A microsurgical study of the anatomy and course of the ophthalmic artery and its possibly dangerous anastomoses

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Object. The authors studied the microsurgical anatomy of the ophthalmic artery (OphA), paying particular attention to its possibly dangerous anastomoses with the middle meningeal artery (MMA).

Methods. The microsurgical anatomy of the OphA and its anastomoses with the MMA were studied in 14 vessels from seven adult cadaveric heads. The origination order of the OphA branches varies in relation to whether the artery, along its intraorbital course, crosses above or below the optic nerve (ON). The central retinal artery is the first branch to course from the OphA when it crosses over the ON, and it is the second branch to course from the OphA when the artery crosses under the ON. Anastomoses between branches of the MMA and the OphA were present in the majority of the specimens examined.

Conclusions. Detailed knowledge of the microanatomy of the OphA and recognition of anastomoses between the external carotid artery and the OphA are critically important in avoiding disastrous complications during endovascular procedures.

Key Words • middle meningeal artery • ophthalmic artery • orbit • microsurgical anatomy • embolization

With recent endovascular technical advances, embolization of vascular and neoplastic lesions supplied by the OphA and its branches is common. Authors of numerous studies have detailed the angiographic anatomy of the OphA and its branches.13,31 However, the microsurgical anatomy of this important artery has not been investigated in detail. Furthermore, there are variable connections between OphA branches and branches of the MMA that clinically are critically important and explain the occasional occurrence of visual impairment and blindness following the embolization of lesions supplied by the MMA.17 The frequency and pattern of these anastomotic channels have not been systematically examined.16,18 The purpose of this study is to describe the microsurgical anatomy of the OphA and its branches, with particular attention to reciprocal connections with the MMA.

Materials and Methods

The course of the OphA and the MMA blood supply to the orbit were examined bilaterally in seven adult cadaveric heads (injected with colored fluid) using a surgical microscope (Wild M695, Leica Microsystems) at a magnification of 3 to 40. The anatomical dissections were performed with microsurgical instruments and a high-speed drill when required. Digital photographs were taken at each step of the dissection. All measurements were performed with an electronic digimatic caliper (± 0.01 mm).

Results

Osseous Relationships

The OphA, the recurrent meningeal artery, and the meningolacrimal artery (when present) enter the orbit through the optic canal, the SOF, and the meningolacrimal canal (when present), respectively (Fig. 1). The optic canal, which allows passage of the ON and the OphA, lies between the superior and inferior roots of the anterior clinoid process (Fig. 1A). The superior root forms the roof of the optic canal and continues medially to form the planum sphenoidale (Fig. 1A). The inferior root (or optic strut) constitutes the inferolateral wall of the optic canal and separates the optic canal from the SOF (Fig. 1A). Both proximal (intracranial) and distal (intraorbital) openings of the optic canal are elliptical in shape. The length of the optic canal varies from 5 to 11 mm (mean 8 mm).

The groove for the MMA starts at the foramen spinosum and then divides into posterior (parietal) and anterior (frontal) furrows 10 to 25 mm (mean 18 mm) anterolateral to the foramen spinosum (Fig. 1B). The frontal groove is larger,
crosses the greater wing of the middle cranial fossa, and usually divides into the smaller medial and lateral grooves (Fig. 1B). The medial division of the frontal groove is usually smaller, originates 5 to 15 mm (mean 8 mm) behind the lesser wing and courses toward the lacrimal foramen (Fig. 1B) (also named the Hyrtl, meningolacrimal, craniornostral, meningoorbital, and stapedial–ophthalmo–lacral foramen), which accommodates the meningolacrimal artery. In general, the existence of the lacrimal foramen is an inconsistent finding, occurring bilaterally in only two of the specimens studied. When present, it is ovoidal and lies 5 to 10 mm (mean 7 mm) laterally to the SOF and below the lesser wing (Fig. 1A). In the remaining specimens without a true foramen, several small foramina were found in the same general area, through which very small intraosseous branches of the MMA enter the orbit.

From the area of the lacrimal foramina, a constant groove runs medially to the narrow lateral apex of the SOF (Fig. 1A and B). In this groove courses the recurrent meningeal artery. Often the sharp lateral margin of the SOF presents a notch for the recurrent meningeal artery, which supplies the dura mater of the SOF and the adjacent periorbita and then anastomoses with the lacrimal artery (a branch of the OphA). In an anterior view of the orbit, the superior orbital fissure is posterior and medial to the lacrimal foramen, which when present is located along the superior edge of the lateral wall of the orbit (Fig. 1C). The anterior and posterior ethmoidal foramina pass through the frontoethmoidal suture at the junction of the roof and the medial wall of the orbit (Fig. 1C).

Arterial Relationships

Origin and Courses of the OphA. On all cadaver sides but one, the OphA arose in the intradural space at an acute angle from the superomedial aspect of the anterior bend of the ICA, just above the distal dural ring (Fig. 2). At its origin, the OphA (mean outer diameter 1.6 mm, range 1.5–1.8 mm) is located inferomedial to the ON, behind the optic canal. In only one specimen did the OphAs on both
sides give rise to intracranial perforating branches directed toward the ventral aspect of the ON (Fig. 2C). Five millimeters (range 2.8–6.5 mm) from its origin, the OphA pierces the dural sheath of the ON along its inferolateral aspect and enters the optic canal (intracanalicular course). The OphA in its intracanalicular course is embedded in the dural sheath of the ON, coursing along its inferolateral aspect. The OphA exits the optic canal inferolateral to the ON and emerges from the optic sheath. In one specimen, the OphA on one side arose from the clinoid segment of the ICA and entered the orbit through the medial aspect of the SOF.

**Intraorbital Course.** After passing through the optic foramen and the anular tendon, the OphA continues its course inferolaterally to the ON. According to previous descriptions, the intraorbital OphA can be divided into three segments\(^9\) (Fig. 3A). The first segment runs along the inferolateral aspect of the ON and extends from the OphA entrance into the orbit to the point where the artery changes direction and becomes the second segment (Fig. 3A). The second segment crosses, in a lateral to medial direction, over (Type 1) or under (Type 2) the ON from the inferolateral to the superomedial aspect of the nerve. At this point, the OphA turns anteriorly. We found the OphA to cross the ON superiorly in four specimens on both sides (57%). In the remaining three specimens (43%), the OphA crossed the ON inferiorly on both sides. The point where the OphA crosses the ON is easily identified on the lateral angiographic projection (Fig. 4). The third segment of the OphA extends from the angle where the second segment bends at the medial aspect of the ON to its termination at the superomedial angle of the orbital opening (Fig. 3A).

The intraorbital OphA gives rise to several branches, which can be schematically classified into four groups: ocular, orbital, extraorbital, and dural. The ocular group includes the CRA and the ciliary arteries supplying the retina and choroid. The orbital group includes the lacrimal and muscular branches. The extraorbital group consists of the supraorbital, anterior and posterior ethmoidal, palpebral, dorsal nasal, and supratrochlear arteries. The dural group includes the two recurrent superficial and deep arteries. The ethmoidal and lacrimal branches of the OphA also contribute to the dural supply.

The order in which the OphA branches originate varies in relation to whether the OphA crosses above (Type 1) or below (Type 2) the ON (Fig. 3). When the OphA crosses above the ON, the first branch is the CRA and the second

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**Fig. 2.** Photographs showing the microanatomical features of the OphA and its intradural origin. **A:** The lateral wall and roof of the left orbit and the intraorbital fat have been removed. After performing an anterior clinoidectomy, the oculomotor (CN III), trochlear (CN IV), and ophthalmic (V1) nerves have been exposed by removing the dura of the lateral wall of the cavernous sinus. The ON is gently retracted to expose the origin of the left OphA. **B:** Enlarged view of panel A. The OphA arises at an acute angle from the superomedial aspect of the ophthalmic segment of the ICA just above the distal dural ring. **C:** After its origin, the OphA courses anteriorly and laterally below the ON on the upper surface of the optic strut, and extends into the dural sheath of the ON on its inferolateral aspect to enter the optic canal. Intracranial perforating branches directed to the ventral aspect of the ON (CN II) can arise from the OphA a few millimeters after its origin. CN = cranial nerve; Lat. = lateral; M. = muscle; Rec. = rectus; Seg. = segment.
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FIG. 3. Photographs showing the two primary patterns of the intraorbital course of the OphA.  A: This posterosuperior view of the right orbit shows the Type 1 pattern of the intraorbital course of the OphA. The orbital roof and the lateral wall of the orbit have been removed and the extraorbital structures dissected. The superior rectus, the levator, and the oblique muscles have been retracted to expose the OphA. The part of the OphA as it extends into the orbit can be divided into three segments. In the Type 1 pattern, the OphA crosses over the ON, passing from the inferolateral to its superomedial aspect.  B: The ON is retracted medially, exposing the early intraorbital branches of the OphA. In Type 1 OphA, the CRA is usually the first branch of the OphA. In this specimen the CRA arises with the lateral posterior ciliary artery from a common trunk.  C: Posterosuperior view of the right orbit in another specimen, showing the Type 2 pattern. The orbital roof and the lateral wall of the orbit have been removed and the intraorbital structures dissected. The superior rectus muscle has been divided near the globe and retracted posteriorly to expose an OphA that courses below the optic nerve.  D: The ON has been divided and retracted to expose the second segment of the OphA. In this pattern, the first branch is usually the lateral posterior ciliary artery, whereas the CRA is the second branch. Cent. = central; Cil. = ciliary; Ethm. = ethmoidal; Med. = medial; Musc. = muscular; N. = nerve; Nasocil. = nasociliary; Obl. = oblique; Ret. = retinal.
Fig. 4. Angiogram of a lateral view of the left common carotid artery, showing the OphA and its main orbital and extraorbital branches. The second part of the OphA presents with a typical bayonet appearance (between the arrowheads) as it crosses the ON in a lateral to medial direction. The “safety point” for embolization of pathological processes supplied by the OphA is beyond the second segment of the OphA after the origin of the CRA. Supratroch. = supratrochlear.

branch a posterior ciliary artery (lateral or medial); the third branch is usually the lacrimal artery (Fig. 3A and B). When the OphA crosses below the ON, the first branch is usually the lateral posterior ciliary artery and the second is the CRA (Fig. 3C and D).

In all specimens, the CRA arose from the first or second part of the OphA at the inferolateral aspect of the ON, medially to the ciliary ganglion. Its diameter at the origin was a mean of 0.2 mm (range 0.1–0.4 mm). In 43% of the orbits, the CRA arose directly from the OphA. In the remaining orbits, the CRA originated from a common trunk with the posterior ciliary and muscular branches (Fig. 3B). The CRA pierced the lower medial aspect of the ON a mean of 10 mm (range 7–15 mm) behind the globe and reached the globe through the center of the ON. In all orbits, the CRA was a terminal branch.

The number of posterior ciliary arteries ranged from two to five, and in all orbits two long posterior ciliary arteries (one medial and the other lateral) were found. The long and short posterior ciliary artery course with the short and long posterior ciliary nerves and extend into the sclera close to the ON to supply blood to the choroid.

The lacrimal artery typically courses with the lacrimal nerve superomedially to the lateral rectus to reach the lacrimal gland (Fig. 5A). The diameter of the lacrimal artery ranges from 0.3 to 0.6 mm (mean 0.5 mm). In the most common pattern of lacrimal gland vasculization (71% of orbits), the lacrimal artery arose as a separate branch from the main OphA trunk (Fig. 5A). In the remaining cases, the lacrimal artery arose from the MMA as a meningo-lacrimal artery (Fig. 5B). When a meningo-lacrimal artery was found in our specimens, we did not observe any anastomosis of this vessel with the main OphA system. The lacrimal artery typically has muscular, zygomatic, and glandular branches. Short ciliary arteries to the choroid can also originate from the lacrimal artery.

The anterior and posterior ethmoidal arteries supply blood to the ethmoid sinuses, the nasal cavity, and the septum. The anterior ethmoidal artery was detected in all orbits as an independent branch of the OphA and was usually larger than the posterior ethmoidal artery. The diameter of the anterior ethmoidal artery at its origin ranged from 0.3 to 1 mm (mean 0.6 mm). This artery courses medially and normally below the superior oblique muscle, and extends toward the anterior ethmoidal foramen. While crossing the anterior ethmoidal foramen, this artery provides small branches to the ethmoidal air cells. Intracranially, the artery courses between the two layers of the falx as the anterior falx artery (also termed the anterior falx artery or artery of falx cerebri), which provides variable branches to the dura of the anterior cranial fossa and anastomotic branches to the posterior ethmoidal artery.

The posterior ethmoidal artery is an inconstant branch of the OphA and was detected in 50% of our orbits. This artery typically arises as a defined branch from the OphA. Its diameter ranges from 0.3 to 0.8 mm (mean 0.4 mm). After its origin, the artery enters the posterior ethmoidal canal, passing over or under the superior oblique muscle. Intracranially, the posterior ethmoidal artery sends branches to the dura of the posterior and medial third of the anterior cranial fossa.

The supraorbital artery arises from the OphA in the second or third segment and exits the orbit through the supraorbital foramen or through a supraorbital notch. Anastomoses between the supraorbital artery and the vascular system of the superficial temporal artery are usually detected along the superior temporal line and form a potential source of collateral blood supply between the ECA and the ICA systems.

The supratrochlear (or frontal) and dorsal nasal (or nasal) arteries are the terminal branches of the OphA. The supratrochlear artery leaves the orbit from the medial portion of the supraorbital ridge, is directed frontally, and has rich anastomoses with the contralateral supratrochlear artery. The nasal artery pierces the orbital septum above the medial palpebral ligament, courses on the root of the nose in the opposite direction to the supratrochlear artery, and anastomoses with the ipsilateral angular artery, the terminal branch of the facial artery, and the contralateral nasal artery at the dorsum of the nose. A single anastomotic channel or a rich and tiny anastomotic network of small vessels can connect the angular artery with the supratrochlear artery (Fig. 6).

The recurrent branches of the OphA, one superficial and the other deep, usually course through the SOF and supply the cavernous sinus dura and the tentorium. The deep recurrent OphA arises from the initial intraorbital portion of the OphA, reaches the cavernous sinus coursing through the tendon of Zinn and the medial aspect of the SOF, and anastomoses with the inferolateral trunk of the intracavernous carotid artery. The superficial recurrent OphA can arise from OphA branches as well as directly from the intraorbital OphA or the MMA. This recurrent branch passes backward through the SOF or optic canal to reach the dura of the roof of the cavernous sinus and can continue caudally as the marginal tentorial artery.

Middle meningeal artery supply to the orbit. The MMA supply to the orbit presents two distinct patterns (Fig. 5). When the lacrimal artery originated from the OphA (in 10
sides of our sample; 71%), we found that the frontal branch of the MMA, while running medially to the sphenoid ridge, provided a recurrent meningeal branch (Fig. 5A). This branch courses in the narrow groove between the greater and lesser wings (Fig. 1B) of the middle cranial fossa, passes through the apex of the SOF, and anastomoses with the lacrimal artery (a branch of the OphA) (Fig. 5A). This branch originating from the MMA has been referred to as a recurrent meningeal branch, orbital branch, or sphenoidal artery of the MMA. Its size has ranged from 0.2 to 0.4 mm (mean 0.3 mm). The anastomosis between the recurrent meningeal artery and the lacrimal artery is located in the apex of the SOF. The recurrent meningeal artery usually provides small branches for the periorbita and for the dura, where the dura blends into the periorbita of the orbital apex.

In four sides (29%) of two specimens in our study, the frontal branch of the MMA provided a meningolacrimal branch, which coursed toward the Hyrtl canal to the lacrimal gland (Fig. 5B). The meningolacrimal artery at the end of the canal extends into the periorbita, accompanies the lacrimal nerve, and courses over the upper aspect of the lateral rectus to reach the lacrimal gland (Fig. 5B). In such cases, we found that the vascularization of the lacrimal gland is provided solely by the MMA through the meningolacrimal artery, without contributions from the OphA system. The meningolacrimal artery, with an average diameter of 0.4 mm (range 0.3–0.5 mm), is also involved in the vascularization of the extraocular muscles, especially the lateral rectus. In two sides of one specimen (14%), the frontal branch of the MMA bifurcated into a meningolacrimal artery and a smaller recurrent meningeal branch, which enters the orbit through the SOF. This smaller recurrent branch provided small muscular vessels and an inferior ramus for the OphA, and in one of the two sides anastomosed with the branches of the OphA.

**Discussion**

**Anatomical Variations of the OphA and Their Clinical Significance**

A thorough understanding of the microsurgical anatomy of the OphA, the appearance of its branches on angiograms, and its anastomoses with the ECA system are all necessary to perform safe and effective endovascular and other surgical procedures involving this critical vascular area. Several anatomical anomalies of the origin of the OphA have been reported. The OphA can originate extradurally from the clinoidal segment or the intracavernous portion of the ICA in 2 to 8% of cases. In such instances, the OphA—instead of entering the orbit through the optic canal—passes through the SOF or through an anomalous foramen in the optic strut termed the ophthalmic foramen or double op-
On rare occasions, a duplicate origin of the OphA from the ICA can be encountered. In these cases, the upper duplicate artery arises from the supraclinoid portion of the ICA and passes through the optic canal, whereas the lower duplicate artery arises from the ICA in its intra-cavernous portion and passes through the SOF. Kyoshima and colleagues reported two cases of an intradural origin of the OphA in a series of patients with juxta–dural ring aneurysms. During surgery for such an aneurysm, if the OphA is not observed intradurally, the surgeon should be reminded of the possible existence of this variation when sectioning the dural ring on the medial side.

The origin of the OphA from the MMA is a rare anomaly. Hayreh and Dass described two cases in 170 anatomical specimens in which the only source of blood supply to the orbit was the MMA. Watanabe and coworkers found only 21 reported cases of this anomaly in their review. An OphA origin from the MMA has important microsurgical and endovascular implications. Shima et al. reported one case in which blindness occurred after a pterional craniotomy due to coagulation of an OphA arising from the MMA, while the dura was elevated in this region. Once an origin of the OphA from the MMA is angiographically confirmed in lesions supplied by the MMA, an endovascular embolization procedure carries the risk of visual impairment due to embolic occlusion of the CRA (if the microcatheter is not positioned distally to the anomalous origin of the OphA, or if reflux of embolization material occurs during injection).

**Anatomical Significance of the Ophthalmic Artery During Neuroendovascular Procedures**

With continued advances in microcatheter and micro-guidewire technology, the OphA and its branches can be selectively catheterized and embolized to treat various vascular and neoplastic processes involving the orbit and/or the anterior skull base. Vascular supply from the OphA can be detected in intraorbital lesions such as meningiomas and arteriovenous malformations, as well as in extraorbital lesions such as meningiomas and ethmoidal dural arteriovenous fistulas. Use of superselective angiography and embolization have been reported in determining a diagnosis and treatment of the aforementioned pathologies and in the management of nonneurosurgical patients with lesions such as epistaxis, facial arteriovenous malformations, and CRA occlusion.

Several anatomical factors make endovascular approaches to lesions supplied by the OphA challenging and potentially hazardous because of the risk of visual impairment and blindness. The critical factor influencing the successful embolization of lesions fed by the OphA or its branches is the location of the CRA. In accordance with previous reports, our study data confirmed that the order in which the CRA arises from the OphA is related to whether the OphA crosses above or below the ON. When the OphA passes over the ON, the CRA was invariably the first branch of the OphA and the posterior ciliary artery was usually the second branch. This pattern was reversed when the OphA crossed under the ON. Embolization of pathological processes supplied by the OphA can be safely performed if the OphA can be superselectively catheterized past the “safety point.” This point occurs beyond the second segment of the OphA, after the origination of the CRA (which arises from the first or second segment of the OphA). The partial regression of the arterial ring, which develops around the ON during embryological development, indicates in the lateral angiographic projection the point at which embolization can be safely continued. When the CRA cannot be conclusively excluded from the region of embolization, a provocative amytal/lidocaine test can be helpful in localizing this critical vessel in relation to the catheter position.

**Internal and External Carotid Artery Collateral Pathways Through the OphA**

The ECA system forms a rich vascular network around the orbit that is able to provide collateral flow to intracranial circulation in the event of severe ICA stenosis or occlusion. The angular branch of the facial artery anastomoses with the nasal artery, a terminal branch of the OphA. The distal branches of the OphA (superior, frontal, inferior, and lateral palpebral arteries) may also anastomose with branches of the superficial temporal artery. The infraorbital and the...
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anterior deep temporal arteries, which are branches of the maxillary artery, provide branches to the inferior lacrimal territory, to supply an additional potential source of collateralization. Reversal of flow through these extracranial–intra-crani-anastomotic channels can provide enough collateral flow to the visual system after surgical or endovascular occlusion of the origin of the OphA. Due to these preexisting anastomotic channels, the risk of vision loss after acute occlusion of the OphA origin is relatively low (approximately 10%), with 90% of patients expected to remain asymptomatic. To test the adequacy of collateral supply to the retina, the use of temporary balloon occlusion of the OphA and the ICA with synchronous visual acuity measurement has been suggested.

Clinical Importance of Anastomoses Between the OphA and the MMA

Detailed knowledge of the anastomoses between the OphA and branches of the MMA is critical for avoiding disastrous complications (such as vision loss) during embolization of lesions fed by the MMA. Anastomoses between the recurrent branch of the MMA and the lacrimal artery at the apex of the SOF are commonly found in anatomical specimens. Hayreh and Dass described this anastomotic connection in nine of ten specimens. In our study, we found this anastomosis in all cases in which the lacrimal artery originated from the OphA (71% of sides). In 29% of sides, we found the blood supply to the lacrimal gland to originate solely from the frontal branch of the MMA. In such cases, an anastomosis between the MMA system and the OphA system through a recurrent meningeal branch was found in only 25% of cases. In all specimens, anastomosis between the recurrent branch of the MMA and the OphA system was observed in 78% of orbits. When a true meningolacrimal artery is detected (a branch of the MMA providing the vascularization of the lacrimal gland without contributions from the OphA system), the recurrent meningeal artery is usually smaller than in the other pattern of MMA supply to the orbit. In such cases, this anastomosis is very thin and can be poorly injected or disrupted during dissection, helping to explain the discrepancies between the results of previous studies and those reported here. Anastomotic connections between the MMA and the OphA represent a potentially dangerous source of complication during endovascular procedures. Mames et al. reported vision loss in a patient after embolization of the internal maxillary artery to control traumatic epistaxis. A cho- roidal blush was observed upon injection of 100 to 200 μm polyvinyl alcohol particles into the internal maxillary artery before embolization, and although the injection was made beyond the origin of the MMA, reflux caused particles to reach the OphA and the CRA through collateral pathways, and caused blindness. The anastomotic connections between the OphA and MMA in patients with occlusion of the ICA may allow for passage of retinal emboli in the presence of atheromatous and/or ECA disease. Amuaroisis fugax in patients with ICA occlusion and atheromatous disease of the ECA have been described and explained on the basis of these and other anastomatic connections. Permanent visual loss, retinal infarction, and ophtalmoparesis have also been reported after injection of dental anesthesia. The plausible explanation for these results is an intraarterial injection of the anesthetic solution into the maxillary artery with backflow into the MMA. The ocular symptoms result from the passage of the solution injected into the CRA through the recurrent meningeal branch of the lacrimal artery. Monocular blindness, reported to be as high as 1.8% of patients with meningiomas following preoperative embolization of MMA branches, can also be explained by the passage of particles through these anastomotic channels.

Conclusions

With recent advances in endovascular procedures, therapeutic embolization of vascular and neoplastic processes involving the area of the OphA are common. Detailed knowledge of the microsurgical anatomy of the OphA is critical to performing safe and effective endovascular procedures. In addition, the common presence of anastomotic connections between the OphA and the MMA can be a source of disabling complications during embolization of lesions supplied by the MMA. Knowledge of these anastomoses and their frequency, pattern, and variance is crucial to minimizing these problems.

References


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