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Review

Persistent Primitive Trigeminal Artery: A Review

Persistant Primitif Trigeminal Arter: Bir Derleme

Waleed AZAB[1], Johnny DELASHAW[2], Mohammed MOHAMMED[3]

[1]*Ibn Sina Hospital, Department of Neurosurgery, Kuwait*
[2]*Oregon Health & Science University, Department of Neurosurgery, Portland, Oregon, USA*
[3]*Ibn Sina Hospital, Department of Neuroradiology, Kuwait*

Correspondence address: Waleed AZAB / E-mail: waleedazab@hotmail.com

ABSTRACT

The trigeminal artery is the largest of the fetal carotid-basilar anastomotic arteries, and it persists for the longest embryonic period. The artery usually involutes after the development of the posterior communicating artery. The exact causes of persistence of this primitive vessel into adulthood are not completely clear. Angiographic and anatomical descriptions of the various persistent trigeminal artery (PTA) configurations and their relation to the remainder of the cerebrovascular tree and the other surrounding structures have been reported. Persistent trigeminal artery can be associated with many other vascular anomalies and disorders including aneurysms, arteriovenous malformations and carotid-cavernous fistulae. A thorough understanding of the anatomical and angiographic features of this persistent embryonic arterial channel is of utmost importance when making therapeutic decisions and embarking on surgical or endovascular intervention for any pertinent pathological condition. We review the embryology, angiographic features, microsurgical anatomy and associated vascular anomalies and disorders of the persistent trigeminal artery.

KEYWORDS: Aneurysm, Artery, Trigeminal

ÖZ

Trigeminal arter, fetal karotik baziler anastomotik arterlerin en büyüklerinden biridir ve en uzun embriyonik dönem boyunca devam eder. Arter sıklıkla posterior komunikan arter geliştikten sonra küçülür. Bu primitif damarın yetişkin döneme kadar devam etmesinin nedenleri açık değildir. Çeşitli persistan trigeminal arter (PTA) konfigürasyonlarının anjiyografik ve anatomik tanıları ve serebrovasküler ağaç ve diğer çevre yapılarla ilişkileri bildirilmiştir. Persistan trigeminal arter anevrizma, arteriyovenöz malformasyonlar ve karotid-kavernöz fistül dahil olmak üzere birçok başka vasküler anomaliyle ilişkili olabilir. Persistan embriyonik arteriyel kanalın anatomik ve anjiyografik özelliklerinin tam olarak anlaşılması terapötik kararlar verirken ve ilgili herhangi bir patolojik durum açısından cerrahi veya endovasküler girişim düşünülürken çok önemlidir. Persistan trigeminal arter embriyolojisi, anjiyografik özellikleri, mikrocerrahi anatomisi ve ilişkili vasküler anomaliler ve bozuklukları gözden geçiriyoruz.

ANAHTAR SÖZCÜKLER: Anevrizma, Arter, Trigeminal

INTRODUCTION

The earliest description of the persistent trigeminal artery dates back to the year 1844 in the original work and drawings by Quain (64). About one century elapsed until the artery was angiographically demonstrated for the first time by Sutton in an article published in the British Journal of Radiology in 1950 (75). Persistent trigeminal artery (PTA) is the most common of the primitive carotid-basilar anastomoses that persist into adulthood, with an estimated incidence of 0.1 to 1.0% on cerebral angiograms (17,20,36,39,47,52,67,70). A number of cases of PTA and its variants found at autopsy (21,30,34,52,60,67,70,82), on cerebral angiograms (2,6,7,17,27,35,73,85), and on MRI and MRA scans (7,18,63) demonstrate the anatomy (30,39,52,67) of this primitive anastomosis and its relationship to various vascular diseases (1,16,19,20,25,30,36, 44,47).

I- EMBRYOLOGY

The trigeminal artery is the largest of the fetal carotid-basilar anastomotic arteries, and it persists for the longest embryonic period, usually being obliterated by the 11.5- to 14-mm embryonic stage (1,16,20,35,39,52 ,59,67) (Figure 1).

In her remarkable treatise, "The development of the cranial arteries in the human embryo" published in 1948, Dorcas Hager Padgett (59) wrote one of the most comprehensive reports of the development and involution of the trigeminal artery. The first evidence of the trigeminal artery is found in the 20-somite (3 mm) embryo. The paired dorsal aortae have two definite branches at their junction with the first aortic arch: the primitive ICA, which extends to the optic vesicles at the forebrain, and the primitive trigeminal artery, which leaves the aorta just caudal to the carotid branch and arches dorsally toward the fifth nerve ganglion. The trigeminal artery at this stage supplies the cranial end of the primordial hindbrain channel whose proliferating endothelium gives rise to the bilateral longitudinal neural arteries (the future basilar artery) and the veins of the hindbrain. During the next stage (4-5 mm), the cranial end of each neural artery is supplied by the trigeminal artery. Development of the diencephalic and mesencephalic regions is accompanied by an extension of

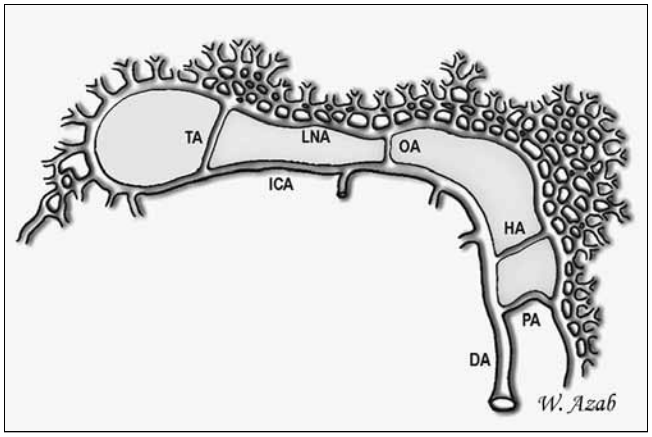

Figure 1: Embryology of the Trigeminal Artery. Trigeminal artey is the largest of the embryonic four carotid-basilar anastomotic arteries and persists for the longest fetal period.

the primary caudal division of the ICA, which becomes the definitive PCoA.

After the development of the PCoA, the trigeminal artery usually involutes. Other factors contributing to the elimination of the trigeminal anastomosis include a shifting in the relative position of the carotid and basilar ends of the anastomosis and the interposition of the basal sphenoid cartilage between the carotid and basilar ends during the 12- to 20-mm stages (59). Furthermore, Ohshiro et al. (52) published an autopsy study of an adult in whom PTA passed through a dural foramen located immediately medial to Meckel's cave and superolateral to Dorello's canal to enter the posterior fossa. The diameter of the PTA varied before, at, and after the dural foramen; measuring 4.0 mm before the foramen, 1.0 mm at the foramen, and 2.0 mm after the foramen. They speculated that the stenosis of the PTA at the foramen suggests that the dural foramen has a role in the regression of the PTA during the fetal stages of development.

The exact causes of persistence of a primitive vessel into adulthood, or non-resorption of a vessel once it reaches a critical size are not completely clear. It is thought that no rigid genetic programming exists in the development of the cerebral blood vessels, and that the momentary needs in the dynamic process of the developing brain continually reshape the vessels by formation, regression and anastomosis (74). Lasjaunias and Berenstein (38) suggest that the hemodynamic constraint imposed near a developing territory orientates that territory toward a particular vessel to maintain a hemodynamic balance. This results in the persistence of that vessel and, thus, an anatomic variant. Failure of regression of the trigeminal artery is thought by some authors to result from occlusion of the proximal portion of internal carotid artery in the fetus, resulting in an inevitable persistence of the trigeminal artery in order to maintain adequate blood supply to the forebrain through a retrograde transport of blood from the basilar to the carotid (56).

PTA variants are arteries that originate directly from the precavernous portion of the internal carotid artery but terminate as cerebellar arteries rather than anastomosing with the basilar artery (2). Persistence of the PTA with incomplete fusion of the longitudinal neural arteries may result in either a superior or an inferior cerebellar vessel arising anomalously from the cavernous ICA (28). This precludes a direct connection of the trigeminal artery with the BA and results in its termination as one of the cerebellar arteries (2).

II- ANGIOGRAPHIC ANATOMY

Saltzman Classification

In 1959, Saltzman (68) reported eight cases and proposed an angiographic classification for the PTA into two main types. In Saltzman Type 1, the PTA inserts into the basilar artery distal to the AICA but proximal to the SCA (2). The BA proximal to the insertion of the PTA may be hypoplastic, and the PCoA may be absent (44). In this type, the entire basilar artery system distal to the anastomosis is filled through the PTA which becomes the main supply to the distal BA, PCA, and SCA territories (44, 68). In Saltzman Type 2, the PTA inserts into the BA but mainly supplies the SCA's bilaterally (2). In this type, the PCAs receive their blood supply predominantly through patent PCoAs (44). The distal end of the basilar artery is angiographically poorly visualized (68).

The relative incidence of Saltzman type 1 and type 2 has been reported to be more or less equal (44). However, in a recent review utilizing 3.0 T MRA in 25 cases of PTA the incidence of type I was 24% while that for type II was only 16% (10).

Saltzman (68) classified one case as a combination of the two types; PCoA supplied the PCA on the same side of the PTA and the PTA supplied both SCAs and the PCA on the opposite side. A similar case was reported in 1974 by Parkinson and Shields (60) who demonstrated both angiographic and anatomic features of a PTA filling both SCAs and the contralateral PCA with a fetal PCoA on the same side of the PTA supplying the ipsilateral PCA; a description which corresponds to a combination of the Saltzman Types I and II. Many Saltzman variants, sometimes referred to as Saltzman type 3, have subsequently been described (12,41,78). The PTA variant directly joins into a cerebellar artery (42). It arises from the ICA and terminates directly without anastomosing with BA as SCA (Saltzman Type 3a), AICA (Saltzman Type3b), or PICA (Saltzman Type3c) (2,8,15,28,50,51,71,78,79). Among the PTA variants, the majority fall under Type 3b with termination at the AICA; with types 3a and 3c being extremely rare in the literature (2,65). It is thought that as the PTA is closer to the origin of the AICA than to the origin of the PICA during embryological development, anterior vessels are more likely to originate anomalously from the carotid artery than are the posterior ones (28). PTA variants are uncommon (2) and are reported to have an incidence of approximately 0.18% (73).

III- SURGICAL ANATOMY

- **ORIGIN AND INITIAL COURSE**

A PTA may originate from left (67) or right (74) ICA. The most common sites of origin for a PTA are the posterior bend or lateral wall of the intracavernous carotid artery (52,60,67). In one autopsy case, the PTA originated from the posterior bend of the cavernous ICA to run posteriorly in the posterolateral space of the cavernous sinus (52). Salas et al. (67) reported the vessel to originate from the posterolateral aspect of the ascending (posterior vertical) cavernous segment of the ICA just medial to the sixth nerve to make an acute inferolateral angle and a course below the sixth nerve immediately at the point of leaving the ICA to exit the cavernous sinus by piercing the reticular layer of the sinus wall, forming a posterior loop around the sphenopetrous (Gruber's) ligament then to run in the medial wall of Meckel's cave. In some reports , however, the PTA arose from the medial wall of the cavernous ICA (70,74). Suttner et al. (74) found a PTA arising from the superomedial portion of the distal horizontal segment of the intracavernous carotid artery, coursing medially and immediately posteroinferiorly, to continue between the posterior bend of the carotid artery laterally and the pituitary gland medially passing the junction of the posterior clinoid process and the pituitary gland to exit the posterior wall of the cavernous sinus.

- **RELATION TO ABDUCENT & TRIGEMINAL AFTER LEAVING CS**

In relation to the dorsum sellae, approximately 50 to 59% of all cases of PTA penetrate the sella turcica, course along their own groove, perforate the dura near the clivus, and then join the basilar artery with thinning of the sellar floor and abnormalities of the dorsum sellae being a frequent finding while in the remaining 41 to 50% of cases, the PTA runs lateral to the sella turcica (39,52). In 1993, Ohshiro et al. (52) reviewed the relation of PTA to the dorsum sellae in 22 of 25 autopsy cases described up to the time of their writing. Analyzing the anatomical data of these cases, they classified PTA into two types: *a medial type* in which the artery runs through the dorsum sellae and perforates the dura mater near the clivus and *a lateral type* in which the artery runs between the sensory root of the trigeminal nerve and the lateral side of the sella to penetrate the dura mater medial to Meckel's cave. These authors also described one case of their own which was classified as lateral type, and the vessel was passing through a dural foramen clearly different from and located immediately medial to Meckel's cave; the foramen was superolateral to Dorello's canal and lateral to the petroclinoid ligament. Inoue et al. (12) reported both the trigeminal and abducens nerves to run lateral to the PTA in one specimen. Tulsi and Locket (83) reported one case in which the trigeminal artery had a medial course crossing below the level of the pituitary fossa and piercing the dura of the dorsum sellae; in two other cases in their study, the PTA had a course lateral to the abducens nerve and pierced the dura of the posterior fossa just medial to the sensory root of the trigeminal nerve.

SALAS CLASSIFICATION

Salas et al. (67) classified the PTA by its relationship to the abducens nerve, distinguishing a lateral (petrosal) and a medial (sphenoidal) variations. When the trigeminal artery courses lateral to the VIth cranial nerve, the artery arises from the posterolateral aspect of the C4 segment of the cavernous carotid and crosses underneath the nerve which may be displaced superiorly by the PTA. This petrosal variation of the PTA pierces the dura just medial to the sensory root of the trigeminal nerve. When the PTA courses medial to the abducens nerve, the artery arises from the posteromedial aspect of the C4 segment of the cavernous carotid artery and pierces the dura of the dorsum sellae (sphenoid variation). Clinically, the lateral variant may be associated with brainstem ischemia, ophthalmoplegia, and trigeminal neuralgia. The medial variant can be associated with posterior fossa symptoms secondary to a steal phenomenon. The surgeon should also be aware of a medial PTA during a transsphenoidal surgery to avoid severe hemorrhage (7).

- **ENTRANCE INTO BASILAR ARTERY** (Figure 2)

PTA joins the BA between the SCA and the AICA (52,74). In one anatomical report, the vessel completed its course to the basilar artery with a communication 2 mm inferior to the left superior cerebellar artery. The length of the artery between the dural (trigeminal) ring and the basilar artery was 22 mm, and the overall length from the carotid to the basilar artery was 33 mm. The mean diameter after the dural ring was 3.5 mm (67).

- **BRANCHES**

Branches from a PTA in adult anatomic specimens have been described. These include pontine perforators and branches to trigeminal ganglion, the meningohypophyseal trunk and its branches and cerebellar arteries.

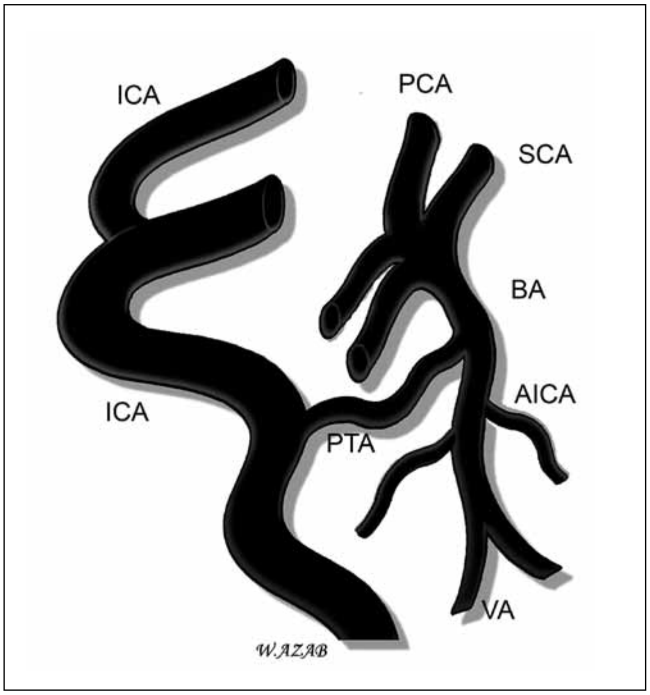

Figure 2: Schematic representation of entrance of the PTA to BA. PTA joins the BA between the SCA and the AICA.

A- Pontine Perforators and Branches to the Trigeminal Ganglion:

Khodadad (34) demonstrated pontine branches from the trunk of the PTA in brains of 4-,6-, and 8-month fetuses. He suggested that the PTAs might become of functional and clinical significance if they persisted. Ohshiro et al. (52) reported a case in which two branches from the cisternal portion of the PTA were present. One branch sent a feeding artery to the left trigeminal nerve root and a perforating artery to the pons. The other branch perforated directly into the pons. Salas et al. (67) described four pontine perforating branches originating from the intradural segment of the artery which were 7, 10, 11, and 17 mm distal from the dural ring in the wall of Meckel's cave. It is highly probable that these branches are functioning vessels in the brain stem even in adult cases; with occlusion of the PTA leading to the ischemic lesions in the brainstem (52,37).

B- Cerebellar Arteries:

Arakawa et al. (3) reported one case in which the AICA arose from the internal carotid artery passing medial to the abducens nerve. This artery gave off a small branch communicating to the basilar artery, passed lateral to the trigeminal nerve root, and continued backward to the dorsal surface of the cerebellum; AICA is thus considered a branch of the PTA. Four arterial twigs branched from this artery at the ventral surface of the brain stem, two twigs distributed to the medial surface of the trigeminal nerve root, the third twig distributed to the lateral surface of the trigeminal nerve root and the fourth twig directly connected with the basilar artery. Finally, the main trunk of the artery wound backward to pass lateral to the trigeminal nerve root and distributed to the anteroinferior surface of the cerebellum. In the other case by these authors, PTA gave off medial and lateral arterial branches to pour into the basilar artery. The medial branch was a pontine branch supplying the basal pons. The lateral branch passed caudally to give off a twig to the lateral surface of the trigeminal nerve root. This arterial branch passed medial to the trigeminal nerve root to divide into two lateral and medial arterial twigs. The lateral twig, which traversed laterally, connected with the AICA. The medial twig passed medialwards to give off a nutrient artery to the ventral surface of the pons near the facial nerve root. The medial twig gave off some pontine branches and finally anastomosed with the lateral surface of the basilar artery.

C- Meningohypophyseal Trunck and its Branches:

Lie (41) described MHT branching off at the origin of the PTA on cerebral angiograms. In a review of various anatomic descriptions, the origins of the PTA and the MHT were found to be common or separate, and the PTA might give rise to vessels normally arising from the MHT (67). Inoue et al. (30) described a specimen in which the dorsal meningeal, tentorial, and inferior hypophyseal arteries, usually branches of the MHT, were arising from the PTA as individual branches. In the case reported by Ohshiro and colleagues (52) the MHT and the ACS branched off at the origin of the PTA. They suggested that the PTA, the MHT, and the ACS might be closely linked in the embryo. Suttner et al. (74) described a case in which PTA gave off two branches: the inferior hypophyseal artery medially and the dorsal meningeal artery to the clivus inferolaterally. The capsular artery of McConnell arose from the inferomedial portion of the intracavernous carotid artery, and crossed below the PTA in its course to the pituitary capsule. The tentorial artery arose directly from the intracavernous carotid artery at its posterior bend. They suggested that the medial (sphenoidal) variation presented by Salas and colleagues (67) may represent a different carotid-basilar anastomosis from the PTA and that the MHT is the possible remnant of this vessel. On the other hand, they considered the lateral (petrosal) variation the true PTA because it can provide blood supply both to the brainstem and to the trigeminal ganglion. Dwight Parkinson pointed out that the MHT may be a remnant of an earlier carotid basilar connection above the sixth nerve distinct from the true PTA below the sixth nerve (52). Parkinson and Shields (60) analyzed the differences between the PTA and MHT and stressed their separate origins, emphasizing that the MHT has three main branches and that the PTA has none.

- **ASSOCIATED ANOMALIES IN CADAVERIC STUDIES**

There is a multitude of anatomical variations and anomalies associated with PTA including ipsilateral fetal PCoA (60,74), bilateral fetal PCAs (Saltzman Type II) (30), hypoplastic BA proximal to the connection with the PTA (60,82), as well as hypoplastic VAs below the junction with the PTA (60). BA hypoplasia proximal to its anastomosis with the PTA is frequently associated with this type of vascular anomaly (60), and is probably caused by a poor-flow-related stimulus for further development (7). Other anomalies include a duplicated SCA and hypoplastic AICA (60), bilateral absence of PICAs (52), fenestrated oculomotor nerve around the PCA (60) and a subdural course of the PTA over the clivus within a dedicated dural sleeve or canal before becoming intradural and anastomosing with the BA has been described in one specimen (60). In some reports, however no other anomalies of the cerebral vessels were noted; both PCoAs had a normal, nonfetal pattern on both sides (67,83).

IV-ASSOCIATED CLINICAL CONDITIONS

(1) Cerebrovascular anomalies

These include ectasia and fenestration of the ACA (81), infraoptic course of A_1 segment of ACA (84), absence of the CCA (66), absence of both ICAs (27), occluded ICA (31), hypoplastic BA and VA (5,58,84), bilateral occlusion of VA (31), primitive otic artery (31) and PHACE syndrome (62).

(2) Aneurysms (Figures 3 and 4A, B)

Davis et al. (14) first reported an aneurysm of the PTA in 1956. Cloft et al. (11) reported a 3% prevalence of cerebral aneurysms with PTA in their series of 34 patients, which is similar to the prevalence of intracranial aneurysms in the general population. Others reported that approximately 13.8 to 27.8% of patients with PTA also had intracranial aneurysms (10,53). A more recent analysis of 103 PTAs detected in 16,415

MRAs reported an incidence of 3.9% of cerebral aneurysms in patients harboring a PTA (58). Cerebral aneurysms associated with PTA have been reported to occur in relation to the bifurcations formed by the PTA and either the ICA (40,46,57) or the BA (45,86). Aneurysms may also be present in other locations of the cerebral circulation (23) including cavernous ICA (40), PCA (69), PCoA (5,24,53), ACoA (49,84) and BA-SCA (29). Aneurysms of the PTA itself are quite rare (9,20), and arise either from the trunk of a PTA (76) or a PTA variant (26). Clinically, patients may present with sixth nerve palsy (46,57), subarachnoid hemorrhage (76) or carotid cavernous fistula secondary to rupture of these aneurysms (11) Direct surgical clipping (76), endovascular coiling (46,57) or stent-assisted coiling (48) have been employed to treat these aneurysms. As the perforating arteries originating from the PTA may be important in the supply of the hindbrain, PTA patency should be preserved if possible during surgery (76).

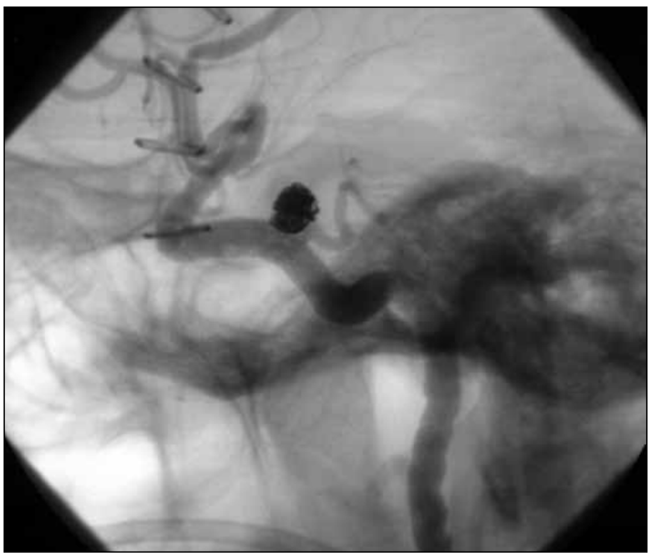

Figure 3: Cavernous ICA-PTA bifurcation aneurysm coiled after a failed surgical clipping.

Ikushima et al. (29) were the first to treat an aneurysm endovascularly via a PTA. These authors reported occlusion of a saccular aneurysm of the right BA-SCA with Guglielmi detachable coils by advancing a microcatheter through the PTA in their patient in whom both VAs and BA proximal to the junction with the PTA were hypoplastic. Similarly, Schlamann and colleagues (69) reported treatment of an acutely ruptured wide-necked PCA aneurysm using Guglielmi detachable coils and remodeling technique through a carotid artery approach via a PTA to selectively catheterize the aneurysm. In patients with hypoplastic VAs and a PTA, this approach may represent an alternative for selective embolization of posterior circulation aneurysms (29,69).

Li et al. (40) for the first time reported opening of a PTA associated with contrast filling of a cavernous ICA aneurysm 4 months after its primary treatment with balloon occlusion of the ICA. They concluded that the possibility of contrast filling of aneurysms via potential PTA should be considered in the event of an aneurysm with parent artery occlusion.

(3) Vertebrobasilar insufficiency and brain stem ischemia

The pathogenesis of vertebrobasilar insufficiency in patients with PTA may be attributed to microemboli originating from an atherosclerotic carotid artery owing to the presence of direct communication between the anterior and posterior circulations (72), or to occlusion of the PTA leading to a decreased blood flow in the basilar artery (32).

(4) Carotid-cavernous fistula

Carotid-cavernous fistula (13,55) and PTA-cavernous sinus fistula (80) may develop either spontaneously or after a traumatic event and are best treated with endovascular occlusion techniques (4,43).

(5) Miscellaneous conditions

PTA has been reported in the context of NF-1 (22), Klippel-Feil syndrome (61), Moyamoya disese (35) as well as infratentorial (49,54) and supratentorial AVMs (77).

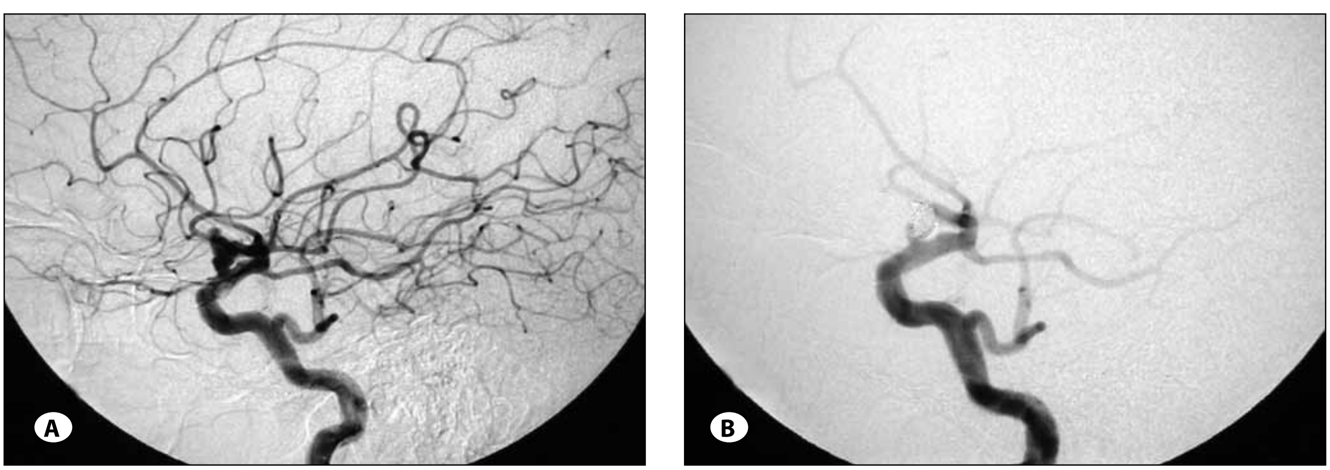

Figure 4: Persistent trigeminal artery and an associated ruptured PCoA aneurysm before **(A)** and after **(B)** endovascular coiling. Note the fetal configuration of the PCoA.

CONCLUSION

Persistent trigeminal artery (PTA) is the most common of the primitive carotid-basilar anastomoses that persist into adulthood. It may be associated with other cerebrovascular variants and disorders that may necessitate treatment. PTA has important anatomical and clinical aspects that should be taken in consideration when managing lesion in its vicinity.

ABBREVIATIONS

ACA Anterior cerebral artery, *ACoA* Anterior communicating artery, *ACS* Artery of the inferior cavernous sinus, *AICA* Anterior inferior cerebellar artery, *BA* Basilar artery, *CCA* Common carotid artery, *DA* Dorsal aorta, *HA* Hypoglossal artery, *ICA* Internal carotid artery, , *LNA* Longitudinal neural artery *MHT* Meningohypophyseal trunk, *NF-1* Neurofibromatosis type 1 , *OA* Otic artery, *PCA* Posterior cerebral artery, *PCoA* Posterior communicating artery, *PHACE* Posterior fossa malformations, Hemangiomas, Arterial anomalies, Coarctation of the aorta and other cardiac defects, and Eye abnormalities. *PICA* Posterior inferior cerebellar artery, *PTA* Persistent trigeminal artery, *SCA* Superior cerebellar artery, *VA* Vertebral artery.

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