# Dural Branches of the Ophthalmic Artery

Sara Bonasia, Thomas Robert, and Michel W. Bojanowski

The ophthalmic artery (OA), which will be widely discussed in chapter "Embryology and Variations of the Ophthalmic Artery," is a very fascinating artery for its complex embryological development as well as for the numerous vascular anastomoses developed with branches of the external carotid artery. The role of the OA in the dural supply is not well-known, but the understanding of the dural function of the OA and of its possible variations is a cornerstone for surgical and endovascular treatment of dural pathologies (dural arteriovenous fistulas, skull base meningiomas, and chronic subdural hematoma embolization). In this chapter, we will focus on the dural branches of the OA with special attention to their rare variations, like the OA origin of the middle meningeal artery (MMA) and the OA origin of the marginal tentorial artery (MTA).

## History

Meyer (1887), who was considered as pioneer in the orbital vascular anatomy, was the first to precisely describe all branches of the ophthalmic artery including its dural territory [1]. Few years before, Curnow (1873) had already described three cadaveric cases of variations in the origin of the OA [2]. One of these three cases was the first description of an OA origin of the middle meningeal artery (MMA). With the advent of digital subtraction angiography (DSA), Kuru (1967) gave a detailed description of the OA meningeal branches, and after him, few authors focused on the variants of the OA and of the MMA [3–10]. Lasjaunias gave his crucial contribution to the comprehension of the orbital and meningeal vascular supply, combining his knowledge of embryology with an accurate angiographic analysis [7, 8, 11]. The last author that gave a comprehensive description of dural vascularization was Rhoton et al. (2005) based on his large cadaveric dissection experience [12, 13].

## Embryology

A detailed description and different hypotheses concerning the embryology of the OA and orbital vascularization are explained in chapter "Embryology and Variations of the Ophthalmic Artery." In this chapter, we will focus on a few points on the embryological development necessary to understand the variants of the OA dural branches.

The OA starts its development when the embryo is about 4 mm and reaches its adult configuration at about 40 mm. Its development is strictly connected with the arterial embryology of the primitive internal carotid artery (ICA), the stapedial artery (SA), and the pharyngeal artery system. In the last centuries, two authors were interested in the comprehension of the complex events of the OA formation: Padget that formulated her theory after the dissection of 22 embryos and Lasjaunias, who added an accurate angiographic evaluation to Padget's knowledge [11, 14]. Both authors agree that the definitive features of the OA depend mostly on two embryonic arteries: the primitive dorsal ophthalmic artery (PDOA) and the primitive ventral ophthalmic artery (PVOA).

According to Padget's theory, the embryological development of the OA could be divided into six stages, which are summarized in Table 1 [14]. The PDOA appears when the embryo is about 4–5 mm (Stage I), originating from the bifurcation of the primitive ICA. In Stage II (9 mm embryos), while the PDOA enlarges through the optic cup as plexiform channels, the PVOA arises from the cranial division of the primitive ICA. The PDOA and PVOA are then destined to elongate following the ventral shifting of the optic cup and the dorsal

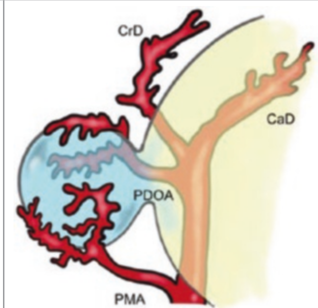
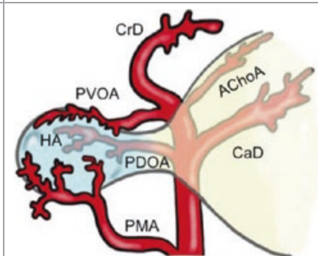
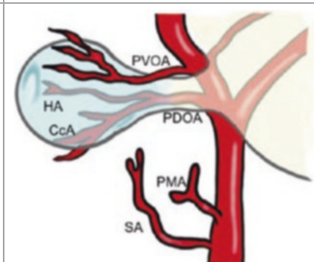
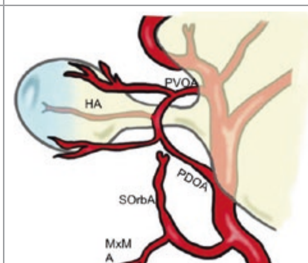
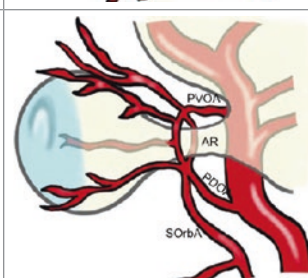
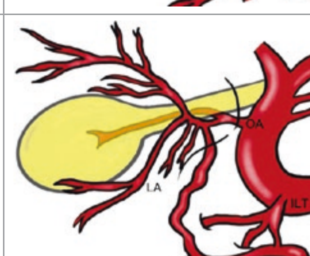
S. Bonasia (✉)
Department of Interventional Neuroradiology, Rothschild Foundation Hospital, Paris, France

T. Robert
University of the Southern Switzerland, Lugano, Switzerland

M. W. Bojanowski
Centre Hospitalier de l'Université de Montréal, Montréal, QC, Canada
e-mail: michel.bojanowski.chum@ssss.gouv.qc.ca


T. Robert et al. (eds.), *Anatomy of Cranial Arteries, Embryology and Variants*, https://doi.org/10.1007/978-3-031-32913-5_25

**Table 1** Stages of embryological development of the ophthalmic artery (OA) (Padget's concept). (Adapted from [14]. Padget DH. The development of cranial arteries in the human embryo. Contrib Embryol Carneg Instn. 1948;212:205–262)

| Stage | Embryo size (mm) | Events | Graphic representation |
|---|---|---|---|
| I | 4–5 | • Primitive maxillary artery (PMA) as temporary branch<br>• PDOA appearance |  |
| II | 9 | • Primitive hyaloid artery (HA) as plexiform channels<br>• PVOA appearance |  |
| III | 14 | • Formation of primitive hyaloid and common ciliary arteries<br>• Stapedial artery (SA) development |  |
| IV | 18 | • Migration of the PDOA origin<br>• Formation of the supraorbital branch (SOrbA) of the SA<br>• Regression of the PVOA |  |
| V | 20 | • Maximal development of the SA<br>• Formation of the anastomotic ring (AR) |  |
| VI | 40 | • Ventral interruption of the AR<br>• Regression of the SOrbA |  |

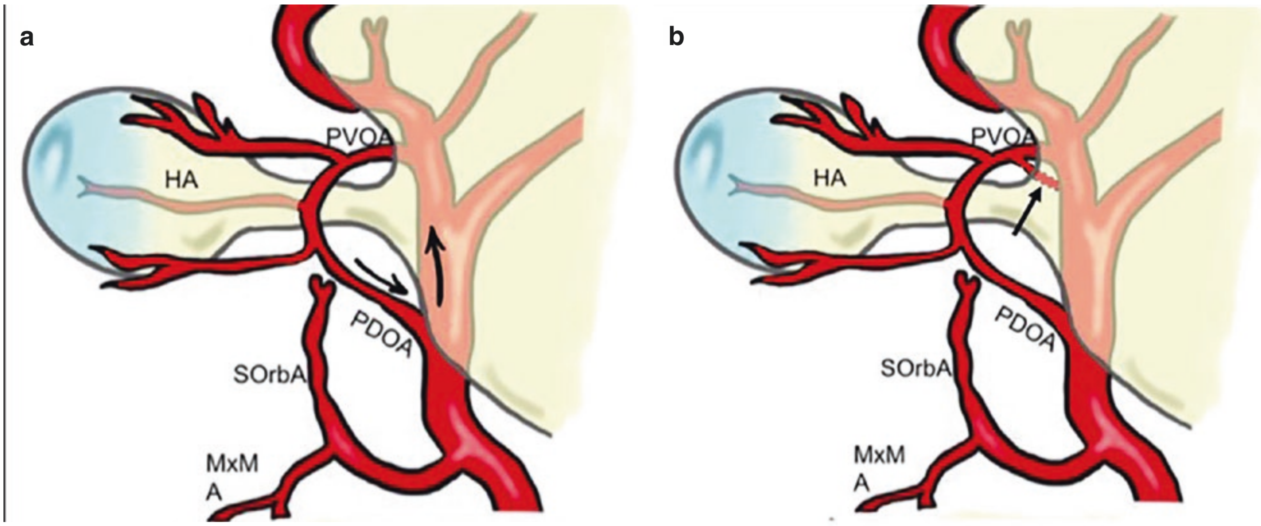



**Fig. 1** Padget's and Lasjaunias' theories about ophthalmic artery (OA) origin migration. When the embryo is about 18 mm, the OA reaches its definitive origin on the supraclinoid internal carotid artery (ICA). This phenomenon is explicated by Padget by the cranial elongation of the ICA during this stage with the consequent movement of the primitive dorsal ophthalmic artery (PDOA) origin (black arrows in figure (**a**)). On the other hand, Lasjaunias hypothesized the presence of an intradural anastomosis between the primitive ventral ophthalmic artery (PVOA) and the primitive ICA (black arrow in figure (**b**)) in correspondence of the future origin with successive regression of the original stem

shifting of the cerebral hemispheres. In embryos of 14–17 mm, it is possible to note the appearance of two branches from the PDOA artery: the primitive hyaloid artery (HA) and the common temporal ciliary artery (future lateral posterior ciliary artery). The PVOA gives off at the same time the common nasal ciliary artery (future medial posterior ciliary artery).

In an embryo of about 18 mm (Stage IV), the OA is invested by the process that will bring to the migration of its origin on the supraclinoid ICA. This phenomenon is explained by Padget by the cranial elongation of the ICA during this stage with the consequent movement of the PDOA. On the other hand, Lasjaunias explained this migration through the presence of an intradural anastomosis between the PVOA and the primitive carotid artery in correspondence of the future origin with consequent regression of the original stem [8, 11, 15]. The two theories about OA origin migration are illustrated in Fig. 1.

From Stage I to IV, another artery grows at the same time and contributes to the adult configuration of the orbital arteries: the SA. In the first stages, the optic cup is supplied in its ventral side by the primitive maxillary artery (PMA). However, it starts to regress at the end of Stage II, which is to be substituted by the SA in its orbital territory. This latter gives off two branches that follow the three divisions of the trigeminal nerve: the maxillomandibular artery and the supraorbital artery. The supraorbital artery enters the orbit through the superior orbital fissure and gives two branches: the ethmoido-nasal and the lacrimal arteries.

The relationship between the PDOA, the PVOA, and the SA reaches the highest importance in the last two Stages (V: embryo of 20 mm; VI: embryo of 40 mm). During Stage V, an anastomotic ring appears around the optic nerve, formed by the anastomosis between the PVOA, the PDOA, and the supraorbital artery (through the ethmoido-nasal artery). However, in Stage VI, this ring is ventrally interrupted to give the definitive configuration of the OA. The part of the anastomotic ring that regresses is crucial to determine which of the two primitive OAs persist to form the adult OA. According to Padget, it is the PDOA that persists, with consequent PVOA proximal regression. On the other hand, Lasjaunias wrote that the distal portion of the PDOA regresses, and its proximal part is destined to form the future inferolateral trunk [8, 11, 15]. Thus, in his opinion, it is the PVOA that mostly contributes to the formation of the definitive OA.

At the same time, the extraorbital part of the supraorbital artery regresses, to let the lacrimal artery be annexed by the OA.

## Dural Branches of the OA

Different dural branches of the OA and their possible anastomoses with other dural arteries are listed in Table 2; their respective dural territories are illustrated in Fig. 2.

**Table 2** Origin of the dural branches of the ophthalmic artery (OA) with their respective supply and anastomoses

| OA branches | Origin from the OA | Foramen | Dural territory | Possible anastomosis |
|---|---|---|---|---|
| Deep recurrent OA | First segment | Superior orbital fissure | Superior orbital fissure (lateral part) Sphenoid wing | Inferolateral trunk (ICA) |
| Superficial recurrent OA | Second segment | Superior orbital fissure | Anterior clinoid process Lesser sphenoid wing Middle fossa (anteromedial portion) | Posterior ethmoidal artery MMA (anterior division) Medial tentorial artery (ICA) |
| Anterior ethmoidal artery | Third segment | Anterior ethmoidal canal | Anterior convexity (anterior meningeal artery) Anterior cranial fossa (medial third) Anterior falx cerebri (anterior falcine artery) | Contralateral anterior ethmoidal artery Bilateral MMAs Posterior ethmoidal artery Olfactory branch (ACA) |
| Posterior ethmoidal artery | Third segment | Posterior ethmoidal canal | Anterior cranial fossa (medial third) Anterior clinoid process Chiasmatic groove | Contralateral posterior ethmoidal artery Anterior ethmoidal artery MMA (anterior division) |

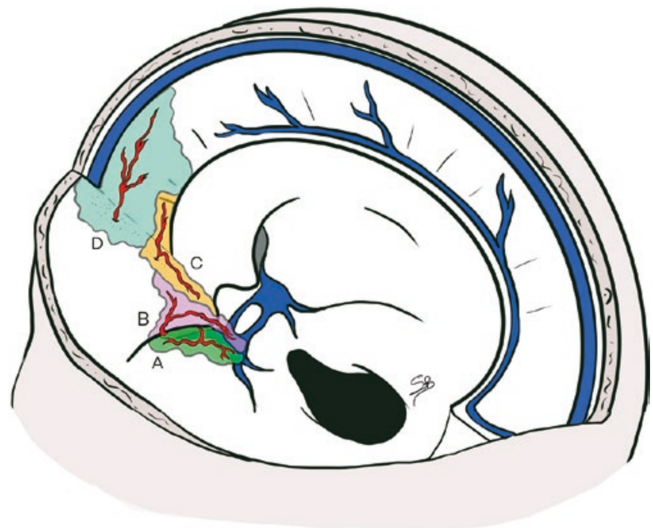



**Fig. 2** Dural territories of ophthalmic artery (OA) branches. A (green): territory of the deep recurrent ophthalmic artery, which exits from the medial part of the superior orbital fissure and supplies the dura of the lateral wall of the cavernous sinus. B (pink): dural territory of the superficial recurrent ophthalmic artery, which passes through the lateral part of the superior orbital fissure to reach the dura over the anterior clinoid process and of the cavernous sinus roof; C (orange): the posterior ethmoidal artery passes through the posterior ethmoidal canal to reach the dura of the planum sphenoidale, the posterior cribriform plate, and the anterior clinoid process. D (light blue): the anterior ethmoidal artery passes through the anterior ethmoidal canal, and its meningeal territory consists of the anterior part of the cribriform plate, the medial part of the orbital roofs, and the anterior third of the falx cerebri

## Deep Recurrent Ophthalmic Artery

The deep recurrent ophthalmic artery arises from the first segment of the OA and has a recurrent course through the medial part of the superior orbital fissure. This artery supplies the dura of the lateral wall of the cavernous sinus. It consistently anastomoses with the anteromedial branch of the inferolateral trunk and often with the cavernous branch of the MMA and with the accessory meningeal artery. It is considered as the remnant of the PDOA [8].

## Superficial Recurrent Ophthalmic Artery

The superficial recurrent ophthalmic artery is a meningeal branch that takes its origin from the proximal part of the lacrimal or directly from the second segment of the OA [8, 11, 16]. This artery passes through the lateral part of the superior orbital fissure to reach the dura over the anterior clinoid process and of the cavernous sinus roof [10, 13]. The superficial recurrent ophthalmic artery also supplies the intradural part of the third and fourth cranial nerves. This artery is the orbital remnant of the supraorbital branch of the SA [11].

## Posterior Ethmoidal Artery

The posterior ethmoidal artery is a small meningeal branch that arises from the third segment of the OA and exits the orbit through the posterior ethmoidal canal [16]. Its average diameter is 0.4 mm and is usually in balance with the diameter of the anterior ethmoidal artery [17]. This artery supplies the dura of the planum sphenoidale, the posterior cribriform plate, and the anterior clinoid process [11]. Martins et al. (2005) showed that the posterior ethmoidal artery often anastomoses with dural branches of the ICA, MMA, and anterior ethmoidal artery [13]. When absent (approximately 20% of cases), its meningeal territory is supplied by these three other arteries.

## Anterior Ethmoidal Artery

The anterior ethmoidal artery is a more constant artery, which has been found in more than 90% of orbits if the OA crosses over the optic nerve and in 80% of cases when the OA crosses under the nerve. It arises from the distal part of the OA and could give from one to five little branches that pass through the anterior ethmoidal canal. Other than its mucosal supply on the nasal septum and nasal fossa, its meningeal territory is limited to the anterior part of the cribriform plate, the medial part of the orbital roofs, and the anterior third of the falx cerebri. The anterior ethmoidal artery gives a branch, well described angiographically by Kuru (1965), along the falx cerebri that is named the anterior falcine artery or the artery of the falx cerebri [10]. This anterior falcine artery could be present bilaterally, but usually one side is predominant. If the anterior ethmoidal artery is well-developed, it can give some branches called "anterior meningeal arteries" that differ from the anterior falcine artery because of their paramedial course and can supply the dura of the anterior convexity.

## Dural Supply of the OA

The four meningeal branches previously described supply the dura of the cribriform plate, the planum, the anterior clinoid process, the superior orbital region, the roof and the lateral part of the cavernous sinus, the medial part of the orbital roof, and the anterior part of the falx cerebri. This vascular territory is very variable, and the OA is in balance with other meningeal arteries of this region like the MMA (cavernous ramus), the accessory meningeal artery, and the inferolateral trunk.

## Variations of Dural Branches of the Ophthalmic Artery

### Ophthalmic Artery Origin of the Middle Meningeal Artery

In a rare case, the MMA could originate from the OA instead of the internal maxillary artery. The incidence of this vascular variation is estimated to 0.5% by Dilenge et al. (1980) based on a large angiographic series [9]. Few cases of the MMA arising from the OA have been described in the literature. The first case was presented by Curnow (1873), and in the same period, Meyer (1887) also cited four cadaveric cases originally described by Zuckerkandl in 1876 during a congress presentation [1, 2]. Two rare cases of this variation are shown in Fig. 3. This vascular anomaly is considered as the consequence of two different embryologic processes. The first one is the failure of the supraorbital branch (SA) regression. The second one is the absence of anastomosis between the maxillomandibular branch of the SA and the internal maxillary artery. Consequently, the MMA originates from the OA and passes through the lateral part of the superior orbital fissure; thus, the foramen spinosum is usually absent. Maiuri et al. (1998) proposed three different types of this vascular variation as highlighted in Table 3 [18]. The first type is the complete MMA territory supplied by the OA through the superficial recurrent OA. In the second type, only the anterior branch of the MMA originates from the OA, and the posterior branch of the MMA keeps its origin from the internal maxillary artery. The third type is not really an OA origin of the MMA but an anastomosis between the OA and the accessory meningeal artery (through the deep recurrent OA). The consequence is that the anterior meningeal territory is supplied by both the MMA and the OA without any communication. It is still matter of debate if the MMA originates from the OA directly or from the proximal part of the lacrimal artery.

### Ophthalmic Artery Origin of the Marginal Tentorial Artery

The marginal tentorial artery (MTA) (or artery of the free margin of the tentorium cerebelli) normally arises from the meningohypophyseal trunk, but its origin is variable, as illustrated in Fig. 4. This artery supplies the medial third of the tentorium, partially the walls of the cavernous sinus, and also the transdural segment of the oculomotor and trochlear nerves [13]. An OA origin of this artery has been described by Lasjaunias (2001), distinguishing two different types [11]. The first one is when the MTA arises from the lacrimal artery. The second one is when the MTA arises directly from the OA and the lacrimal artery originates from the MMA (meningolacrimal type).

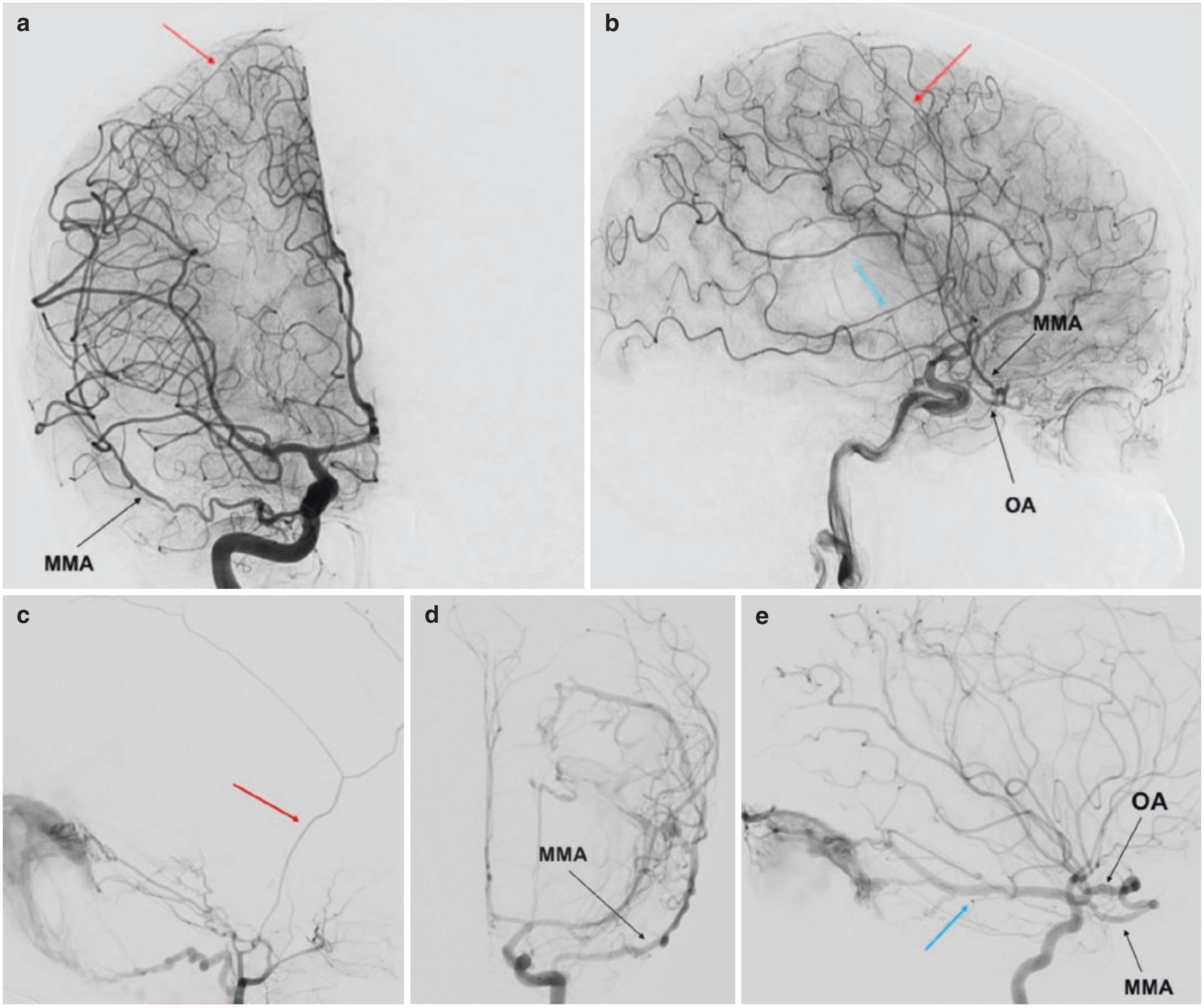



**Fig. 3** Middle meningeal artery (MMA) origin from ophthalmic artery (OA). The anteroposterior and lateral view angiograms ((**a**) and (**b**)) show a rare case of complete MMA origin from the OA. The OA, through the superficial recurrent OA, gives birth to the MMA, which passes through the lateral part of the superior orbital fissure and gives its anterior (red arrow) and posterior division (blue arrow). In the angiograms (**c**–**e**), a rare case of partial origin of the MMA from the OA is shown. The angiograms d and e show a left internal carotid artery (ICA) injection in frontal and lateral view, where the posterior branch of the MMA (blue arrow) originates from the OA and feeds a tentorial arteriovenous fistula. After the ECA injection (**c**), only the anterior branch of the MMA is enhanced (red arrow)

**Table 3** Different types of ophthalmic artery (OA) origin of the middle meningeal artery (MMA) by Maiuri et al. (Adapted from [18])

| Type | Vascular anatomy | Foramen spinosum |
|---|---|---|
| I | Complete OA origin of the MMA | Absence |
| II | Partial OA origin of the MMA<br>Anterior division from the OA<br>Posterior division from the IMA | Reduced in size |
| III | OA origin of the accessory meningeal artery | Normal |

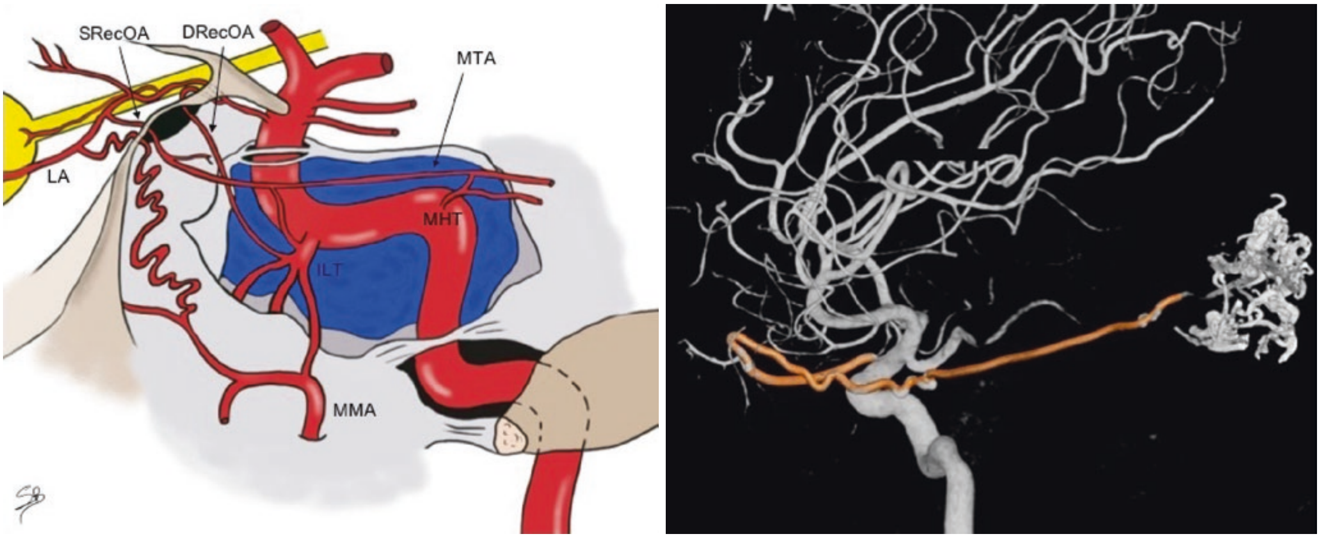



**Fig. 4** Marginal tentorial artery (MTA) origin and course. The marginal tentorial artery, also called artery of the free margin of the tentorium or artery of Bernasconi-Cassinari, may have different origins, which are shown in graphic representation. It can arise from the lacrimal artery (LA) within the orbit, through the superficial recurrent ophthalmic artery (SRecOA), from the inferolateral trunk (ILT), and from the meningohypophyseal trunk (MHT). The artery courses posterolaterally along the free margin of the tentorium. The figure also shows a 3D DSA reconstruction of a rare case of MTA (highlighted in red) origin from the ophthalmic artery (OA). The MTA exits the orbit through the superior orbital fissure (SOF) and directs posteriorly to feed an arteriovenous malformation

## Clinical Implications

Knowledge of the dural branches arising from the OA and their variations represents the cornerstone for interventional neuroradiologists and neurosurgeons who approaches anterior and middle cranial fossa pathologies. Two critical examples are the cribriform plate dural arteriovenous fistulas (dAVFs) and anterior and middle skull base meningiomas.

### Cribriform Plate Dural Artero-Venous Fistulas

Cribriform plate dAVFs are usually mostly supplied by the anterior ethmoidal artery and the MMA. A bilateral supply of the dAVF, found in approximately 10% of cases, is well-explained by the anastomoses between the two anterior ethmoidal arteries within the dural or ethmoidal sinuses. Endovascular treatment of such pathologies consists of embolization, usually through branches of the MMA. The neuroradiologists must consider the presence of dural MMA–OA anastomoses during the injection of the liquid agent to avoid retrograde flow into ocular branches of the OA. In case of direct embolization of the dAVF through the ophthalmic artery, attention should be paid to the possible retrograde flow of the embolic agent into ocular branches. Since the central retinal artery usually arises from the second segment of the OA, the injection should be performed as distal as possible in order to limit the eventual damage caused by the reflux.

The surgical exclusion of a cribriform plate dAVF also necessitates a precise knowledge of dural branches of the OA. The aim of the treatment is to exclude the cortical venous drainage of the dAVF, clipping or coagulating the draining vein at its exit point from the dura. A case of a cribriform plate dAVF treated surgically is shown in Fig. 5. Knowledge of the arterio-arterial anastomoses between anterior ethmoidal, posterior ethmoidal, and middle meningeal arteries is necessary to understand the dAVF and the technical difficulties of the treatment. Another case of dAVF fed by dural branches of the OA is shown in Fig. 6, with also a contribution from the MTA.

Knowledge of the dural branches of the OA and MMA origin from the OA also well explains the possible participation of OA branches in the supply of carotid-cavernous fistulas or tentorial pathologies (Figs. 3 and 4).

### Anterior and Middle Cranial Fossa Meningioma

The surgical removal of a cribriform plate or sphenoid wing meningiomas requires a detailed knowledge of vascular normal anatomy and tumor vascular supply. Meningeal tumors of the anterior and middle skull base are usually supplied by dural branches of the MMA, ICA, and by the ophthalmic artery. It is of paramount importance for interventional neuroradiologists who plan an embolization, usually performed through the MMA, to consider the possible variations in the supply of the skull base dura to avoid involuntary OA reflux of embolic liquid agent.

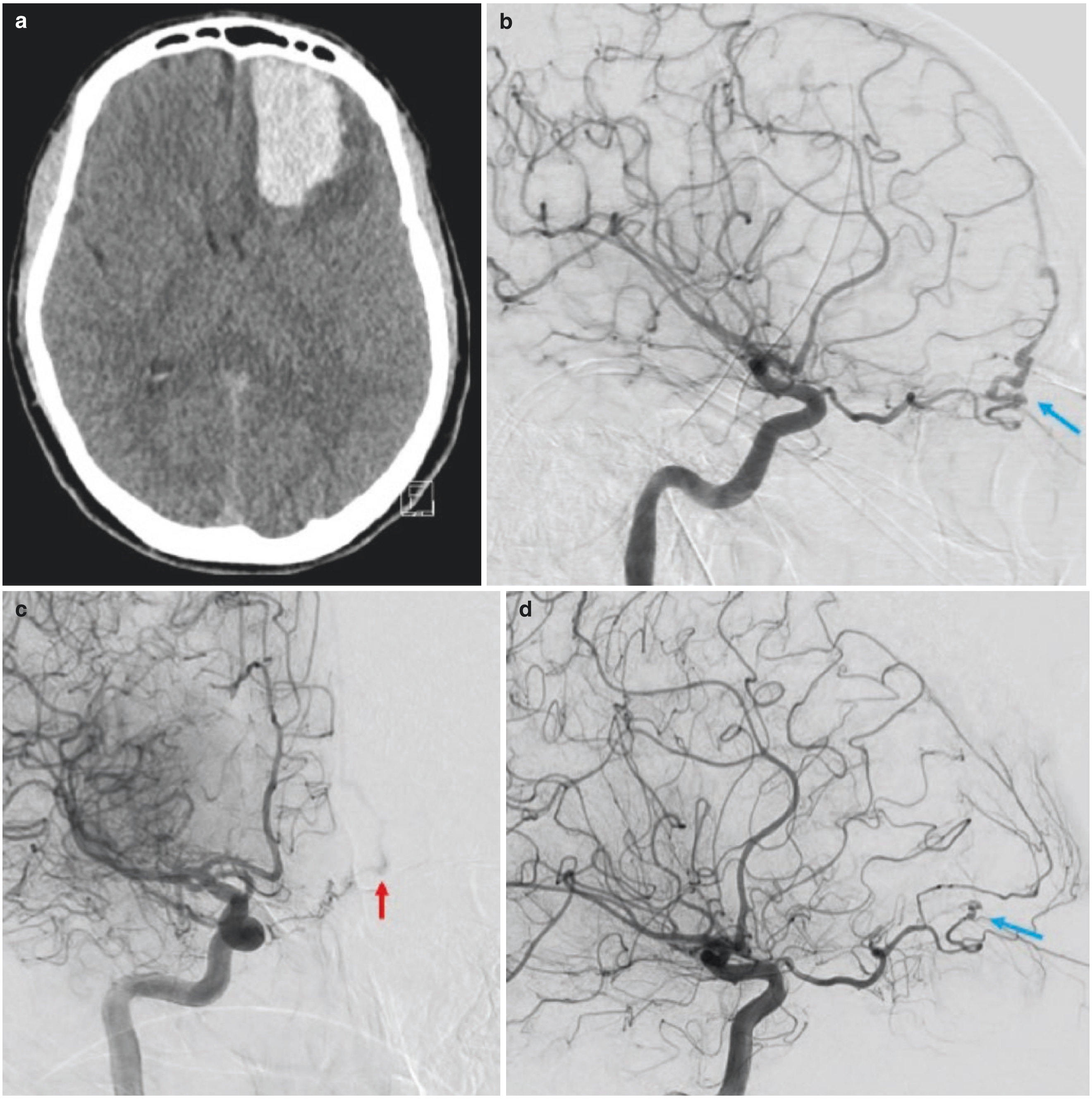



**Fig. 5** Clinical case of ruptured cribriform plate dural arteriovenous fistula (dAVF). The figure shows the case of a 49-year-old man, taken in charge for sudden onset of unusual headache with nausea and vomiting. The CT scan performed in ER (**a**) showed a left frontal basis intraparenchymal hematoma. The DSA highlighted a cribriform plate dAVF with major feeders represented by the left anterior ethmoidal artery from left ophthalmic artery (OA) (blue arrow in figure (**b**)). The right internal carotid artery (ICA) injection showed also a contribution from the contralateral OA through its ethmoidal branches (red arrow in figure (**c**)). The venous drainage was represented by a single cortical vein directed into the superior sagittal sinus (Type III according to Cognard-Lariboisière classification [25]). The patient underwent successfully left supraorbital craniotomy and clipping of the dAVF (figure (**d**)), with no enhancement of the dAVF in the postoperative DSA (blue arrow) and clinical complete recovery

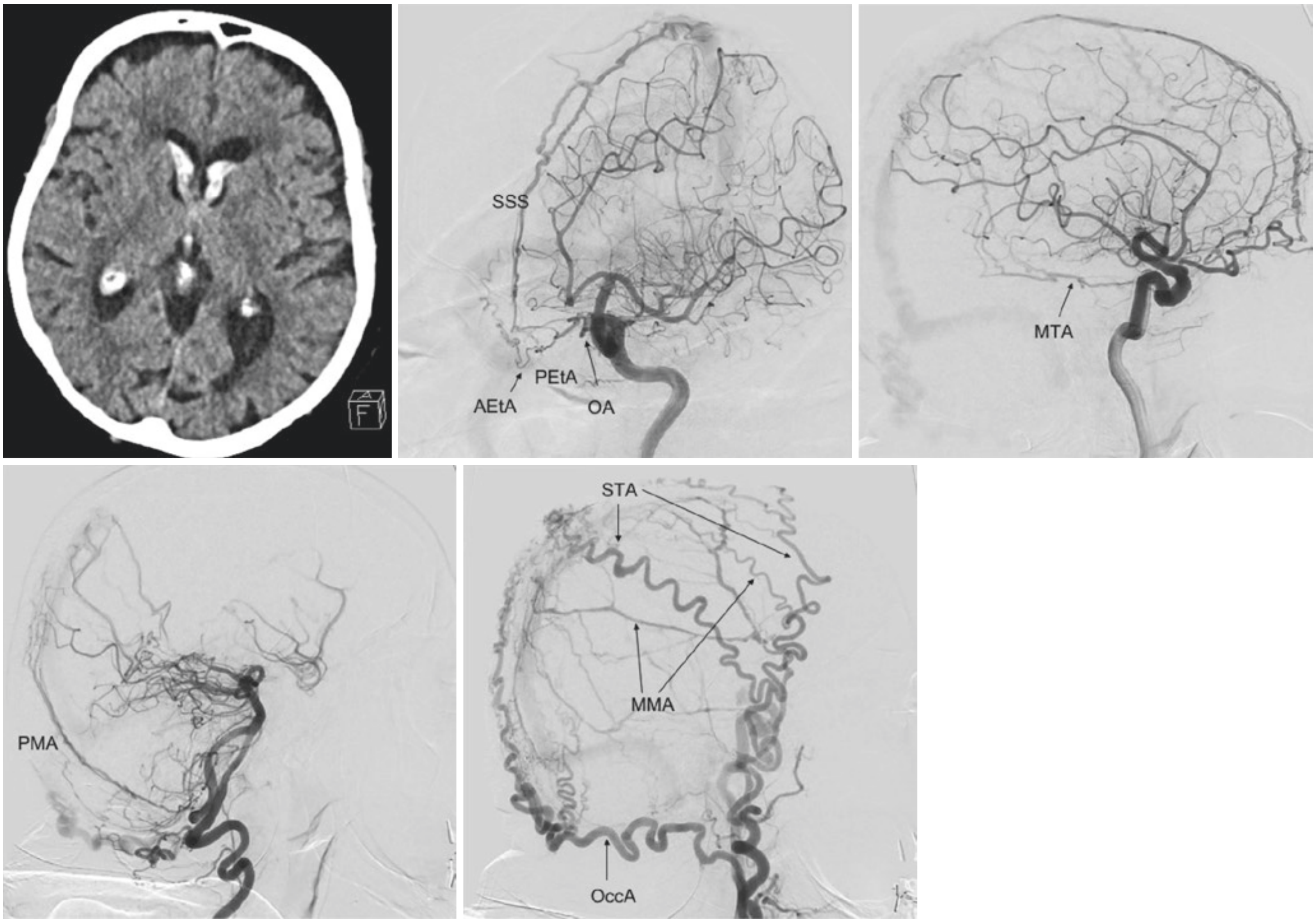



**Fig. 6** Clinical case of dural arteriovenous fistula (dAVF) fed by multiple ophthalmic artery (OA) dural branches. The figure shows the case of an 89-year-old woman, previously operated for pituitary adenoma, taken in charge for unusual headache associated with vomiting. The CT scan showed an intraventricular hemorrhage with mild hydrocephalus. The diagnostic DSA showed a complex dAVF (Cognard-Lariboisière Grade IIa + b [25]) supplied by the OA through the anterior and posterior ethmoidal arteries (AEtA and PEtA), with both direct and indirect shunt with the superior sagittal sinus (SSS). Another point of shunt with the SSS is reached by the marginal tentorial artery (MTA) and by the posterior meningeal and middle meningeal artery (PMA and MMA). Also, other branches from the ECA contribute to the shunt, like the occipital artery (OccA) and the superficial temporal artery (STA). Because of age, the complexity of the dAVF, the high risks associated with every treatment option, and the absence of alteration of consciousness, we managed the dAVF conservatively

In case of surgery of middle cranial fossa meningioma, the devascularization of the tumor as first step could be helpful to better understand the arterial supply of the lesion and to limit drastically the blood loss.

## Intra-Arterial Injection of Chemotherapy for Retinoblastoma

The classical technique used to inject chemotherapeutic agents into the OA for the treatment of retinoblastoma requires the super-selective catheterization of the OA [19]. However, knowledge of OA dural branches acquires a more important role when direct catheterization of the OA is not possible, like it can happen in children for its reduced size. In these cases, alternative ways to indirectly reach the OA have been described, especially through the catheterization of the MMA [20]. In this way, the pharmacologic agents can be injected through the anterior division of the MMA, incannulating its meningo-lacrimal branch. The reflux into the OA could be provided from anastomoses between MMA orbital branches and the recurrent branches of the OA, granted by the lacrimal artery or sometimes from the direct origin of the OA from the MMA.

## Surgical and Endovascular Treatment of Refractory Epistaxis

Refractory epistaxis may be caused by a lot of clinical conditions and occurs in about 60% of the adult population, and most of them are considered idiopathic. Among them, about

6% of the epistaxis is refractory to conservative management and requires a surgical or interventional treatment [21].

The best way to understand which is the source of bleeding in case of refractory epistaxis is to perform a diagnostic DSA including ICA and external carotid artery (ECA). The DSA allows to identify the so-called "vascular blush," an anastomotic plexus located in the nasal septum, considered as the source of 90% of epistaxis. The sphenopalatine artery represents its main blood supply, and it's most commonly responsible for refractory epistaxis, even if in rare cases also the ethmoidal arteries could be involved [22]. If these latter are involved in the bleeding, they can be ligated through a surgical approach. On the other hand, if the sphenopalatine artery is responsible for bleeding, it can be occluded through an endonasal approach, or it can be embolized [22]. The diagnostic DSA allows to identify possible dangerous anastomoses between branches of the ECA and the OA, which can result in post-embolization visual or central deficits. The occurrence of cerebrovascular accident and obstruction of the central retinal artery has been described to occur in about 0–2% of cases [23]. The most important anastomoses to consider during such procedures are those between the sphenopalatine and anterior ethmoidal arteries via the turbinate and infraorbital arteries and those between the lacrimal artery and the MMA through the recurrent meningeal artery [22, 23]. The relevance of these anastomoses and the periprocedural risk can be estimated analyzing the "choroidal blush." This blush is commonly visualized after contrast injection into the ICA. However, if the anastomoses between the posterior ciliary arteries, the lacrimal artery, and the MMA are very consistent or if the lacrimal artery and the OA branch directly from the MMA, the choroidal blush can be seen after the ECA injection [23].

## Embolization of Facial Tumors

Even if epistaxes are mostly idiopathic, some cases can be due to neoplastic erosion of vascular structures or as result of tumor necrosis after treatment. In these cases, the symptoms can also cause hemoptysis due to the frequent nasopharyngeal localization of these tumors. Endovascular treatment should be considered in these cases to treat uncontrollable epistaxis or hemoptysis. Also benign tumors, like paragangliomas and nasopharyngeal angiofibromas, can benefit from endovascular embolization, a preoperative procedure to reduce intraoperative blood loss. In these cases, the embolization of the sphenopalatine artery could be insufficient, and devascularization requires embolization of the facial artery and ascending pharyngeal artery [22]. In these cases, neuroradiologists should pay attention to the known anastomoses between the facial artery and the dorsal nasal artery (through the angular artery) [24]. For these pathologies, the neuroradiologists should observe the same rules previously described to avoid complications due to ICA–ECA anastomoses [22].

In conclusion, knowledge of embryology and anatomy of the dural branches of the OA is mandatory for treating pathology of the dura mater located in the anterior and middle cranial fossa. These arteries show high variability and supply territories in competition with the MMA and ICA branches.

## References


1. Meyer F. Zur anatomie der Orbitalarteien Morph Jahr. 1887;12:414–458.
2. Curnow J. Two instances of irregular ophthalmic and middle meningeal arteries. J Anat Physiol. 1873;8(Pt 1):155–6.
3. Gabriele OF, Bell D. Ophthalmic origin of the middle meningeal artery. Radiology 1967;89(5):841–84844. doi: https://doi.org/10.1148/89.5.841.
4. Royle G, Motson R. An anomalous origin of the middle meningeal artery. J Neurol Neurosurg Psychiatry. 1973;36(5):874–6. https://doi.org/10.1136/jnnp.36.5.874.
5. McLennan JE, Rosenbaum AE, Haughton VM. Internal carotid origins of the middle meningeal artery. The ophthalmic-middle meningeal and stapedial-middle meningeal arteries. Neuroradiology. 1974;7(5):265–75. https://doi.org/10.1007/BF00344246.
6. Vignaud J, Hasso AN, Lasjaunias P, Clay C. Orbital vascular anatomy and embryology. Radiology. 1974;111(3):617–26. https://doi.org/10.1148/111.3.617.
7. Lasjaunias P, Moret J, Manelfe C, Theron J, Hasso T, Seeger J. Arterial anomalies at the base of the skull. Neuroradiology. 1977;13(5):267–72. https://doi.org/10.1007/BF00347072.
8. Lasjaunias P, Brismar J, Moret J, Theron J. Recurrent cavernous branches of the ophthalmic artery. Acta Radiol Diagn (Stockh). 1978;19(4):553–60. https://doi.org/10.1177/028418517801900402.
9. Dilenge D, Ascherl GF Jr. Variations of the ophthalmic and middle meningeal arteries: Relation to the embryonic stapedial artery. AJNR Am J Neuroradiol. 1980;1(1):45–54.
10. Kuru Y. Meningeal branches of the ophthalmic artery. Acta Radiol Diagn (Stockh). 1967;6(3):241–51. https://doi.org/10.1177/028418516700600304.
11. Lasjaunias P, Bereinstein A, Ter Brugge KG. Surgical neuroangiography. Berlin: Springer edition; 2001.
12. Rhoton AL Jr. The orbit. Neurosurgery. 2002;51(4 Suppl):S303–34.
13. Martins C, Yasuda A, Campero A, Ulm AJ, Tanriover N, Rhoton A Jr. Microsurgical anatomy of the dural arteries. Neurosurgery. 2005;56(2 Suppl):211–51.; discussion 211−251. https://doi.org/10.1227/01.neu.0000144823.94402.3d.
14. Padget DH. The development of cranial arteries in the human embryo. Contribution to embryology. Carnegie Institution: Washington, 1948;212:205–2262.
15. Lasjaunias P, Moret J, Mink J. The anatomy of the inferolateral trunk (ILT) of the internal carotid artery. Neuroradiology. 1977;13(4):215–20.
16. Hayreh SS. The ophthalmic artery: iii Branches. Br J Ophthalmol. 1962;46(4):212–47. https://doi.org/10.1136/bjo.46.4.212.
17. Lang J, Kageyama I. The ophthalmic artery and its branches, measurements and clinical importance. Surg Radiol Anat. 1990;12(2):83–90. https://doi.org/10.1007/BF01623328.
18. Maiuri F, Donzelli R, de Divitiis O, Fusco M, Briganti F. Anomalous meningeal branches of the ophthalmic artery feeding meningio-

mas of the brain convexity. Surg Radiol Anat. 1998;20(4):279–84. https://doi.org/10.1007/BF01628491.
19. Yamane T, Kaneko A, Mohri M. The technique of ophthalmic arterial infusion therapy for patients with intraocular retinoblastoma. Int J Clin Oncol. 2004;9(2):69–73. https://doi.org/10.1007/s10147-004-0392-6.
20. Klufas MA, Gobin YP, Marr B, Brodie SE, Dunkel IJ, Abramson DH. Intra-arterial chemotherapy as a treatment for intraocular retinoblastoma: alternatives to direct ophthalmic artery catheterization. AJNR Am J Neuroradiol. 2012;33(8):1608–14. https://doi.org/10.3174/ajnr.A3019.
21. Christensen NP, Smith DS, Barnwell SL, Wax MK. Arterial embolization in the management of posterior epistaxis. Otolaryngol Head Neck Surg. 2005;133(5):748–53. https://doi.org/10.1016/j.otohns.2005.07.041.
22. Reyre A, Michel J, Santini L, Dessi P, Vidal V, Bartoli JM, et al. Epistaxis: The role of arterial embolization. Diagn Interv Imaging. 2015;96(7–8):757–73. https://doi.org/10.1016/j.diii.2015.06.006.
23. Mames RN, Snady-McCoy L, Guy J. Central retinal and posterior ciliary artery occlusion after particle embolization of the external carotid artery system. Ophthalmology. 1991;98(4):527–31. https://doi.org/10.1016/s0161-6420(91)32261-9.
24. Bertelli E, Regoli M, Bracco S. An update on the variations of the orbital blood supply and hemodynamic. Surg Radiol Anat. 2017;39(5):485–96. https://doi.org/10.1007/s00276-016-1776-9.
25. Cognard C, Gobin YP, Pierot L, Bailly AL, Houdart E, Casasco A, et al. Cerebral dural arteriovenous fistulas: Clinical and angiographic correlation with a revised classification of venous drainage. Radiology 1995;194(3):671–6680. doi: https://doi.org/10.1148/radiology.194.3.7862961.