Periventricular Anastomosis

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Takeshi Funaki and Susumu Miyamoto

Abstract

Periventricular anastomosis is a term used to describe fragile, hemorrhage-prone collateral vessels typical of moyamoya disease. It is defined as pathological anastomoses between the perforating or choroidal arteries and the medullary arteries in the periventricular area. This chapter discusses the anatomic characteristics, the relationship to hemorrhage, and representative radiological findings.

Keywords

Moyamoya disease · Intracranial hemorrhage · Periventricular anastomosis

Periventricular anastomosis is a unique phenomenon occurring in moyamoya disease. It is defined as pathological anastomoses between the perforating or choroidal arteries and the medullary arteries in the periventricular area that serve as collaterals to the cortex via retrograde flow in the medullary arteries (Fig. 13.1). Periventricular anastomosis well explains the mechanism of intracranial hemorrhage in moyamoya disease, given that anastomotic sites are especially fragile because of histologically abnormal connections between vessels. Small pseudoaneurysms indicating bleeding points are commonly observed at the exact site of the anastomoses (Fig. 13.2) (See also Chap. 9).

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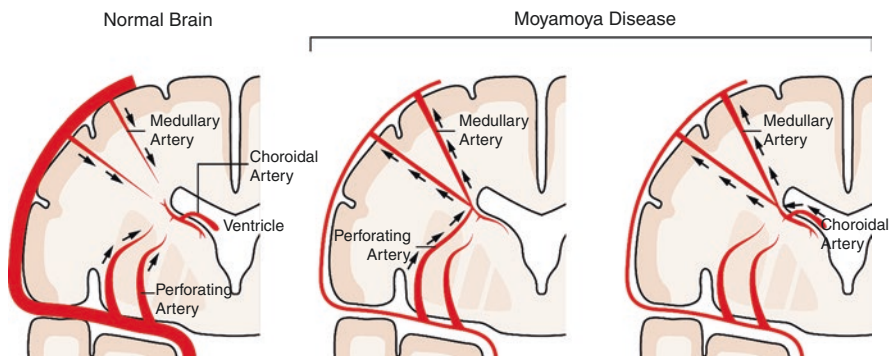e-mail: tfunaki@kuhp.kyoto-u.ac.jp; miy@kuhp.kyoto-u.ac.jp

Fig. 13.1 Schematic illustrations showing periventricular anastomosis in coronal planes of the right hemisphere, reprinted with permission from Funaki (Nihon Iji Shimpo 4884: 28–35, 2017)

Fig. 13.2 3D rotational internal carotid angiography showing periventricular anastomosis in a coronal plane. Many medullary arteries (arrowheads) radiate from the plexal portion of the anterior choroidal artery (arrow). Note that a pseudoaneurysm is observed at the exact site of the anastomosis (asterisk)
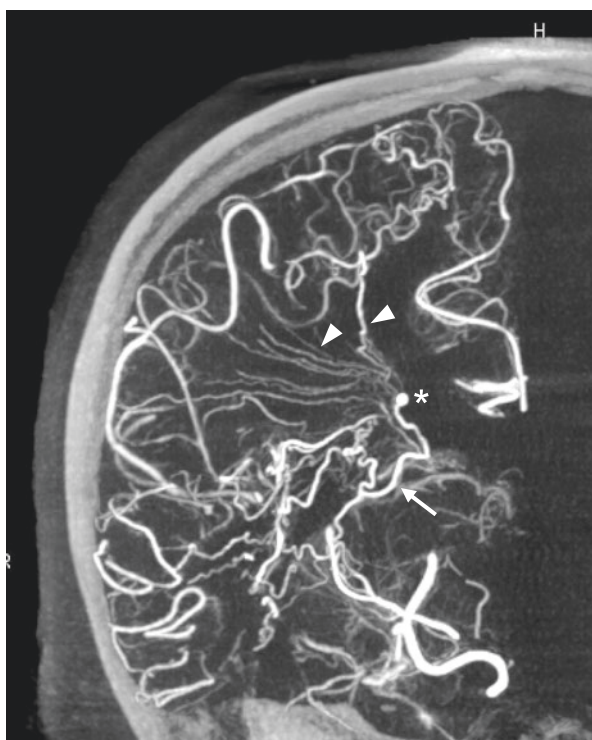
13.1 Anatomy

The traditional theory of vascular supply in the periventricular area provides a clue for understanding the development of periventricular anastomosis. In 1969, Van den Bergh advocated two terminal arteries in the periventricular area, the ventriculofugal

and ventriculopetal arteries [1]. According to his original article, ventriculofugal (or centrifugal) arteries originate from subependymal arteries, which consist of the branches from the choroidal or lenticulostriate artery, and diverge "ventriculofugally" (in a direction away from the ventricle). Ventriculopetal (or centripetal) arteries consist of the medullary or lenticulostriate arteries, which are directed toward the ventricle. Van den Bergh's theory became famous because Yasargil introduced the schematic figure in his book [2]. De Reuck classified the patterns of periventricular arterial border zone and considered that the ventriculofugal arteries consist of the choroidal or perforating arteries [3]. According to his description, ventriculofugal arteries originate from the choroidal arteries of the lateral and third ventricles and penetrate into the brain substance from the choroid plexus to meet the ventriculopetal branches at a distance of 3–10 mm from the ventricular walls [3]. Ventriculofugal and ventriculopetal arteries form no anastomosis in the normal brain [1, 3], as the border zone between these arteries is believed to be the cause of periventricular ischemia.

Although the existence of the ventriculofugal artery was once denied in the 1990s [4], Marinkovic and Gibo et al. rediscovered the phenomenon; they showed that tiny vessels arising from all choroidal arteries extended through the subependymal layer of a larger part of the ventricular wall and referred to them as the subependymal artery [5]. The existence of such arteries was confirmed by a clinical study on glioma resection, during which the coagulation of the plexal portion of the choroidal arteries causes infarct in the periventricular white matter [6].

Long-standing cortical ischemia in moyamoya disease might induce an abnormal connection between the perforating or choroidal arteries and the medullary arteries via the ventriculofugal subependymal arteries and result in periventricular anastomosis. Kodama and Suzuki were the first to describe arterial connections between perforating and medullary arteries in fetus brain [7]. In their pioneering work, they considered such connections, which they denoted as "anastomoses," as the rationale of moyamoya vessels. The term "periventricular anastomosis" is named after their contribution. Takahashi was the first to describe angiographic findings showing anastomoses between perforating and medullary arteries in 1980 [8]. Recent angiographic techniques using a microcatheter can more clearly reveal these connections [9, 10], although the procedure is invasive.

The development of high-resolution magnetic resonance (MR) imaging has facilitated non-invasive, meticulous visualization of periventricular anastomosis [11, 12]. Coronal thin-slab maximal-intensity-projection (MIP) reformation of 3 T MR angiography is an especially useful technique for visualizing periventricular anastomosis (Fig. 13.3) [11]. This imaging has also facilitated the systematization of periventricular anastomosis, which is classified into three subtypes according to its origin: lenticulostriate, thalamic, and choroidal (Fig. 13.3; see also Chap. 9). Excellent delineation of periventricular anastomotic channels was reported in a study using 7 T MR angiography [13].

Table 13.1 summarizes the anatomic characteristics of the three subtypes of periventricular anastomosis. The spatial relationship along the anterior-posterior axis helps to understand their anatomic characteristics [14–16].
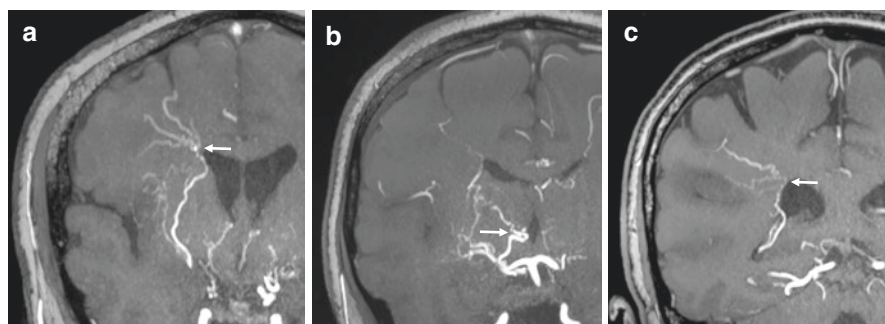
Fig. 13.3 Coronal thin-slab MIP reformation of 3 T MR angiography showing periventricular anastomosis (arrows). (**a**) lenticulostriate anastomosis. (**b**) thalamic anastomosis. (**c**) choroidal anastomosis

Table 13.1 Anatomic characteristics of three subtypes of periventricular anastomosis

	Lenticulostriate Anastomosis	Thalamic Anastomosis	Choroidal Anastomosis
Origin	Lenticulostriate a.	Thalamotuberal a. (from PCoA) Thalamoperforating a. (from P1) Thalamogeniculate a.	Anterior choroidal a. Lateral posterior choroidal a. (medial posterior choroidal a.)
Common site of anastomosis	Subependymal area of the frontal horn or anterior body of LV	Subependymal area of third V	Subependymal area of the atrium of LV
Common type of hemorrhage	ICH in the basal ganglia or frontal lobe IVH at the frontal horn or anterior half of the body of LV	ICH in the thalamus IVH in the third V or LV	IVH in the atrium or posterior part of the lateral ventricle ICH in the temporal or parietal lobe
Common cortical distribution	Anterior to CS Interhemispheric fissure	Insular cortex Around CS	Posterior to CS (occasionally, insular cortex)

a. artery; *CS* central sulcus; *LV* lateral ventricle; *PCoA* posterior communicating artery; *third V* third ventricle

13.2 Relationship between Periventricular Anastomosis and Bleeding

Experts of moyamoya disease have always focused on the choroidal artery in relation to hemorrhage. Kodama and Suzuki described aneurysms occurring in the choroidal arteries in the early days of angiography [17]. They considered the aneurysms as "pseudoaneurysms," indicating the bleeding point. Irikura et al. were perhaps the first to pay special attention to the angiographic finding of choroidal anastomosis; they described "the medullary arteries that were filled from the plexal segment of the choroidal arteries" [18]. They also revealed that this finding was more frequently observed

in the hemorrhagic group than in the ischemic group. Morioka et al. revealed in a larger cross-sectional study that "angiographic dilatation and branch extension of the anterior choroidal arteries" was associated with hemorrhagic presentation [19]. Although they did not clearly define the abnormal branches from the choroidal arteries, it is obvious that the medullary arteries represent such branches. The causal relationship between choroidal anastomosis and hemorrhage was proved by longitudinal analyses using the data of a nonsurgical cohort in the Japan Adult Moyamoya Trial (see Chap. 9) [20, 21]. Wang et al. also revealed in a longitudinal study that lateral posterior choroidal anastomosis was an independent predictor of rebleeding [22].

Evidence is being accumulated suggesting that periventricular anastomoses, including choroidal anastomosis, is a potential bleeding source in moyamoya disease. Kazumata et al. demonstrated a topographical correspondence between cerebral microbleeds, which were frequently observed in the periventricular area, and moyamoya vessels detected with source images of time-of-flight MR angiography [23]. They also implied an early concept of periventricular anastomosis. Our cross-sectional study revealed that scoring of periventricular anastomosis with coronal thin-slab MIP MR angiography was highly reliable and that an increase of periventricular anastomosis score was significantly associated with hemorrhagic presentation in a multivariate analysis [11].

While any subtypes of periventricular anastomosis might be associated with hemorrhage, the bleeding risk in a certain period might vary across subtypes [11]. Considering many recent findings, choroidal anastomosis seems to present the highest risk of bleeding among subtypes [14, 20, 24, 25].

Periventricular anastomosis is a common finding not only in adult patients but also in pediatric patients. Although pediatric patients rarely suffer from intracranial hemorrhage, Liu P et al. revealed that the grade of choroidal anastomotic channel in the hemorrhagic group was significantly higher than that in the ischemic group among pediatric patients [26]. Interestingly, Ryu et al. revealed that the periventricular anastomosis score in the child ischemic group was equivalent to that in the adult hemorrhagic group [27]. This suggests the following hypothesis. Pediatric patients with abundant periventricular anastomosis, which moderates ischemic symptoms, could grow up without being diagnosed as moyamoya disease. Such a population might exhibit hemorrhage after they reach adulthood, given that the bleeding risk of periventricular anastomosis might increase with longer duration of its existence.

13.3 Radiological Findings

See also Table 13.1.

13.3.1 Lenticulostriate Anastomosis

This type of periventricular anastomosis arises from the lenticulostriate arteries and connects to the medial end of the medullary arteries at the lateral corner of the
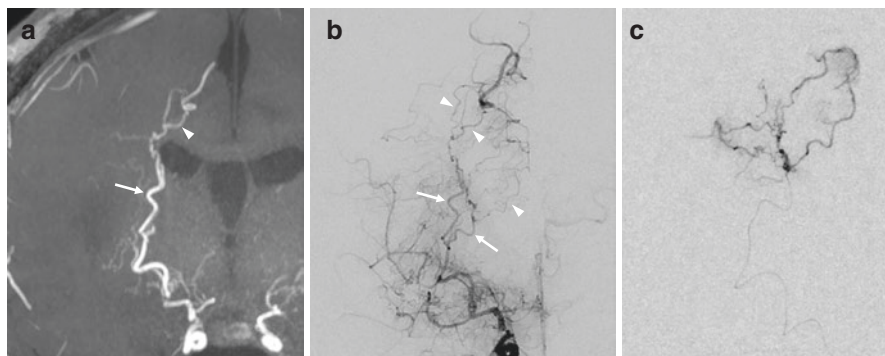
Fig. 13.4 lenticulostriate anastomosis. (**a**) coronal thin-slab MIP MR angiography. (**b**) anterior-posterior view of left internal carotid angiography. (**c**) anterior-posterior view of a superselective injection of one of the lenticulostriate arteries, clearly showing the medullary arteries. Arrows indicate lenticulostriate artery; arrowheads, medullary artery

frontal horn or body of the lateral ventricle (Figs. 13.3a and 13.4) [11]. The medullary arteries from the lenticulostriate anastomosis radiate toward the cortex and reach the cortical arteries located anterior to the central sulcus, mainly to the superior and inferior frontal sulcus [16]. Lenticulostriate anastomosis thus outflows more anteriorly than thalamic or choroidal anastomosis (Fig. 13.5). It should be noted that lenticulostriate anastomosis often shows outflows to the interhemispheric fissure (the cingulate sulcus) (Fig. 13.4) [16, 28]. This might be attributable to the anatomic relationship that lenticulostriate anastomosis is located nearest toward the anterior cerebral artery territory, almost always hemodynamically compromised in moyamoya disease. The characteristic adds an intractable nature to this type [28].

A positive angiographic indicator of lenticulostriate anastomosis is extreme dilation and extension of the lenticulostriate arteries with at least one artery extending beyond the level of the pericallosal artery in the lateral view (Fig. 13.5) [14]. In such a situation, the lenticulostriate arteries are reasonably considered to connect to the medullary arteries at the lateral corner of the lateral ventricle because the position of the pericallosal artery approximates the upper margin of the lateral ventricle.

13.3.2 Thalamic Anastomosis

This type of periventricular anastomosis arises from the thalamotuberal arteries (perforator from the posterior communicating artery) or the thalamoperforating arteries (perforator from the P1 segment of the posterior cerebral artery) and connects to the medullary or insular arteries beneath the ependyma of the third or lateral ventricle (Figs. 13.3b and 13.6) [11]. Thalamic anastomosis can also arise from the thalamogeniculate (or rarely, choroidal) arteries and connect to the insular artery superior to the inferior horn or at the lateral corner of the body of the lateral ventricle. Thalamic anastomosis shows outflows to the sulcus around the central sulcus

Fig. 13.5 Lateral view of internal carotid angiography showing both lenticulostriate anastomosis (arrow) and choroidal anastomosis (double arrow)
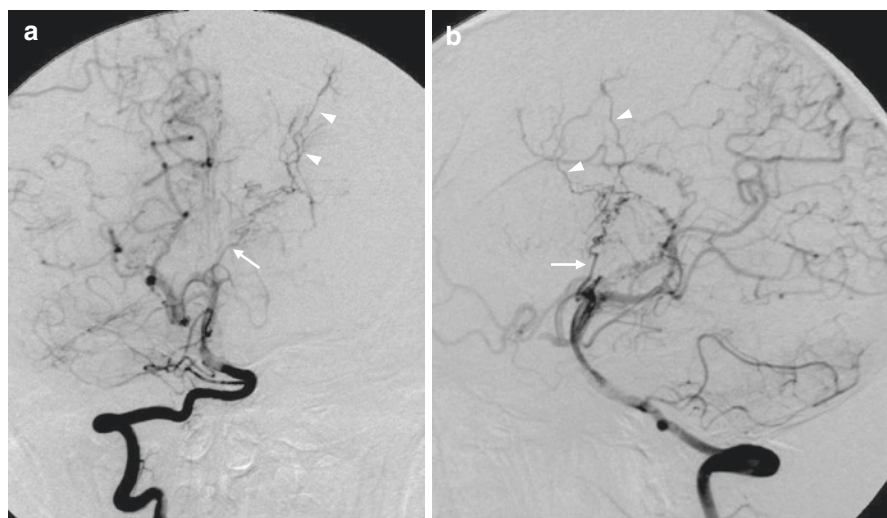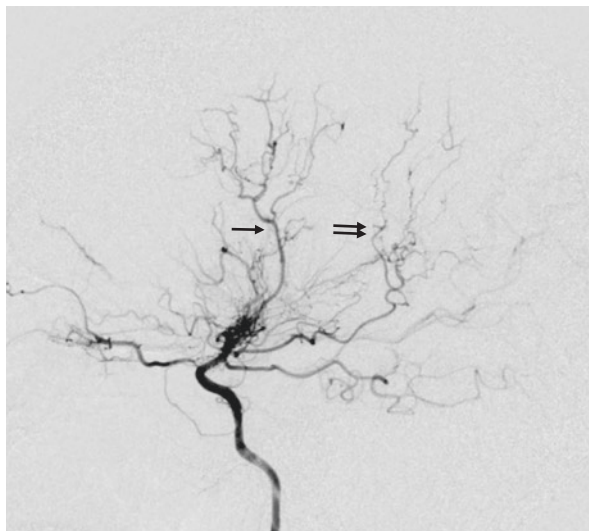

Fig. 13.6 Thalamic anastomosis observed by vertebral angiography. (**a**) anterior-posterior view. (**b**) lateral view. Arrows indicate thalamoperforating artery; arrowheads, medullary artery

via medullary arteries (Fig. 13.6) or to the insular cortex [16]. Unlike lenticulostriate and choroidal anastomoses, however, thalamic anastomosis less commonly outflows to the cortex independently and tends to anastomose with other collateral vessels [16].

A positive angiographic indicator of thalamic anastomosis is extreme dilation and extension of the thalamic perforators with at least one artery extending beyond the position of the medial posterior choroidal artery in the lateral view (Fig. 13.6).
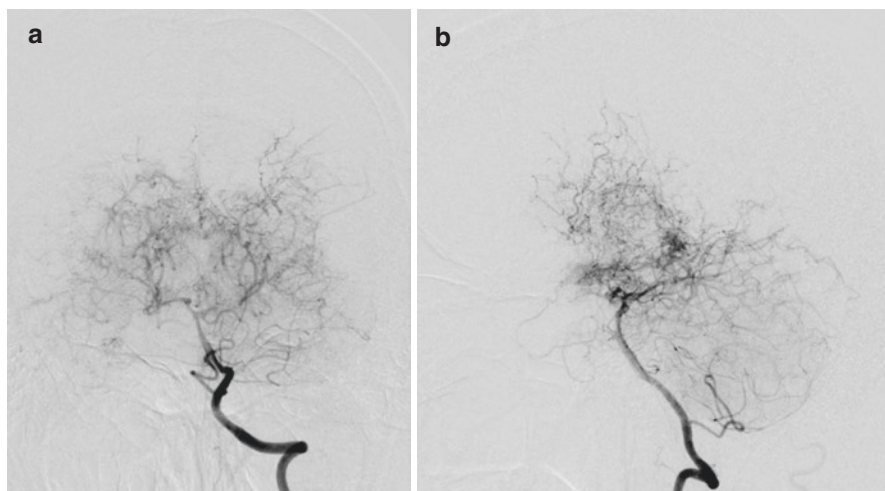
Fig. 13.7 Occlusion of the posterior cerebral artery and cluster of thalamic anastomosis ("posterior basal moyamoya") observed by vertebral angiography. (**a**) anterior-posterior view. (**b**) lateral view

In such a situation, the thalamic perforators are reasonably considered to extend beyond the thalamus to connect to the medullary arteries because the position of the medial posterior choroidal artery approximates the upper margin of the thalamus.

Thalamic anastomosis often develops in relation to occlusion of the posterior cerebral artery (PCA). The senior author (S.M.) has referred to the cluster of thalamic anastomotic channels accompanied with the PCA involvement as "posterior basal moyamoya" [29] (Fig. 13.7).

13.3.3 Choroidal Anastomosis

This type of periventricular anastomosis arises at the plexal segment of the anterior choroidal or lateral posterior choroidal arteries and connects to the medullary arteries beneath the lateral wall of the atrium of the lateral ventricle (Figs. 13.3c and 13.9a) [11]. The medullary arteries typically radiate toward the cortex and reach the cortical arteries located in or posterior to the central sulcus [16]. Choroidal anastomosis thus outflows more posteriorly than lenticulostriate or thalamic anastomosis (Fig. 13.5). Unlike lenticulostriate anastomosis, choroidal anastomosis rarely shows outflows to the interhemispheric fissure, except for one formed by the medial posterior choroidal arteries. Choroidal anastomosis sometimes seems to outflow to the insular cortex. In such cases, however, strictly classifying such collateral channel as either choroidal or thalamic anastomosis might be difficult.

A positive angiographic (lateral view) indicator of choroidal anastomosis is extreme dilation and extension of the choroidal arteries with sudden deviation from the shape of the lateral ventricle at its peripheral portion to connect to the medullary
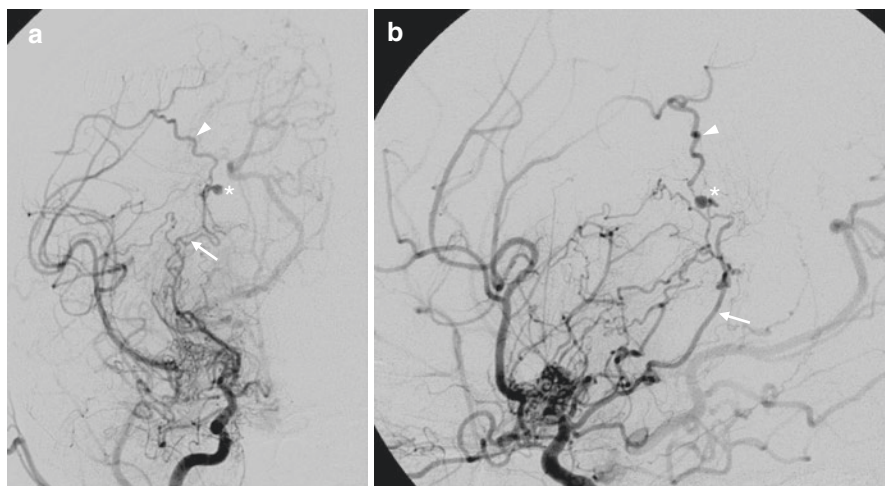
Fig. 13.8 Choroidal anastomosis from the anterior choroidal artery, observed by internal carotid angiography. (**a**) anterior-posterior view. (**b**) lateral view. The plexal portion of the anterior choroidal artery (arrows) connects to the medullary artery (arrowheads), which finally extend to the cortical artery. Note that a pseudoaneurysm is observed at the exact site of the anastomosis (asterisks)
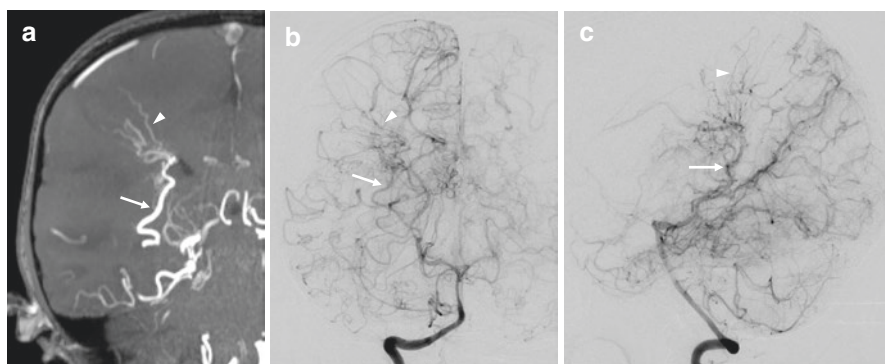

Fig. 13.9 Choroidal anastomosis from the lateral posterior choroidal artery. (**a**) coronal thin-slab MIP MR angiography. (**b**) anterior-posterior view of the right vertebral angiography. (**c**) lateral view of the right vertebral angiography. Arrows indicate the plexal portion of the lateral posterior choroidal artery; arrowheads, medullary artery

arteries (Figs. 13.5 and 13.8); in the anteroposterior view, this collateral has a typical sharp inflection laterally (Fig. 13.8a) [14]. When choroidal anastomosis is formed via the lateral posterior choroidal arteries, careful interpretation of vertebral angiography is required because many overlapping vessels might obscure the anastomotic channel (Fig. 13.9).

Another relatively rare subtype classified as choroidal anastomosis is formed by the medial posterior choroidal arteries, which connects to the pericallosal arteries by penetrating the corpus callosum (Fig. 13.10) [10].
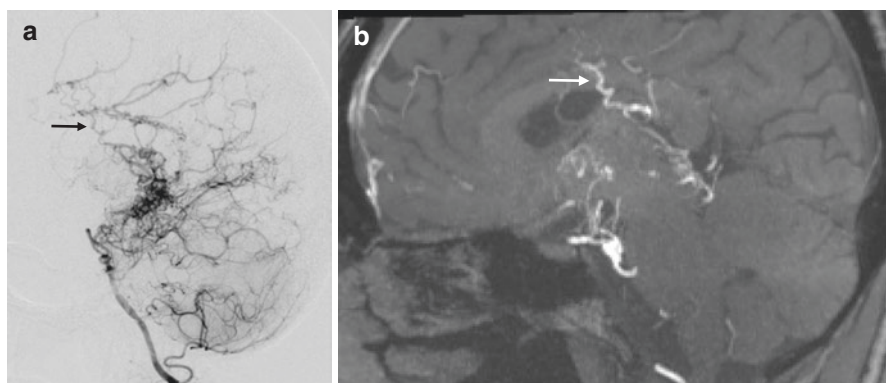
Fig. 13.10 Choroidal anastomosis from the medial posterior choroidal artery (arrows). (**a**) lateral view of the vertebral angiography. (**b**) sagittal thin-slab MIP MR angiography

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