# Developmental Anatomy, Angiography, and Clinical Implications of Orbital Arterial Variations Involving the Stapedial Artery

[Q2][Q3] Philippe Gailloud*, Lydia Gregg, Diego San Millán Ruiz [Q4][Q5]

[Q7] KEYWORDS
[Q8] • ■ • ■ • ■

Over the past 200 years, classical anatomists have provided a detailed description of the arterial collateral pathways that can be found in the head and neck. The small branches building this intricate arterial network often are difficult to access, as they are located near or within the skull base. They have been revealed, one at a time, at the price of precise but painstaking anatomic dissections. The arterial map inherited from the anatomists recently has been put to the test with detailed high-resolution vascular imaging. Superselective angiography, in particular, has helped rediscover the complexity of the craniocervical arterial network under normal and pathologic conditions.[1,2] The concept of dangerous collaterals or dangerous anastomoses was born with the advent of endovascular therapy. Until then, the arterial network of the skull base had been seen as a safety mechanism bringing relief to areas that had lost their primary source of blood supply (eg, the classic cerebral collateral supply through the ophthalmic artery [OA] in case of proximal carotid occlusion). With the introduction of transarterial embolization, these beneficial pathways also have become a potential source of procedural complications, mostly by inadvertent passage of embolic material into branches supplying important structures, such as the eye or the brain. In addition to confirming the accuracy of anatomic knowledge, superselective angiography has shown that most of the so-called dangerous collaterals, although consistently present under normal and abnormal conditions, may become angiographically conspicuous only under particular hemodynamic circumstances. For example, a connection between the occipital artery and the vertebral artery may “appear” (ie, become detectable) during the course of an embolization dealing with a distal occipital artery lesion. Such a phenomenon emphasizes the need for strict embolization techniques and the necessity to master the complex anatomy of these dangerous connections. Although dangerous anastomoses of the skull base are well described in the literature,[2,3] the variations and collateral pathways related to the orbital arteries often have been overlooked or misunderstood, in spite of their importance for safe extraorbital embolization procedures. This article presents a review of the normal orbital arterial vascularization and its principal variations, with particular emphasis placed on abnormal pathways involving residual segments of the stapedial artery.

## ARTERIAL VASCULARIZATION OF THE ORBIT [Q9]

### *Development*

The arterial supply to the orbit combines, in its normal adult configuration, vascular elements taken from several primitive arterial systems.

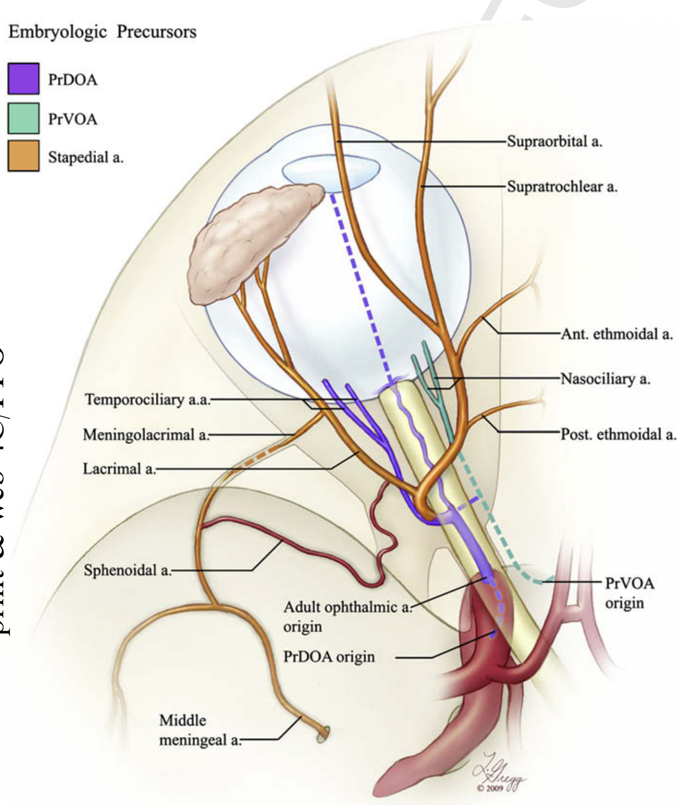
[Q6] Division of Interventional Neuroradiology, The Johns Hopkins Hospital, Baltimore, MD 21287, USA
* Corresponding author.
*E-mail address:* phg.jhu@me.com (P. Gailloud).

Neuroimag Clin N Am ■ (2009) ■–■
doi:10.1016/j.nic.2009.02.001

A few basic embryonic concepts are introduced to clarify the type of variations and collateral pathways existing in the orbital region. The following summary is based on works published by Padget[4] and by Maillot and colleagues.[5]

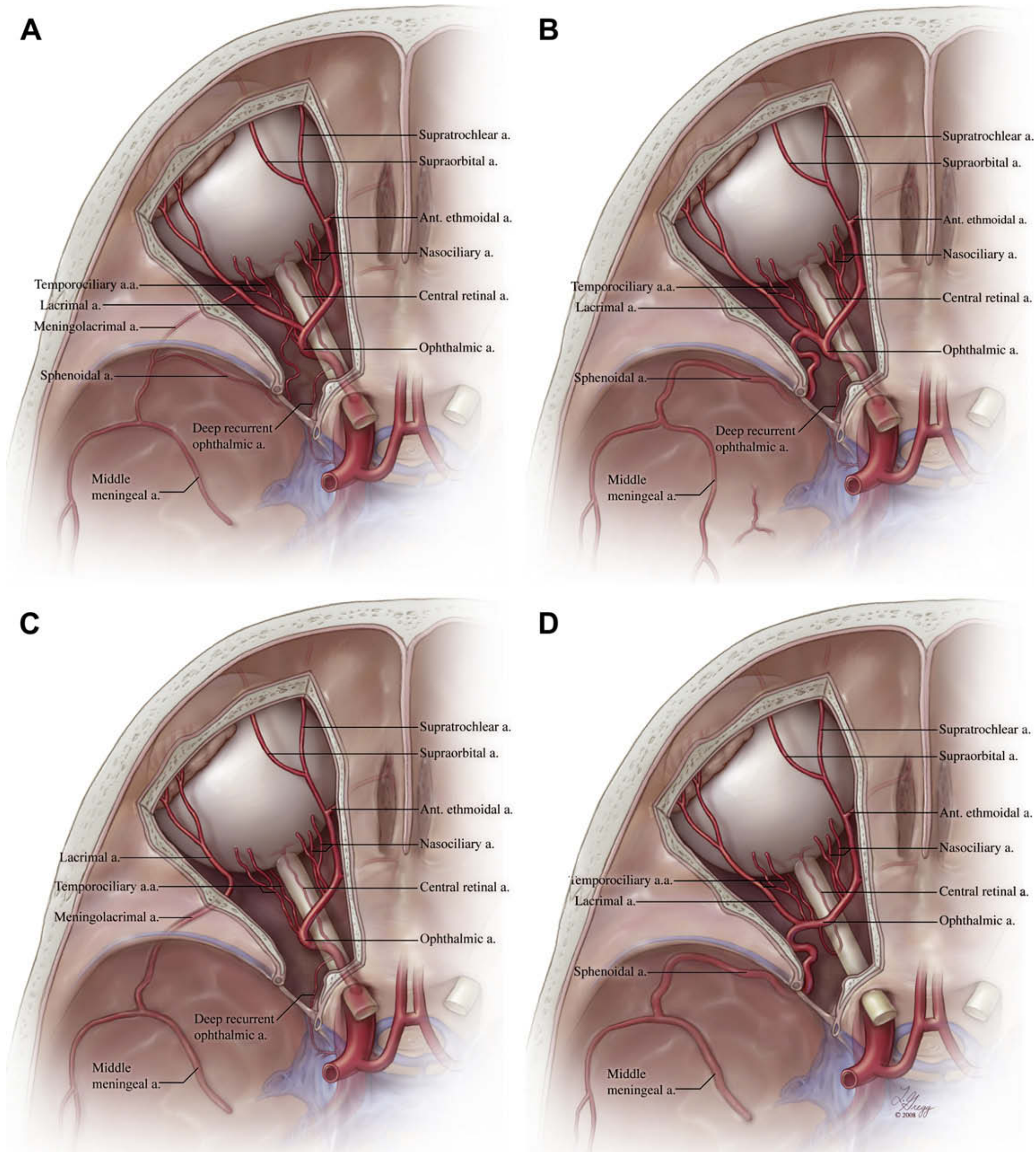
Early in the fetal life, the blood supply to the eye and optic nerve is provided by two primitive OAs. The primitive dorsal OA (PrDOA) appears first in the 4-mm embryo, followed by the primitive ventral ophthalmic artery (PrVOA) in the 9-mm embryo. The PrVOA is a branch of the cranial division of the internal carotid artery (ICA) (future anterior and middle cerebral arteries), whereas the PrDOA originates from the intracranial portion of the ICA, near its termination, distally to the final point of emergence of the adult OA. The PrDOA, therefore, is not a branch of the cavernous segment of the ICA; this misconception, disseminated in the literature, finds its source in a misreading of Padget's splendid work on the embryology of the cranial [Q10] arteries.[4] In the 16- to 19-mm embryo, the temporociliary branch of the PrDOA and the nasociliary branch of the PrVOA fuse around the optic nerve, the PrDOA becomes dominant, and the PrVOA starts regressing. Concomitantly, the PrDOA migrates from its initial point of origin to a more proximal location consistent with the origin of the adult OA. The blood supply to the connective apparatus surrounding the optic elements comes, alternatively, from the primitive orbital artery, a branch of the ramus superior of the stapedial artery (ie, the future middle meningeal artery [MMA]). These various embryonic OA components are illustrated in **Fig. 1**.

In order to reach its normal adult configuration, the OA establishes a connection with the primitive orbital artery and takes over most of the orbital blood supply. The proximal segment of the primitive orbital artery involutes to become an anastomosis between the anterior division of the MMA and the lacrimal artery. This anastomosis has classically received different names for its intraorbital and intracranial segments (ie, the recurrent meningeal branch of the lacrimal artery and the orbital branch of the anterior division of the MMA, respectively). This arterial network seems more complex than initially appreciated, however, and the existence of a double connection between the MMA and the lacrimal artery has been demonstrated by several investigators.[6,7] One connecting branch is short and straight; it crosses the foramen of Hyrtl (or cranio-orbital foramen) and takes the name, meningolacrimal artery. The other is long and tortuous; it passes through the superior orbital




print & web 4C/FPO

**Fig. 1.** Schematic representation of the OA developmental anatomy and its adult derivatives. The dotted vascular segments normally are absent at the adult stage. The primitive OAs and their branches are shown in green (PrVOA) and purple (PrDOA). The segment of the hyaloid artery located within the vitreous humor starts involuting at approximately the 10th week of gestation (dotted purple), whereas its proximal segment becomes the adult central retinal artery. The structures shown in orange are derivatives of the stapedial artery (primitive orbital artery). The sphenoidal artery (red) is a late-appearing neomorph.




print & web 4C/FPO

**Fig. 2.** The OA and its principal variants involving the MMA. (*A*) In its normal adult configuration, the OA originates from the ICA immediately after its passage through the dural ring and enters the orbital cavity through the optic canal. Connections with the MMA are established via the meningolacrimal artery through the foramen of Hyrtl and via the sphenoidal artery through the lateral aspect of the SOF. The meningolacrimal artery, short and straight, is the true vestige of the anterior ramus of the stapedial artery. The sphenoidal artery, long and tortuous, is a neomorph present only in hominids. The deep recurrent OA stems from the first part of the OA and courses backward through the medial aspect of the SOF to connect with the inferior-lateral trunk of the ICA. (*B*) The MMA can originate from the OA. The connection between the lacrimal artery and the MMA is believed to rely on the sphenoidal artery (as illustrated), although the meningolacrimal also could be involved. (*C*) The OA can originate from the MMA via the sphenoidal artery or via the meningolacrimal artery. In the latter instance (as illustrated), the abnormal OA has a relatively straight course and it penetrates the orbital cavity through the foramen of Hyrtl. The connection to the lacrimal artery is distal, a factor possibly explaining why, in this configuration, the OA tend to supply the orbit only partially, generally through the lacrimal artery. (*D*) When the sphenoidal artery is involved, the abnormal OA has a more tortuous course, enters the orbit via the lateral aspect of the SOF, and establishes a more proximal connection with the lacrimal artery. The authors believe that the potential for the abnormal OA to supply the entire orbital content, including the optic apparatus, is [Q19] higher in this configuration (as illustrated).

fissure (SOF) and takes the name, sphenoidal artery.[7] It remains uncertain if only one or both branches are derived from the stapedial artery (Fig. 2A). A recent review of available phylogenetic and ontogenetic data seems to indicate that the meningolacrimal artery is the true vestige of the stapedial artery, whereas the sphenoidal artery is a neomorph that appears late in the ontogenic development and seems restricted to hominids (man and orangutans).[8] Variations in the mode of connection of these various arteries and in their regression patterns are at the origin of the principal variants of the orbital supply and of several related dangerous collaterals. These variants (discussed later) include the origin of a part or of the whole MMA from the OA (see Fig. 2B) and the origin of the OA or one of its branches from the MMA (Fig. 2C, D).

## Anatomy

### The ophthalmic artery and its branches

The nomenclature used in this section is based, whenever possible, on the last edition of *Terminologia Anatomica*.[9] The OA (arteria ophthalmica) is the first major branch of the ICA. As the site of origin of the OA usually is located at or close to the superior dural ring, it often is used as a point of demarcation between the intra- and extradural segments of the ICA. This landmark is somewhat imprecise: whereas the OA generally branches off the ICA immediately after the latter has pierced the roof of the cavernous sinus, in most cases within the subdural space,[10] this site of origin can vary proximally from the cavernous sinus up distally to the ICA bifurcation. Rarely, the OA can originate within the two layers of the dural roof.[10]

The intracranial segment of the OA has a short course within the subdural space before it enters the optic canal. It is followed by the intracanalicular portion of the OA, which often can be identified by a slight decrease of its caliber throughout the length of the optic canal.[11] The OA courses below the optic nerve in its intracranial and intracanalicular segments.[11] The intraorbital segment of the OA has been divided in three parts by Hayreh and Dass.[12] As it penetrates the orbital cavity through the common anular ring (annulus of Zinn), the OA first lies inferiorly and laterally to the optic nerve (first part). It then loops above (82.6%) or below (17.4%) the nerve to reach its superior-medial aspect (second part). This semicircular course around the nerve is a vestige of the connection between the nasociliary and temporociliary branches of the primitive OAs. From that point, the OA aims anteriorly and medially toward the orbital wall (third part), ending at the superior-medial aspect of the orbital opening, although its caliber often is already significantly reduced distal to the take off of the anterior ethmoidal artery.[12]

A complete description of the branches of the OA is beyond the scope of this article. For more detailed reference, readers are directed to the classic work of Hayreh.[13] It is convenient to classify the branches of the OA according to their topography.[13] The ocular group, which includes the branches supplying the optic apparatus (central retinal, ciliary, and collateral arteries), are not discussed further. The lacrimal and muscular arteries remain within the confine of the orbital cavity and constitute the orbital group, along with various smaller branches supplying the surrounding connective structures. Finally, the extra-orbital group includes branches that exit



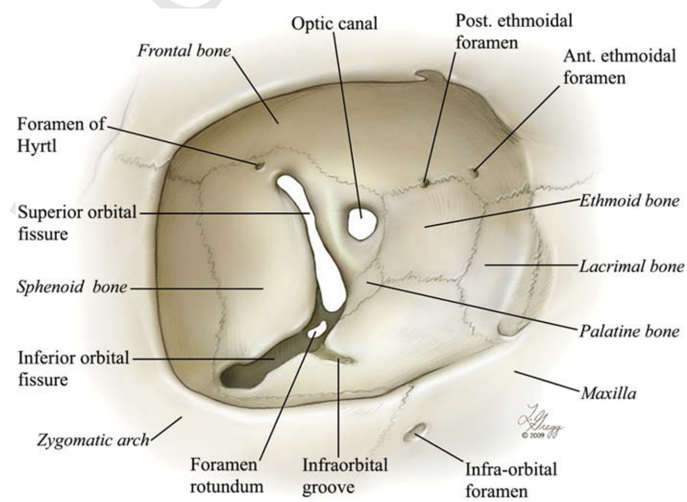



Fig. 3. The principal orbital foramina.

the orbital cavity, such as the posterior and anterior ethmoidal, the medial palpebral, the dorsal nasal, and the supratrochlear arteries. Several branches of the lacrimal artery are part of this group, including the sphenoidal and meningolacrimal arteries. The first part of the OA also provides two small recurrent arteries. One of them exits the orbit through the medial aspect of the SOF and establishes a connection with the inferior-lateral trunk of the cavernous ICA (C4 segment). This branch, known as the deep recurrent OA, seems to be a stable feature of the OA anatomy[14] and plays a significant role in several OA variations. The second recurrent branch, the superficial recurrent OA, seems less constant and represents one of the possible origins of the marginal tentorial artery.[14]

### *The orbital foramina*

A brief description of some of the various foramina connecting the orbital cavity to its surroundings helps understand most of the variants and anastomoses (discussed later). These principal foramina are illustrated in **Fig. 3**.

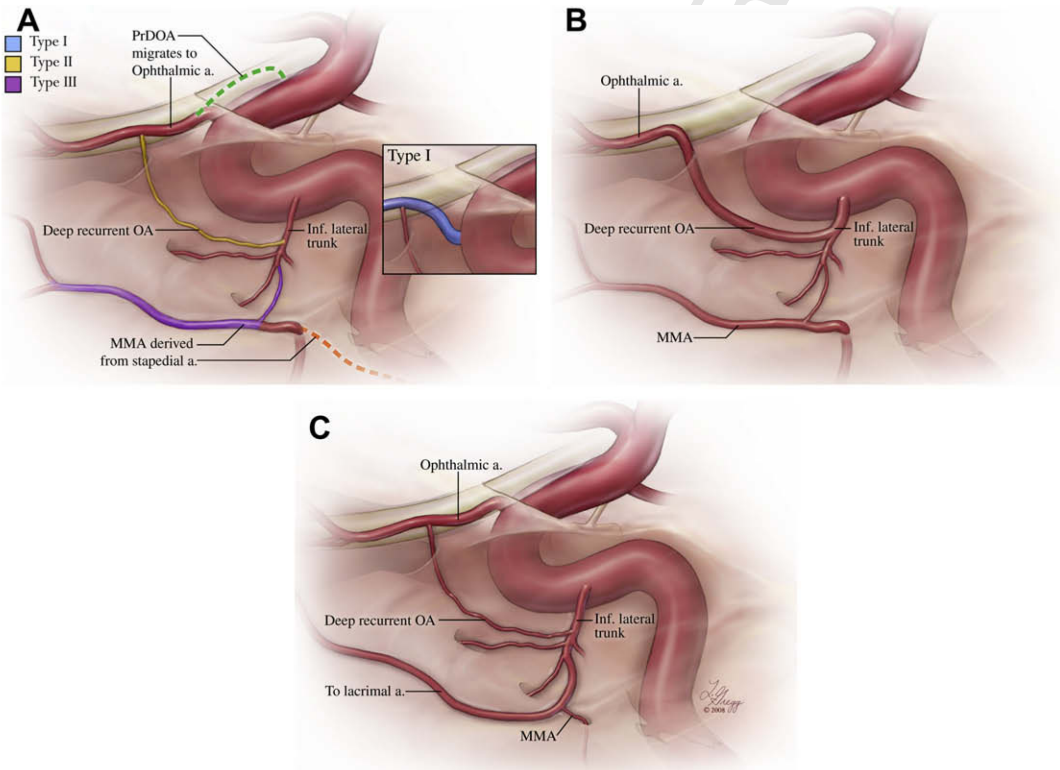





**Fig. 4.** Cavernous origin of the OA types I, II, and III. (*A*) This illustration depicts the embryonic precursors of the OA and their role in several variants of the OA origin. The green dotted line represents the primary origin of the PrDOA. A true persistence of the fetal configuration results in an OA arising from the ICA at the level of the posterior communicating artery. The deep recurrent OA is shown in yellow. The stapedial artery and a persistent connection with the inferior lateral trunk of the ICA are shown in purple, whereas its involuted origin from the petrous ICA is shown in orange. The inset illustrates a cavernous OA type I. In this variant, the OA originates from the ICA close to the dural ring; it then assumes a sharp upward curve to enter the optic canal. From that point on, a cavernous OA type I has the course and distribution of a normal OA. (*B*) In a cavernous OA type II, the OA originates from the horizontal segment of the cavernous ICA; it corresponds to the deep recurrent OA, a branch of the inferior-lateral trunk. The abnormal OA, therefore, penetrates the orbit via the medial aspect of the SOF and continues as the first part of the OA. This proximal connection implies that cavernous OA type II supply the entire ophthalmic distribution, including the optic apparatus. (*C*) A cavernous OA type III also originates from the horizontal segment of the ICA, but in this case, the connection is established with the stapedial artery (or, at the adult stage, with the MMA). A cavernous OA type III has the course and distribution of the anterior ramus of the stapedial artery, in a way that is similar to the variants presented in **Fig. 1**. It enters the orbital cavity via the foramen of Hyrtl if it involves the meningolacrimal artery or via the lateral aspect of the SOF if it involves the sphenoidal artery.

1. The optic canal (canalis opticus) is contained within the base of the lesser wing of the sphenoid bone. The optic nerve and the OA enter the orbital cavity through the optic canal. In rare instances, the OA can penetrate a separate osseous canal that joins the optic canal near its orbital end.[10]
2. The SOF (fissura orbitalis superior) is delimited superiorly by the lesser wing and inferiorly by the greater wing of the sphenoid bone. It is pear-shaped, with a wide medial-inferior base and a narrow lateral-superior tail. The two edges of the fissure usually remain separate until they reach the frontal bone. A small foramen, the ophthalmomeningeal foramen of Hyrtl (or cranio-orbital foramen), can be seen laterally to the SOF, sometimes close enough to be confluent with its lateral extremity.[8] When present, this foramen gives way to an anastomosis between the lacrimal artery and the MMA, the meningolacrimal artery, which is believed to represent the vestige of the superior ramus of the stapedial artery (ie, the primitive orbital artery). A second anastomosis between the lacrimal artery and the MMA, the sphenoidal artery (often confusingly identified as the recurrent meningeal branch of the lacrimal artery), is believed to be a neomorph present only in some hominids, including man. The sphenoidal artery passes through the lateral aspect of the SOF[15] and is involved in several major OA variants. The middle portion of the SOF contains the superior ophthalmic vein, whereas the medial portion gives way to the inferior ophthalmic vein. The deep recurrent OA also passes through the medial portion of [Q12] the SOF, crossing the tendon of Zinn.[14]

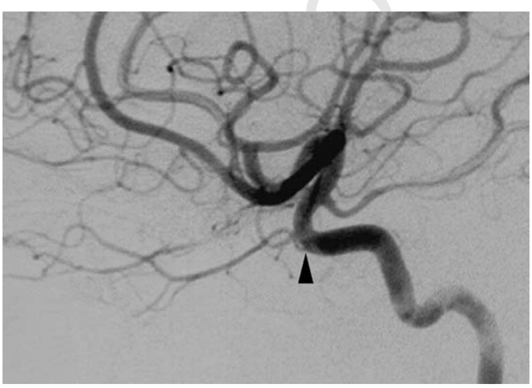


**Fig. 5.** Cavernous OA type I seen in a left ICA angiogram, lateral projection. The OA originates from the ICA close to the dural ring (*black arrowhead*) and curves sharply upwards to enter the optic canal.

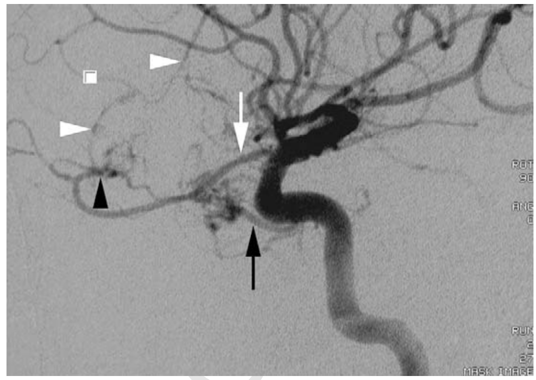


**Fig. 6.** Right ICA angiogram (lateral projection) in a 17-year-old boy who had orbital fibrous dysplasia. The inferior lateral trunk participates in the vascularization of the osseous pathology via several branches including a prominent deep recurrent OA (*black arrow*). The latter can be followed from the inferior-lateral trunk up to its connection with the first part of an OA of normal origin (*white arrow*). Note that in this patient, the lacrimal artery (*black arrowhead*) branches off the MMA (*white arrowheads*).

3. The inferior orbital fissure (IOF) (fissura orbitalis inferior) connects the orbital cavity with the infratemporal fossa and, through the latter, with the more medially located pterygopalatine fossa. Coming from the pterygopalatine fossa, the infraorbital artery (with its vein) enters the orbit via the IOF. It first follows the infraorbital groove that stems anteriorly from the IOF (sulcus infraorbitalis), then courses within the infraorbital canal (canalis infraorbitalis) and

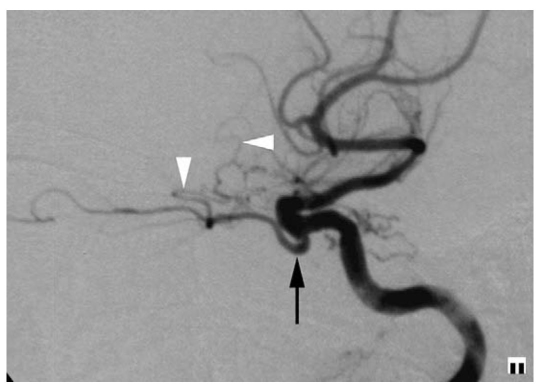


**Fig. 7.** Right ICA angiogram, lateral projection, showing a cavernous OA type II. The OA originates from the horizontal segment of the cavernous ICA (*black arrow*) and penetrates the orbital cavity through the medial aspect of the SOF to continue as the first segment of the OA, supplying the entire OA distribution. In this case, the lacrimal artery provides the MMA (*white arrowheads*).

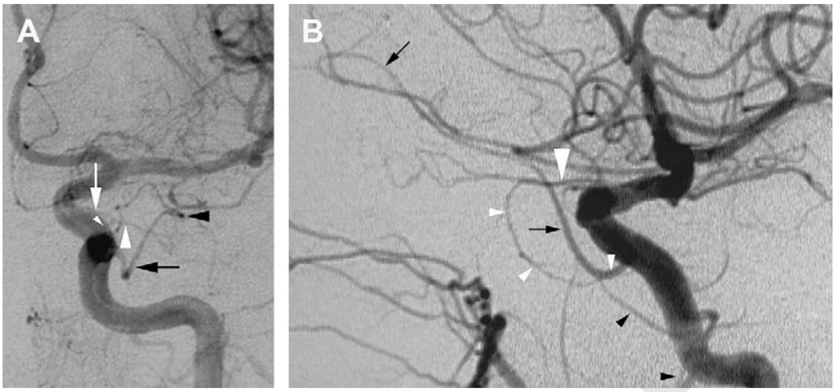



**Fig. 8.** Cavernous OA type III seen on a left common carotid angiogram. (*A*) In this anteroposterior projection, a small OA of normal origin (*white arrow*) enters the orbital cavity through the optic canal (*white arrowhead*) to supply the optic apparatus. A cavernous OA type III (*black arrow*) originates from the cavernous ICA and enters the orbit through the foramen of Hyrtl (*black arrowhead*). This branch supplies the orbital content other than the optic apparatus. This configuration reproduces the embryonic stage during which the orbital vascularization is shared between the primitive orbital artery (from the stapedial artery) and the PrDOA. In addition, a deep recurrent OA is partially seen projecting over the distal ICA (*small white arrowhead*). (*B*) The lateral oblique projection confirms the presence of a "normal" OA supplying the optic apparatus (*white arrowhead*) in addition to a cavernous OA type III (*black arrows*). The course of the deep recurrent OA is shown by the small white arrowheads back to its connection with the inferior-lateral trunk. Note the presence of a diminutive MMA (*black arrowheads*) connecting to the proximal segment of the cavernous OA type III, confirming the homology of the latter with the anterior ramus of the stapedial artery. [**Q20**]

exits the orbit through the infraorbital foramen (foramen infraorbitale).

4. The anterior ethmoidal foramen (foramen ethmoidale anterius) and the posterior ethmoidal foramen (foramen ethmoidale posterius) contain the anterior and posterior ethmoidal arteries, respectively. The anterior ethmoidal artery provides an important meningeal branch, the anterior meningeal artery, which enters the cranial cavity via the ethmoidal foramen of the cribriform plate.

## Anatomic Variants and Dangerous Collaterals

### Cavernous origin of the ophthalmic artery

Three types of cavernous origin of the OA can be differentiated (Fig. 4A–C). In type I, the origin of the OA lies close to the dural ring, and the vessel


**Fig. 9.** OA origin of the MMA. (*A*) Angiography of the left ICA, lateral projection, in a patient who had embolic occlusion of the distal ICA (the image has been flipped horizontally for consistency with other figures). The lacrimal artery (*black arrowhead*) is providing the MMA. Note the tortuous appearance of the arterial segment running between the lacrimal artery and the MMA (*white arrowhead*), consistent with the course of the sphenoidal artery. (*B*) Angiography of the left ECA, lateral projection, confirming the absence of a normal MMA from the maxillary artery.

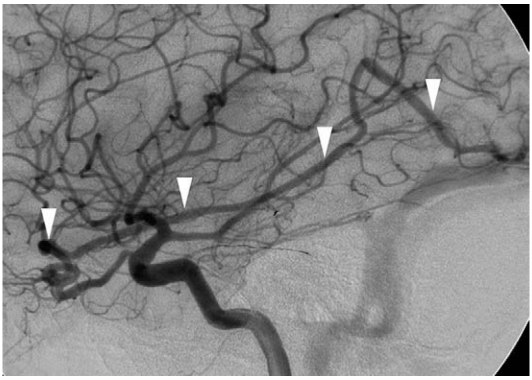


Fig. 10. Right ICA angiography, lateral projection, showing a prominent MMA (*white arrowheads*) originating from the lacrimal artery and feeding a right transverse sinus DAVF.

assumes a sharp upward curve to enter the optic canal (Fig. 5). In this variant, the proximal segment of the OA derives from the PrDOA, as it is the case in the normal adult configuration. The proximal origin of the OA could be related to an exaggerated caudal migration of the PrDOA.[5]

Types II and III often are described as persistent dorsal OAs, although these variants are better labeled as cavernous origins of the OA, because they do not represent the persistence of the PrDOA. The PrDOA is not a branch of the cavernous segment of the ICA.[4] The exceptional adult persistence of the origin of the PrDOA results in an OA coming from the ICA distally to its expected adult position. In types II and III, the OA arises more proximally from the ICA (C3 or C4 segment) and penetrates into the orbit via the medial aspect of the SOF (type II) or through its lateral aspect or the foramen of Hyrtl (type III). The abnormal vessel can be the only detectable OA (generally type II) or it can partially supply the orbit, generally providing only the lacrimal artery (type III). In the latter instance, the cavernous OA is associated with a second OA, which usually has a normal adult origin. The authors believe that types II and III have different embryonic origins. Type II seems to correspond to the deep recurrent OA, a branch of the inferior lateral trunk that normally penetrates the orbit via the medial aspect of the SOF and the tendon of Zinn (Fig. 6). Because the deep recurrent OA is connected with the first part of the OA, a cavernous OA type II generally takes over the supply of the entire orbital content (Fig. 7). [Q13] Cavernous OAs type III represent, in the authors' opinion, a true vestige of the stapedial artery, more precisely of the proximal segment of the primitive orbital artery, and of its connection with the C4 segment of the ICA, an idea put forward by Maillot and coworkers.[5] This developmental anatomy is consistent with the observation that a cavernous OA type III often is associated with a small or absent ipsilateral MMA and that it enters the orbit crossing the lateral aspect of the SOF or the foramen of Hyrtl (Fig. 8). Cavernous OAs type III and variants in which the OA originates from the MMA, therefore, are similar. Both have the same distal anatomy and vary only by their site of origin (ie, from the ICA for the former [connection of the

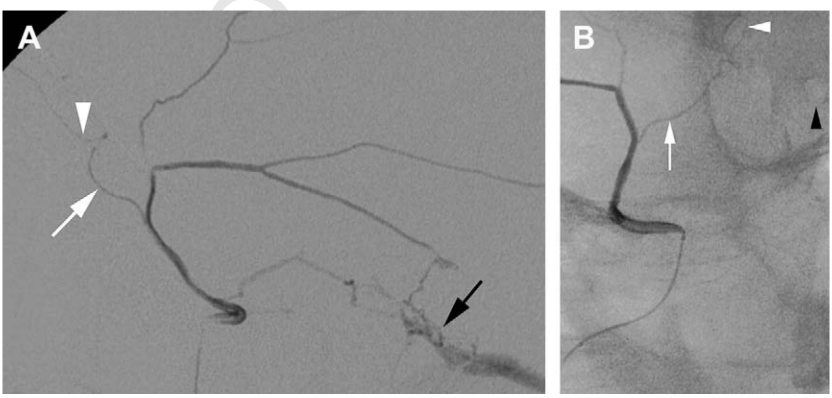



Fig. 11. Right external carotid artery angiography in a case of transverse sinus DAVF. (*A*) The lateral projection shows the meningolacrimal artery (anterior ramus of the stapedial artery) (*white arrow*) continuing within the orbital cavity as the lacrimal artery (*white arrowhead*). Note the straight course of the connecting segment consistent with the anatomy of the meningolacrimal artery. The MMA is feeding a transverse sinus DAVF (*black arrow*). (*B*) The anteroposterior projection confirms the passage of the connecting segment of the meningolacrimal artery (*white arrow*) through the foramen of Hyrtl or the lateral end of the SOF (*whiter arrowhead*), at distance from the optic canal (*black arrowhead*).

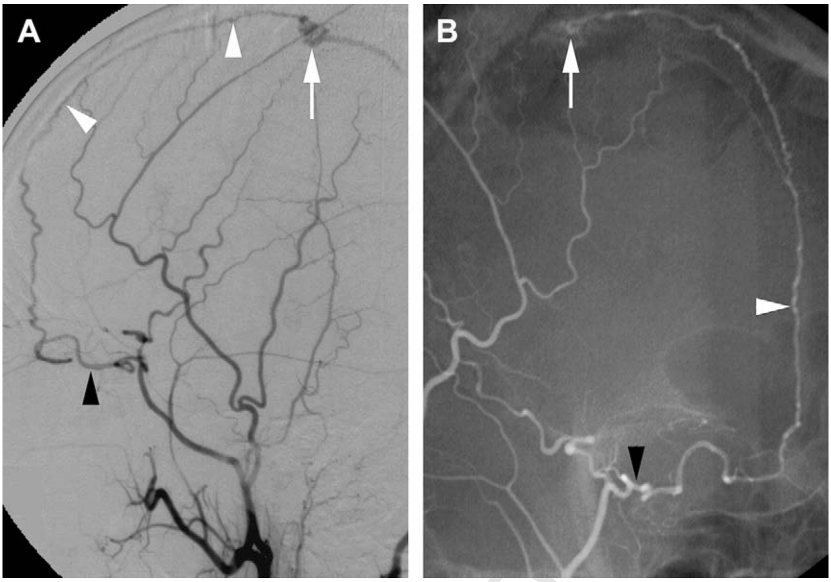



**Fig. 12.** Right external carotid artery angiography in a case of transverse sinus DAVF. (*A*) The lateral view shows a prominent OA coming from the MMA (*black arrowhead*) and feeding a superior sagittal sinus DAVF (*white arrow*) via the anterior meningeal artery (a branch of the anterior ethmoidal artery) (*white arrowheads*). Note the tortuous appearance of the proximal segment of the OA (sphenoidal type). (*B*) The right anterior oblique view shows the tortuous path followed by the proximal segment of the OA (*black arrowhead*), consistent with the anatomy of a sphenoidal artery, and its medial course across the orbital cavity ending near the anterior [Q21] ethmoidal foramen, through which it provides a large branch vascularizing the DAVF (*white arrow*).

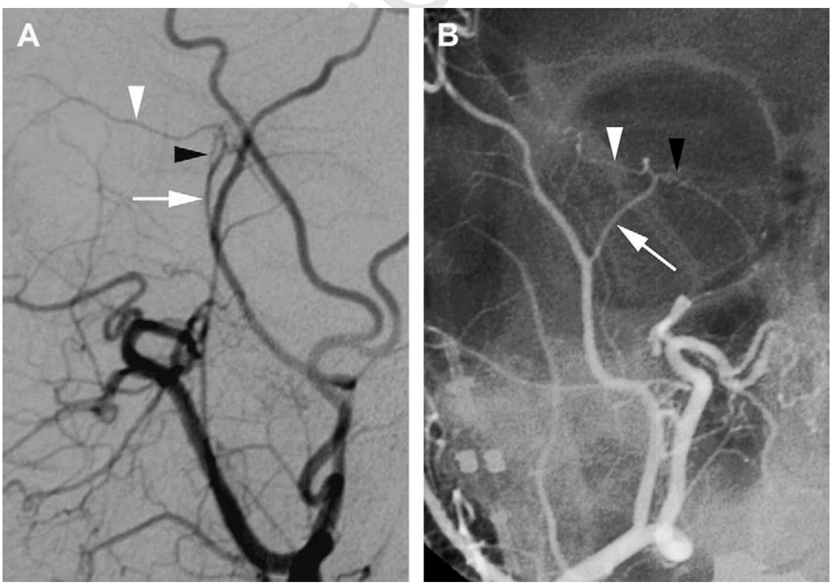



**Fig. 13.** Right external carotid artery angiography in a case of MMA origin of the lacrimal artery. (*A*) The lateral view shows the smooth continuation of the anterior branch of the MMA (*white arrow*) into the lacrimal artery (*white arrowhead*), typical of the meningolacrimal configuration. A second, more tortuous and medially oriented branch is observed (*black arrowhead*). (*B*) The anteroposterior projection confirms the presence of a meningolacrimal artery entering the orbital cavity laterally and continuing as the lacrimal artery (*white arrowhead*). The second branch has a medial course and the typical tortuosity of a sphenoidal artery (*black arrowhead*). The risk linked to the presence of a dangerous connection with branches supplying the optic apparatus through the sphenoidal artery is higher in this configuration than in cases where the meningolacrimal artery is isolated and provides only [Q22] the lacrimal artery. The white arrow indicates the anterior branch of the MMA.

stapedial artery with the ICA] and from the MMA for the latter [connection of the stapedial artery with the ECA]). The connection of cavernous OAs type III with the orbital arterial system is established at the level of the lacrimal artery via a meningolacrimal artery or a sphenoidal artery. As discussed later, the extent of orbital supply provided by the variant may depend in part on which of these two connections is involved.

### *Ophthalmic origin of the middle meningeal artery*

The MMA may originate partially or completely from the lacrimal artery. Two arterial segments can explain such a variation. The MMA can result from the persistence of the segment of stapedial artery corresponding to the primitive orbital artery (later known as the meningolacrimal artery) and exit the orbit via the foramen of Hyrtl. Alternatively, the connection can involve an arterial segment believed to be a late-acquired neomorph, the sphenoidal artery, and exit the orbit via the lateral aspect the SOF. In both instances, the foramen spinosum is hypoplastic or absent. It has been proposed that a MMA arising from the OA is derived more often from a sphenoidal artery[8]; this seems consistent with the observation that, in such a variant, the proximal segment of the MMA usually has a tortuous course, a typical feature of the sphenoidal artery (Fig. 9).

A MMA arising from the OA may be involved in various pathologic processes and can in particular participate in the vascularization of meningeal lesions, such as a meningioma or a dural arteriovenous fistula (DAVF) (Fig. 10).

### *Middle meningeal origin of the ophthalmic artery*

The MMA can partially or completely provide blood supply to the orbital content. Again, two pathways may link the MMA to the lacrimal artery. The original connection of the primitive orbital artery with the intraorbital network can remain patent and prominent. In this case, the MMA generally provides only the lacrimal artery via a short and straight connection through the foramen of Hyrtl. This anatomy is consistent with the typical appearance of the meningolacrimal artery and with its relatively distal connection with the lacrimal artery (Fig. 11). The second pathway involves the sphenoidal artery. In this case, the connection often shows significant

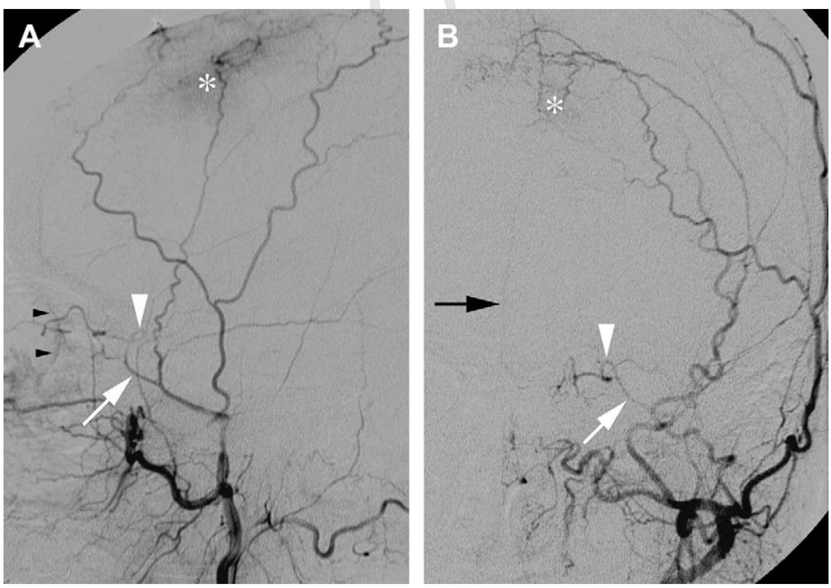



Fig. 14. Left external carotid artery angiography in a patient who had a frontal meningioma. (*A*) The lateral projection shows a prominent OA arising from the anterior division of the MMA (*white arrow*). Note the tortuous course of the OA as it enters the orbital cavity, an appearance consistent with a sphenoidal type (*white arrowhead*). The presence of a choroid blush (*black arrowheads*) confirms the participation of the variant to the blood supply of the optic apparatus. The white asterisk indicates the tumoral blush of the meningioma. (*B*) The anteroposterior projection confirms the sinuous medial trajectory of the extraorbital segment of the OA (sphenoidal type) (*white arrowhead*) and the extent of its intraorbital supply, including a small lacrimal artery traveling laterally and a larger main stem aiming medially toward the anterior ethmoidal foramen. The anterior meningeal branch of the anterior ethmoidal artery (*black arrow*) is involved in the supply of the meningioma (*asterisk*). [Q23] The white arrow indicates the anterior division of the MMA.

tortuosity as the connecting segment travels medially, and the MMA tends to provide a larger part of the orbital supply, sometimes its entirety. This is in keeping with the appearance of the sphenoidal artery and its relatively proximal connection with the lacrimal artery (Fig. 12). The meningolacrimal and sphenoidal arteries can at times be observed simultaneously (Fig. 13).

Although all of these OA variations need to be considered dangerous anastomoses, the possibility that the MMA supplies important optic structures (in particular via the central retinal artery) is higher for variants of the sphenoidal type than for those of the meningolacrimal type, a fortiori when the latter is associated with a well-defined second [Q14] OA. Transarterial embolization in the MMA territory must be considered high risk and attempted only after careful evaluation of the procedural risks and benefits whenever the MMA provides the main trunk of the OA and likely supplies the optic apparatus (eg, in the sphenoidal type of the variation, with or without an angiographically detectable choroid blush) (Fig. 14).

An OA originating from the MMA may be involved in various neurovascular conditions. Through the anterior ethmoidal artery and its anterior meningeal branch, it can supply blood to a meningioma or a DAVF (see Figs. 11 and 14). A MMA that vascularizes the optic apparatus may be involved in a central retinal artery occlusion and become the target vessel for intra-arterial thrombolysis (Philippe Gailloud and colleagues, [Q15] unpublished data).

## SUMMARY

Three types of cavernous origins of the OA can be distinguished. In a cavernous OA type I, the OA has an extradural origin but a normal course through the optic canal and a normal intraorbital branching pattern. A cavernous OA type II derives from the deep recurrent OA. As the latter branch is normally connected to the first part of the OA, type II generally supplies the entire ophthalmic territory. Embolization of a cavernous OA type II, therefore, requires the same risk-benefit analysis as does embolization in the distribution of a normal [Q16] OA. Cavernous OA type III involves the anterior ramus of the stapedial artery and, except for its origin from the ICA, is similar to variants in which the OA comes from the MMA. In both instances, the connection with the ophthalmic circulation is established more distally, at the level of the lacrimal artery, via a meningolacrimal artery (through the foramen of Hyrtl) or via a sphenoidal artery (through the lateral aspect of the SOF). Although they still must be considered high-risk vessels for embolization, a cavernous OA type III or an OA coming from the MMA is less likely to be involved in the vascularization of the optic apparatus, particularly when they are derived from the meningolacrimal artery (straight connection) or when a second OA coming from the ICA is detected. The same reasoning can be applied to OAs arising from the MMA.

## REFERENCES

1. Merland JJ, Djindjian R, Bories J. Superselective arteriography of the branches of the external carotid artery. Recent findings concerning the exo- and endocranial base of the skull. Berlin. New York: Springer-Verlag; 1975.
2. Lasjaunias PL, Berenstein A. Craniofacial and upper cervical arteries: functional, clinical, and angiographic aspects. Baltimore (MD): Williams & Wilkins; 1981.
3. Marinkovic S, Gibo A, Brigante L, et al. Arteries of the brain and spinal cord. Anatomic features and clinical significance. Avellino (Italy): De Angelis; 1997.
4. Padget DH. The development of cranial arteries in the human embryo. Contrib Embryol 1948;32:205–61.
5. Maillot C, Froelich S, Kehrli P. [Ophthalmic artery, optic nerve and meninges: reciprocal relations]. J Neuroradiol 2000;27:93–100.
6. Moret J, Lasjaunias P, Theron J, et al. The middle meningeal artery. Its contribution to the vascularisation of the orbit. J Neuroradiol 1977;4:225–48.
7. Lasjaunias P, Vignaud J, Hasso AN. Maxillary artery blood supply to the orbit: normal and pathological aspects. Neuroradiology 1975;9:87–97.
8. Diamond MK. Homologies of the meningeal-orbital arteries of humans: a reappraisal. J Anat 1991;178:223–41.
9. Federative Committee on Anatomical Terminology. Terminologia anatomica: international anatomical terminology. Stuttgart (NY): Thieme; 1998.
10. Hayreh SS, Dass R. The ophthalmic artery: I. Origin and intra-cranial and intra-canalicular course. Br J Ophthalmol 1962;46:65–98.
11. Dilenge D. L' angiographie par soustraction de l'artère ophtalmique et de ses branches, par D. Dilenge [et al]. Paris: Masson; 1965. [Q17] [Q18]
12. Hayreh SS, Dass R. The ophthalmic artery: II. Intra-orbital course. Br J Ophthalmol 1962;46:165–85.
13. Hayreh SS. The ophthalmic artery: III. Branches. Br J Ophthalmol 1962;46:212–47.
14. Lasjaunias P, Brismar J, Moret J, et al. Recurrent cavernous branches of the ophthalmic artery. Acta Radiol Diagn (Stockh) 1978;19:553–60.
15. Martins C, Yasuda A, Campero A, et al. Microsurgical anatomy of the dural arteries. Neurosurgery 2005;56:211–51 [discussion: 51].