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The arteries of the lacrimal gland

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Summary. The vascularization of 70 lacrimal glands was studied by orbital dissection subsequent to injection of the arterial bed with red-dyed latex. The origin, diameter and collateral branches of the lacrimal artery and its anatomical relations were investigated. Three types of lacrimal vascularization were seen. In the type I variety, the lacrimal artery originates from the ophthalmic artery and runs along the margin of the rectus lateralis muscle. In this case, the lacrimal artery is a major source of vascular supply to the muscle. In the type II variety, the lacrimal artery originates from the middle meningeal artery. In this case, the lacrimal artery is only a very modest source of vascular supply to the muscle. The type III variety features two lacrimal arteries vascularizing the lacrimal gland. One of the arteries originates from the ophthalmic, while the other arises from the middle meningeal. In this case, the lacrimal gland is the site of an intraorbital anastomosis between the internal and external carotid systems. The lacrimal gland is innervated by the lacrimal nerve and the lacrimal rami of the maxillary nerve. Preliminary results regarding certain morphological features of the lacrimal nerve are reported in this paper.

Les artères de la glande lacrymale

Résumé. La vascularisation artérielle de 70 glandes lacrymales a été étudiée par dissection orbitaire, après injection du lit artériel par du latex coloré en rouge. L'origine, le calibre, les branches collatérales de l'artère lacrymale ainsi que ses rapports ont été notés. Les auteurs décrivent 3 types de vascularisation : Type I : l'artère lacrymale nait de l'artère ophtalmique, longe le bord supérieur du muscle droit latéral, dont elle assure en grande partie la vascularisation; Type II : l'artère lacrymale provient de l'artère méningée moyenne. Dans ce cas, elle ne participe que très modérément à la vascularisation musculaire. Type III : deux artères lacrymales assurent simultanément l'apport artériel glandulaire; l'une nait de l'artère ophtalmique et l'autre de l'artère méningée moyenne. La glande est alors le siège d'une anastomose intra-orbitaire entre les deux systèmes carotidiens interne et externe. L'innervation lacrymale est assurée par le nerf lacrymal et par des rameaux lacrymaux issus du nerf maxillaire. Quelques aspects morphologiques du nerf lacrymal sont rapportés, à titre préliminaire.

Key words : Lacrimal gland – Arteries

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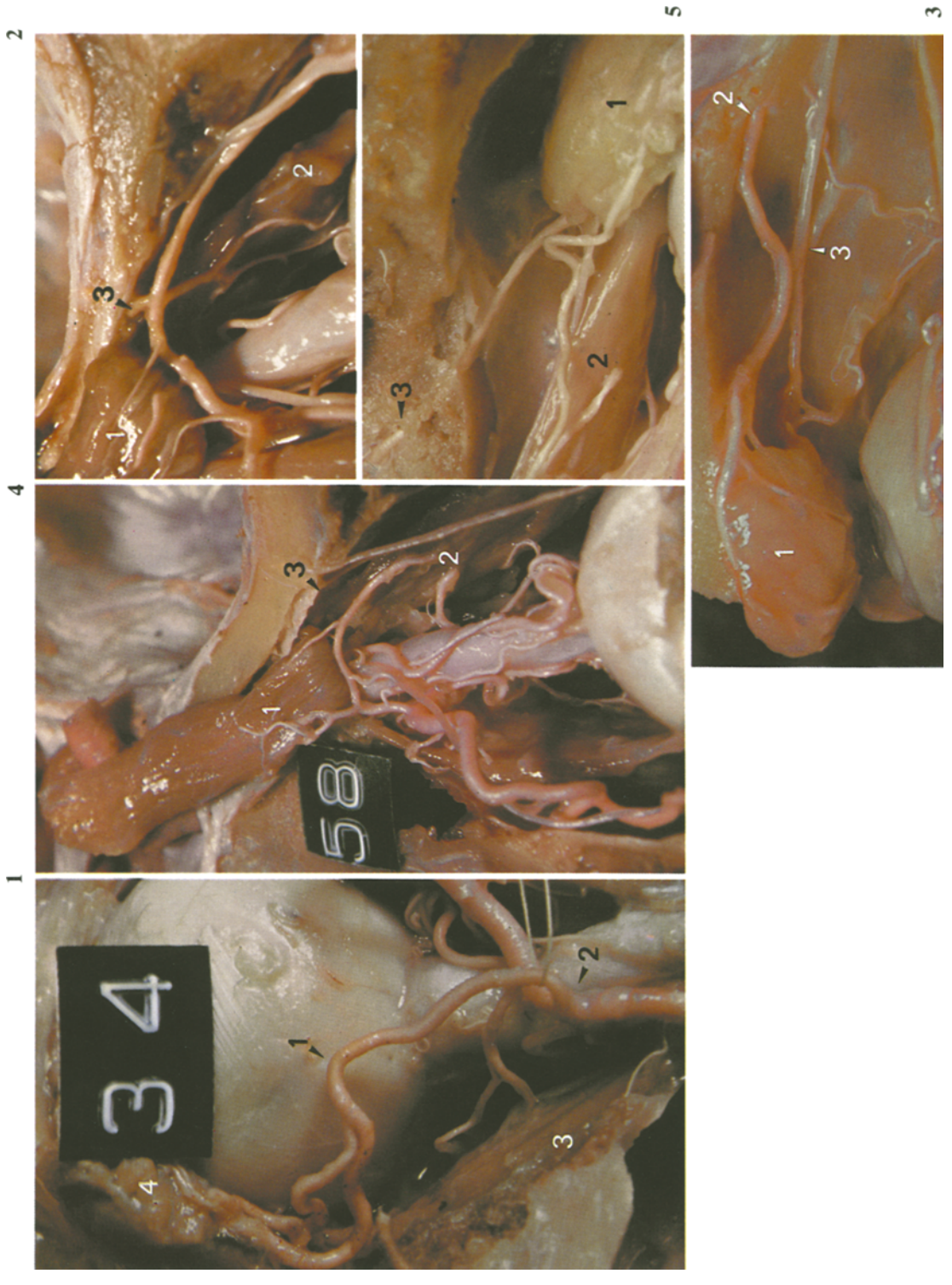
The lacrimal gland is part of the orbital structures and, according to classical descriptions, receives its vascular supply from a collateral branch of the ophthalmic artery, i.e. the lacrimal artery. The gland is innervated by the lacrimal nerve, a branch of the ophthalmic nerve, and by the so-called secretory rami of the maxillary nerve.

In a previous study of the lacrimal artery [5], our attention was drawn to the existence of possible anatomical variations of the glandular vascularization. The lacrimal artery usually originates from the ophthalmic artery, but in some cases may arise from the middle meningeal artery.

Accordingly, we propose to classify the arterial vascularization of the lacrimal gland into three main types. In the type I variety, which is the most frequent, the lacrimal artery is a branch of the ophthalmic. In this case, the lacrimal artery is the sole source of vascular supply to the lacrimal gland. In type II, the lacrimal artery originates from the middle meningeal artery and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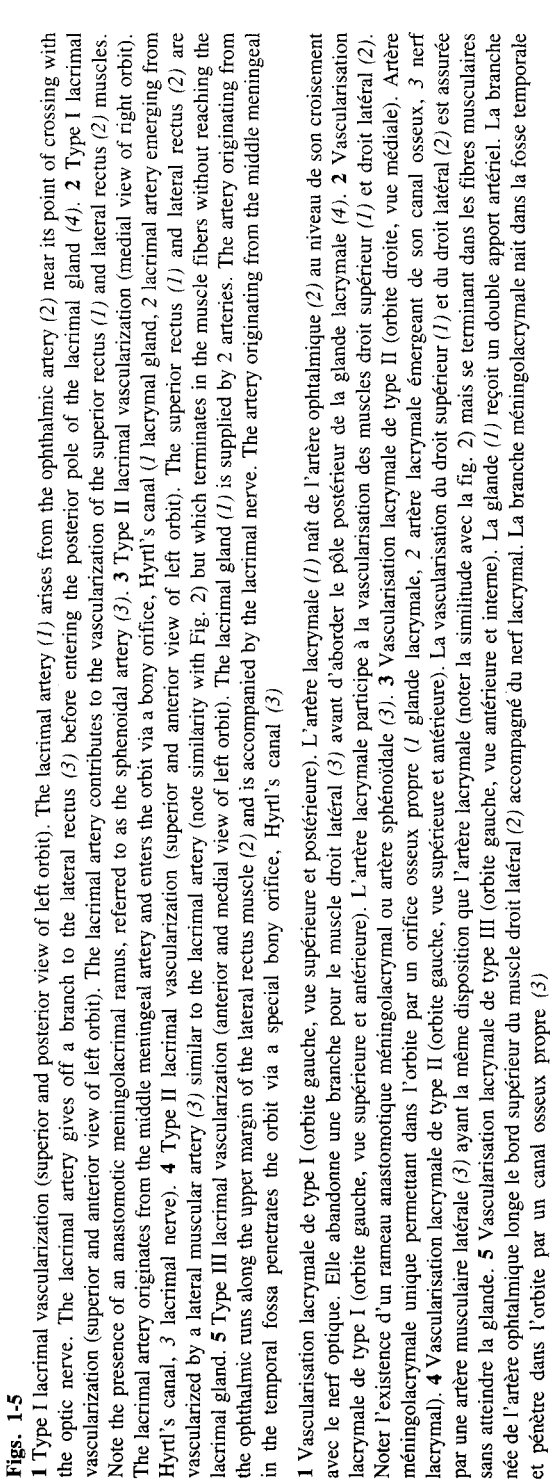

Figs. 1-5
1 Type I lacrimal vascularization (superior and posterior view of left orbit). The lacrimal artery *(1)* arises from the ophthalmic artery *(2)* near its point of crossing with the optic nerve. The lacrimal artery gives off a branch to the lateral rectus *(3)* before entering the posterior pole of the lacrimal gland *(4)*. **2** Type I lacrimal vascularization (superior and anterior view of left orbit). The lacrimal artery contributes to the vascularization of the superior rectus *(1)* and lateral rectus *(2)* muscles. Note the presence of an anastomotic meningolacrimal ramus, referred to as the sphenoidal artery *(3)*. **3** Type II lacrimal vascularization (medial view of right orbit). The lacrimal artery originates from the middle meningeal artery and enters the orbit via a bony orifice, Hyrtl's canal (*1* lacrymal gland, *2* lacrimal artery emerging from Hyrtl's canal, *3* lacrimal nerve). **4** Type II lacrimal vascularization (superior and anterior view of left orbit). The superior rectus *(1)* and lateral rectus *(2)* are vascularized by a lateral muscular artery *(3)* similar to the lacrimal artery (note similarity with Fig. 2) but which terminates in the muscle fibers without reaching the lacrimal gland. **5** Type III lacrimal vascularization (anterior and medial view of left orbit). The lacrimal gland *(1)* is supplied by 2 arteries. The artery originating from the ophthalmic runs along the upper margin of the lateral rectus muscle *(2)* and is accompanied by the lacrimal nerve. The artery originating from the middle meningeal in the temporal fossa penetrates the orbit via a special bony orifice, Hyrtl's canal *(3)*

1 Vascularisation lacrymale de type I (orbite gauche, vue supérieure et postérieure). L'artère lacrymale *(1)* naît de l'artère ophtalmique *(2)* au niveau de son croisement avec le nerf optique. Elle abandonne une branche pour le muscle droit latéral *(3)* avant d'aborder le pôle postérieur de la glande lacrymale *(4)*. **2** Vascularisation lacrymale de type I (orbite gauche, vue supérieure et antérieure). L'artère lacrymale participe à la vascularisation des muscles droit supérieur *(1)* et droit latéral *(2)*. Noter l'existence d'un rameau anastomotique méningolacrymal ou artère sphénoïdale *(3)*. **3** Vascularisation lacrymale de type II (orbite droite, vue médiale). Artère méningolacrymale unique permettant dans l'orbite par un orifice osseux propre (*1* glande lacrymale, *2* artère lacrymale émergeant de son canal osseux, *3* nerf lacrymal). **4** Vascularisation lacrymale de type II (orbite gauche, vue supérieure et antérieure). La vascularisation du droit supérieur *(1)* et du droit latéral *(2)* est assurée par une artère musculaire latérale *(3)* ayant la même disposition que l'artère lacrymale (noter la similitude avec la fig. 2) mais se terminant dans les fibres musculaires sans atteindre la glande. **5** Vascularisation lacrymale de type III (orbite gauche, vue antérieure et interne). La glande *(1)* reçoit un double apport artériel. La branche née de l'artère ophtalmique longe le bord supérieur du muscle droit latéral *(2)* accompagné du nerf lacrymal. La branche méningolacrymale naît dans la fosse temporale et pénètre dans l'orbite par un canal osseux propre *(3)*

enters the orbital cavity via an orifice in its lateral wall referred to as Hyrtl's canal. In the type III variety, the gland is simultaneously supplied by 2 arteries, one originating from the ophthalmic, the other from the middle meningeal. In this case, the lacrimal gland is the site of an anastomosis between the internal and external carotid systems.

An external carotid origin of the lacrimal artery has been known for quite some time and can be explained on the basis of embryological findings.

The aim of this study was to identify the relative incidence of these three main types of lacrimal vascularization and to look for a possible relationship between the presence of lacrimal branches of the external carotid artery and the overall vascularization of the orbital structures.

Historical data

The arterial vascularization of the orbital region has been the object of many studies. As early as 1755, Zinn [16] made reference to the lacrimal artery in his work entitled "descriptio anatomica oculi". The first report of the lacrimal artery originating from the middle meningeal artery dates back to the work of Haller [7] in 1781, who described 4 such cases. The middle meningeal origin of the lacrimal artery has since then been reported in many treatises, among which are those of J Cloquet [3] in 1822, Blandin [1] in 1826 and Velpeau [15] in 1833.

More recently published studies gave fuller descriptions of the lacrimal artery. Special emphasis should be given to the work of Henry [10] in 1959, who investigated 15 orbits injected with latex, and especially to the studies or Hayreh [8, 9] in 1961 and 1962. In his review of the cases published in the literature, this author also referred to the lacrimal artery originating from the deep anterior temporal artery (Arnold and Merkel in Hayreh [8]). In Hayreh's personal series of 59 orbits (including 15 cases where the ophthalmic artery crossed under the optic nerve) the lacrimal artery did not arise from the ophthalmic artery in 11 cases. According to Hayreh, such "absence" of the lacrimal artery is far more frequent in cases where the ophthalmic artery crosses over the optic nerve (10 cases reported by the author) than when it crosses under the nerve (1 case reported by the author).

The significance of vascular anastomoses between the internal and external carotid systems was clearly underlined in 1980 by Lasjaunias [11, 12].

Embryology

The description given below is derived from the work of Padget [14] who described an evolutive pattern of

embryological development of the orbital and cephalic arterial system.

In the 4-5 mm embryo, the ocular vesicle is vascularized by the primitive dorsal ophthalmic artery, a branch of the internal carotid artery. The latter originates from the third aortic arch. At the 7-12 mm stage, the primitive ventral ophthalmic artery appears. This artery arises from the cranial branch (future anterior cerebral artery) of the internal carotid artery. At a later stage, the primitive ventral ophthalmic artery becomes anastomosed to the supracavernous part of the internal carotid artery.

In the 12-14 mm embryo, the dorsal ophthalmic artery has given rise to the hyaloid artery which enters the optic cup via the embryonic choroid fissure. The part of the dorsal ophthalmic artery lying distal to the origin of the hyaloid artery becomes the common ciliary temporal artery.

In the 16-18 mm embryo, the two primitive ophthalmic arteries are anastomosed to each other beneath the optic nerve. The anastomosis is formed by the ventral ophthalmic artery which incorporates the distal part of the dorsal ophthalmic artery. The distal part of the ventral ophthalmic artery becomes the common ciliary nasal artery. The proximal part of the primitive dorsal ophthalmic artery apparently disappears.

In the 18 mm embryo the vascularization of the ocular structures is formed by 3 branches of the internal carotid artery. These branches are : a) the common ciliary temporal artery which becomes the lateral long posterior ciliary artery; b) the hyaloid artery, which becomes the central artery of the retina; c) the common ciliary nasal artery, which becomes the medial long posterior ciliary artery.

A the stage of the 20 mm embryo, the orbit is penetrated by an additional vessel, the stapedial artery. This artery, derived from the 2nd aortic arch [4, 6], divides into two branches, i.e. maxillo-mandibular and supraorbital. In the orbit, the supraorbital artery divides into 2 branches. One of these is the medial nasociliary artery which runs along the course of the ciliary nasal artery and anastomoses with the ophthalmic arterial axis. The medial nasociliary artery later forms the third portion of the ophthalmic artery which gives rise to the supraorbital, frontal and ethmoidal arteries. The supraorbital artery also gives off a second lateral branch in the orbit from which originates the lacrimal artery.

The anastomosis between the ophthalmic artery and supraorbital branch of the stapedial artery is fully achieved around the 45th day of embryonic life. The middle segment of the supraorbital branch lying in the superior orbital fissure regresses. In this way, the proximal part of the supraorbital artery becomes the middle meningeal artery while its distal segment develops into the lacrimal artery and the third segment of the ophthalmic artery [13].

Certain anatomical variations can be accounted for on the basis of the above-described evolutionary pattern. Indeed, the ophthalmic artery may originate from the middle meningeal artery (we have never encountered this variation). Similarly, although the supraorbital artery divides into medial and lateral branches at an extraorbital site, the lacrimal artery can originate from the middle meningeal artery and then penetrate the orbit through Hyrtl's canal, an orifice located of the lateral bony wall of the orbit. Finally, partial persistence of the middle segment of the supraorbital artery leads to the formation of an anastomosis between the lacrimal and middle meningeal arteries which is referred to by many authors as the sphenoidal artery [2].

Conversely, the above described evolutionary pattern does not offer an explanation for the existence of two lacrimal arteries of different origin.

Material and methods

This study was carried out on 70 human orbits in which the arterial system was injected with red-dyed latex neoprene 601A. Subsequent to thorough lavage of the arterial system, both common carotid arteries were injected under pressure to opacify the internal and external carotid systems.

Subsequent to opening of the cranium and collapsing of the orbital roof, dissection was done layer by layer. In the course of dissection of each orbit the arteries encountered were noted, as well as their origin, diameter, course, branches and anatomical relations.

Results

The lacrimal artery is a constant intraorbital branch. At least one lacrimal artery was found in each orbit. In the 70 orbits studied, 58 lacrimal arteries were seen originating from the ophthalmic artery, 19 from the middle meningeal artery and 1 from the anterior deep temporal artery.

Classical origin of the lacrimal artery

In 58 orbits (32,6% of cases) the lacrimal artery originated from its classical site, the ophthalmic artery. In most of the orbits (44 cases), the artery arose from the 2nd segment of the ophthalmic, either from its superior surface (25 cases), lateral surface (16 cases) or anterior surface (3 cases). An origin on the proximal part of the ophthalmic (on its lateral surface) was less common (9 cases), as was that on the superior surface of the distal segment (5 cases).

The position of the origin of the lacrimal artery with respect to the optic nerve can be accounted for by the above-described variations. Indeed, the origin of the lacrimal artery was seen lateral to the nerve (25 cases), above or above and lateral to the nerve (27 cases) and more rarely medial to the nerve (5 cases) or below the

nerve (1 case). In 2 cases the lacrimal artery crossed upwards over the lateral surface of the nerve.

The lacrimal artery often showed a large diameter at its origin. This diameter was 0.9 to 1.5 mm in 35 cases, less than 0.8 mm in 14 cases and greater than 1.5 mm in 3 cases. *These findings demonstrate that the lacrimal artery (along with the inferior muscular branch) is the largest collateral branch of the ophthalmic artery.*

The intraorbital segment of the lacrimal artery may or may not display a large loop lateral to the optic nerve. Accordingly, two types of lacrimal artery were identified : 1) an artery presenting a loop (38 cases) which was either vertical with anterior concavity (26 cases) or horizontal (12 cases) with anterior or medial concavity. This loop was seen to bring the lacrimal artery close to the superior orbital fissure : 2) an artery not presenting a loop. In this case the lacrimal artery was seen to run forwards, upwards and laterally. Such arteries were practically rectilinear from their origin up to the lacrimal gland. These two types of lacrimal artery seemingly corresponded to the presence or absence of an anastomotic ramus between the lacrimal and middle meningeal arteries, referred to as the sphenoidal artery. In cases where the lacrimal artery formed a pronounced loop, this anastomotic ramus was usually present (33/38 cases). Conversely, the anastomotic ramus was consistently lacking in cases where the lacrimal artery was rectilinear. These findings suggest that the presence of the anastomosis influences the course of the lacrimal artery. Furthermore, the anastomotic ramus was seen to join the apex of the loop-shaped lacrimal artery.

Certain authors have suggested that the so-called sphenoidal artery is a constant finding. However, in our material is was present in only 38 orbits (54.3% of cases), forming an anastomosis between the middle meningeal artery and lacrimal artery (33 cases), artery of the lateral rectus (4 cases) or artery of the medial rectus muscle (1 case). The diameter of the sphenoidal artery was between 0.3 and 0.5 mm in 19 cases, less than 0.2 mm in 11 cases and greater than 0.5 mm but less than or equal to 1 mm in 8 cases.

In both of the above-described types, the lacrimal artery was seen to run forwards along the lateral orbital wall in a position superior to the lateral rectus to finally reach the lacrimal gland.

The "classical" lacrimal artery was often seen to contribute significantly to the vascularization of the muscle, giving off at least 1 branch to the lateral rectus in 56 orbits (96,5% of cases), to the superior rectus in 53 orbits (91.4% of cases) and to the levator palpebrae superioris in 30 orbits (51.7% of cases). These branches distributed to the medial surface (posterior and middle third) and upper margin of the lateral rectus, and to the inferior surface (posterior third) of the superior rectus. Distribution to the levator palpebrae superioris was usually via a postglandular branch terminating on the anterior and lateral third of the upper surface of the muscle.

Vascularization of the lacrimal gland was via a single arterial branch in 33 cases and via 2 branches, which split off from each other 5 to 15 mm posterior to the gland, in 25 cases. These branches were seen to approach and then divide on the ocular surface or superomedial margin of the gland.

The lacrimal artery was often found to be the 2nd or 3rd large collateral branch of the ophthalmic artery, and less often the 1st or 4th collateral branch (Fig. 6).

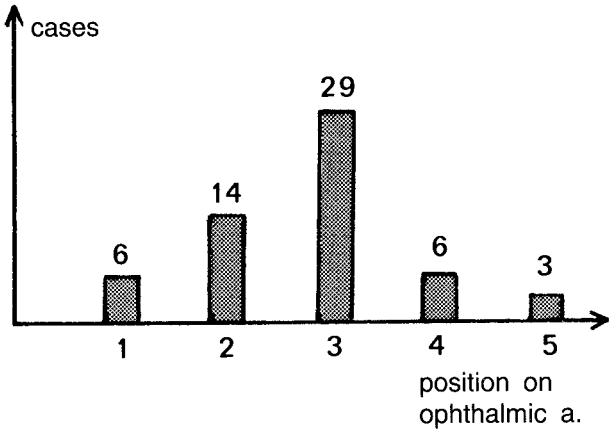

Fig. 6
Position of the lacrimal artery on the ophthalmic artery. Most of the time, the lacrimal artery is the 3rd branch of the ophthalmic artery

Position de l'artère lacrymale sur l'artère ophtalmique. L'artère lacrymale est, le plus souvent, la 3e branche de l'artère ophtalmique

Lacrimal arteries originating from the external carotid system

In these cases the lacrimal artery most often originated from the middle meningeal artery (19 cases) and vascularized the lacrimal gland either alone (11 cases) or in addition to a typical lacrimal artery (8 cases).

In one case the lacrimal gland was vascularized by a single vessel originating from the anterior deep temporal artery.

The lacrimal artery of external carotid origin showed different features compared to the typical variety. Indeed, the former was seen to enter the orbit in a far more anterior position and in many cases via a special bony orifice in the lateral wall of the orbit, i.e. Hyrtl's canal. Furthermore, the caliber of the lacrimal artery of external carotid origin was often smaller, ranging in diameter from 0.9 to 1.5 mm in only 7 cases, and was less thant 0.9 mm in 13 cases.

Vascularization of the muscle was far less marked than in the typical variety of lacrimal artery. In our

series, the lacrimal artery originating from the external carotid system vascularized the lateral rectus in only 4 cases, the superior rectus in 2 cases and the levator palpebrae superioris in 5 cases. In cases where no lacrimal artery originating from the ophthalmic was seen, the lateral rectus often received its arterial supply from a lateral muscular artery displaying the same origin, course and relations as the typical lacrimal artery but terminating in the muscle and not the lacrimal gland.

Since the "meningo-lacrimal" artery entered the orbit in a more anterior position compared to the classical variety, it displayed a much shorter course. Furthermore, it entered the gland at a low site on the posterior pole or at the superomedial surface of the gland. In some cases the artery divided before entering the lacrimal gland. In 10 cases a single artery entered the gland, while in 10 others 2 branches were seen to penetrate the gland.

Relations to the lacrimal nerve

In contrast to the lacrimal artery, the anatomy of the lacrimal nerve was relatively constant. The nerve was seen as a rectilinear structure spanning from the superior orbital fissure to the ocular surface of the lacrimal gland.

The relations with the lacrimal arterial axis were dependent upon the type of lacrimal artery found. In cases where the "classical" variety of lacrimal artery was present the nerve was seen in a superolateral position with respect to the origin of the artery. The nerve then crossed over the artery in a downward and medial direction to finally come to lie on the medial surface to the artery, after which it accompanied the vessel to the gland. Conversely, in cases where a meningolacrimal artery was seen the nerve was found to lie on the medial surface of the artery and did not cross over it.

Discussion

One of the aims of this study was to determine whether a special type of orbital circulation is associated with the presence of a lacrimal artery originating from the external carotid system. In our series, the ophthalmic artery crossed beneath the optic nerve in 16 of 10 orbits (22.8%). A single, meningolacrimal artery was seen in 12 cases (17.1%), while vascularization of the lacrimal gland via both types of lacrimal artery was found in 8 cases (11.4%). Finally, a lateral muscular artery was observed in 18 cases (25.7%). It was thus of interest to determine whether these different findings bear some type of interrelationship. In 8 of cases where vascularization was via a single meningolacrimal artery, the ophthalmic artery was seen to cross beneath the optic nerve. This anatomical pattern was thus found in two-thirds of the cases where a single meningolacrimal artery was seen. As a corollary to this finding, in 50% of the cases where the ophthalmic artery crossed under the optic nerve, a meningolacrimal artery was observed. Consequently, the presence of a single meningolacrimal artery is apparently far more frequent when this undercrossing pattern is seen.

The presence of 2 lacrimal arteries was accompanied by this undercrossing pattern in only two of 8 cases, i.e. twin lacrimal vascularization was seen in one eighth of the cases where the ophthalmic artery crossed under the optic nerve.

In 10 of the 20 cases where the lacrimal artery originated from the external carotid system, the ophthalmic artery crossed beneath the optic nerve, i.e. one half of the meningolacrimal arteries were accompanied by the undercrossing pattern and in more than 50% of the cases of undercrossing (10/16 cases) a meningolacrimal artery was found.

Finally, the existence of an artery to the lateral rectus (18 cases) was apparently more frequent when an undercrossing pattern (8 cases) and especially, a single meningolacrimal artery (10/12 cases) were seen.

In summary, the presence of an undercrossing pattern of the ophthalmic artery with respect to the optic nerve is apparently associated with a high incidence of the meningolacrimal artery and, when the latter is the sole source of vascularization of the lacrimal gland, it is very often accompanied by a branch to the lateral rectus muscle.

Conclusion

The vascularization of the lacrimal gland can be divided into three types. In the type I pattern, seen in 50 of our cases (71.4%), the lacrimal artery is a large collateral branch of the ophthalmic artery, usually originating from the second segment of the latter at a point where it crosses with the optic nerve. This type of lacrimal artery often displays a large diamater (0.8-1.5 mm) and may or may not receive an anastomotic ramus originating from the middle meningeal artery. The type I lacrimal artery originates above and lateral to the optic nerve and runs along the lateral rectus muscle to finally enter the gland as single or twin vessels. In its course, the lacrimal artery is crossed over by the optic nerve which comes to lie on the medial surface of the artery. The type I lacrimal artery contributes significantly to the vascularization of the lateral rectus, superior rectus and levator palpebrae superioris muscles.

In the type II vascular pattern seen in 12/70 cases (17.1%), the lacrimal artery originates from the middle meningeal artery or from another branch of the external carotid system (anterior deep temporal artery). In this case, the lacrimal artery enters the orbit in a far more

anterior position via a special orifice in the lateral bony orbital wall, i.e. Hyrtl's canal. Compared to the type I pattern, the type II lacrimal artery often shows a smaller diameter (0.8 mm) and contributes much less to the muscular vascularization. The type II pattern is more frequently seen in cases where the ophthalmic artery crosses under, rather than over, the optic nerve and is often associated with the presence of a branch vascularizing the lateral rectus muscle.

In the type III pattern, two lacrimal arteries supply the lacrimal gland. In this case one of the lacrimal arteries originates from the ophthalmic while the other arises from the middle meningeal as seen in 8 (11.4 %) of our cases. These twin vessels form an intra-orbital anastomosis between the internal and external carotid systems. The type III pattern is difficult to account for on the basis of the embryological development presented in this paper.

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