of resorption of cerebrospinal fluid (Fig. 13.9). In its anterior portion, it can be replaced by two frontal parasagittal veins. It receives venous blood from the frontal, superior, medial, and lateral surfaces of the cerebral hemispheres (Fig. 13.8).

13.2.4.2. Inferior sagittal sinus

The inferior sagittal sinus lies within the free margin of the falx cerebri. It begins near the junction of the



1. Cerebral cortex
2. Pia-mater
3. Arachnoid
4. Arachnoidal trabeculations
5. Arachnoidal granulations
6. Dura-mater
7. Sub-dural space
8. Cortical vein
9. Superior sagittal sinus
10. Lateral expansions of superior sagittal sinus
11. Falx cerebri
12. Calvaria
13. Diploic vein
14. Emissary vein

Fig. 13.9. Coronal section of the superior sagittal sinus.

anterior and middle third of the falx by the union of veins from the falx and a variable number of corpus callosum and cingulum veins. It extends backwards, increasing in size, until it enters the straight sinus with the great cerebral vein of Galen (Fig. 13.8).

13.2.4.3. Straight sinus

The straight sinus originates behind the splenium of the corpus callosum by the union of the inferior sagittal sinus and the great cerebral vein of Galen. It runs its course along the line of junction of the falx cerebri and the tentorium cerebelli to the torcular herophili. The straight sinus may receive cerebellar veins near its termination. Some segments of the straight sinus can be doubled or tripled. Venous patterns at the junctions of the inferior sagittal sinus, vein of Galen, and straight sinus show comparable developmental inconstancies (Browder et al., 1976) (Fig. 13.8).

13.2.4.4. Lateral sinus

The lateral sinuses extend bilaterally from the internal occipital protuberance to the jugular foramen and divide into two segments: the transverse sinus and the sigmoid sinus. The first horizontal segment, known as the transverse sinus, follows its course in the bony sulcus of the layer of the occipital bone that corresponds to the tentorium cerebelli. The second S-shaped segment, called the sigmoid sinus, bends inwards at the petrous part of the temporal bone and descends along the petromastoid fissure towards the jugular foramen. The lateral sinuses are frequently asymmetrical, the right lateral sinus more often draining the superior sagittal sinus.

The transverse sinus receives the veins from the lateral and inferior parts of the temporal and occipital lobes as well as the cerebellar veins. The sigmoid sinus receives the superior petrous sinuses and the veins from the pons and the medulla oblongata (Fig. 13.10).

13.2.4.5. Occipital sinus

The occipital sinus is a small venous channel situated near the attachment of the falx cerebri. It passes upward from the margin of the foramen magnum to drain into the torcular herophili. It communicates with the internal vertebral venous plexus and the marginal sinus that surrounds the foramen magnum (Fig. 13.10).

13.2.4.6. Superior petrosal sinuses

The superior petrosal sinuses run along each side of the superior surface of the petrous part of temporal bone at the level of the insertion of the tentorium cerebelli and extend from the initial part of the sigmoid sinus to the posterior part of the cavernous sinuses. They can receive veins from the brainstem (Fig. 13.8).

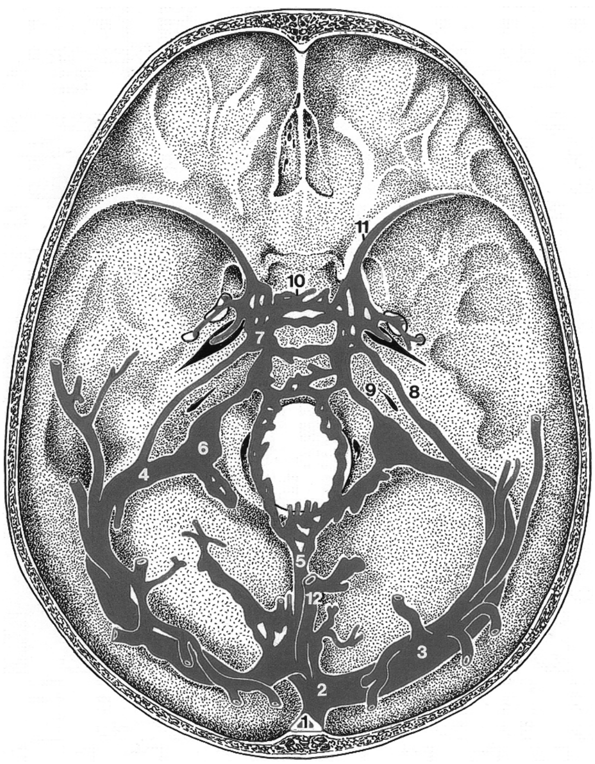


Fig. 13.10. The dural sinuses at the base of the skull.

13.2.4.7. Inferior petrosal sinuses

The inferior petrosal sinuses run along each side of the petrobasilar suture from the posteroinferior part of the cavernous sinus to the jugular foramen. They can also receive veins from the brainstem (Fig. 13.8).

13.2.4.8. Sphenoparietal sinuses

The sphenoparietal sinus is the continuation of the anterior middle meningeal vein. It arches just beneath the union of the greater wing of the sphenoid and the orbital surface of the frontal bone to reach the cavernous sinus. There are conflicting views regarding the site of drainage of the superficial middle cerebral vein. It is often regarded as terminating in the sphenoparietal sinus or as an independent vein terminating in isolation in the cavernous sinus (Bisaria, 1985b; San Millán Ruíz et al., 2004) (Fig. 13.10).

13.2.4.9. Cavernous sinus

The cavernous sinus is made up of two parts located on both sides of the hypophysial fossa and joined by the intercavernous sinuses contained in the diaphragma sellae and the basilar plexus. It extends to the superior orbital fissure at the front, to the foramen lacerum behind, and laterally to the foramen ovale. The cavernous sinus is a venous confluence of blood from the meninges, the orbital cavity, the brain, and the extracranial blood, particularly by its connection with the facial vein. It constitutes a rigid space in which the internal carotid artery beats, surrounded by the sympathetic plexus, by veins, and by the abducens nerve. The oculomotor, trochlear, and ophthalmic nerves pass along the lateral wall of the cavernous sinus.

At the front, the cavernous sinus drains the superior and inferior ophthalmic veins and the sphenoparietal sinus and communicates with the pterygoid plexus by veins in the foramen rotundum. The cavernous sinus joins the pterygoid plexus laterally, through the veins of foramen ovale. At the back, the cavernous sinus is connected to the basilar plexus, to the transverse sinus through the superior petrosal sinus, and to the internal jugular vein through the inferior petrosal sinus (Fig. 13.10).

13.2.4.10. Emissary veins

An anastomotic system exists between the superficial veins of the face and the scalp and the dural sinuses. This system is represented by the emissary veins. The frontal emissary vein, one of the most consistent veins, is worthy of mention. It unites the facial vein and the superior sagittal sinus, the parietal emissary vein, which unites the branches of the superficial temporal vein and the superior sagittal sinus, the occipital emissary vein, which unites the occipital vein to the torcular, and the mastoidal emissary vein, which unites the occipital vein and the lateral sinus. Numerous other emissary veins use the foramen of the base of the skull to reach the pterygoid plexus (Fig. 13.8).

13.2.5. Posterior fossa veins

13.2.5.1. Brainstem veins

The disposition of the brainstem veins (Stephens and Stilwell, 1969; Huang and Wolf, 1974b; Duvernoy, 1975; Lazorthes, 1976; Matsushima et al., 1983; Fig. 13.11) is similar to that of the veins in the spinal cord. Three large venous currents can be described: anterior, lateral, and dorsal veins.

13.2.5.1.1. Anterior veins

The anterior veins are organized around an anteromedian axis formed by the anteromedian medullary vein. They run in the anteromedian medullary sulcus following the anterior spinal vein and being followed by the anteromedian pontine vein. The latter communicates with the two interpeduncular veins, which join the basal veins.

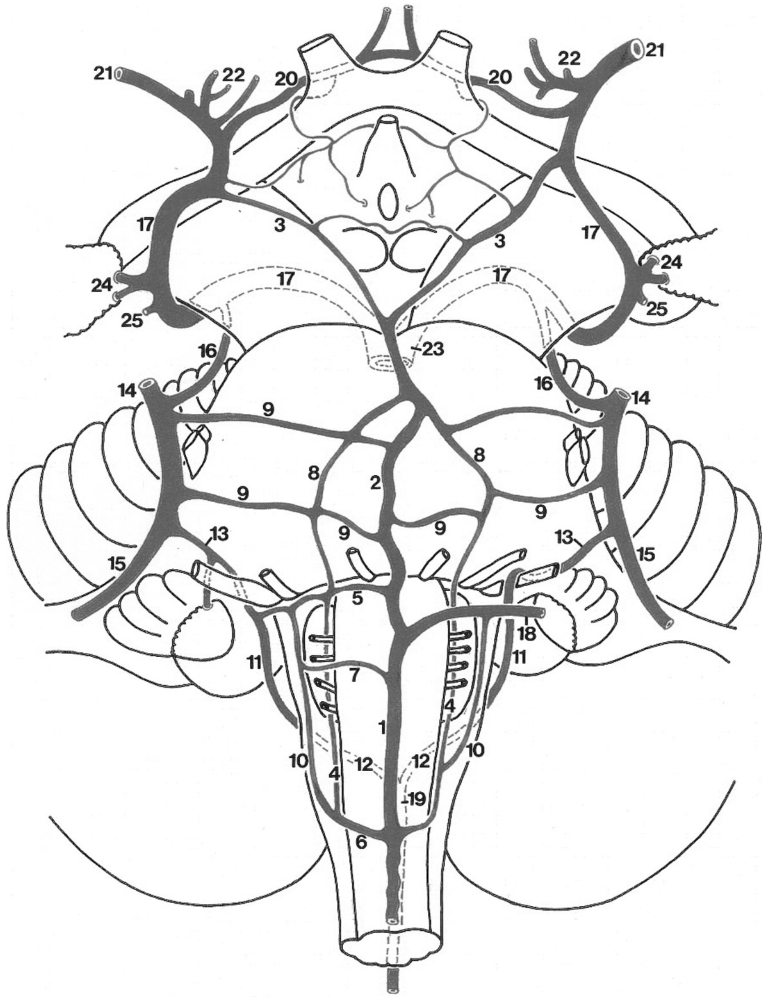
An anterolateral system can sometimes form at the level of the medulla oblongata by the lateral anterior medullary veins (preolivary veins) and partially hidden by the rootlets of the hypoglossal nerve. It is connected above by the pontomedullary sulcus vein and below with the inferior transverse medullary vein uniting the anteromedian system to the anterolateral one. Other transverse medullary veins unite the two systems. The lateral anterior medullary system can sometimes be prolonged by an anterolateral pontine system connected by transverse veins to the anteromedial pontine system.

13.2.5.1.2. Lateral veins

Two longitudinal veins participate in the lateral medullary system: the lateral medullary vein and the retro-olivary vein. The lateral medullary vein follows a course slightly dorsal to the retro-olivary sulcus along the rootlets of the accessory, vagus, and glossopharyngeal nerves. It receives the inferior cerebellar peduncle vein and flows into the pontomedullary sulcus vein to form the lateral pontine vein.

The retro-olivary vein runs a course parallel to the lateral medullary vein but is anterior to it and has a smaller caliber. It is usually connected below to the inferior transverse medullary vein and above to the pontomedullary sulcus vein.

An important element for lateral drainage called the superior petrosal vein (of Dandy) is situated at



1. Antero-median medullary vein
2. Antero-median pontine vein
3. Interpeduncular vein
4. Lateral anterior medullary (pre-olivary) vein
5. Ponto-medullary sulcus vein
6. Inferior transverse medullary vein
7. Transverse medullary vein
8. Antero-lateral pontine vein
9. Transverse pontine vein
10. Retro-olivary vein
11. Lateral medullary vein
12. Inferior cerebellar peduncle vein
13. Lateral pontine vein
14. Superior petrosal vein
15. Anterior cerebellar vein
16. Lateral mesencephalic vein
17. Basal vein
18. Inferior petrosal vein
19. Postero-median medullary vein
20. Anterior cerebral vein
21. Deep middle cerebral vein
22. Inferior striate veins
23. Great cerebral vein (of Galen)
24. Vein of the temporal horn
25. Inferior temporal vein

Fig. 13.11. The posterior fossa veins.

the pontomesencephalic level. It is formed by the union of the anterior cerebellar vein, which emerges from the horizontal fissure of the cerebellum and receives the lateral pontine vein, transverse pontine veins, and lateral mesencephalic vein arriving from the basal vein (of Rosenthal). The superior petrosal vein flows into the superior petrosal sinus. In certain cases, an inferior petrosal vein can exist, forming a lateral drainage pathway of the anteromedial medullary vein.

13.2.5.1.3. Dorsal veins

The posteromedian medullary vein is an upward prolongation of the posteromedian spinal vein. It divides into two branches at the obex level: the inferior cerebellar peduncle veins, which pass along the fourth ventricle and flow into the lateral medullary veins draining the choroidal plexus and the floor of the fourth ventricle. The posterior system and the lateral and anterolateral systems are widely anastomosed by veins surrounding the lateral sides of the medulla oblongata.

At the mesencephalic level, dorsal drainage is carried out by the basal veins, the lateral mesencephalic veins, and the epithalamic veins.

13.2.6. Cerebellar veins

The collecting veins of the cerebellum (Stephens and Stilwell, 1969; Huang and Wolf, 1974b; Lazorthes, 1976; Matsushima et al., 1983) run over its external surfaces. The precise morphological description of these veins is well known but is of chiefly neurosurgical interest. At a functional level, they are usually classed into three principal groups: superior, inferior, and anterior cerebellar veins.

The group of *superior cerebellar veins* comprises the superior vermian veins, which drain the upper part of the vermis, the superior hemispheric veins, which drain the adjacent part of the hemispheres, and the veins from the precentral cerebellar sulcus. The mesencephalic and pineal veins also participate in draining the upper part of the cerebellum. These veins all flow into the great cerebral vein (of Galen).

The veins of the *inferior group* drain the inferior part of the cerebellum. They may also be divided into inferior vermian veins, inferior hemispheric veins, and tonsillar veins. The inferior vermian veins usually consist of two large veins arising from the undersurface of the vermis. They empty into the dural sinus near the torcular. The inferior hemispheric veins arise on the inferior surface of the hemisphere and run to the transverse sinus.

The veins of the *anterior group* are chiefly represented by the anterior cerebellar veins. In particular, they drain venous blood from the middle part of the hemispheres and the lateral recess of the fourth ventricle. They flow into the superior petrosal vein, which joins the superior petrosal sinus (Fig. 13.11).

13.3. The arterial circulation of the spinal cord

Unlike the brain, which receives its blood supply from arteries having a common origin in the aortic arch, the spinal cord is supplied by arteries of diverse origin (Herren and Alexander, 1939; Gillilan, 1958; Corbin, 1961; Turnbull et al., 1966; Lazorthes et al., 1973; Lasjaunias and Berenstein, 1990; Rodriguez-Baeza et al., 1991; Alleyne et al., 1998). The arterial architecture is organized around horizontal axes; the radicular arteries, which anastomose with the longitudinal axes, the anterior, and posterior spinal axes. It is also possible to view the arterial blood supply of the spinal cord in three different networks: the intraspinal arteries, the perispinal arteries forming a pial network organized around the longitudinal axes, and the extraspinal radicular arteries.

The density of arterial supply to the spinal cord varies according to each level. The cervical and lumbosacral segments are richly supplied whereas the thoracic segment has few arteries (Fig. 13.12).

13.3.1. Radicular arteries

Each radicular artery penetrates the spine following the spinal nerve and then its roots. It has an ascending movement whose obliqueness depends on the spinal level in question. In the early stages of development, each nerve carries a radicular artery, which divides into a ventral branch that follows the ventral root of the nerve and a dorsal branch that follows the dorsal root. The arterial blood supply is therefore clearly segmented in response to the metameric nature of the spinal cord. Arterial desegmentation occurs throughout the development. Certain arteries regress and others hypertrophy, resulting in the adult disposition. The theoretical figure of 62 radicular arteries is thus never reached.

The radicular artery penetrates the dura mater, which it supplies with blood, and disappears quite deeply in the vertebral canal supplying blood to the roots to the spinal nerve, the pia mater, and in certain cases the spinal cord. The radicular arteries have been classed into three groups: radicular arteries, radiculopial arteries and radiculomedullary arteries.

13.3.1.1. Radicular arteries

This is the most spindly of the three types. They represent the minimal contribution of the embryonic segmental system to the neural crest derivatives. The arteries disappear in the roots before reaching the pia mater and the spinal cord. They are not involved in supplying blood to the spinal cord.

13.3.1.2. Radiculopial arteries

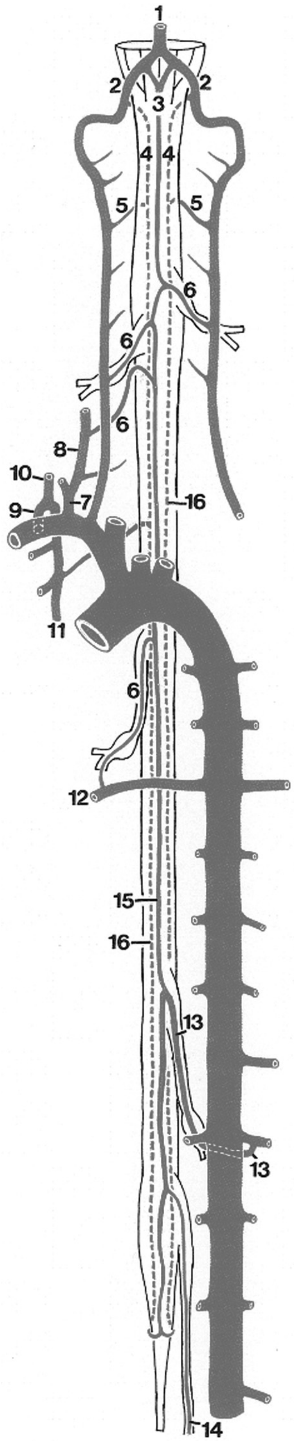
These correspond to a group of arteries that reach the spinal cord pial network. They supply the spinal nerve root and run ventral to its anterior root or ventral to its dorsal root to reach the spinal cord surface. They participate in the pial network, which gives off radial perforators centripetally to the spinal cord. Radiculopial arteries do not participate in the supply of the anterior spinal axis but may be anastomosed with the anterior spinal axis. They participate in the posterior arterial axis.

13.3.1.3. Radiculomedullary arteries

These represent the arteries that contribute in both the segmental and longitudinal supply to the spinal cord. Two types of radiculomedullary artery are described: anterior, participating in the anterior spinal axis, and posterior, participating in the posterior pial network. Their trajectory follows that of the roots of the spinal nerve.

The anterior radiculomedullary arteries vary in number between five and ten. They participate in constituting the pial network before feeding the ventral spinal axis. The caliber of the anterior radiculomedullary arteries varies. It is smaller at the thoracic spinal level and larger at the cervical and lumbar segments.

At the lumbar region, one of the anterior radiculomedullary arteries is particularly developed: the artery of the lumbar enlargement (arteria radicula magna of Adamkiewicz). The origin of this artery varies greatly but it originates most often between levels T9 and T12, most frequently on the left. In a few rare cases, an anterior radiculomedullary artery accompanying the L5 or S1 root can participate in the supply of blood to the conus medullaris (Desproges–Gotteron artery)



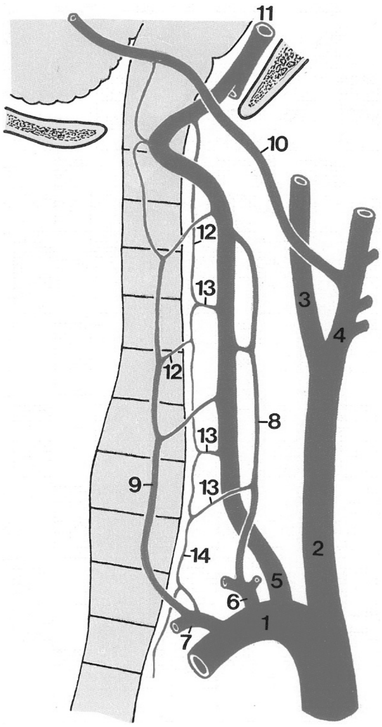
1. Basilar artery
2. Vertebral artery
3. Anterior spinal artery
4. Posterior spinal artery
5. Radiculo-pial artery
6. Anterior radiculo-medullary artery
7. Thyro-cervical trunk
8. Cervical ascending artery
9. Costocervical trunk
10. Deep cervical artery
11. Supreme intercostal artery
12. Intercostal artery
13. Arteria radicularis magna (of Adamkiewicz)
14. L5 anterior radiculo-medullary artery (of Desproges-Gotteron)
15. Anterior arterial spinal axis
16. Posterior arterial spinal axis

Fig. 13.12. Arterial vascularization of the spinal cord.

(Fig. 13.12). Radicular compression could thus be responsible for spinal ischemia.

The cervical cord is fed by the numerous anterior radiculomedullary arteries of varied origin: vertebral, ascending cervical, deep cervical arteries, which ensure a rich supply of arterial blood (Fig. 13.13).

The posterior radiculomedullary arteries vary in number between 10 and 20. Their caliber is much smaller than the anterior ones. It is often difficult to clearly identify their course because they divide into numerous branches in the pial network. From now on, it is proposed to consider them to be radiculopial arteries.



1. Sub-clavian artery
2. Common carotid artery
3. Internal carotid artery
4. External carotid artery
5. Vertebral artery
6. Thyro-cervical trunk
7. Costocervical trunk
8. Cervical ascending artery
9. Deep cervical artery
10. Occipital artery
11. Basilar artery
12. Anterior spinal artery
13. Anterior radiculo-medullary artery
14. Anterior arterial spinal axis

Fig. 13.13. Arterial vascularization of the cervical spinal cord (right lateral view).

13.3.2. Longitudinal arterial axes

Three principal longitudinal axes exist, represented in front by the anterior spinal axis and behind by a pial network across which derive two privileged circulation pathways: the posterior spinal axes.

13.3.2.1. Anterior spinal axis

The anterior spinal axis is a discontinuous axis running along the cord at all levels compared with the median ventral fissure. The anterior radiculomedullary arteries feed the anterior spinal axis.

At cervical level, the anterior spinal axis is organized from the anterior spinal artery formed by the union of two branches that originate in the intracranial vertebral artery. Then at thoracic spinal level, the anterior spinal axis is often discontinuous. At lumbar level, the anterior arterial axis is larger and fed by the branches of the superior and inferior division of the anterior arteria radicula magna (of Adamkiewicz).

13.3.2.2. Pial network and posterior spinal axes

The dorsal part of the spinal cord is covered by a large arterial plexus, supplied by the radiculopial arteries and by the posterior radiculomedullary arteries, which, as we observed earlier, must be considered to be really radiculopial arteries. The posterior spinal axes can be regarded as predominant arterial currents in this important arterial plexus. At cervical spinal level, these predominant currents anastomose with the vertebral system. Indeed, two posterior spinal arteries originate bilaterally from each side of the vertebral artery or from the proximal part of the posterior and inferior cerebellar artery to join the posterior axes. The posterior arterial axis ends caudally at the conus medullaris, where it anastomoses with the anterior arterial axis.

13.3.3. Intrinsic blood supply to the spinal cord

Intrinsic blood supply to the spinal cord is organized around two large systems: the sulcocommissural arteries and the radial perforating arteries.

The sulcocommissural arteries originate in the ventral spinal axis compared to the longitudinal ventral fissure and distribute bilaterally into the cord. In the ventral median fissure, and before penetrating the spinal cord, they give off ascending and descending branches that anastomose with adjacent caudal and rostral sulcal arteries on the same side. In general a right and left sulcocommissural artery exist. A common trunk is also often noted. They supply the ventral horns as well as the ventral funiculus of the spinal cord, which means that they drain an essentially motor territory. The extent of this territory varies according to spinal level and the development of anastomoses.

The radial perforating arteries originate in the pial network to penetrate the white matter and supply the anterior and lateral cords. Radial arteries can also originate behind at the level of the posterior spinal axes to supply the posterior cords.

This intraspinal disposition makes it possible to delimit three large valid territories whatever the spinal level (Fig. 13.14).

13.4. Venous circulation of the spinal cord

The intraspinal veins radiate from the capillary network to flow into the veins of the perispinal network. The perispinal network is drained by the radicular veins towards the epidural plexus as well as the peri- and prevertebral plexuses.

This system (Gillilan, 1970; Lazorthes et al., 1973; Lasjaunias and Berenstein, 1990) differs from the arterial circulation in two important ways: the veins are not satellites of the arteries inside the parenchyma and vein density is greater on the dorsal side than on the ventral side of the cord.

Three large units can be distinguished by analogy with the arterial blood supply: an intrinsic venous system, an extrinsic venous system, and the radicular veins (Fig. 13.14).

13.4.1. Intrinsic venous system

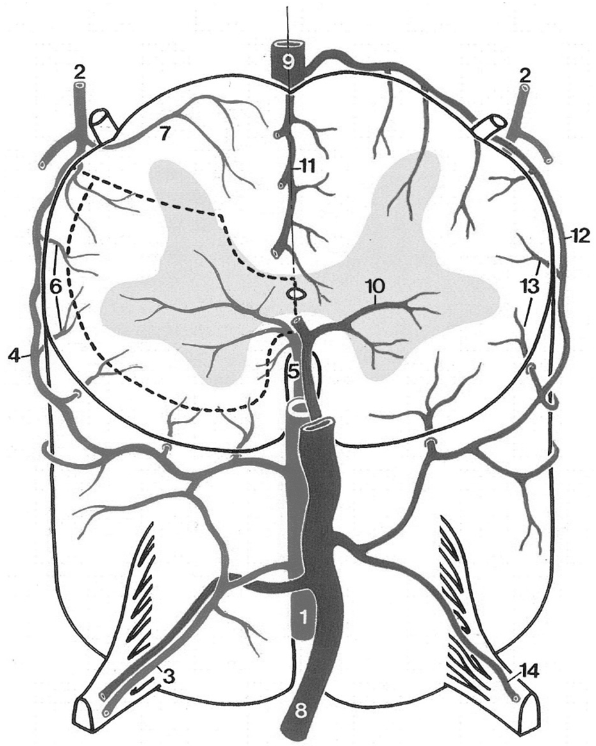
The intraspinal veins drain the venous blood towards the extrinsic venous axes. They can be divided into three groups: central or sulcocommissural veins, posterior veins, and peripheral veins. Contrary to the arterial system, venous drainage occurs predominantly towards the posterior part of the spinal cord.

13.4.1.1. Central or sulcocommissural veins

The disposition of the sulcocommissural veins is analogous to the arteries of the same name and they originate at the bottom of the median ventral fissure. They are less numerous than the corresponding arteries and are a result of the union of a right and left branch. They flow into an anterior median venous axis satellite to the arterial axis. Their drainage area does not correspond to that of the sulcocommissural arteries but rather is less developed towards the dorsal part of the cord.

13.4.1.2. Posterior veins

These are of large caliber and extend as far as the median posterior sulcus. They form at the level of the gray commissure and are a result of the union of a right and left branch. Their density is much greater than that of the central veins with a far more extensive drainage area. Transmedullary anastomoses usually exist between the ventral and dorsal territories. They terminate in the median posterior venous axis in the median dorsal sulcus.



1. Anterior arterial spinal axis
2. Posterior arterial spinal axis
3. Anterior radiculo-medullary artery
4. Pial arterial network
5. Sulco-commissural artery
6. Radial perforating arteries arising from pial network
7. Radial perforating arteries arising from posterior spinal axis
8. Anterior venous spinal axis
9. Posterior venous spinal axis
10. Sulco-commissural veins
11. Posterior intrinsic veins
12. Pial venous network
13. Peripheral intrinsic veins
14. Radicular vein

Fig. 13.14. Spinal cord vascularization.

13.4.1.3. The peripheral veins

These are located in the unoccupied space left by the central veins and the posterior veins. Their area of drainage is the most lateral and peripheral part of the cord. They drain the peripheral part of the cord and join the perispinal venous plexus.

13.4.2. Extrinsic venous system

The extrinsic system comprises the pial venous network and the longitudinal collectors.

The anastomotic pial venous system is located on the surface of the cord, in the layers of the pia mater. Its disposition cannot be superimposed on the pial arterial network. Indeed, the veins are more numerous and more developed in the dorsal part of the cord and less so in the lateral parts. As is the case for the arterial system, there are two types of principal longitudinal pathways: the ventral spinal venous axis and the dorsal spinal venous axis.

13.4.2.1. Anterior median spinal axis

This is situated in the median sulcus and winds around the ventral arterial axis. Its caliber is irregular throughout the spinal axis. It is generally larger at the cervical and lumbar level and smaller in the thoracic segment. In certain cases, the axis is discontinuous. In the upper portion, the vein continues with the other veins of the brainstem.

13.4.2.2. Posterior median spinal axis

This runs in the dorsal median sulcus of the cord. Its caliber is larger and more regular than that of the anterior venous axis. It is nevertheless smaller in the thoracic region, where it can be replaced by two thin, anastomotic veins. In the upper part, it generally terminates in the radicular cervical vein.

13.4.2.3. Pial venous network

In the dorsal portion of the cord, the posterior axis is largely anastomosed with the radicular veins and the ventral venous system, forming the perimedullary venous plexus. As is the case for arterial axes, there are privileged passageways in this plexus that can adopt the aspect of a posterolateral venous axis along the point of emergence of the posterior roots of the spinal nerve. This venous plexus is therefore more developed in the dorsal part of the cord and less so in the anterolateral parts.

13.4.3. Radicular veins

The radicular veins drain the venous blood from the perimedullary system towards the vertebral plexus. They vary in number and are generally larger than the radicular arteries. There are an estimated 25 anterior radicular veins and 30 posterior radicular veins. It is exceptional to find a radicular artery and a radicular vein at the same level. The radicular ventral veins most notably drain the anterior median venous axis. The dorsal radicular veins anastomose between themselves and with the median dorsal axis, which principally drains the pial plexus.

The final drainage takes place in the direction of the intra- and extraspinal venous plexus and the intervertebral foramens, with extensive anastomosis between the different systems.

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