Japanese Journal of Radiology (2019) 37:565–578
https://doi.org/10.1007/s11604-019-00847-x

PICTORIAL ESSAY

Carotid-vertebrobasilar anastomosis: magnetic resonance and computed tomographic angiographic demonstration

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Received: 19 January 2019 / Accepted: 11 June 2019 / Published online: 18 June 2019

Abstract
Carotid-vertebrobasilar (VB) anastomoses are rare and usually found incidentally, but they can have clinical significance. Their variance can represent aneurysm formation at the origin of the anomalous artery, cerebral ischemia due to unique blood flow, or other complications. Thus, recognition and correct diagnosis of these anomalous vessels are important when interpreting magnetic resonance (MR) and computed tomography (CT) angiography. This pictorial essay presents MR and CT angiographic images of several types of persistent fetal carotid-VB anastomoses, including those involving the proatlantal, hypoglossal, and trigeminal arteries as well as their variants. Images depict types 1 and 2 proatlantal arteries, persistent second cervical intersegmental artery, persistent hypoglossal artery (PHA), PHA of external carotid origin, two types of the PHA variant, posterior inferior cerebellar artery arising from the jugular branch of the ascending pharyngeal artery, lateral and medial types of persistent trigeminal arteries (PTAs), and four types of PTA variants.

Keywords Carotid-vertebrobasilar anastomosis · Cerebral arterial variations · Persistent hypoglossal artery · Persistent trigeminal artery · Proatlantal artery

Introduction

There are several types of persistent carotid-vertebrobasilar (VB) anastomosis. Padget [1] described four types of fetal anastomosis between the carotid and VB arteries at 5 weeks gestation (at stage 3–5 mm); from caudal to cranial position, these involve the proatlantal intersegmental, hypoglossal, otic, and trigeminal arteries. The otic artery never persists, and other arteries may persist rarely, with each type manifesting several variations. Normally, numerous primitive arteries regress and/or fuse with each other to form the mature arterial system, but regression failure or fusion error can lead to the formation of an array of arterial variants. In the neck region, primitive cervical intersegmental arteries play an important role in forming arterial system.

Schematic illustrations and magnetic resonance (MR) or computed tomography (CT) angiographic images demonstrate these variants to aid radiologists recognition and correct interpretation of these arterial variations in daily clinical practices and to avoid complications in catheter or surgical interventions.

Proatlantal artery, two types

Type 1 proatlantal artery

There are two types of proatlantal artery (Fig. 1), both extremely rare. Type 1 arises from the proximal internal carotid artery (ICA), ascends posteriorly to the cervical ICA, continues to the V3 segment of the vertebral artery (VA), and enters the posterior fossa via the foramen magnum (Fig. 2) [2]. The prevalence of these two very rare types remains unreported, but experience at our institution suggests a slightly greater prevalence of type 2 than type 1.

Type 2 proatlantal artery, persistent first cervical intersegmental artery

The type 2 proatlantal artery arises from the proximal external carotid artery (ECA), runs postero-superiorly, following the same course as that of the occipital artery (OA),

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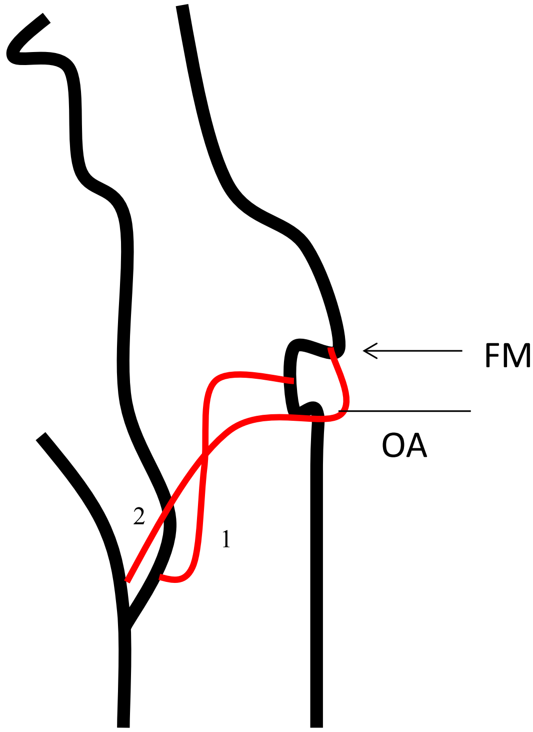

Fig. 1 Schematic illustration of two types of proatlantal artery. 1: type 1; 2: type 2 (persistent first cervical intersegmental artery); *FM* foramen magnum, *OA* occipital artery (Modified from Ref. [2])

continues to the distal V3 segment of the VA, and enters the posterior fossa via the foramen magnum. The distal segment of the OA arises from this artery (Figs. 1, 3) [3]. The type 2 proatlantal artery is thought to be a persistent first cervical intersegmental artery rather than a true proatlantal artery [4].

Normally, there are small direct or indirect anastomoses between the OA and the VA, but a pressure gradient between the two vessels, such as that from occlusion of the proximal VA, can cause these anastomoses to dilate. These postnatal collaterals should not be confused with the type 2 proatlantal artery [3].

This anastomosis is dangerous during transcatheter arterial embolization of the ECA system including the OA; other types of ECA-VB anastomoses described below are also dangerous during catheter intervention; and all types of extracranial carotid-VB anastomosis are dangerous in cervical and/or craniovertebral junction surgery..

Persistent second cervical intersegmental artery

The persistent second cervical intersegmental artery arises from the proximal ECA, runs posteriorly under the course of the OA, continues to the proximal V3 segment of the VA,

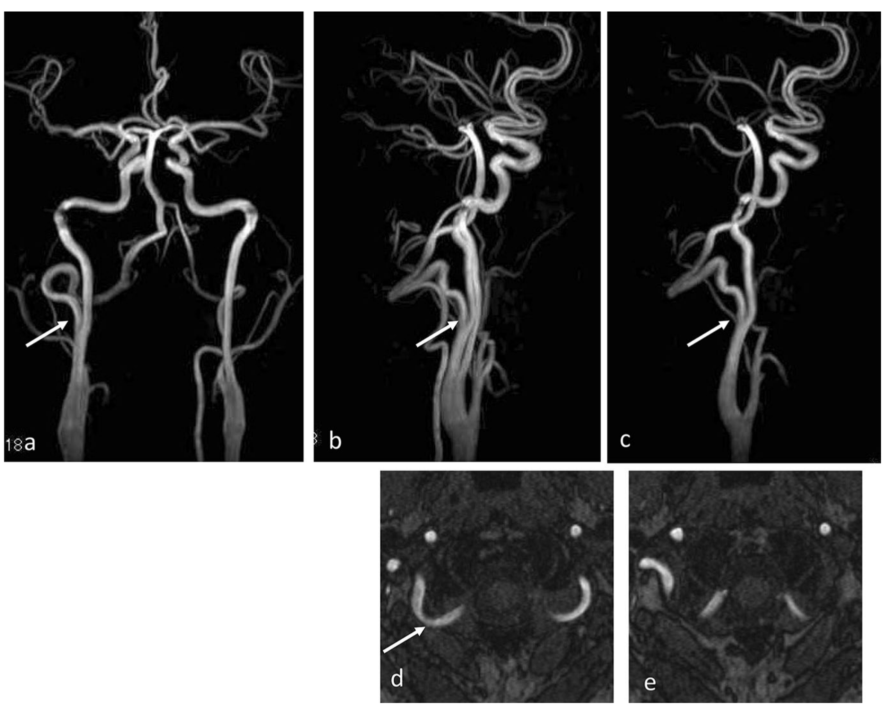

Fig. 2 A 38-year-old woman with a right type 1 proatlantal artery. Magnetic resonance (MR) angiographic images of **a** anteroposterior and **b** right lateral projections show an anomalous artery arising from the right cervical internal carotid artery (ICA) (arrows) and continuing to the right vertebral artery (VA). The proximal right VA is absent. **c** A partial maximum intensity projection (MIP) image of the right carotid system clearly demonstrates the course of the anomalous artery (arrow). **d**, **e** MR angiographic source images shows entry of this artery via the foramen magnum (**d**, arrow), a course just like the normal course of the left VA

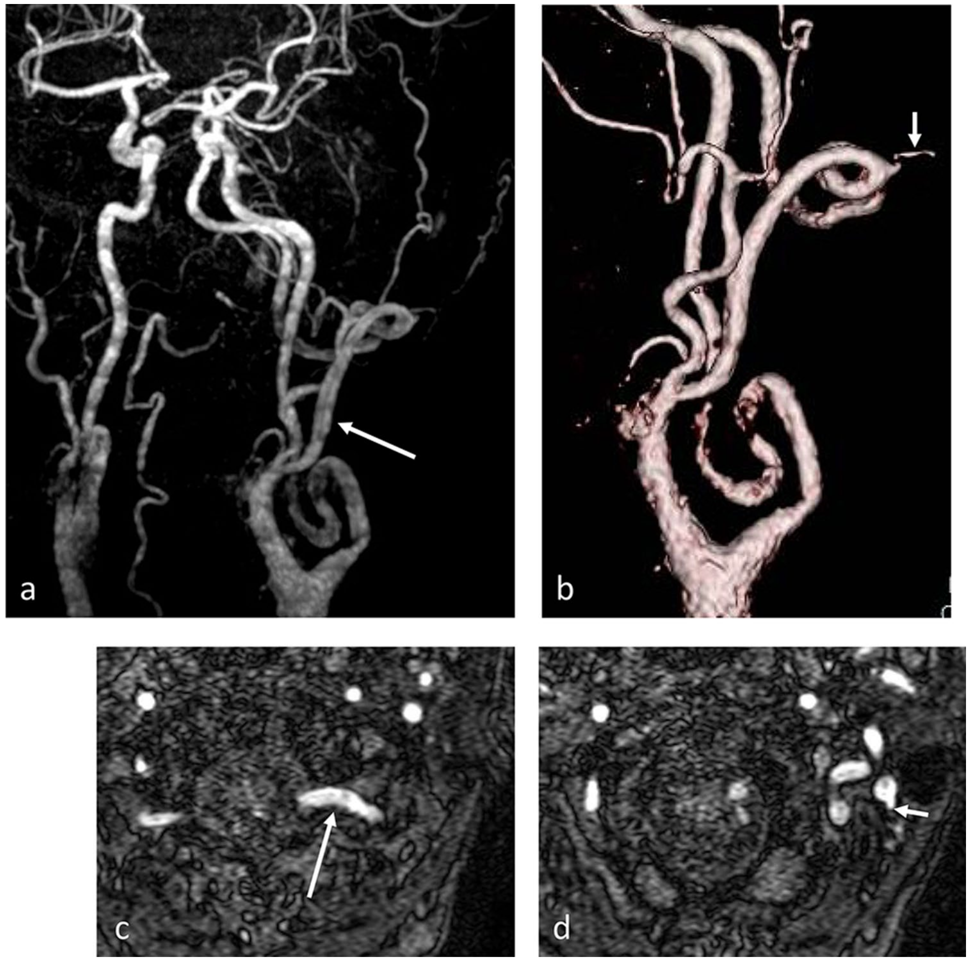

Fig. 3 An 83-year-old man with a left type 2 proatlantal artery (persistent first cervical intersegmental artery). **a** An MR angiographic image of the left slightly anterior oblique projection shows an anomalous artery arising from the left external carotid artery (ECA) (arrow) that continues to the left VA, and the proximal left VA is absent. **b** A partial volume-rendering (VR) image of the left carotid system shows the left occipital artery arising from the anomalous artery (short arrow). **c**, **d** MR angiographic source images show entry of this artery via the foramen magnum (**c**, arrow). The short arrow in **d** indicates the origin of the left occipital artery

penetrates the C1 transverse foramen, and enters the posterior fossa via the foramen magnum (Fig. 4) [5]. Thus, the level of anastomosis is regarded as one vertebral body lower than that of the type 2 proatlantal artery.

Persistent hypoglossal artery (PHA), two types and their variants

PHA, usual type, type 1

The PHA is the second most common anastomosis, with reported prevalence on CT angiography of 0.29% [6]. There are two types of PHA (Fig. 5). Type 1, the usual type, arises from the proximal ICA, ascends posteriorly to the cervical ICA, enters the posterior fossa via the hypoglossal canal, and continues to the V4 segment of the ipsilateral VA (Fig. 6). This PHA is usually large, in which case bilateral VAs are hypoplastic; if the PHA is small, bilateral VAs are normally present (Fig. 7). Extremely rarely, a patient has bilateral PHAs [7].

PHA arising from the ECA, type 2

The recently named type 2 PHA [6] is extremely rare. This artery arises from the proximal ECA (Figs. 5, 8) [8], and its proximal segment ascends anteriorly to the cervical ICA.

PHA variant

A small PHA is regarded as variant when it continues to the posterior inferior cerebellar artery (PICA) without connecting to the basilar artery (BA) (Figs. 9, 10) [9]. The prevalence of this extremely rare variation is unknown, and occlusion of the terminal segment of the small PHA after

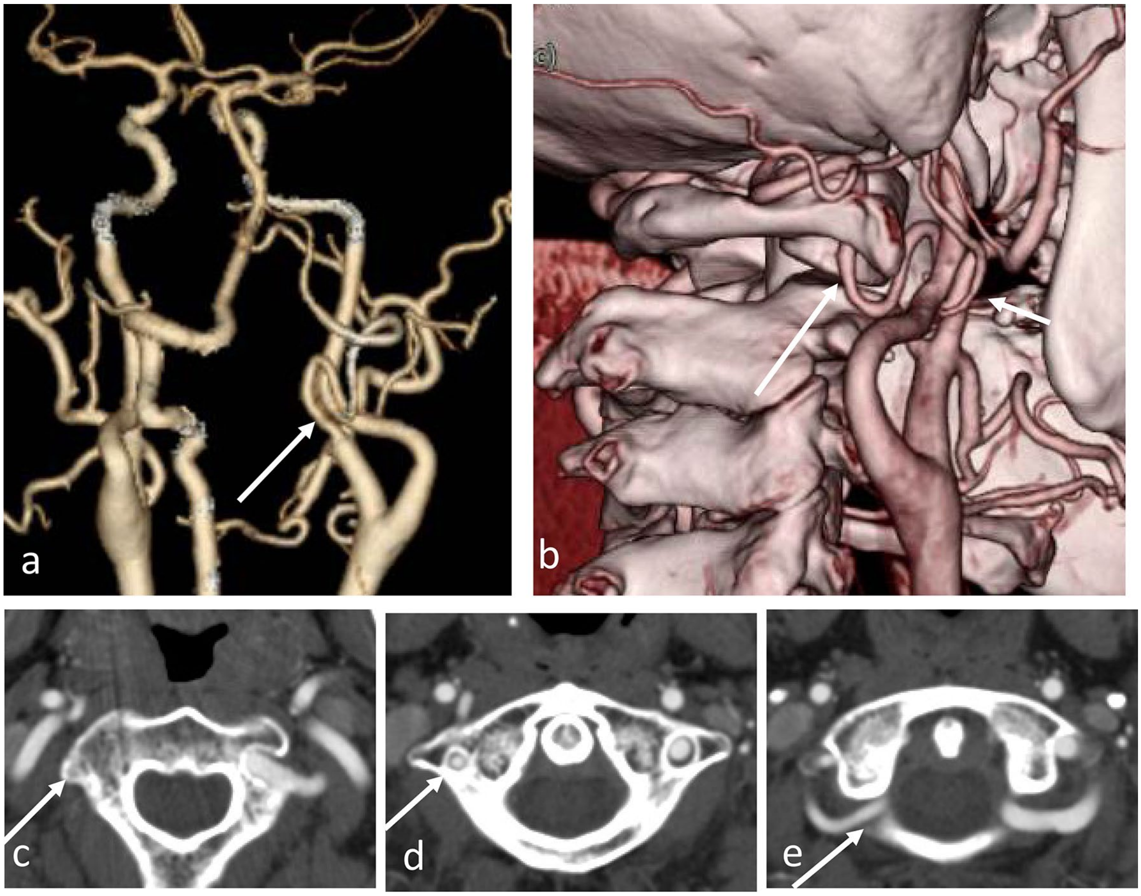

Fig. 4 A 59-year-old woman with a right persistent second cervical intersegmental artery. **a** A computed tomographic (CT) angiographic image in the posterior projection shows an anomalous artery arising from the right ECA (arrow) that continues to the right VA. The proximal right VA is absent. **b** A right lateral projection with bone image shows entry of the anomalous artery via the C1–C2 intervertebral space (long arrow). The occipital artery arises separately from the ECA trunk (short arrow). **c**–**e** CT angiographic source images show that the C2 right transverse foramen is absent (arrow in **c**), the C1 right transverse foramen is present (arrow in **d**), and the artery enters via the foramen magnum (arrow in **e**)

birth can make differentiation of this vessel from the PHA variant difficult.

PICA arising from the ECA, type 2 PHA variant

In the extremely rare case in which the PICA arises from the ECA and enters the posterior fossa via the hypoglossal canal (Figs. 9, 11), this anastomotic artery is regarded as the hypoglossal branch of the ascending pharyngeal artery (APA) [6]. The variant forms as the VA-PICA junction regresses and the APA branch anastomoses with the PICA via the hypoglossal canal.

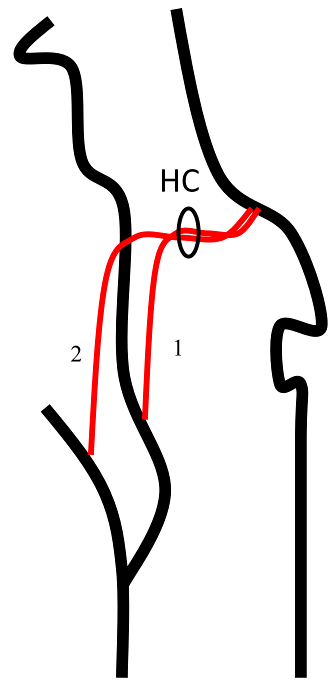

Fig. 5 Schematic illustration of two types of persistent hypoglossal artery (PHA). 1: usual PHA; 2: PHA of external carotid artery origin (type 2 PHA); *HC* hypoglossal canal (Modified from Ref. [2])

PICA arising from the jugular branch of the APA

In the extremely rarely case in which the PICA arises from the ECA and enters the posterior fossa via the jugular foramen, this anastomotic artery is regarded as the jugular branch of the APA (Figs. 9, 12) [10]. This very rare variant forms as the VA-PICA junction regresses and the dural branch of the APA anastomoses with the PICA via the jugular foramen. Thus, it does not represent a type of PHA variant.

Persistent trigeminal artery (PTA), two types and their variants

PTA, usual type, lateral type

The combined prevalence on MR angiography reported for PTA, the most common anastomosis, and its variants is 0.68% [11]. There are two types of PTA (Figs. 13, 14).

The usual, or lateral, type arises from the proximal cavernous or precavernous segment of the ICA, runs posteriorly, turns medially in the prepontine cistern, and anastomoses to the BA (Figs. 15, 16, 17). When it is low-lying, like that pictured in Fig. 17, this anastomosis may be misdiagnosed as a persistent otic artery (POA). Indeed, all POAs previously reported using catheter angiography are regarded as this type of PTA [12]. Extremely rarely, PTAs and their variants are observed bilaterally [13].

The traditional Salzman's classification [14] of PTAs is based on the absence of the ipsilateral posterior communicating artery (PCoA) (type 1) or the P1 segment of the ipsilateral posterior cerebral artery (PCA) (type 2). However, this classification seems meaningless because the PCA is supratentorial and the PTA is infratentorial, and no developmental relationship exists between the two arteries [11, 15]. In addition, both the ipsilateral PCoA and P1 segment can be seen in patients with PTAs.

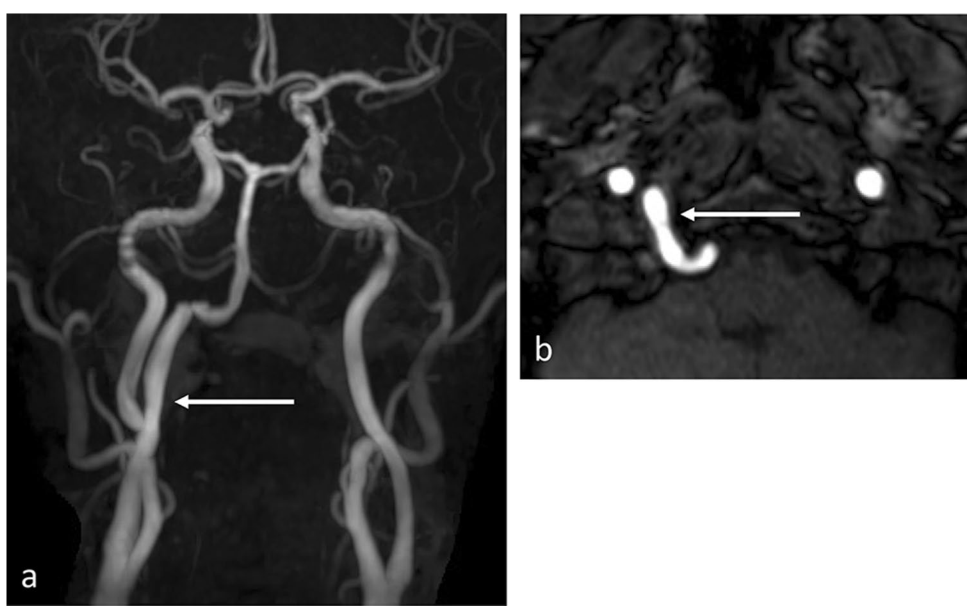

Fig. 6 A 62-year-old man with a right PHA. **a** An anteroposterior projection of MR angiography shows a large artery arising from the right cervical ICA (arrow), and the bilateral VAs are absent. **b** An MR angiographic source image shows entry of the artery via the right hypoglossal canal (arrow)

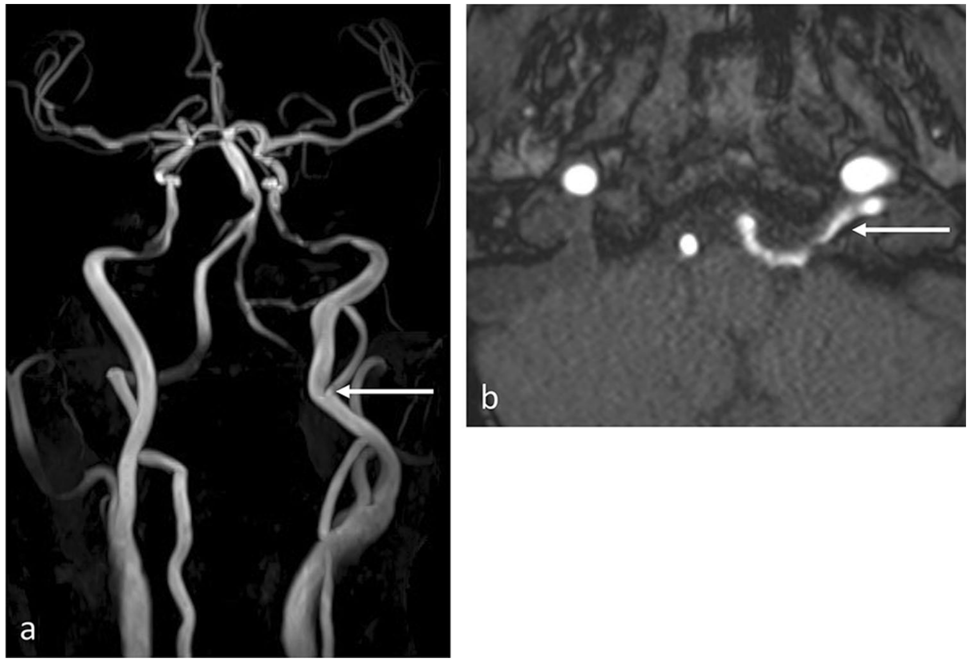

Fig. 7 A 62-year-old man with a left PHA. **a** An anteroposterior projection image of MR angiography shows a small artery arising from the left cervical ICA (arrow) with bilateral VAs present. **b** An MR angiographic source image shows entry of the artery via the left hypoglossal canal (arrow)

PTA, intrasellar type, medial type

Rarely, the PTA originates from the middle or distal cavernous segment of the ICA, more distally than that of usual type, runs medially, turns posteriorly in the sella, penetrates the dorsum sellae, and anastomoses to the BA (Figs. 13, 14, 18); the reported prevalence of this variation is only about 10% [11, 15]. This type of PTA is dangerous during transsphenoidal pituitary surgery.

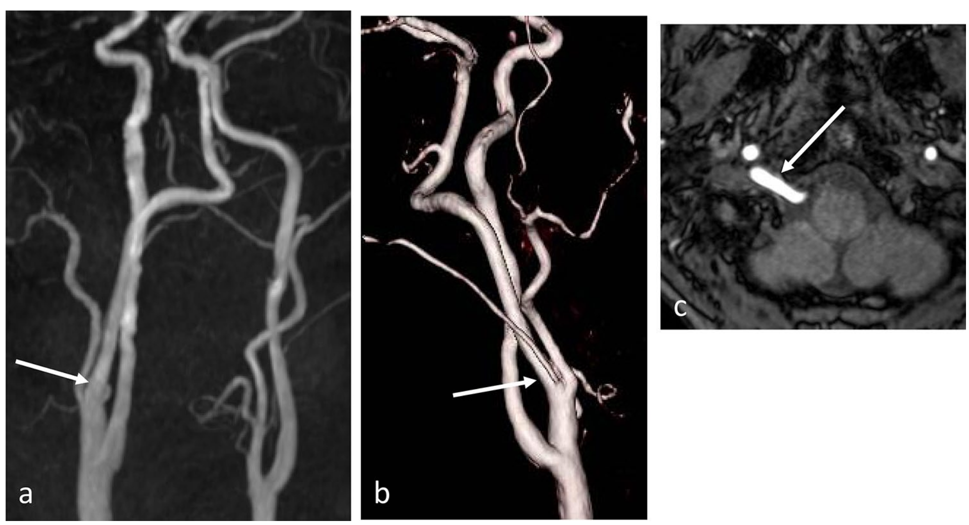

Fig. 8 A 59-year-old woman with a right PHA arising from the ECA (type 2 PHA). MR angiographic images of the **a** slightly left anterior oblique projection and **b** right lateral projection of a partial VR image show a large artery arising from right ECA (arrows) that continues to the right VA, and the bilateral VAs are absent. **c** An MR angiographic source image shows entry of the artery via the right hypoglossal canal (arrow)

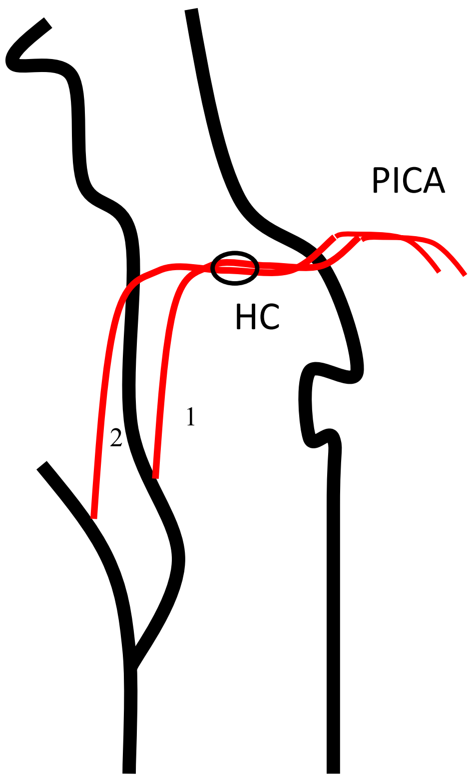

Fig. 9 Schematic illustration of persistent hypoglossal artery (PHA) variants. 1: PHA variant; 2: type 2 PHA variant (ECA origin); *HC* hypoglossal canal, *PICA* posterior inferior cerebellar artery (Modified from Ref. [2])

PTA variant

Ascension of the cerebellar artery directly from the cavernous ICA without connecting to the BA is considered one type of PTA variant (Figs. 13, 14). Its proximal segment takes a similar course to that of the lateral type PTA. The reported prevalence of this variant on MR angiography is 0.17% [15], but this estimation may be low because the vessels small caliber may preclude its detection on MR angiography. The most common type involves the anterior inferior cerebellar artery (AICA) (Fig. 19), and the second most common involves the superior cerebellar artery (SCA) (Fig. 20). A PICA type is extremely rare and cannot be identified on MR angiography because of the caudal course of its distal segment (Fig. 21).

Cerebellar artery arising from the PTA

Another PTA variant occurs when the SCA or AICA or one of their branches arises from a lateral type PTA (Figs. 13, 14, 22) [11, 15]. This type of variation is rare and may be misdiagnosed as a PTA variant because of faint visualization of the distal segment of the PTA.

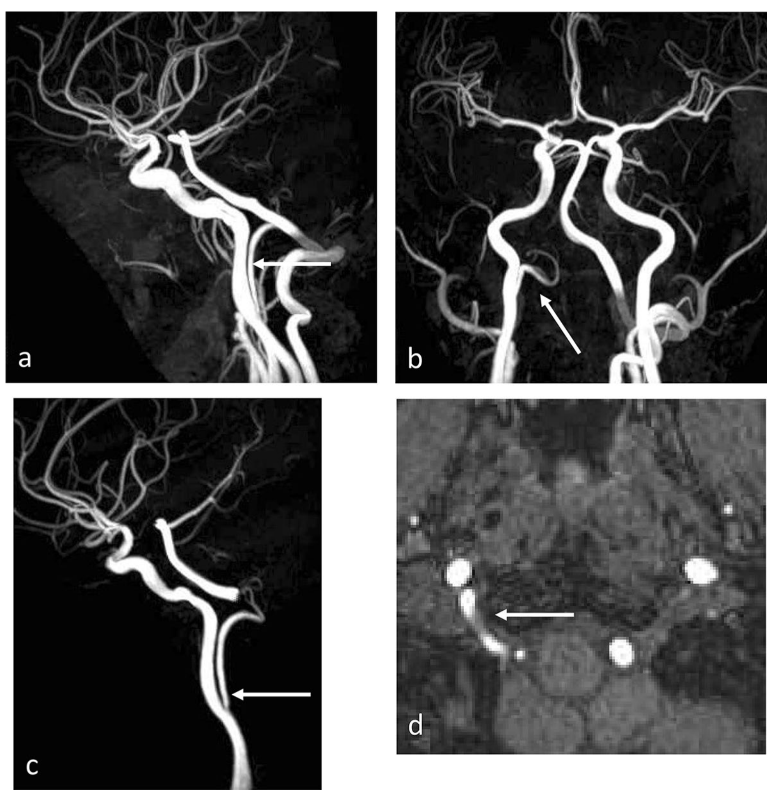

Fig. 10 A 57-year-old woman with a right PHA variant. MR angiographic images of the **a** left lateral and **b** anteroposterior projections show the right PICA arising from the right carotid system (arrows), and the right VA is absent. **c** A partial MIP image of the right carotid system clearly demonstrates the artery arising from the cervical ICA (arrow). **d** An MR angiographic source image shows the artery passing through the right hypoglossal canal (arrow)

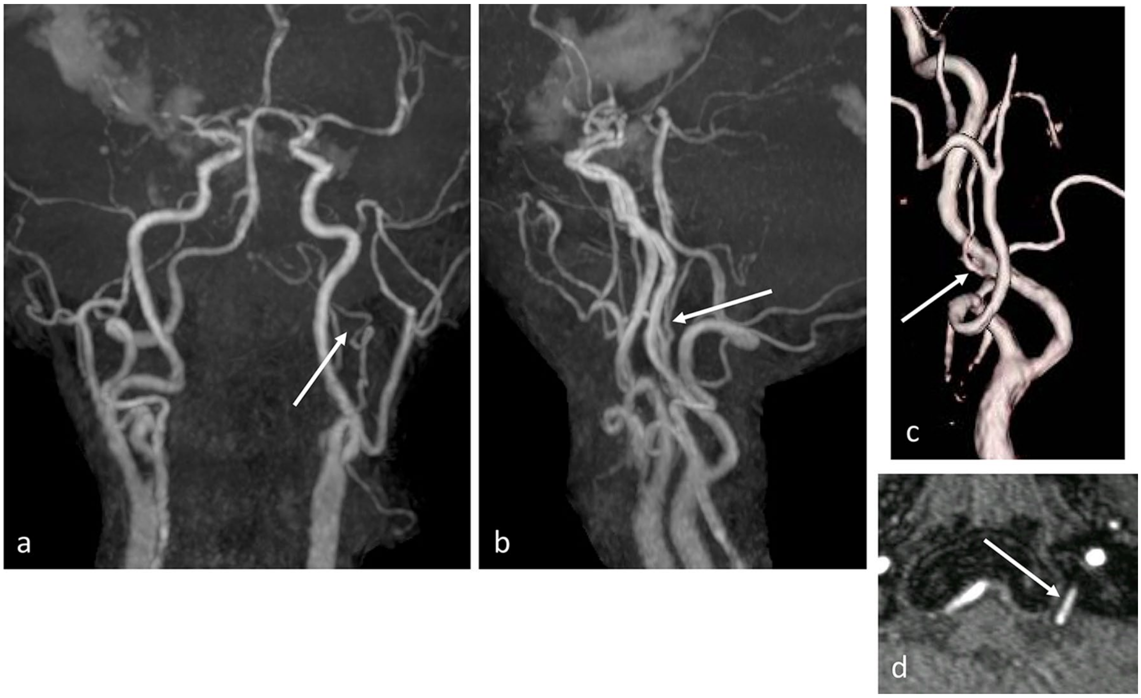

Fig. 11 A 52-year-old woman with a left type 2 PHA variant. MR angiographic images of the **a** anteroposterior and **b** left lateral projections show the left PICA arising from the left carotid system (arrows), and the left VA is absent. **c** A partial VR image of the left carotid system clearly demonstrates the artery arising from the ECA (arrow). **d** An MR angiographic source image shows passage of the artery through the left hypoglossal canal, which indicates the hypoglossal branch of the ascending pharyngeal artery (APA) (arrow)

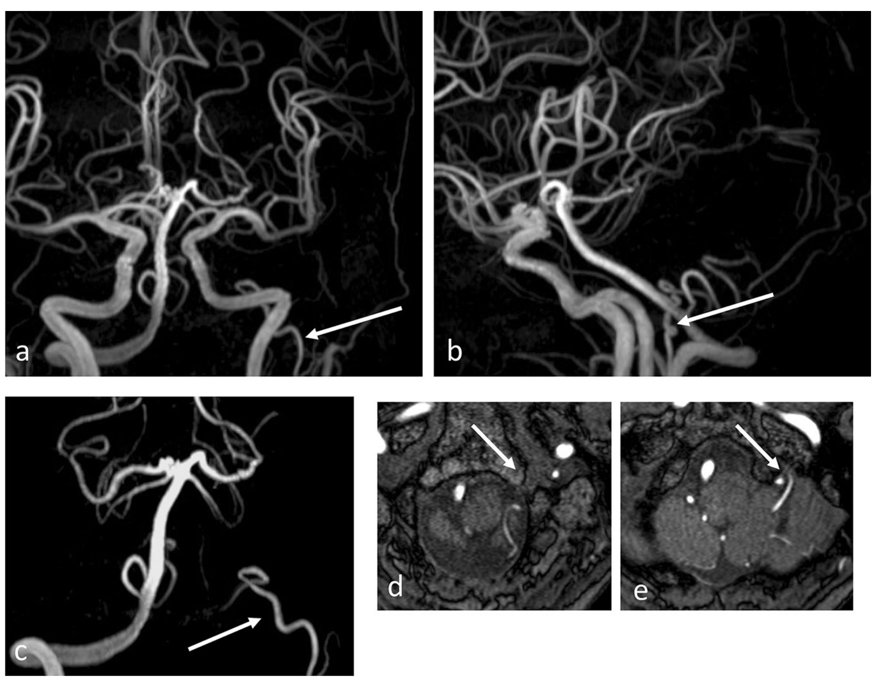

Fig. 12 An 80-year-old woman with a left PICA arising from the jugular branch of the APA. MR angiographic images of the **a** anteroposterior and **b** left lateral projections show the left PICA arising from the left carotid system (arrows), and the left VA is absent. **c** A partial MIP image of the vertebrobasilar system clearly demonstrates the anomalous artery (arrow). **d**, **e** MR angiographic source images show the artery passing through the left jugular foramen and not the hypoglossal canal (arrows)

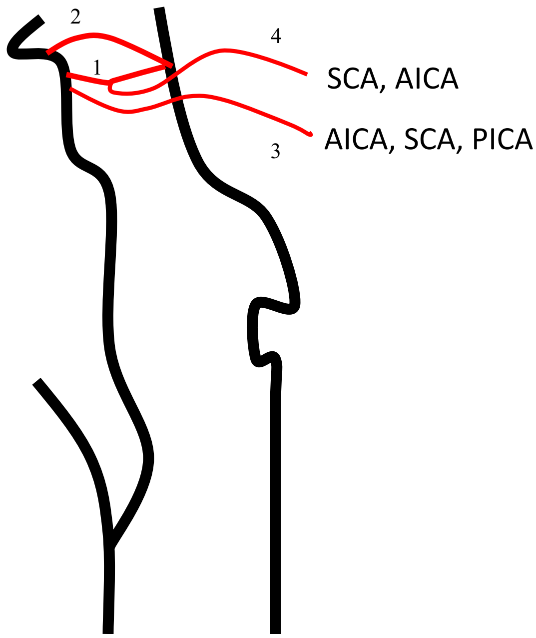

Fig. 13 Schematic illustration of the persistent trigeminal artery (PTA) and its variants. 1: lateral (usual) type PTA; 2: medial type PTA; 3: PTA variant; 4: cerebellar artery arising from the PTA; *AICA* anterior inferior cerebellar artery, *PICA* posterior inferior cerebellar artery, *SCA* superior cerebellar artery (Modified from Ref. [2])

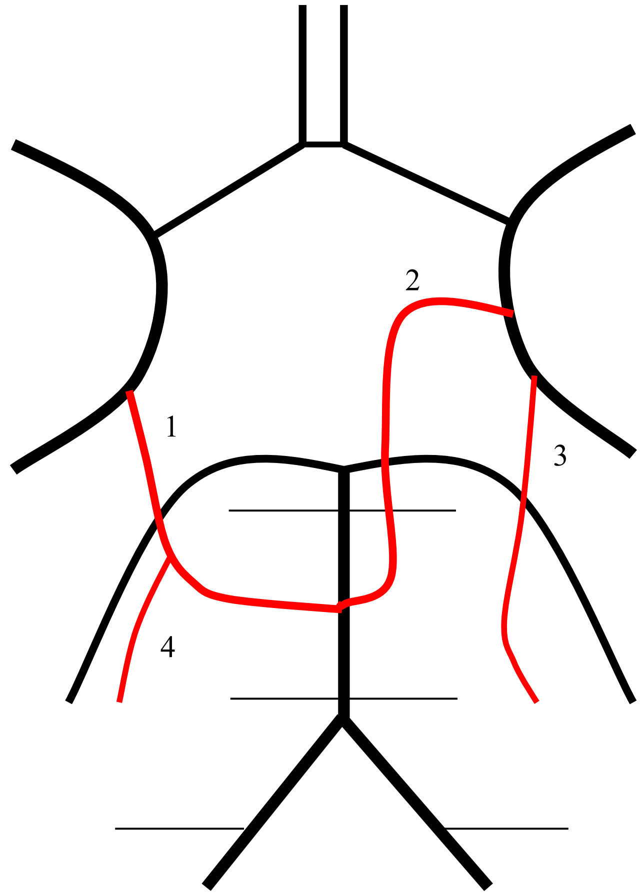

Fig. 14 Schematic illustration of the PTA and its variants. 1: lateral (usual) type PTA; 2: medial type PTA; 3: PTA variant (AICA type); 4: cerebellar artery arising from the PTA (SCA type) (Modified from Ref. [15])

Conclusion

There are many types of persistent fetal carotid-vertebrobasilar anastomosis and their variants. Improved image quality of both MR and CT angiography has led to examination of increasing numbers of patients using these imaging modalities and the subsequently more frequent observation of these arterial variations in daily clinical practice. Variations are usually found incidentally, but some, such as aneurysm formation at the origin of the anomalous artery and cerebral ischemia resulting from unique blood flow, can have clinical significance that may impact endovascular and surgical interventions. Moreover, preoperative recognition and correct interpretation of these arterial variations are important to avoid complications during such procedures.

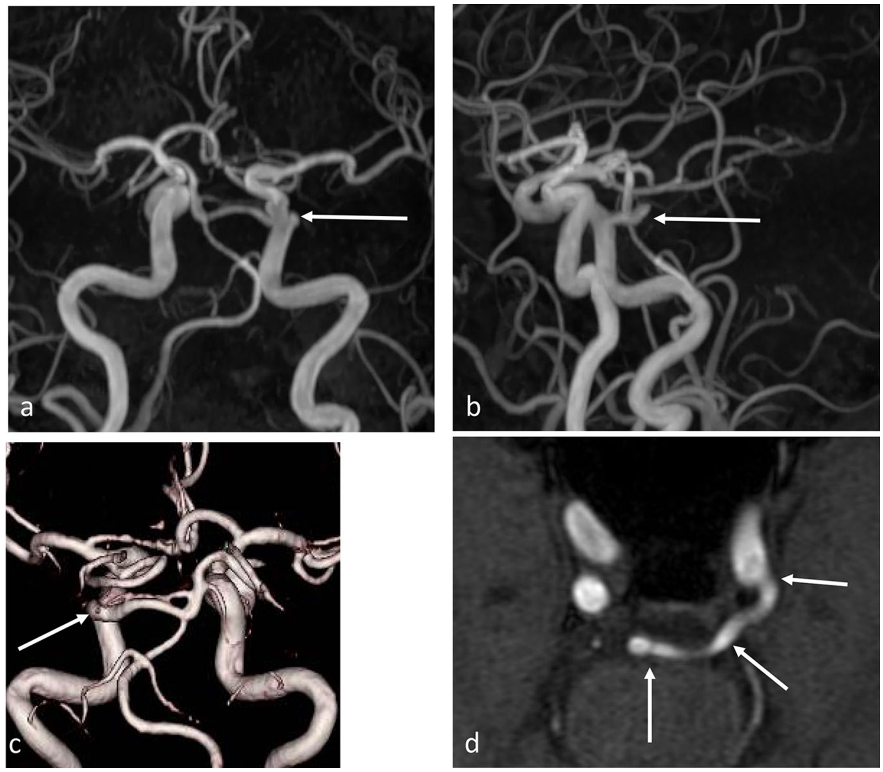

Fig. 15 A 59-year-old man with a left lateral type PTA. MR angiographic images of the **a** anteroposterior and **b** left lateral projections and **c** VR image of the posteroanterior projection show an anomalous artery arising from the proximal cavernous segment of the left ICA, following a posterior course (arrows), and finally anastomosing to the basilar artery (BA). The vertebrobasilar (VB) system, especially the left VA, is hypoplastic. **d** An MR angiographic source image clearly demonstrates the origin, course, and termination of this anastomotic artery (arrows)

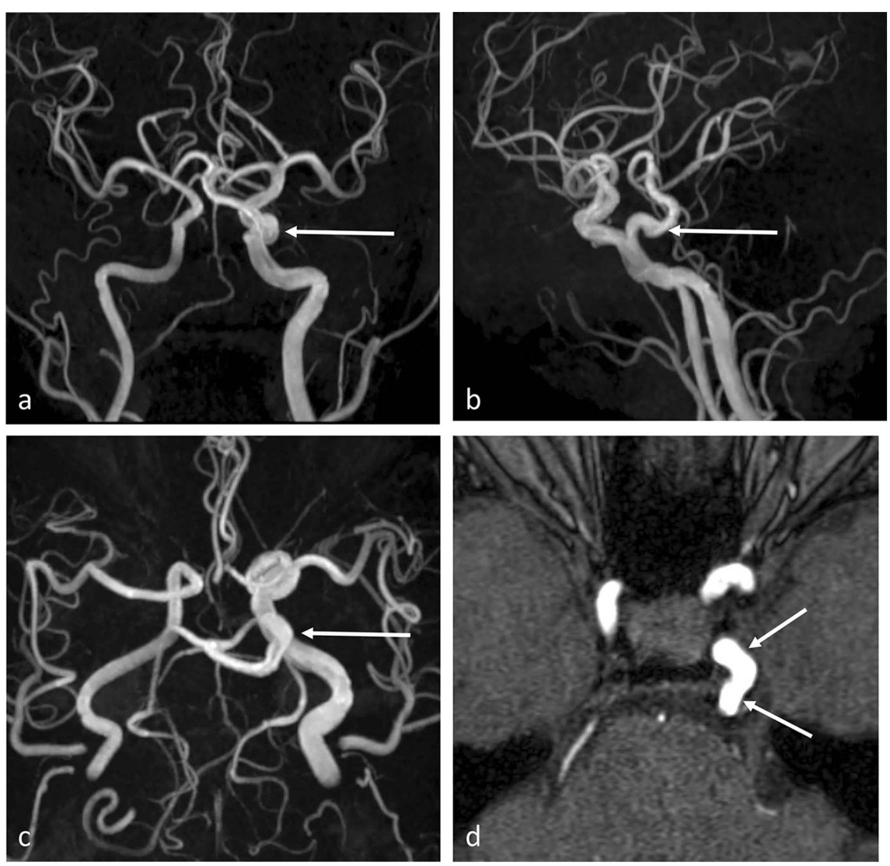

Fig. 16 A 60-year-old woman with a large left lateral type PTA. MR angiographic images of the **a** anteroposterior, **b** left lateral, and **c** inferosuperior projections show a large artery arising from the cavernous segment of the left ICA, taking a posterior course (arrows), and finally anastomosing to the BA. The VB system is extremely hypoplastic. **d** An MR angiographic source image clearly demonstrates the origin and course of this large anastomotic artery (arrows)

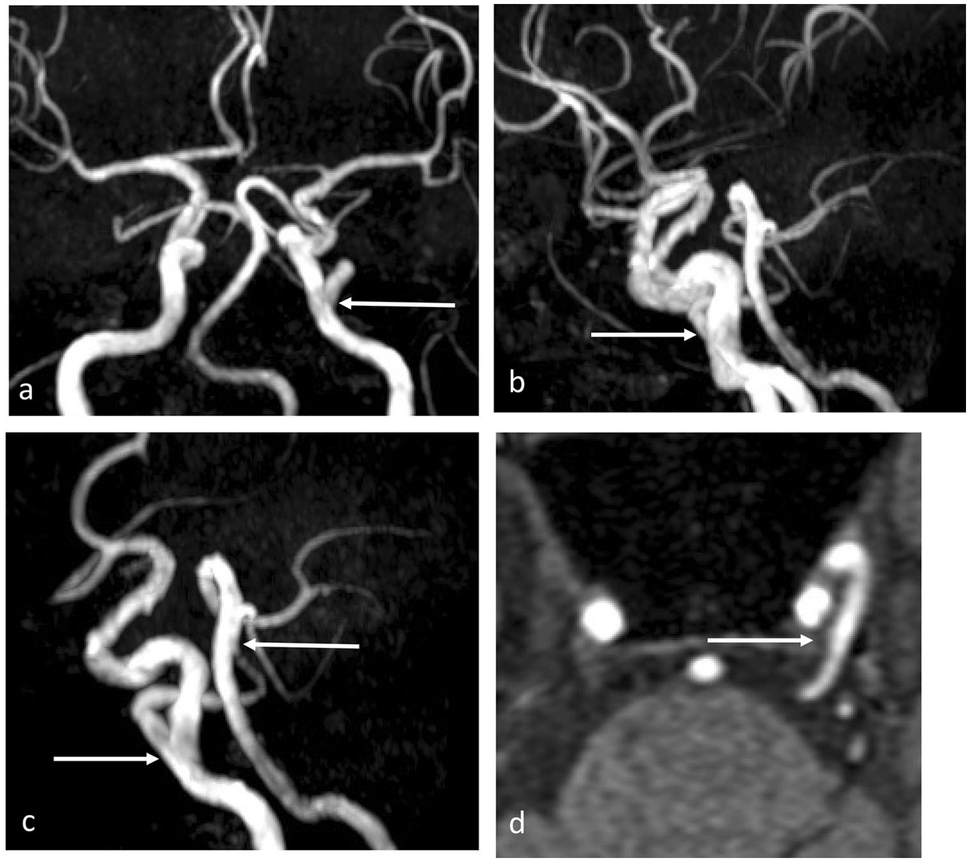

Fig. 17 An 83-year-old man with a low-lying left lateral type PTA (same patient as in Fig. 3). MR angiographic images of the **a** anteroposterior and **b** left lateral projections show an anomalous artery arising from the proximal precavernous segment of the left ICA, taking an anterosuperior and posterior course (arrows), and finally anastomosing to the BA. **c** A partial MIP image of the left carotid and left VB systems clearly shows the origin and termination of the anastomotic artery (arrows). **d** An MR angiographic source image clearly demonstrates the course of this anastomotic artery (arrow)

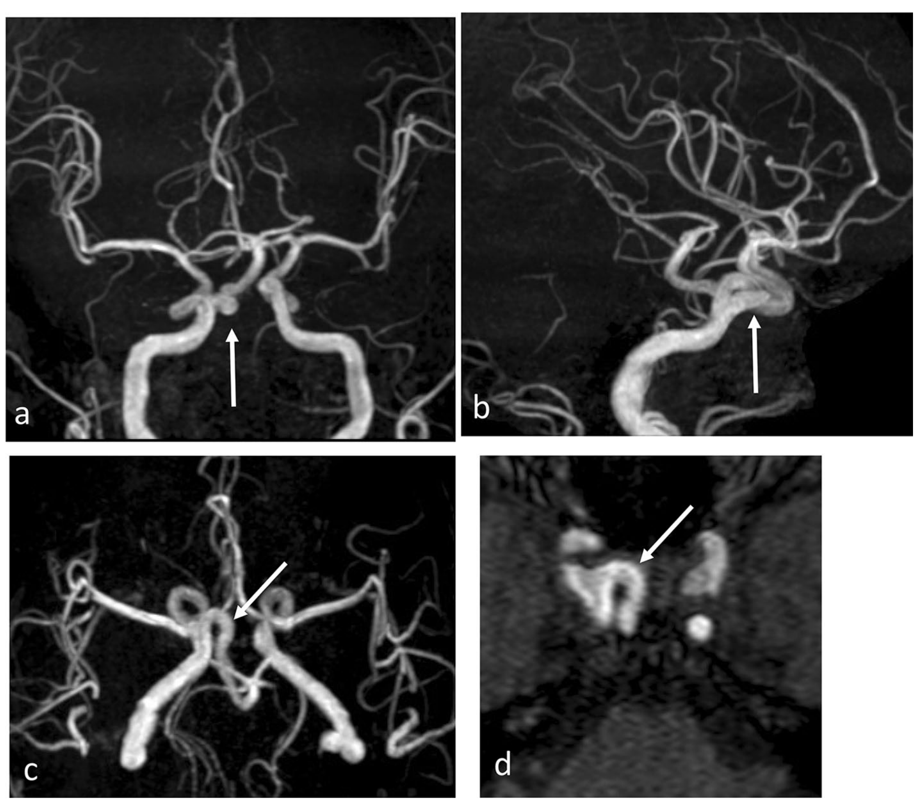

Fig. 18 A 68-year-old woman with a large right medial type PTA. MR angiographic images of the **a** anteroposterior, **b** right lateral, and **c** inferosuperior projections show a large artery arising from the midportion of the cavernous segment of the right ICA, taking a medial and subsequent posterior course (arrows), and finally anastomosing to the BA. The VB system is extremely hypoplastic. **d** An MR angiographic source image clearly demonstrates the origin and proximal course of this large anastomotic artery (arrow)

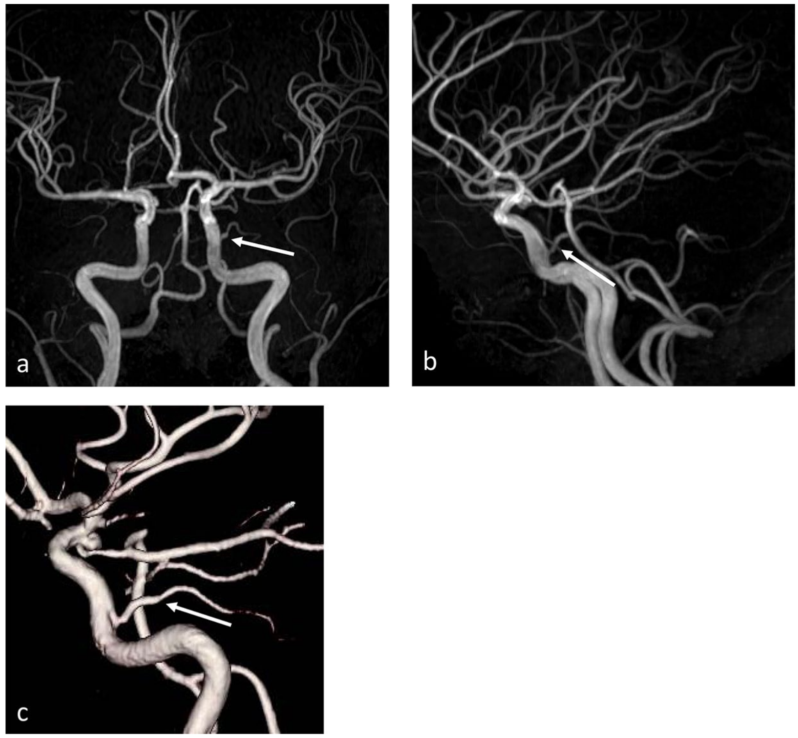

Fig. 19 A 62-year-old woman with a left PTA variant (anterior inferior cerebellar artery [AICA] type). MR angiographic images of the **a** anteroposterior and **b** left lateral projections show a small artery arising from the precavernous segment of the left ICA and taking a posterior course (arrows). **c** A partial VR image of the left carotid and left side of the VB system clearly shows the origin and course of the artery (arrows). There is no connection to the BA, and its distal course is similar to that of the AICA

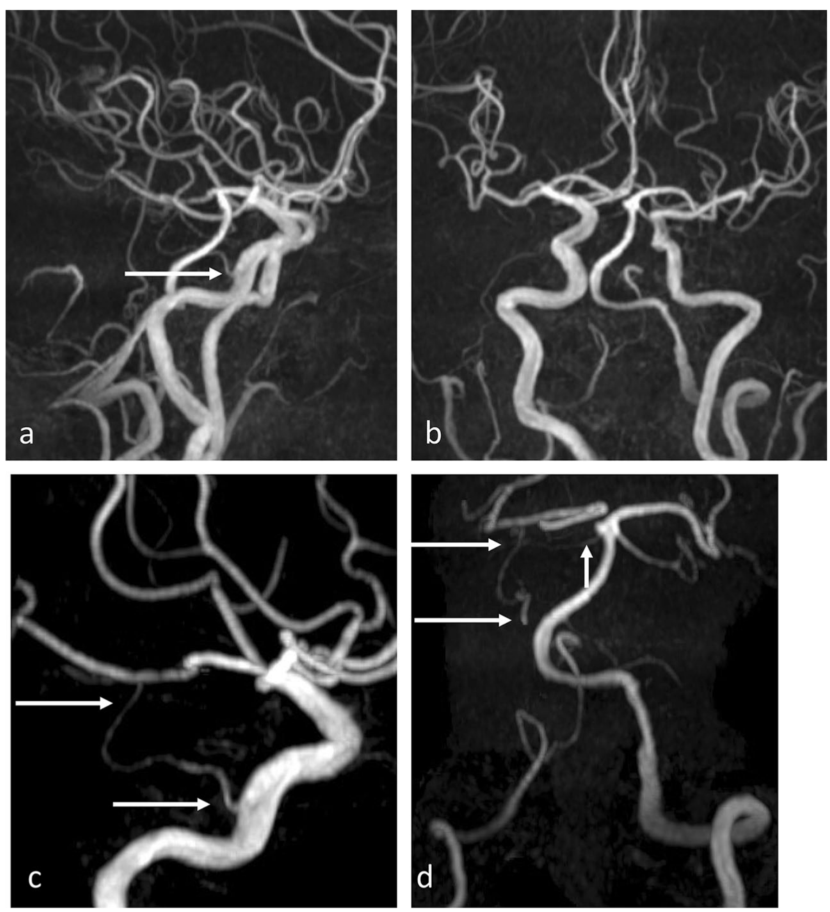

Fig. 20 An 81-year-old woman with a right PTA variant (superior cerebellar artery [SCA] type). **a** An MR angiographic image of the right lateral projection shows a small artery arising from the precavernous segment of the right ICA (arrow). **b** On the anteroposterior projection, this artery cannot be identified. **c** A partial MIP image of the right carotid system shows a similar course of the small artery to that of the SCA (arrows). **d** A partial MIP image of the VB system clearly shows the course of the artery (long arrows). There is no connection to the BA, and its distal course is similar to that of the SCA. A tiny right SCA also originates from the BA (short arrow)

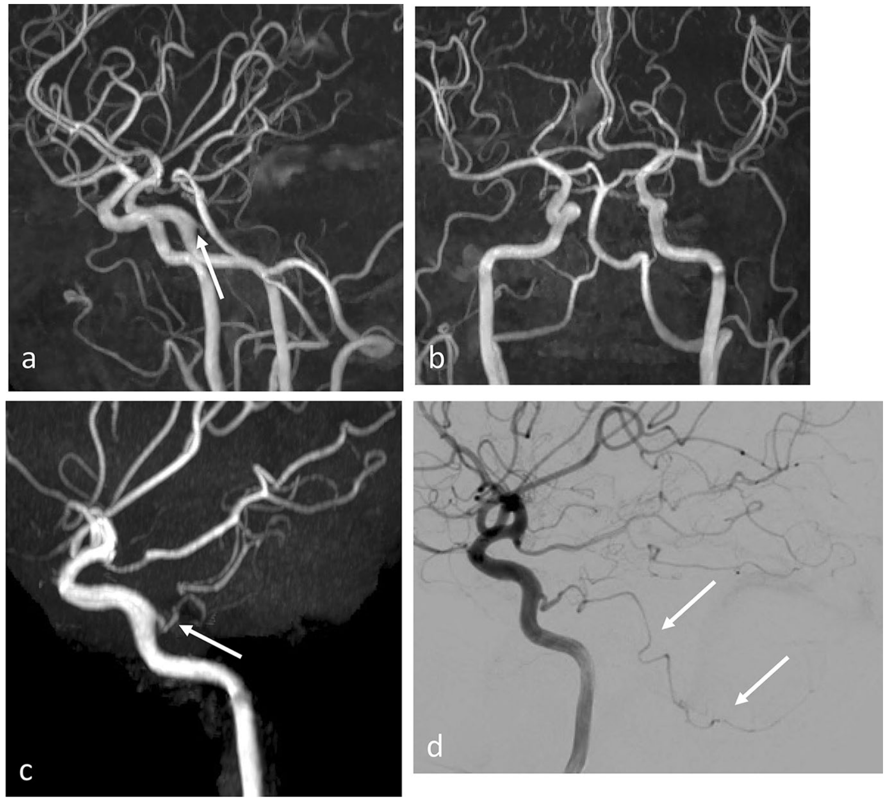

Fig. 21 A 60-year-old man with a left PTA variant (PICA type). **a** An MR angiographic image of left lateral projection shows a small artery arising from the precavernous segment of the left ICA (arrow). **b** On the anteroposterior projection, this artery cannot be identified. **c** A partial MIP image of the left carotid system clearly shows the origin and proximal course of the small artery (arrow), but the distal segment of this artery cannot be identified. **d** Catheter angiography of the left internal carotid artery injection reveals that this is the PICA (arrows)

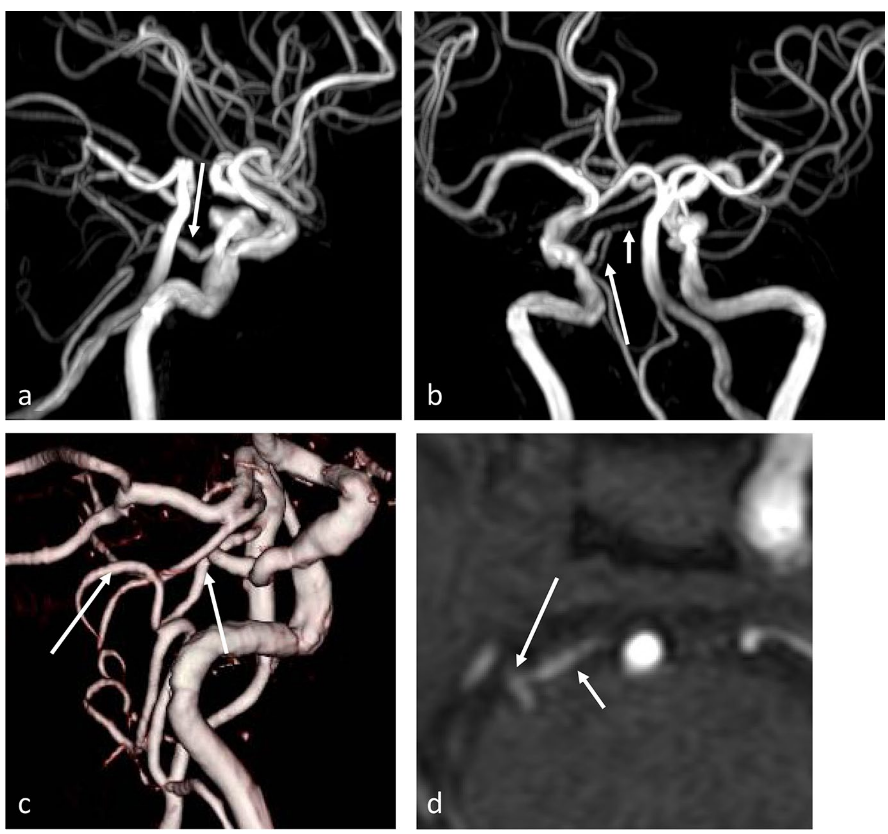

Fig. 22 A 65-year-old man with a right AICA arising from the PTA. **a** An MR angiographic image of the right lateral projection shows an anomalous artery arising from the cavernous segment of the right ICA (arrow). **b** The slightly left anterior oblique projection shows a right lateral type PTA, from which another artery is branching (long arrow), and the distal segment of the PTA is faintly visualized (short arrow). **c** A partial VR image of the right carotid and right side of the VB systems shows a branch of the SCA originating from the PTA (arrows). **d** An MR angiographic source image clearly depicts the tiny distal segment of the PTA (short arrow). The long arrow indicates the junction between the PTA and a branch of the SCA

Acknowledgements We thank Rosalyn Uhrig for editorial assistance in the preparation of this manuscript.

Funding No funding was received.

Compliance with ethical standards

Conflict of interest The author declares no conflict of interest.

Ethical approval This work was carried out in accordance with the ethical standards of the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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