

## THE OPHTHALMIC ARTERY\*

### III. BRANCHES

BY

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THE pioneer worker in the study of the ophthalmic artery, particularly its branches and their variations, was Meyer (1887), whose observations on twenty cases have been accepted more or less as classical for the last three-quarters of a century. No detailed investigation has since been carried out in this field and the descriptions of the branches of this artery which appear in the various text-books of anatomy and ophthalmology merely reflect his conclusions. Moreover, little information regarding the branches and their anomalies is available in the literature. It was therefore thought desirable to study this problem afresh in detail.

#### Material

This study was carried out on 59 human orbits obtained from 36 cadavers from the dissection room. In 23 cadavers both orbits were examined, and only one side in the remaining thirteen. All the cadavers were those of persons past middle age, except three which were of children aged 4, 11, and 12 years.

#### Method

Neoprene latex was injected *in situ*, either through the internal carotid artery or through the most proximal part of the ophthalmic artery, after opening the skull and removing the brain. The artery was first irrigated with water. After the injection, the part was covered with cotton wool soaked in 10 per cent. formalin for from 24 to 48 hours to coagulate the latex. The roof of the orbit was then opened and the ophthalmic artery and its branches were carefully studied with a low-power stereoscopic binocular dissection microscope.

In the present paper the pattern of each of the various branches is described separately, depending on whether the ophthalmic artery crosses *over* or *under* the optic nerve in the second part of its course (Hayreh and Dass, 1962b); the two arrangements lead to obvious differences, each with its own characteristics.

#### Observations and Discussion

The branches of the ophthalmic artery may be classified conveniently in three ways (Whitnall, 1932):

(A) According to the order of origin of the branches.

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- (B) Topographically into ocular, orbital, and extra-orbital groups, supplying the eyeball, orbital structures, and extra-orbital structures respectively.
- (C) According to the relationship of the site of origin from the ophthalmic artery with the optic nerve.

(A) **Order of Origin.**—This was described as very variable by Meyer (1887), Quain (1892), Whitnall (1932), Duke-Elder (1932), Sudakevitch (1947), Wolff (1954), and Hollinshead (1954). Certain authors have described the so-called “normal” pattern (Table I), but the present series shows a marked diversity in the order of origin of the various branches and consequently a so-called “normal” pattern is a misnomer, a fact pointed out by Meyer (1887) and also by Sudakevitch (1947). A “usual” pattern, which is seen more frequently than others, is all that can be accepted.

TABLE I  
ORDER OF ORIGIN OF BRANCHES OF OPHTHALMIC ARTERY  
(VARIOUS AUTHORS)

Author	Meyer	Whitnall	Quain	Brash	Wolff	Bedrossian	Duke-Elder	Johnston and Others	Wood Jones	Hollinshead	Schaeffer
Date	1887	1932	1892	1951	1954	1958	1932	1958	1949	1954	1953
Order of Branches	1	CAR + MPCA	CAR + MPCA	CAR			CAR		MPCA	MPCA	CAR
	2	LPCA	LPCA	Posterior ciliary			Lacrimal		CAR	MPCA + CAR	Lacrimal
	3	Lacrimal	Lacrimal	Lacrimal			Muscular		LPCA	Lacrimal	Posterior ciliary
	4	Supero-lateral muscular	Recurrent branches	Recurrent branches			Posterior ciliary		Lacrimal	LPCA	Muscular
	5	Supra-orbital + posterior ethmoid	Muscular	Muscular			Supra-orbital		Muscular	Supra-orbital	Supra-orbital
	6	Infero-medial muscular	Supra-orbital	Supra-orbital			Posterior ethmoid		Supra-orbital	Posterior ethmoid	Posterior ethmoid
	7	Anterior ethmoid	Posterior ethmoid	Posterior ethmoid			Anterior ethmoid		Posterior ethmoid	Anterior ethmoid	Anterior ethmoid
	8	—	Anterior ethmoid	Anterior ethmoid			Anterior meningeal		Anterior ethmoid	Medial palpebral	Medial palpebral
	9	—	Superior and inferior medial palpebral	Superior and inferior medial palpebral			Medial palpebral		—	—	—
	Terminal	Medial palpebral Frontal Dorsal nasal	Frontal Nasal	Frontal Nasal			Frontal Dorsal nasal		Two medial palpebrals Supra-trochlear Dorsal nasal	Frontal Dorsal nasal	Frontal Dorsal nasal

CAR = Central retinal  
LPCA = Lateral posterior ciliary  
MPCA = Medial posterior ciliary

Only Meyer (1887) gave a detailed description of the many variations in the order of origin. According to him, the origins of the central retinal and the posterior ciliary arteries, because of their intimate association in supplying

the eyeball, are closely related. He found the central retinal and the medial posterior ciliary as the first branch, the lateral posterior ciliary as the second, and the lacrimal as the third. In his twenty specimens, the lacrimal arose after the medial posterior ciliary in thirteen (in ten of which the medial posterior ciliary arose in common with the central retinal) and before the medial posterior ciliary in seven. The ratio with the lateral posterior ciliary was fourteen after and six before. He further noticed that the origin of the posterior ethmoid was very variable. Sudakevitch (1947) found the order of origin of first three branches to be similar to that described by Meyer (1887), and added that the lacrimal arose at the angle.

The order of origin of the branches when the ophthalmic artery crosses *under* the optic nerve has been described by Sudakevitch (1947), who found the medial posterior ciliary arising from the second part of the ophthalmic and after the lacrimal. Meyer (1887) is the only other author who mentioned finding three cases showing this arrangement, and no definite pattern could be made out from them. However, the lateral posterior ciliary was the first branch in two out of his three cases, and was then followed by the central retinal.

The findings in the present series help to elucidate certain points. There is such a marked degree of variation in the order of origin that no two specimens, not even from the same person, showed identical patterns. Certain broad generalizations could, however, be made. Whether the ophthalmic artery crossed *over* or *under* the optic nerve in the second part of its course made an evident difference in the order of its branches. This difference was effective as far as the origin of the anterior ethmoid, beyond which point the pattern was more or less similar. This observation has not been made by previous workers. It is therefore essential to discuss the order of branching separately under these two headings.

(1) *The Ophthalmic Artery crossed Under the Optic Nerve* (Fig. 1, opposite).—The first branch was invariably the lateral posterior ciliary arising usually alone or rarely with some other branch. The second branch was the central retinal, usually independent but sometimes with the medial posterior ciliary or others. The next was usually the medial muscular, and then the medial posterior ciliary, but these two sometimes arose in reverse order or both at once. The lacrimal usually arose next and this was sometimes followed or accompanied by a muscular branch to the superior rectus and/or the levator palpebrae superioris. Next to emerge were the posterior ethmoid and the supra-orbital, arising jointly or separately. The muscular branch to the superior oblique and/or the medial rectus arose next, either jointly or independently. The anterior ethmoid usually followed this, and was followed in turn by an areolar branch, though the latter branch sometimes preceded the former.

(2) *The Ophthalmic Artery Crossed Over the Optic Nerve* (Fig. 2).—The order of the first two branches was reversed; the first was invariably the central retinal, usually arising with the medial posterior ciliary and less frequently with other branches or independently. The second was the lateral posterior ciliary, usually arising independently and less frequently with other branches. The next was usually the lacrimal.

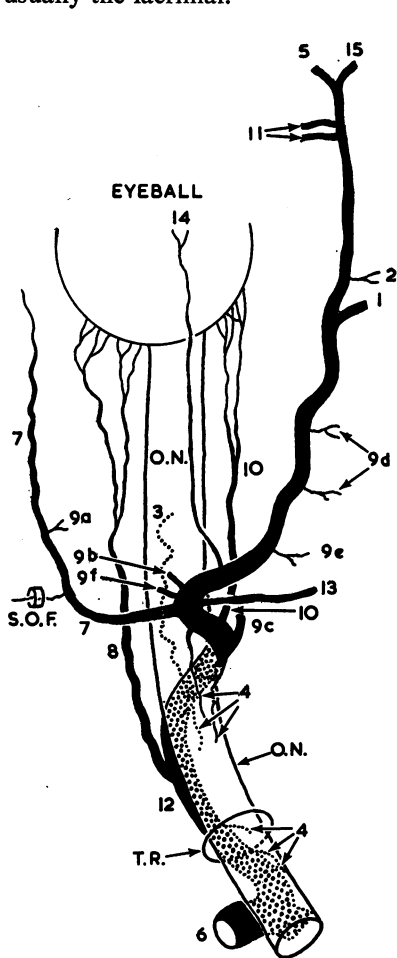


FIG. 1.—The pattern of the branches of the ophthalmic artery when it crosses *under* the optic nerve.

1. Anterior ethmoid artery.
2. Areolar branch.
3. Central retinal artery.
4. Collateral branch.
5. Dorsal nasal artery.
6. Internal carotid artery.
7. Lacrimal artery.
8. Lateral posterior ciliary artery.
9. Muscular artery:
  - (a) To lateral rectus.
  - (b) To levator palpebrae superioris.
  - (c) Medial muscular.
  - (d) To medial rectus.
  - (e) To superior oblique.
  - (f) To superior rectus.

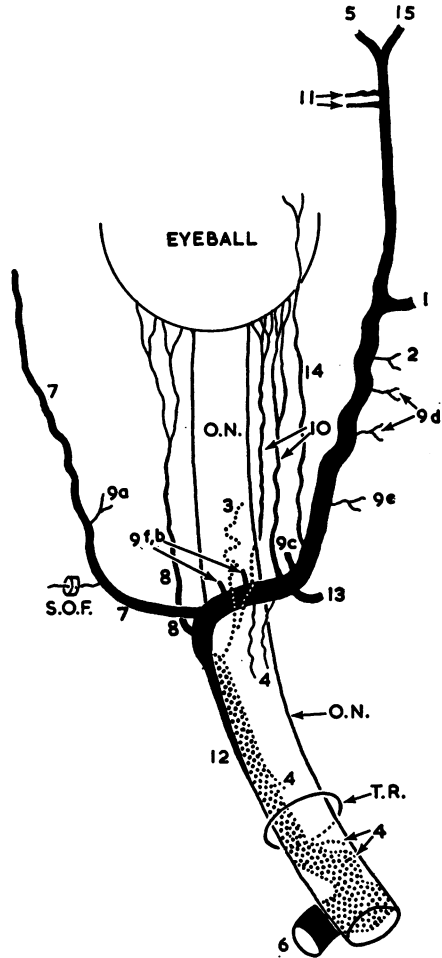


FIG. 2.—The pattern of the branches of the ophthalmic artery when it crosses *over* the optic nerve.

10. Medial posterior ciliary artery.
  11. Medial palpebral artery.
  12. Ophthalmic artery.
  13. Posterior ethmoid artery.
  14. Supra-orbital artery.
  15. Supra-trochlear artery.
- O.N. Optic nerve.  
 S.O.F. Superior orbital fissure.  
 T.R. Tendinous ring.

The pattern of these three branches is nearly similar to that described by Meyer (1887) and Sudakevitch (1947). The branches which arose after the lacrimal were invariably the muscular, those to the levator and/or superior rectus first, then the medial muscular, and then branches to the superior oblique and medial rectus (to either one or both, jointly or independently). Among these muscular arteries were distributed the medial posterior ciliary, the posterior ethmoid, and the supra-orbital. The medial posterior ciliary usually preceded the medial muscular. The arrangement of the posterior ethmoid and supra-orbital was very variable, these vessels being distributed among the muscular arteries differently in different cases. The posterior ethmoid sometimes preceded the muscular arteries, and the supra-orbital usually followed them. The two sometimes arose together; when they arose separately, the posterior ethmoid usually preceded the supra-orbital. All these branches beyond the lacrimal were usually located close together, which helps to explain all these variations. The next branch to arise was the anterior ethmoid, which was preceded or followed by a branch to the areolar tissue.

(3) *The Ophthalmic Artery crossed both Over and Under the Optic Nerve.*—After the anterior ethmoid the next branch was the medial palpebral; if the medial palpebral arose in two branches as the inferior and superior medial palpebrals, then the inferior came first. Last of all were the terminal branches, usually the dorsal-nasal and the supra-trochlear.

All kinds of variations were seen in the patterns described above, though these were less numerous when the ophthalmic artery crossed *under* the optic nerve. The variations are so marked that it is wrong to look for the so-called “normal” pattern, but it is possible to speak of a “usual” pattern, which is more frequent than many of the others (Table II, opposite).

*First Branch of Ophthalmic Artery.*—This is variably described by different workers, as is evident from Table III (overleaf). Most authors mention the central retinal, arising independently or in common with the medial posterior ciliary as the most frequent first branch. Small collateral branches to the optic nerve were not taken into consideration in assessing the first branch by Meyer (1887) or in the present series.

## (B) Topographical Classification

(1) *Ocular Group.*—This includes the central retinal and ciliary arteries, and the collateral branches going to the optic nerve.

(2) *Orbital Group.*—This is composed of the lacrimal and muscular arteries and a few small branches to the orbital periosteum, areolar tissue, etc.

(3) *Extra-Orbital Group.*—This includes the posterior and anterior ethmoid, supra-orbital, medial palpebral, dorsal-nasal, and supra-trochlear, and a few branches of the lacrimal artery, *e.g.* the zygomatic and lateral palpebrals, and those to the anterior and middle cranial fossae.

TABLE II  
ORDER OF ORIGIN OF BRANCHES OF OPHTHALMIC ARTERY AS SEEN IN  
PRESENT SERIES

Order of Origin	Ophthalmic Artery Crossed	
	<i>Over</i> Optic Nerve (Fig. 2)	<i>Under</i> Optic Nerve (Fig. 1)
1	Central retinal + Medial posterior ciliary	Lateral posterior ciliary
2	Lateral posterior ciliary	Central retinal
3	Lacrimal	Medial muscular
4	Muscular to superior rectus and/or levator	Medial posterior ciliary
5	Posterior ethmoid and supra-orbital, jointly or separately	Lacrimal
6	Medial posterior ciliary	Muscular to superior rectus and levator
7	Medial muscular	Posterior ethmoid and supra-orbital, jointly or separately
8	Muscular to superior oblique and medial rectus, jointly/separately/to either	Muscular to superior oblique and medial rectus, jointly/separately/to either
9	To areolar tissue	Anterior ethmoid
10	Anterior ethmoid	To areolar tissue
11	Medial palpebral or Inferior medial palpebral	Medial palpebral or Inferior medial palpebral
12	Superior medial palpebral	Superior medial palpebral
Terminal	i. Dorsal nasal ii. Supratrochlear	i. Dorsal nasal ii. Supratrochlear

(C) **Site of Origin.**—This refers to the part of the ophthalmic artery from which the branches arise in relation to the optic nerve. The various branches are not precisely located in the literature, but the available information is summarized in Table IV (overleaf). The detailed localization, as seen in the present series, is shown in Table V (overleaf), which demonstrates the difference when the ophthalmic artery crosses *over* and *under* the optic nerve. The two groups show different characteristic patterns. The branches tend to cluster together at two points—the “angle” and the “bend” of the ophthalmic artery (Hayreh and Dass, 1962b), particularly the latter, whereas at other sites they are distributed irregularly.

Sudakevitch (1947) stressed the importance of haemodynamics in governing the order of branching. He stated that the ocular arteries drew their blood along the shortest route and therefore arose from the first part.

TABLE III  
FIRST BRANCH OF OPHTHALMIC ARTERY (VARIOUS AUTHORS)

Author	Date	First Branch	Percentage Incidence	Number of Specimens Examined
Zinn	1780	CAR		—
Haller	1781	Lacrimal		—
Meyer	1887	CAR + MPCA CAR + LPCA CAR + MPCA + Muscular Lacrimal LPCA Supra-orbital + Small Muscular LPCA + Small Muscular CAR	45 10 10 10 10 5 5 5	20
Quain	1892	CAR + MPCA		—
Testut	1911	Lacrimal		—
Whitnall	1932	CAR + MPCA		—
Duke-Elder	1932	CAR		—
Sudakevitch	1947	CAR + MPCA CAR LPCA Lacrimal	48.5 19.3 18.4 13.5	103
Wood Jones	1949	MPCA		—
Brash	1951	CAR		—
Schaeffer	1953	CAR		—
Wolff	1954	CAR		—
Hollinshead	1954	MPCA		—
Bedrossian	1958	CAR		—
Johnston and Others	1958	CAR		—
Hayreh	1958	CAR + MPCA CAR CAR + MPCA + Muscular CAR + LPCA CAR + Muscular Others	31.4 21.4 3.0 14.3 3.0 27.1	70
Singh and Dass	1960	CAR—Alone or With Other Branches Other Branches	77.45 22.55	102
Gillilan	1961	CAR		—
Present Series	1962	CAR CAR + MPCA CAR + LPCA CAR + MPCA + Muscular CAR + Muscular CAR + LPCA + MPCA CAR + LPCA + MPCA + Muscular LPCA Recurrent Meningeal CAR + LPCA + Lacrimal MPCA LPCA LPCA + Lacrimal LPCA + Lacrimal + Muscular + Anastomotic Branch CAR	23.5 40.0 12.9 5.9 4.7 3.5 2.4 2.4 2.4 1.2 1.2 82.6 4.3 4.3 8.7	85 in which the ophthalmic artery crossed <i>over</i> the optic nerve  23 in which the ophthalmic artery crossed <i>under</i> the optic nerve

CAR = Central retinal

LPCA = Lateral posterior ciliary

MPCA = Medial posterior ciliary

TABLE IV

SITE OF ORIGIN OF BRANCHES FROM OPHTHALMIC ARTERY IN RELATION TO THE OPTIC NERVE (VARIOUS AUTHORS)

Author	Date	From First Part of Ophthalmic, <i>i.e.</i> below/infero-lateral to Optic Nerve	From Second Part of Ophthalmic, <i>i.e.</i> Lateral to and over Optic Nerve	From Third Part of Ophthalmic, <i>i.e.</i> Medial to Optic Nerve
Meyer	1887	Central retinal Posterior ciliary	Lacrimal Supero-lateral muscular Supra-orbital Posterior ethmoid	Infero-medial muscular Anterior ethmoid Medial palpebral Terminals
Quain	1892	Central retinal Posterior ciliary	Lacrimal Supra-orbital Posterior-ethmoid	Anterior ethmoid Medial palpebral Terminals
Whitnall	1932	Central retinal Lacrimal	Supra-orbital Posterior ciliary Muscular	Posterior and anterior ethmoid Medial palpebral Terminals
Wood Jones	1949	Central retinal Posterior ciliary	Lacrimal Supra-orbital Muscular	Posterior ethmoid Anterior ethmoid Medial palpebral Terminals
Schaeffer	1953	Central retinal Lacrimal	Posterior ciliary	Supra-orbital Posterior ethmoid Anterior ethmoid Medial palpebral Terminals
Wolff	1954	Central retinal Posterior ciliary	Lacrimal Supra-orbital	Posterior ethmoid Anterior ethmoid Medial palpebral Terminals
Hollinshead	1954	Central retinal Medial posterior ciliary	Lacrimal Lateral posterior ciliary	Supra-orbital Posterior ethmoid Anterior ethmoid Medial palpebral Terminals

Occasionally the medial posterior ciliary arises from the second part and may be followed by the central retinal. In these abnormal cases, the correlation of forces is disturbed and, according to Sudakevitch, Nature provides anastomoses and accessory branches to compensate for the disadvantageous arrangement. The findings in the present series, however, do not support this view. The branches are described as tortuous; this was also seen in the present series, the tortuosity being most marked in the central retinal and posterior ciliaries.

### Individual Branches of the Ophthalmic Artery

#### Collateral Branches to the Optic Nerve

Small twigs running on the dural sheath of the optic nerve have been described by Zinn (1780), Haller (1781), Meyer (1887), Quain (1892), Tichomiroff (1900), and Wolff (1954). These have been found to run backwards on the dural sheath of the nerve by Quain (1892) and Wolff (1954). Meyer (1887) and Tichomiroff (1900) divided these twigs into two sets: those passing backwards from the distal part of the ophthalmic artery and those passing forwards from the proximal part, both sets being located on the lower and inner surface of the dural sheath. Anastomoses with similar branches



TABLE V  
SITE OF ORIGIN OF BRANCHES FROM OPHTHALMIC ARTERY AS SEEN IN  
PRESENT SERIES

Site of Origin from Ophthalmic Artery	When Ophthalmic Artery crossed					
	Over Optic Nerve			Under Optic Nerve		
	Number of Specimens with Branches	Incidence of Various Branches in Specimens		Number of Specimens with Branches	Incidence of Various Branches in Specimens	
Name		No.	Name		No.	
Apex of Orbit	1	CAR LPCA	1 1	3	LPCA	3
First Part of Ophthalmic	16	CAR + MPCA CAR CAR + LPCA LPCA MPCA Recurrent Meningeal	8 5 2 1 1 2	8	LPCA LPCA + Lacrimal + Muscular	7 1
Angle of Ophthalmic	36	CAR + MPCA CAR + LPCA CAR + MPCA + Muscular CAR + MPCA + Medial Muscular CAR + MPCA + Lateral Muscular CAR CAR + Muscular CAR + Medial Muscular CAR + MPCA + LPCA CAR + MPCA + LPCA + Medial Muscular LPCA LPCA + Superior Posterior Ciliary Lacrimal LPCA + Lacrimal Recurrent Meningeal Muscular	11 3 1 1 1 6 1 1 1 1 1 9 1 4 1 1 1	8 <i>Where Angle Infero-medial to Nerve</i>	Lacrimal CAR + MPCA MPCA Medial Muscular	4 4 1 2 2 1 1
Second Part of Ophthalmic	20	<i>Lateral to Optic nerve:</i> LPCA Lacrimal LPCA + Lacrimal MPCA Muscular LPCA + Lacrimal + Lateral Muscular Recurrent Meningeal	12 8 2 1 2 1 1	13	<i>Under Optic Nerve:</i> CAR MPCA Muscular Medial Muscular MPCA + Muscular Collateral Branch	8 1 1 4 1 6
		<i>Supero-lateral to Optic Nerve:</i> Lacrimal LPCA Lacrimal + LPCA LPCA + Muscular LPCA + Lateral Muscular Superior Posterior Ciliary + Lateral Muscular Muscular Lateral Muscular + Recurrent Meningeal Recurrent Meningeal LPCA + MPCA CAR + Muscular	16 8 1 2 1 1 3 1 1 1 1 1		<i>Infero-medial to Optic Nerve:</i> Medial Muscular MPCA MPCA + Medial Muscular CAR Muscular to Medial Rectus	3 3 1 1 1
	28	<i>Over Optic Nerve:</i> Collateral Branch Muscular MPCA LPCA Superior Posterior Ciliary Lacrimal Supra-orbital + Posterior Ethmoid Supra-orbital + Lateral Muscular	20 12 2 2 1 1 1 1	11	<i>Medial to Optic Nerve:</i> MPCA Medial Muscular Collateral Branch Muscular to Medial Rectus Posterior Ethmoid	7 3 4 4 1

TABLE V—continued

Site of Origin from Ophthalmic Artery	When ophthalmic artery crossed					
	Over Optic Nerve			Under Optic Nerve		
	Number of Specimens with Branches	Incidence of Various Branches in Specimens		Number of Specimens with Branches	Incidence of Various Branches in Specimens	
Name		No.	Name		No.	
Bend of Ophthalmic	40	Medial Muscular Posterior Ethmoid Muscular MPCA MPCA + Medial Muscular Supra-orbital + Posterior Ethmoid Supra-orbital + Posterior and Anterior Ethmoid Supra-orbital LPCA	20 21 17 11 5 6 1 7 1	15	Lacrimal Posterior Ethmoid Lacrimal + Posterior Ethmoid Lacrimal + Posterior Eth- moid + Supra-orbital Supra-orbital Supra-orbital + Posterior Ethmoid Supra-orbital + Ethmoid Lacrimal + MPCA MPCA Medial Muscular LPCA + Medial Muscular Muscular Superior Posterior Ciliary + Muscular Superior Posterior Ciliary + Lacrimal LPCA + Lacrimal	6 4 2 1 1 2 1 1 1 3 2 1 1 3 1 1 1
Third Part of Ophthalmic	44	Remaining Branches		15	Remaining Branches	
Total Number of Specimens Examined	44			15		

from the internal carotid through the optic foramen (Zinn, 1780; Quain, 1892), or from beginning of the ophthalmic artery (Quain, 1892), or between the two sets mentioned above (Meyer, 1887; Tichomiroff, 1900) have been described in literature. Meyer (1887) saw this formation in only one of his twenty specimens, but stated that the conditions for its existence were always present. Wolff (1954) described six to twelve such small branches piercing the dural sheath of the nerve at different places, mostly above and on the sides, and posterior to the entrance of the central retinal; he supposed that they were derived from the ophthalmic artery and its branches.

In the present series, variable numbers of these branches always arose from the ophthalmic artery or its branches. They ran first on the dural sheath of the optic nerve, and some of them later pierced the sheath to ramify on the pia of the nerve, sometimes entering the nerve itself. These branches were mostly much smaller than any other named branches of the ophthalmic artery, but a few were quite prominent. They mostly ran backwards on the sheath, and very rarely forwards, medially, or laterally. Since these branches were usually so small and did not all fill satisfactorily with latex, these data cannot be submitted to statistical analysis.

These branches to the optic nerve may be classified as intracanalicular or intra-orbital, depending upon the section of optic nerve with which they are related.

*Intracanalicular.*—These were almost always present; their apparent absence in a few cases may have been due to incomplete injection.

ORIGIN.—They arose from the ophthalmic artery between its origin and its entry into the orbit, including the part lying at the apex of the orbit (in three specimens), *i.e.* before, during, and just after its penetration into the dural sheath.

NUMBER.—This varied from one to three, though rarely there were more.

SIZE.—They were so minute that they could not all be traced to the optic nerve.

FUNCTION.—Because the ophthalmic artery was closely related to the inferior surface of the optic nerve, it usually supplied this aspect of the nerve and its sheath.

*Intra-orbital.*—These were nearly always present.

ORIGIN.—They arose from that part of the artery which lay in close relationship to the nerve, *i.e.* from the first part to the proximal portion of the third part.

When the ophthalmic artery crossed *over* the nerve, the branches were more or less uniformly distributed between the first part, the angle, over the nerve, the bend, and the initial portion of the third part; most of them came from the region of the bend when the artery lay *over* the nerve. Very rarely they arose from a site lateral to the optic nerve.

When the ophthalmic artery crossed *under* the nerve, most of the branches were evenly distributed on the part of the artery lying under and medial to the nerve and also at the bend. Very rarely they came from the first part or the angle of the ophthalmic artery.

MODE OF ORIGIN.—When the ophthalmic artery crossed *over* the optic nerve, about 75 per cent. of the specimens had an independent collateral branch; it was a branch from the medial muscular, medial posterior ciliary, or central retinal in about 25 to 30 per cent. of specimens in each group respectively; and very rarely it came from the posterior ethmoid, supra-orbital, or muscular branches to the medial rectus, superior rectus, or superior oblique.

When the ophthalmic artery crossed *under* the nerve, about 50 per cent. had an independent collateral branch; a branch came from the medial posterior ciliary, central retinal, or lacrimal in about 20 to 25 per cent. of specimens in each group respectively; less commonly it came from the posterior ethmoid, and very rarely from the lateral posterior ciliary and the muscular branch to the medial rectus.

LOCATION ON OPTIC NERVE SHEATH.—This also varied accordingly as the ophthalmic artery crossed *over* or *under* the nerve.

In the former case, the branches were mostly found on the superior surface of the sheath, in about half they were on the inferior surface (arising from the central retinal or less commonly from the medial posterior ciliary), and in about a third they were on the medial surface, and in only a very few on other surfaces.

In the latter case they were usually on the inferior surface of the sheath (mostly independent branches and less commonly from the central retinal), in about half on the superior surface (arising from the lacrimal or the posterior ethmoid) and on the medial surface.

NUMBER.—There were usually one to three, rarely more. There seemed to be no difference in number when the ophthalmic artery crossed *over* or *under* the optic nerve. There was no connexion between the number and size of the intra-canalicular and intra-orbital branches.

No anastomoses were seen between these collateral branches on the dural sheath of the nerve. Many of those branches which pierced the sheath and ramified on the pia anastomosed with one another, and also with pial branches of the central retinal and the recurrent pial branches of the circle of Zinn, and they supplied the optic nerve, as previously described (Hayreh, 1958; Hayreh and Dass, 1959; Singh and Dass, 1960b).

### Central Retinal Artery

Detailed studies of this artery have already been published (Hayreh, 1958; Hayreh and Dass, 1959; Singh and Dass, 1960a and 1960b), and two specimens were described as having duplicate central retinal arteries. A further search of the literature revealed a doubtful report of such duplicated arteries by Mariotte (1717); Barkow (1866) reported seeing two arteries emerging from the optic disc on to the retina, but those could have been two branches of the central retinal and not truly duplicated arteries. Beaunis and Bouchard (1880) stated that the central retinal frequently arose by two roots, and Haller (1781) had seen the artery with two trunks.

An interesting anomaly of the central retinal arising directly from the internal carotid was reported by Lauth (1830) from a case seen by his father, but no other details (*e.g.* its mode of entry into the orbit, the ophthalmic artery, and its branches) are available. No variation of this kind was seen in the present series.

### Posterior Ciliary Arteries

There has been a slight confusion in the nomenclature applied to these arteries. Many authors have designated them the "long" posterior ciliary arteries right from their point of origin. This seems to be a misnomer, because each divides into multiple branches, and only two of these (one medial and the other lateral) are "long" posterior ciliaries going to the ciliary body to take part in forming the major iridic arterial circle, the rest being "short" posterior ciliaries.

NUMBER.—The statements of various authors are summarized in Table VI (overleaf).

From the available details given by Meyer (1887), it appears that, when there were three ciliary trunks, two were the usual medial and lateral posterior ciliaries; the third was an upper posterior ciliary in three, a medial posterior ciliary in two, and a lateral posterior ciliary in three. When there were four ciliary trunks, the extra one formed an additional medial and lateral posterior ciliaries in one case and two additional medial posterior ciliaries in another case.

In the present series the number varied from one to five, usually two or three. The number of medial and lateral posterior ciliaries in any one specimen also varied (Table VII, overleaf). A superior posterior ciliary was also seen in some specimens, in which it formed an additional branch to the lateral and medial posterior ciliaries and was never substituted for one of them. If there was only one posterior ciliary, it was always the medial one.

MODE OF ORIGIN.—The posterior ciliaries have been described as arising independently from the ophthalmic artery by all workers. Arnold (1847) mentioned that several additional ciliaries arose from the lacrimal and musculars. Meyer's findings are contrasted with those in the present series in Table VIII (overleaf).

In three of Meyer's specimens in which the ophthalmic artery crossed *under* the optic nerve, the lateral posterior ciliary arose independently in two, and in common with the lacrimal and musculars in the third one; the medial posterior ciliary arose in common with the musculars in all three. No other worker has given any such details. Gillilan (1961) has expressed the view that the mode of origin of the ciliaries is variable.

TABLE VI  
NUMBER OF POSTERIOR CILIARY ARTERIES SEEN IN A SPECIMEN  
(VARIOUS AUTHORS)

Author	Date	Number of Arteries
Haller	1781	2 in one, 3 in three, 4 in six, and 6 in three cases
Murray	1794	3
Hildebrandt	1831	3
Theile	1841	3 trunks; often 2 (posterior outer and anterior inner)
Arnold	1847	2 (posterior and anterior); also several more
Meyer	1887	2 (inner and outer) in ten, 3 in eight, 4 in two
Quain	1892	2 (inner and outer); often 1 or 2 additional
Whitnall	1932	Variable—2 trunks or 6 to 8 vessels
Duke-Elder	1932	2 trunks or 6 to 8 vessels
Sudakevitch	1947	2 (medial and lateral), rarely 3 to 5
Wood Jones	1949	2 (lateral and medial)
Brash	1951	6 to 8
Schaeffer	1953	Short 5 or 6
Wolff	1954	2
Hollinshead	1954	Long set 2, sometimes multiple Short set multiple
Bedrossian	1958	1 or 2
Johnston and others	1958	Long 2, short 7
Gillilan	1961	Variable

SITE OF ORIGIN.—Some authors state that these arteries arise from the first part of the ophthalmic artery (Quain, 1892; Sudakevitch, 1947; Wood Jones, 1949; Wolff, 1954), some that they arise superior to the nerve in the second part (Whitnall, 1932; Schaeffer, 1953; Bedrossian, 1958), and some that they arise medial to the nerve (Duke-Elder, 1932). Schaeffer (1953) said that they arose on either side of the optic nerve. Theile (1841) mentioned that the posterior outer (*i.e.* the lateral posterior) ciliary arose earlier than the lacrimal, while the anterior medial (*i.e.* medial posterior) ciliary arose above the optic nerve. Meyer (1887) described the medial posterior ciliary and the central retinal as arising together first, followed by the lateral posterior ciliary, and then by the lacrimal. In eleven of his seventeen specimens in which the ophthalmic artery crossed *over* the optic nerve, the medial posterior ciliary with the central retinal arose before the lateral posterior ciliary; in the remaining six the lateral posterior ciliary (alone or with other branches such as the central retinal or musculars) arose before the medial posterior ciliary. In the three specimens in which the ophthalmic artery crossed *under* the optic nerve, the lateral posterior ciliary always arose first, followed by the central retinal and then by the medial posterior ciliary in common with the muscular arteries. Thus the medial posterior ciliary

TABLE VII

NUMBER AND PERCENTAGE OF POSTERIOR CILIARY ARTERIES ARISING FROM AN OPHTHALMIC ARTERY AS SEEN IN PRESENT SERIES

Name of Artery	Ophthalmic Artery Crossed			
	<i>Over</i> Optic Nerve		<i>Under</i> Optic Nerve	
	Number	Per cent.	Number	Per cent.
All Posterior Ciliaries	One Two Three Four Five	4.5 50.0 34.1 9.1 2.3	One Two Three Four Five	Nil 40.0 53.3 6.7 Nil
Medial Posterior Ciliary	Nil One Two	Nil 72.7 27.3	Nil One Two	Nil 66.7 33.3
Lateral Posterior Ciliary	Nil One Two Three	4.5 72.7 20.5 2.3	Nil One Two Three	Nil 80.0 20.0 Nil
Superior Posterior Ciliary	One Two	9.1 Nil	One Two	Nil 6.7

TABLE VIII

ORIGIN OF POSTERIOR CILIARY ARTERIES AS SEEN IN PRESENT SERIES COMPARED WITH THAT REPORTED BY MEYER (PERCENTAGES)

Mode of Origin	Medial Posterior Ciliary		Lateral Posterior Ciliary		Superior Posterior Ciliary	
	Meyer (1887)	Present Series	Meyer (1887)	Present Series	Meyer (1887)	Present Series
Independent Branch	10	57.6	80	72.9	10	3.4
With Central Retinal	45	35.6	20	8.5	Nil	Nil
With Muscular	25	22.0	5	5.1	Nil	3.4
With Muscular + Central Retinal	10	5.1	Nil	Nil	Nil	Nil
With Muscular + Lacrimal	Nil	Nil	10	1.7	5	Nil
LPCA + MPCA + CAR + Muscular	Nil	1.7	Nil	1.7	Nil	Nil
CAR + LPCA + MPCA	Nil	1.7	Nil	1.7	Nil	Nil
MPCA + LPCA	Nil	1.7	Nil	1.7	Nil	Nil
MPCA + LPCA + Muscular	10	Nil	10	Nil	Nil	Nil
With Lacrimal	Nil	1.7	Nil	18.6	Nil	1.7
LPCA + Superior Posterior Ciliary	Nil	Nil	Nil	1.7	Nil	1.7

CAR = Central retinal  
 LPCA = Lateral posterior ciliary  
 MPCA = Medial posterior ciliary

originated before the lacrimal artery in thirteen cases and from it or after it in seven. On the other hand, with the lateral posterior ciliary, this ratio was 14:6.

In the present series when the ophthalmic artery crossed *over* the optic nerve and the lacrimal was present (34 specimens), the medial posterior ciliary arose before the lacrimal in twelve and after it in fifteen. In seven specimens there were two medial posterior ciliaries, and they arose one on each side of the lacrimal. The lateral posterior ciliary arose before the lacrimal in 22 cases, with it in five, after it in two, and both before and after it in three; in the remaining two it was absent.

When the ophthalmic artery crossed *under* the optic nerve and the lacrimal was present (14 specimens), the medial posterior ciliary arose before the lacrimal in ten and after it in four specimens, and the lateral posterior ciliary arose before the lacrimal in twelve and with it in two specimens.

Whitnall (1932) described the origin of the posterior ciliaries as variable.

According to Sudakevitch (1947), the medial posterior ciliary in common with the central retinal is usually the first branch of the ophthalmic artery, the lateral posterior ciliary is the second, and both arise before the lacrimal, which is situated at the angle. The medial posterior ciliary followed by the central retinal may occasionally arise from the second part. When the ophthalmic artery crossed *under* the optic nerve, he found that the medial posterior ciliaries originated from the second part of the ophthalmic artery after the lacrimal. The importance of the site of origin of the posterior ciliaries from the haemodynamic point of view, as discussed by Sudakevitch, has already been mentioned (*vide supra*).

According to Sudakevitch, when they arise from the second part of the ophthalmic artery, they are unfavourably situated, and to compensate for this, anastomoses and accessory branches appear. When, as a compensatory mechanism, there are more than two posterior ciliaries, the extra ones may arise not only from the second but also from the third part of the artery.

In the present series, however, the medial and lateral posterior ciliaries originated from the first part in 25 specimens, and from the angle in 39, and 48 medial and 37 lateral posterior ciliaries arose distal to the angle (Table IX). Where the origin was distal to the angle, the ciliaries arose not only from the second part but even from the bend and the initial portion of the third part, especially the medial posterior ciliary. In nine specimens all the posterior ciliaries arose distal to the angle, and in all these the ophthalmic artery crossed *over* the optic nerve. In the remaining specimens one or both of the medial and lateral posterior ciliaries arose before the angle. There was no relationship of any kind between the number of posterior ciliaries which might be present in a specimen and their site of origin. Those in which one of the posterior ciliaries was situated distal to the angle were more numerous than those in which they arose before the angle (*vide supra*) and there were no special accessory branches and anastomoses in such cases. All these points contradict the views expressed by Sudakevitch (1947).

In cows and pigs, Sudakevitch (1947) noticed that the ophthalmic artery ended behind the eyeball in two strong posterior ciliaries. Such a variation may be possible in man, but has not so far been recorded.

The site and mode of origin of the posterior ciliary arteries as seen in the present series are shown in Table IX (opposite).

*Superior Posterior Ciliary Artery.*—This was seen in five specimens, and the ophthalmic artery crossed *over* the optic nerve in four of these and *under* it in one.

When the ophthalmic artery crossed *over* the optic nerve, the superior posterior ciliary arose as an independent branch over the nerve in one, from the third part

TABLE IX  
ORIGIN OF POSTERIOR CILIARY ARTERIES IN PRESENT SERIES (PERCENTAGES)

Site of Origin	Ophthalmic Artery Crossed											
	Over Optic Nerve						Under Optic Nerve					
	Medial Posterior			Lateral Posterior			Medial Posterior			Lateral Posterior		
	Independent Brch	In Common with Other Branches of Ophthalmic		Independent Brch.	In Common with Other Branches of Ophthalmic		Independent Brch.	In Common with Other Branches of Ophthalmic		Independent Brch.	In Common with Other Branches of Ophthalmic	
Incidence		Branch	Incidence		Branch	Incidence		Branch	Incidence		Branch	
Total Incidence	47.7	75.0		68.2	40.9		86.7	26.7		86.7	26.7	
Apex of Orbit				2.3						20.0		
First Part of Ophthalmic	2.3	18.2	CAR	2.3	4.5	CAR				53.8	6.7	Lacrimal + Muscular
Angle of Ophthalmic		25.0	CAR	20.5	6.8	CAR	6.7	13.3	CAR	26.7		
			2.3	CAR + Lateral muscular		2.3	Lacrimal					
			2.3	CAR + Muscular		2.3	Superior posterior ciliary					
			2.3	CAR + Medial muscular		2.3	CAR + MPCA					
			2.3	CAR + LPCA + Medial muscular		2.3	CAR + MPCA + Medial muscular					
			2.3	CAR + LPCA								
Second Part of Ophthalmic	Lateral to Optic Nerve	2.3		29.5	13.6	Lacrimal*						
	Supero-lateral to Optic Nerve		2.3	LPCA	18.2	4.5	Lacrimal*					
						2.3	MPCA					
					4.5	Muscular						
	Over Optic Nerve	4.5		4.5								
	Under Optic Nerve						6.7	6.7	Muscular			
Infero-medial to Optic Nerve						20.0	6.7	Medial muscular				
Medial to Optic Nerve						46.7						
Bend of Ophthalmic		25.0	11.4	Medial muscular	2.3		20.0	6.7	Lacrimal		6.7	
										6.7	Medial muscular	
Third part of Ophthalmic	13.6	11.4	Medial muscular									

CAR = Central retinal      LPCA = Lateral posterior ciliary      MPCA = Medial posterior ciliary  
\* = Lacrimal or rarely an artery representing the lacrimal as mentioned in the text.



in one, in common with the lateral muscular supero-lateral to the nerve in one, and with the lateral posterior ciliary at the angle in the last. In the one in which the ophthalmic artery crossed *under* the optic nerve, there were two superior posterior ciliaries, one arising in common with the lacrimal and the other with the muscular, both at the bend.

The posterior ciliaries run forward, divide into multiple branches, and pierce the sclera close to the optic nerve medially, laterally, or superiorly. The two long posterior ciliaries, however, pierce the sclera on the medial and lateral surfaces slightly further from the optic nerve than the majority of the short posterior ciliaries. When the medial posterior ciliary arose from the ophthalmic artery lateral to the nerve, it usually crossed medially under the nerve, but in four specimens (in which the ophthalmic artery crossed *over* the optic nerve) it crossed over. The posterior ciliaries were usually markedly tortuous.

### Lacrimal Artery

**SITE OF ORIGIN.**—The lacrimal has been described as arising at the apex of the orbit close to the optic canal (Duke-Elder, 1932; Schaeffer, 1953; Hollinshead, 1954; Johnston and others, 1958), from the first part in the orbit (Meyer, 1887; Quain, 1892; Whitnall, 1932; Duke-Elder, 1932; Wood Jones, 1949; Brash, 1951; Schaeffer, 1953; Hollinshead, 1954; Wolff, 1954; Bedrossian, 1958), from the angle (Sudakevitch, 1947), over the optic nerve (Hollinshead, 1954), before the ophthalmic artery has entered the orbit (Johnston and others, 1958), and from the ophthalmic artery as it lies in the optic canal (Duke-Elder, 1932). At times the lacrimal arises from the middle meningeal instead of the ophthalmic artery (Haller, 1781; Murray, 1794; Velpeau, 1833; Blandin, 1834; Arnold, 1847; Barkow, 1866; Cruveilhier, 1871; Merkel, 1874; Meyer, 1887; Adachi, 1928; Whitnall, 1932; Duke-Elder, 1932; Brash, 1951; Schaeffer, 1953; Hollinshead, 1954; Johnston and others, 1958; Gillilan, 1961) or may be reinforced by the former. Similarly, it may arise from the anterior deep temporal (Arnold, 1847; Merkel, 1874), or be reinforced by it (Quain, 1892; Whitnall, 1932; Wolff, 1954). In one case reported by Meyer (1887), the lacrimal arose from the internal carotid and entered the orbit through the superior orbital fissure, but Haller (1781) had denied the possibility of any such origin. Schaeffer (1953) said that the lacrimal arose from the ophthalmic artery outside the orbit. Origin from the middle meningeal is the most common of these abnormal formations; Haller (1781) saw it in four of seventeen cadavers, and Meyer (1887) saw it in five of his twenty specimens (as well as one which arose directly from the internal carotid). In one of these five, another completely separate lacrimal artery also arose from the ophthalmic artery. These abnormal lacrimal arteries passed through the most lateral part of the superior orbital fissure or through a foramen in the greater wing of the sphenoid. In one specimen, Meyer (1887) saw the lacrimal entering the cranial cavity from the orbit through the superior orbital fissure and then through a special foramen in the greater wing of the sphenoid back into the orbit.

In the present series, the site of origin of the lacrimal differed according as the ophthalmic artery crossed *over* or *under* the optic nerve (Table X, opposite).

When the lacrimal did not arise from the ophthalmic artery, it usually arose from the middle meningeal, though this could not be traced in all cases because of poor injection. This absence of the lacrimal artery was bilateral in 83.3 per cent. and unilateral in 16.7 per cent. Where the lacrimal was absent from the ophthalmic artery, its origin was represented by one of its usual branches, *e.g.* the recurrent meningeal, the branch to the lateral rectus, etc. This absence of the lacrimal was relatively much less frequent in cases in which the ophthalmic artery crossed *under* the optic nerve than in those in which it crossed

TABLE X

SITE AND ORDER OF ORIGIN OF LACRIMAL ARTERY AS SEEN IN PRESENT SERIES (PERCENTAGES)

Origin		Ophthalmic Artery Crossed	
		Over Optic Nerve	Under Optic Nerve
Site	First part of ophthalmic	Nil	6.7
	Angle of ophthalmic	11.4	6.7
	Second	25.0	Nil
	part of } Lateral to optic nerve	38.6	Nil
	ophthalmic } Supero-lateral to optic nerve	2.3	Nil
	Bend of ophthalmic	Nil	80.0
Order	First	Nil	13.3
	Second	27.3	Nil
	Third	36.4	13.3
	Fourth	13.6	Nil
	Fifth	Nil	26.7
	Sixth	Nil	26.7
	Seventh	Nil	13.3
Total Number of Specimens Studied		44	15
Lacrimal Artery Absent (per cent.)		22.7	6.7

over the optic nerve, *i.e.* in 6.7 per cent. (1 specimen) and 22.7 per cent. (10 specimens) respectively. Thus the lacrimal may have some haemodynamic relationship with the course of the ophthalmic artery. This idea is further supported by the fact that, whenever the ophthalmic artery arises completely or partially from a site other than the internal carotid, the origin is invariably through the lacrimal, despite the many other prominent anastomoses of the ophthalmic artery with the surrounding vessels (Hayreh and Dass, 1962a).

**ORDER OF ORIGIN.**—The lacrimal was said to be the first branch of the ophthalmic artery by Haller (1781), Testut (1911), and Schaeffer (1953). Meyer (1887) and Suda-kevitch (1947) saw it mainly as the third branch, and as a first branch in only 10 and 13.5 per cent. respectively. The findings in the present series (Table X) are in sharp contrast with the above. Table X shows that the crossing of the ophthalmic artery over or under the optic nerve had a marked effect on the arrangement.

**COURSE.**—The lacrimal usually first runs laterally and then bends forwards over the upper margin of the lateral rectus to reach the lacrimal gland. During its initial course, when it arose from the bend and when the ophthalmic artery crossed *under* the optic nerve, the lacrimal crossed *over* the nerve. From the lacrimal gland the main trunk may continue as the lateral palpebral. Like other branches of the ophthalmic artery, the lacrimal may be very tortuous.

**BRANCHES.**—Most authors have described the branches of the lacrimal as the recurrent meningeal, zygomatic, glandular (to the lacrimal gland), and lateral palpebral branches; additional muscular and posterior ciliary branches have also been mentioned. Branches piercing the roof of the orbit and supplying the periosteum were seen by Meyer (1887) in two specimens.\*

\* This type of branch, never encountered in my dissections, was seen in a skull in which a foramen was present in the roof of the orbit laterally, and a vascular groove passed forwards and upwards in the skull cavity from this foramen.

In the present series, the various branches given off by the lacrimal were also the muscular, recurrent meningeal, glandular, zygomatic, and lateral palpebral. A lateral posterior ciliary and a few branches to areolar tissue in the lateral part of orbit and periosteum were also given off in some cases. Where the lacrimal arose from the ophthalmic artery crossing *under* the optic nerve, certain additional branches were seen: the superior posterior ciliary, collateral branches to the optic nerve, and the posterior ethmoid and supra-orbital.

*Recurrent Meningeal.*—This branch arises from the lacrimal and passes either through the most lateral part of the superior orbital fissure or through a special foramen in the greater wing of the sphenoid; it has been described by all workers as invariably present. It anastomoses with the anterior branch of the middle meningeal; the significance of this anastomosis has already been discussed in detail (Hayreh and Dass, 1962a), and the ophthalmic and lacrimal arteries may be wholly or partially replaced by it. Meyer (1887) stated that this anastomosis was regularly present in all those of his specimens which showed a lacrimal artery; it was strongly developed in six, and in five the lacrimal arose from the middle meningeal through its enlargement. In one of Meyer's specimens, these branches anastomosed with both the middle meningeal and the internal carotid.

In the present series, the recurrent meningeal branch was not always present (Table XI), but this apparent absence may have been caused by poor injection. In addition to this branch, there was rarely a meningeal branch to the dura of the middle cranial fossa; in one specimen it reached to the lateral wall of the cavernous sinus and in another it anastomosed with a branch from the cavernous part of the internal carotid; there were also branches to the orbital periosteum and areolar tissue on the lateral side of the orbit.

The size varied; it was usually sufficient to allow the latex to pass through and fill the middle meningeal, and at times it was as big as the main lacrimal.

*Muscular.*—Branches to the lateral rectus (Meyer, 1887; Duke-Elder, 1932; Brash, 1951; Schaeffer, 1953; Hollinshead, 1954), the superior rectus (Meyer, 1887; Whitnall, 1932; Duke-Elder, 1932; Brash, 1951), the medial rectus (Meyer, 1887; Whitnall, 1932), and the levator palpebrae superioris and inferior oblique (Meyer, 1887) have been described. Wood Jones (1949) also described muscular branches from the lacrimal. Meyer (1887) was the only author to give details of the muscles supplied by branches from the lacrimal in his fourteen specimens in which the lacrimal arose from the ophthalmic artery. He found it supplying the lateral rectus in three; the superior rectus in two; the lateral and superior recti in four; the lateral and medial recti in one; the lateral and superior recti and levator in one; the superior and medial recti and levator in one; the lateral rectus and inferior oblique in one; and the medial rectus in one.

In the present series, these were more than one, usually two or three in about 25 per cent. of branches to the lateral rectus and less frequently to the superior rectus. The branch to the levator was given out by the lacrimal from within the lacrimal gland in about 50 per cent. of these cases (Table XI).

*Posterior Ciliaries.*—The short posterior ciliaries (Meyer, 1887; Wood Jones, 1949; Hollinshead, 1954), and anterior ciliaries (Whitnall, 1932; Duke-Elder, 1932; Wood Jones 1949) are also described as arising from the lacrimal. Meyer (1887) saw these branches in three specimens; in two it was the lateral posterior ciliary and in one the upper posterior ciliary trunk. Lateral and superior posterior ciliaries were also seen occasionally in the present series (Table XI).

*Glandular.*—These supply the lacrimal gland and usually terminate there.

In the present series, the lacrimal supplied the lacrimal gland in all cases in which it was present (Table XI). Rarely a branch to the lacrimal gland arose from the middle meningeal or infra-orbital, as well as the regular one. In some cases, they anastomosed freely with one

another in the substance of the gland. In specimens in which the lacrimal did not arise from the ophthalmic artery, its branches could not be traced because there was no injection except in two specimens: in one of these (in which the ophthalmic artery crossed *over* the optic nerve), the lacrimal was filled from the ophthalmic artery by an anastomosing trunk connecting the branches to the levator from the two sources; in the other (in which the ophthalmic artery crossed *under* the optic nerve) the lacrimal was filled through a channel connecting it with the bend of the ophthalmic artery. The branches given out were of the usual pattern in each case.

TABLE XI  
INCIDENCE OF BRANCHES OF LACRIMAL ARTERY AS SEEN IN PRESENT SERIES (PERCENTAGES)

Name of Branch		Ophthalmic Artery Crossed	
		<i>Over</i> Optic Nerve	<i>Under</i> Optic Nerve
Lateral Posterior Ciliary		17.6	16.7
Superior Posterior Ciliary		Nil	8.3
Muscular Arteries to	Superior rectus	58.8	66.7
	Lateral rectus	100.0	100.0
	Levator	38.2	25.0
	Inferior rectus	5.9	25.0
	Medial rectus	2.9	8.3
	Inferior oblique	5.9	Nil
Recurrent Meningeal		88.2	75.0
Glandular		100.0	100.0
Lateral Palpebral		73.5*	58.3*
Zygomatic		76.5*	58.3*
Collateral		2.9	16.7
Posterior Ethmoid		Nil	16.7
Supra-orbital		Nil	8.3
Lacrimal Artery from Ophthalmic Artery Present		34	12

\* - In the remaining specimens these branches were not properly injected, so that no definite opinion can be given.

*Zygomatic*.—Two branches (zygomatico-temporal and zygomatico-facial) are usually distinguished by most workers; they were designated as "temporal" and "zygomatic" by Quain (1892), Whitnall (1932), Wolff (1954), and Bedrossian (1958). They pass through bony canals in the zygomatic bones (the zygomatico-temporal and zygomatico-facial canals) and anastomose with the anterior deep temporal and transverse facial arteries respectively. Enlargement of the anastomoses with the anterior deep temporal leading to reinforcement or replacement of the lacrimal has already been discussed (Hayreh and Dass, 1962a). The zygomatic branches were not mentioned by Meyer (1887).

In the present investigation, they invariably arose from within the lacrimal gland, either jointly or separately as the zygomatico-temporal and zygomatico-facial branches, and there were sometimes more than two. Very rarely they arose from branches of the ophthalmic artery other than the lacrimal. These usually entered the zygomatic bone to appear on the face and temporal fossa but not always. In some cases they anastomosed in the orbit with branches from the infra-orbital, and rarely they derived their blood supply mainly from the latter.

*Lateral Palpebrals*.—There are usually two of these, the superior for the upper lid and the inferior for the lower lid. They are described as arising after the lacrimal has passed

through the substance of the gland. They anastomose with the corresponding medial palpebrals to form arterial arches in the lids and to supply the lids and conjunctiva. They were not mentioned by Meyer (1887).

In the present series, the superior and inferior lateral palpebrals emerged anteriorly from within the lacrimal gland to run along the free margins of the lids and anastomose with the corresponding medial palpebrals. They usually arose from within the substance of the gland, but rarely branched off from the lacrimal before it reached the gland. Very rarely they arose from branches of the ophthalmic artery other than the lacrimal. They sometimes emerged from the lacrimal gland jointly and sometimes independently. Only rarely was there more than one branch in either lid.

**ANASTOMOSES.**—Whitnall (1932) mentioned anastomoses between the lacrimal and the infra-orbital. These were seen quite frequently in the present series, so that the latter sometimes filled with latex from the former. Its anastomoses with the middle meningeal and internal carotid have been discussed above.

### Muscular Arteries

Most of the authors describing the muscular branches of the ophthalmic artery have distinguished three sets of such branches—two trunks of muscular arteries and a third set composed of a large number of additional branches to the muscles. The first two trunks have been called the lateral and medial muscular trunks (Quain, 1892; Wood Jones, 1949; Wolff, 1954; Bedrossian, 1958), or the superior and inferior muscular trunks (Arnold, 1847; Whitnall, 1932; Duke-Elder, 1932; Schaeffer, 1953; Johnston and others, 1958). Meyer (1887) designated them as the superior external and inferior internal muscular branches. The third set of additional branches of variable number was described by Meyer (1887), Whitnall (1932), Wood Jones (1949), Wolff (1954), and Johnston and others (1958).

*Medial and Lateral.*—The lateral/superior muscular branch is thought to be more variable than the medial/inferior (Meyer, 1887; Quain, 1892; Johnston and others, 1958) and also smaller (Meyer, 1887; Quain, 1892; Wolff, 1954). This has been confirmed in the present series; the medial muscular was present in 98.3 per cent., and the lateral/superior in only 16.95 per cent. of the specimens. Meyer (1887) found that the lateral/superior muscular trunk arose immediately after the lacrimal from the initial part of the ophthalmic artery or from the lacrimal itself, while the medial/inferior muscular trunk arose medial to the optic nerve. About a quarter of Meyer's specimens had a typical superior branch; six had a typical inferior branch, and of the remainder, in three it arose in common with the lateral rectus, in one with the superior oblique, and in eight it was atypical, supplying only the medial and inferior recti.

The lateral/superior muscular trunk is described as supplying the lateral and superior recti, levator, and superior oblique, while the medial/inferior muscular trunk supplies the inferior and medial recti and inferior oblique (Arnold, 1847; Meyer, 1887; Quain, 1892; Whitnall, 1932; Schaeffer, 1953; Wolff, 1954; Bedrossian, 1958). Duke-Elder (1932), however, described the lateral rectus as being supplied not by the lateral/superior but by the medial/inferior.

Table XII (opposite) shows the details of the muscles supplied by these muscular branches in the present series.

TABLE XII  
SITE AND MODE OF ORIGIN AND MUSCLES SUPPLIED BY MEDIAL AND LATERAL MUSCULAR ARTERIES IN PRESENT SERIES (PERCENTAGES)

Muscular Artery		Ophthalmic Artery Crossed		
		Over Optic Nerve (44)	Under Optic Nerve (15)	
Medial	Site of Origin	Angle	7.0	6.7
		Second part		
		Under optic nerve	Nil	26.7
		Infero-medial to optic nerve	Nil	26.7
		Medial to optic nerve	Nil	20.0
	Bend	60.5	20.0	
	Third part	32.4	Nil	
	Mode of Origin	Independent	69.8	86.7
		With medial posterior ciliary	23.3	6.7
		With central retinal + medial posterior ciliary	2.3	Nil
With central retinal + anastomotic		2.3	Nil	
With central retinal + medial and lateral posterior ciliary		2.3	Nil	
With lateral posterior ciliary	Nil	6.7		
Muscles Supplied	Medial and inferior recti + inferior oblique	51.2	33.3	
	Medial, inferior, and lateral recti + inferior oblique	30.2	66.7	
	Medial, inferior, and lateral recti	4.7	Nil	
	Medial and inferior recti	9.3	Nil	
	Medial, inferior, and superior recti + inferior oblique + levator	2.3	Nil	
	Medial, inferior, and lateral recti + inferior oblique + levator	2.3	Nil	
Number of Specimens with Medial Muscular		43	15	
Lateral	Site of Origin	Angle	10	Nil
		Second part		
		Lateral to optic nerve	20	Nil
		Supero-lateral to optic nerve	40	Nil
		Over optic nerve	10	Nil
	Third part	20	Nil	
	Mode of Origin	Independent	10	Nil
		With lateral posterior ciliary	10	Nil
		With superior posterior ciliary	10	Nil
		With central retinal + medial posterior ciliary	10	Nil
From lacrimal		30	Nil	
From supra-orbital		10	Nil	
From posterior ethmoid		10	Nil	
From recurrent meningeal	10	Nil		
Muscles Supplied	Lateral and superior recti + levator	40	Nil	
	Lateral and superior recti + inferior oblique	10	Nil	
	Lateral and inferior recti + inferior oblique	30	Nil	
	Superior rectus + superior oblique + levator	20	Nil	
Number of Specimens with Lateral Muscular		10	Nil	

The medial was nearly always present, but the lateral was seen in only a few cases and that too *only* when the ophthalmic artery crossed *over* the optic nerve. The medial was usually independent and quite prominent; it usually arose near the bend (when the ophthalmic artery crossed *over* the nerve) or from the second part (when the ophthalmic artery crossed *under* the nerve). A short distance from its origin it divided into branches to the various muscles. It nearly always supplied the medial and inferior recti and inferior oblique, and sometimes one of the other orbital muscles, usually the lateral rectus.

The lateral, on the other hand, was very indefinite in occurrence, origin, and destination. It usually arose with some other branch of the ophthalmic artery and was very rarely independent. This branch has therefore no definite place in the localization of the branches of the ophthalmic artery, a view contrary to that of Meyer (1887).

*Additional.*—No definite pattern of additional branches has been reported; they are described as small in size, arising from ophthalmic, lacrimal, and supra-orbital arteries (Meyer, 1887; Quain, 1892; Wood Jones, 1949; Wolff, 1954; Johnston and others, 1958), and also from the posterior ethmoid, anterior ethmoid, or any large branch of the ophthalmic artery (Meyer, 1887).

In seven of Meyer's twenty specimens, they arose in common with the medial posterior ciliary, and two of these also arose in common with the lateral posterior ciliary, and one with the central retinal. The muscular branches were very variable in their supply, most of them went to one or more of the infero-medial muscles and a few to the supero-lateral muscles. In eight specimens they arose from the supra-orbital, in another eight from the posterior ethmoid, and in three from the joint trunk of the supra-orbital and posterior ethmoid. The muscular branches arising in common with these two arteries usually went to one or more of the supero-lateral muscles. The anterior ethmoid gave out branches to the medial rectus alone in one, and to the superior oblique in two. The lacrimal gave out branches in fourteen specimens, as mentioned above. Muscular branches arising independently from the ophthalmic artery showed no constant pattern in Meyer's series.

In describing the blood supply of the various orbital muscles, Wolff (1954) stated that the inferior and medial recti and the inferior oblique were supplied by the inferior muscular trunk, while the superior oblique and lateral rectus were supplied by the superior muscular trunk and the lacrimal respectively.

In the present series, the mode and site of origin of the branches to the various orbital muscles were studied in detail.

MODE OF ORIGIN.—This was very variable, particularly in the branches to the superior and medial recti, the superior oblique, and the levator (Table XIII). They arose either independently from the ophthalmic artery or in common with or from some other branch. No independent branches to the inferior rectus and inferior oblique were seen, as these always arose jointly with some other branch. When the branch to the lateral rectus arose from the lacrimal or recurrent meningeal, it rarely arose in common with the lateral posterior ciliary; and still more rarely a muscular branch, particularly one to the superior rectus, was also seen to arise in common. In 43 of the 44 specimens in which the ophthalmic artery crossed *over* the optic nerve, there were branches to the lateral rectus; in the one exception, with no branch from the ophthalmic artery, it might have been from

TABLE XIII  
MODE OF ORIGIN OF MUSCULAR ARTERIES SUPPLYING VARIOUS ORBITAL MUSCLES AS SEEN IN PRESENT SERIES (PERCENTAGES)

Muscle Supplied		Lateral Rectus		Superior Rectus		Medial Rectus		Inferior Rectus		Inferior Oblique		Superior Oblique		Levator		
		Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	
Total Number of Specimens Examined		43	15	44	15	43	15	44	15	44	15	43	15	41	12	
Mode of Origin	Independent from ophthalmic artery	2.3		34.1	13.3	81.4	80.0					49.0	60.0	19.5	16.7	
	From lacrimal	76.7	80.0	43.2	53.3	2.3	6.7*	2.3	20.0	4.5				31.7	25.0	
	From recurrent meningeal	7.0	Nil	2.3												
	From medial muscular	37.2	66.7	2.3		100	100	97.7	100	84.1	100				4.9	
	From lateral muscular	18.6		15.9				6.8		9.1		4.7			14.6	
	From supra-orbital			15.9	13.3							14.0	6.7	36.6	33.3	
	From posterior ethmoid			6.8	6.7	4.7	6.7					49.0	40.0	24.4	33.3	
	From lateral posterior ciliary			4.5					6.7						2.4	
	From medial posterior ciliary				6.7										8.3	
	From superior posterior ciliary				6.7											
	With muscular arteries to:	(i) Superior rectus	7.0				2.3						2.3		24.4	33.3
		(ii) Lateral rectus			6.8											
		(iii) Medial rectus			2.3								20.9	13.3	2.4‡	
		(iv) Superior oblique			2.3		20.9	13.3							4.9	
		(v) Medial rectus + levator											4.7			
(vi) Levator				20.5	26.7	2.3†						4.7				
From anterior ethmoid												23.3	26.7	8.3		
With central retinal					2.3§					2.3□ 2.3△						
From medial palpebral														8.3		

\* = With other recti. † = With superior oblique. ‡ = With superior oblique.  
§ = With inferior oblique. □ = With medial rectus. △ = With medial posterior ciliary.

the lacrimal, a branch of the middle meningeal, and the latter was not injected. About 25 to 30 per cent. of branches to the superior rectus and levator muscles arose by a common stem, particularly when they arose from the lacrimal, supra-orbital, posterior ciliary, and ophthalmic arteries. This was the case in about 50 per cent. of the specimens in which the branch to the levator arose directly from the ophthalmic artery. A branch to the inferior rectus from the lacrimal arose in common with those to other rectus muscles in one and with the lateral rectus in two specimens, the ophthalmic artery crossing *under* the optic nerve in all three. In one specimen the lacrimal gave out a branch to the inferior, lateral, and superior recti and also to the levator in common with the lateral



posterior ciliary, and a lateral muscular branch was also present, with the ophthalmic artery crossing *over* the optic nerve. The number of independent branches to the medial rectus varied: there was one in about 25 to 30 per cent., two in about 50 to 55 per cent., three in about 17 per cent., and four in up to 8 per cent. of the specimens; they usually arose before the anterior ethmoid and at times jointly with a branch to the superior oblique. Similarly, there was one independent branch to the superior in 80 per cent., two in about 10 per cent., and three in about 10 per cent. of the specimens; these also usually arose before the anterior ethmoid. When branches to the levator were derived from the lacrimal, they arose from within the lacrimal gland in about 50 per cent. of the specimens.

SITE OF ORIGIN.—This was also very variable (Table XIV).

TABLE XIV  
SITE OF ORIGIN OF MUSCULAR ARTERIES SUPPLYING VARIOUS ORBITAL MUSCLES AS SEEN IN PRESENT SERIES (PERCENTAGES)

Muscle Supplied		Lateral Rectus		Superior Rectus		Medial Rectus		Inferior Rectus		Inferior Oblique		Superior Oblique		Levator		
		Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	
Independent from Ophthalmic Artery	Total Number of Specimens	1		15	2	35	12					21	9	8	2	
	Angle	100														
	Second part	Supero-lateral to optic nerve			6·7											
		Over optic nerve			60·0										37·5	
		Medial to optic nerve						16·7								
	Bend			20·0		5·7									37·5	
	Third part			13·3	100	97·1	83·3					100	100	25·0	100	
	From or With Other Branches of Ophthalmic Artery	Total Number of Specimens	43	15	39	15	43	15	44	15	44	15	35	12	40	12
		First part		13·3		6·7				6·7						
		Angle	20·9	20·0	2·6	6·7	9·3	6·7	9·1	13·3	11·4	6·7	2·9		2·5	8·3
Second part		Lateral to optic nerve	34·9		23·1				4·5		4·5				12·5	
		Supero-lateral to optic nerve	51·2		41·0		2·3				2·3				22·5	
		Over optic nerve	4·7		10·3		2·3						5·7		10·0	
		Under optic nerve		20·0		6·7		26·7		26·6		26·7		8·3		8·3
		Infero-medial to optic nerve		6·7				26·7		26·7		26·7				
Medial to optic nerve			13·3				20·0		20·0		20·0					
Bend		23·3	93·3	38·5	80·0	74·4	26·7	59·1	33·3	54·5	26·7	65·7	50·0	57·5	75·0	
Third part	9·3		17·9	13·3	46·5	20·0	31·8		27·3		62·9	50·0	35·0	50·0		

NUMBER.—This varied from one to five (Table XV, opposite).

Meyer (1887) showed that in six of his seven specimens in which the medial posterior ciliary did not arise from the first part but more distally, it arose in common with some inner lower muscular artery. Table IX shows that

TABLE XV  
 NUMBER OF BRANCHES TO VARIOUS ORBITAL MUSCLES AS SEEN IN  
 PRESENT SERIES (PERCENTAGES)

Muscle	Ophthalmic Artery Crossed											
	Over Optic Nerve					Under Optic Nerve						
	Total Number of Specimens	Number of Branches in Specimen					Total Number of Specimens	Number of Branches in Specimen				
		1	2	3	4	5		1	2	3	4	5
Lateral rectus	43	44.2	39.5	11.6	4.7		15	26.7	60.0	13.3		
Superior rectus	44	52.3	34.1	13.6			15	53.3	40.0	6.7		
Medial rectus	43	18.6	11.6	41.9	27.9		15	20.0	13.3	53.3	26.7	6.7
Inferior rectus	44	95.5	2.3	2.3			15	73.3	26.7			
Inferior oblique	44	100					15	100				
Superior oblique	43	39.5	46.5	9.3	2.3	2.3	15	53.3	20.0	20.0		6.7
Levator	41	56.1	36.6	4.9	2.4		12	58.3	25.0	16.7		

the findings in the present series do not support this view, particularly when the ophthalmic artery crossed under the optic nerve.

Meyer (1887) stated that the four trunks of the muscular arteries (superior external, inferior internal, arising in common with the medial posterior ciliary, and small inconstant branches from the ophthalmic artery) are just as important in charting the branches of the ophthalmic artery as such regular branches as the supra-orbital and posterior ethmoid. However, in the present series, although the various independent muscular arteries (*e.g.* the medial muscular, and those supplying the superior rectus, levator, superior oblique, and medial rectus: Table II) can often be localized, the lateral muscular is too inconstant to deserve a place in this localization.

Most authors have described the anterior ciliaries as arising from these muscular arteries which pierce the sclera anteriorly. Because they did not fill properly with Neoprene, these branches were not studied in the present series.

### Posterior Ethmoid Artery

This branch is small and inconstant according to Quain (1892), Whitnall (1932), Wolff (1954), and Gillilan (1961). Meyer (1887) found it to be absent in four, weakly developed in three, strong in two, and of the usual type in eleven of his twenty specimens. According to Meyer and also to Gillilan (1961), the volume of this artery is reciprocal to that of the anterior ethmoid.

In the present series, the posterior ethmoid was present in 81.8 per cent. of the specimens in which the ophthalmic artery crossed *over* the optic nerve and in 85.7 per cent. of those in which it crossed *under*.

**SIZE.**—This was variable, being of the usual type in 66·7 per cent., exceptionally large in 30·6 per cent., and exceptionally small in 2·8 per cent. when the ophthalmic artery crossed *over* the optic nerve; the percentages were 41·7, 41·7, and 16·7 per cent. respectively when the ophthalmic artery crossed *under* the optic nerve. When the anterior ethmoid was absent, the posterior ethmoid was large in all except one specimen in which it was small. There was little correlation between the sizes of the two ethmoid arteries, though at times it appeared that one tried to compensate the other.

**ORIGIN.**—It arises from the ophthalmic artery, independently, in common with supra-orbital (Meyer, 1887; Quain, 1892), or from the lacrimal (Haller, 1781); Zuckerkandl (1876) described a case in which it arose from the supra-orbital as anomalous. Only Meyer (1887) has given details of the sixteen specimens in which it was present. He found that it arose in common with supra-orbital in eight, before the supra-orbital in five, and after the supra-orbital in two, in one of which the supra-orbital was absent.

The mode, order, and site of origin of the posterior ethmoid artery as seen in the present series are shown in Table XVI.

TABLE XVI  
ORIGIN AND MUSCLES SUPPLIED BY POSTERIOR ETHMOID ARTERY AS SEEN IN PRESENT SERIES (PERCENTAGES)

Origin and Supply		Ophthalmic Artery Crossed	
		<i>Over</i> Optic Nerve	<i>Under</i> Optic Nerve
Site of Origin	Second part of ophthalmic: Over optic nerve	2·8	Nil
	Medial to nerve	Nil	8·3
	Bend of ophthalmic	77·8	83·3
	Third part of ophthalmic	19·4	8·3
Relationship with Supra- Orbital	Before	50·0	50·0
	After	8·3	Nil
	Only posterior ethmoid present	16·7	8·3
	Both arising together	25·0	41·7
Mode of Origin	Independent branch	75·0	41·7
	With supra-orbital	22·2*	25·0
	With supra-orbital + anterior ethmoid	2·8*	8·3
	With supra-orbital + lacrimal	Nil	8·3
	With lacrimal	Nil	8·3
	With lacrimal + lateral posterior ciliary	Nil	8·3
Muscles Supplied	Total supplying muscles	66·7	66·7
	Superior oblique	58·3	50·0
	Superior rectus	8·3	8·3
	Levator	27·8	33·3
	Medial rectus	5·6	8·3
Specimens where Present		36	12
Total Number of Specimens Studied		44	14

\* Branch to levator arising in common, in one specimen in each.

**COURSE.**—After its origin the artery is said to run between the medial rectus and superior oblique to enter the posterior ethmoid canal through which it enters the cranial cavity and goes to the nose. Occasionally, it passes over the superior oblique (Meyer, 1887; Adachi, 1928; Hollinshead, 1954).

In the present series, it entered the posterior ethmoid canal by passing between the superior oblique and levator in 31 specimens and between the superior oblique and medial rectus in four specimens, when the ophthalmic artery crossed *over* the optic nerve; it took the former course in eleven and the latter course in one when the ophthalmic artery crossed *under* the optic nerve. Very rarely, instead of passing between the superior oblique and levator, it pierced the levator. This artery terminated in the canal without entering the cranial cavity in some cases.

**BRANCHES.**—Only Meyer (1887) gives details of these. Half of his cases showed muscular branches (to the superior oblique in 3; to the levator and superior oblique in 2; to the levator, superior oblique, and superior rectus in 2; to the levator, superior oblique, and medial rectus in 2; and to medial rectus and superior oblique in 1). In addition to these intra-orbital muscular branches, various workers have described certain extra-orbital branches, *e.g.* to the posterior ethmoid cells, meningeal branches to the anterior cranial fossa, and nasal branches.

In the present series the posterior ethmoid supplied superior oblique, the superior and medial recti, and the levator (Table XVI). It also sometimes supplied the nose, ethmoid air sinuses, and less commonly the falx and dura in the anterior cranial fossa, the periosteum and areolar tissue in the orbit, and very rarely the sphenoid air sinus.

### Supra-orbital Artery

This artery is usually present, though Quain (1892) and Whitnall (1932) described it as inconstant. Meyer (1887) observed that it was missing in one of his twenty specimens and weakly developed in three.

In the present series it was absent in 18.2 per cent. of the specimens in which the ophthalmic artery crossed *over* the optic nerve and in 7.1 per cent. of those in which it crossed *under*.

**SIZE.**—It was of medium size in about 70 per cent., abnormally big in about 20 per cent., and very small in about 10 per cent.

**SITE OF ORIGIN.**—It was said to arise from the ophthalmic artery as the latter lies *over* the optic nerve (Haller, 1781; Meyer, 1887; Quain, 1892; Whitnall, 1932; Wood Jones, 1949; Brash, 1951; Wolff, 1954; Bedrossian, 1958; Johnston and others, 1958) or *medial* to the optic nerve (Meyer, 1887; Duke-Elder, 1932; Schaeffer, 1953). It was also seen to arise from the first part of the ophthalmic artery (Meyer, 1887) and at the apex of the orbit (Haller, 1781), at the level of the origin of the central retinal (Meyer, 1887) or posterior to it (Haller, 1781). It arose in common with the posterior ethmoid in eight out of twenty specimens seen by Meyer (1887) and also in cases seen by Whitnall (1932). Haller (1781) stated that it rarely arose from the lacrimal, and Meyer (1887) saw this in one of his specimens. Meyer (1887) also found it arising after the anterior ethmoid in one other specimen.

The site and mode of origin as seen in the present series are shown in Table XVII.

TABLE XVII  
SITE AND MODE OF ORIGIN OF SUPRA-ORBITAL ARTERY AS SEEN IN  
PRESENT SERIES (PERCENTAGES)

Origin		Ophthalmic Artery Crossed	
		<i>Over</i> Optic Nerve	<i>Under</i> Optic Nerve
Mode	Independent branch	69.4	61.5
	With posterior ethmoid	22.2*	23.1
	With ethmoid	2.8*	7.7
	With supra-trochlear	2.8	Nil
	With posterior ethmoid + lacrimal	Nil	7.7
	With lateral muscular	2.8	Nil
Site	Second part of ophthalmic over the optic nerve	5.6	Nil
	Bend of ophthalmic	38.9	38.5
	Third part of ophthalmic	47.2	46.1
	Terminal branch	8.3	15.4
Number of Specimens in which this Artery was Present		36	13
Total Number of Specimens Studied		44	14

\* A branch to the levator arose in common with it in one specimen.

**COURSE.**—It passed between the superior oblique on the medial side and the levator and superior rectus on the lateral side. It then ran under cover of the orbital periosteum to the supra-orbital notch or foramen where it entered the scalp.

**BRANCHES.**—Those in the orbit have been very variably described. Some go to the levator (Meyer, 1887; Whitnall, 1932; Duke-Elder, 1932; Schaeffer, 1953; Wolff, 1954; Bedrossian, 1958; Johnston and others, 1958), some to the superior rectus (Meyer, 1887; Duke-Elder, 1932; Schaeffer, 1953; Johnston and others, 1958), some to the superior oblique (Meyer, 1887), some to the orbital periosteum (Whitnall, 1932; Duke-Elder, 1932; Schaeffer, 1953; Wolff, 1954; Bedrossian, 1958), and some to the diploe of the frontal bone (Whitnall, 1932; Duke-Elder, 1932; Schaeffer, 1953; Wolff, 1954; Bedrossian, 1958; Johnston and others, 1958), as well as the usual branches to the scalp and upper eyelids. In three specimens, Meyer (1887) observed that a branch from the supra-orbital pierced the roof of the orbit and supplied the periosteum of the anterior cranial fossa.

In the present series, branches from the supra-orbital were seen in 21 specimens in which the ophthalmic artery crossed *over* the optic nerve, and in seven in which it crossed under the optic nerve. Muscular branches to the superior rectus, superior oblique, and levator were given off by the majority of these (to the superior rectus in 4, the levator in 12, the superior rectus + levator in 3, and to the superior oblique in 6, in which the ophthalmic artery crossed *over* the optic nerve, the numbers being one, three, one, and one respectively in those in which the ophthalmic artery crossed *under* the optic nerve). In addition branches ran to the orbital periosteum and areolar tissue, and very rarely to the trochlea and the dura of the anterior cranial fossa. It also sometimes gave off branches to the upper lids, and ultimately it supplied the scalp.

**Anterior Ethmoid Artery**

This is usually larger than the posterior ethmoid (Quain, 1892; Whitnall, 1932; Wood Jones, 1949; Brash, 1951; Schaeffer, 1953; Wolff, 1954; Hollinshead, 1954) and is constantly present (Whitnall, 1932). Meyer (1887) observed it to be very weakly developed in two, strong in five, very strong in three, and of the usual type in ten—of his twenty specimens, the size being reciprocal to that of the posterior ethmoid. Haller (1781) and Zuckerkandl (1876) pointed out that it might be absent or weakly developed.

In the present series, the anterior ethmoid was present in 90·9 per cent. of the specimens in which the ophthalmic artery crossed *over* the optic nerve, and in 80 per cent. of those in which it crossed *under*. If the anterior ethmoid was absent, the posterior ethmoid was always present and *vice versa*.

**SIZE.**—In the forty specimens in which the ophthalmic artery crossed *over* the optic nerve and the anterior ethmoid was present, the size of the latter was variable (22 specimens were large, 16 were of medium size, and two were small). The anterior ethmoid represented the main continuation of the ophthalmic artery in two cases in which the actual ophthalmic artery beyond this was abnormally small, in two it was bigger than the ophthalmic artery continuation, and in six specimens it was of the same size as the ophthalmic artery continuation. When the ophthalmic artery crossed *under* the optic nerve, the anterior ethmoid was large in eight specimens, medium in three, and small in one; it formed the main continuation of the ophthalmic artery in two cases in which the continuation was very small and in four specimens the two arteries were equal in size.

**ORIGIN.**—It was said to arise from the ophthalmic artery as the latter lies between the medial rectus and the superior oblique by Schaeffer (1953) and Wolff (1954), and was once seen to arise from the temporal artery by Zuckerkandl (1876).

The site and mode of origin as seen in the present series are shown in Table XVIII.

TABLE XVIII  
SITE AND MODE OF ORIGIN OF ANTERIOR ETHMOID ARTERY AS SEEN IN PRESENT SERIES (PERCENTAGES)

Origin		Ophthalmic Artery Crossed	
		<i>Over</i> Optic Nerve	<i>Under</i> Optic Nerve
Site	Bend of ophthalmic	2·5	8·3
	Third part of ophthalmic	97·5	91·7
Mode	Independent branch	97·5	91·7
	With posterior ethmoid + supra-orbital	2·5	8·3
Number of Specimens in which this Artery was Present		40	12
Total Number of Specimens Studied		44	15

**COURSE.**—This is described by various workers in the same way. It passes through the anterior ethmoid canal into the cranial cavity, passes through the cribriform plate, enters the nose, and ultimately supplies the skin of the nose.

In the present series, the anterior ethmoid ran medially and usually entered the anterior ethmoid foramen by passing under the superior oblique immediately after its origin. But very rarely (in two specimens in which the ophthalmic artery crossed *over* the optic nerve and in one in which it crossed *under*) the anterior ethmoid crossed over the superior oblique. The ophthalmic artery was usually anchored to the medial wall of the orbit by the anterior ethmoid.

**BRANCHES.**—It gives these off to the ethmoid cells—usually anterior and middle, the frontal sinus, the meningeal to the dura in the anterior cranial fossa, the nasal, and the skin of the nose. Meyer (1887) found branches going to the medial rectus in one specimen and to the medial rectus and superior oblique in the two others.

In the present series the anterior ethmoid gave out intra-orbital branches to the superior oblique in ten specimens in which the ophthalmic crossed *over* the optic nerve and in four in which it crossed *under*. It rarely gave out branches to the orbital periosteum and areolar tissue on the medial side of the orbit. During its intra-canalicular course, branches were given off to the ethmoid air cells. During its intra-cranial course, a variable number of branches was given off to the dura of the anterior cranial fossa, the falx cerebri, the frontal air sinus, anastomotic branches connecting the two anterior ethmoid arteries lying close to each other, and branches dipping in to the nose. Since all these branches were not always filled completely, their exact incidence cannot be given.

### Medial Palpebral Arteries

These run to the upper and lower lids from the medial side.

**ORIGIN.**—They arise below the trochlea of the superior oblique, either separately or jointly (Wood Jones, 1949; Schaeffer, 1953; Hollinshead, 1954). According to Quain (1892) they usually arise together and soon divide, but Whitnall (1932) found them arising separately. Duke-Elder (1932) described them as arising from the dorsal nasal artery below the trochlea.

In the present series, arteries running in the medial part of the eyelids usually arose as separate branches for the upper and lower lids, which may be called the superior and inferior medial palpebrals, but less commonly they arose together or with some other branch of the ophthalmic artery (Table XIX). When the superior and inferior medial palpebrals arose together, the inferior followed the main direction of the parent stem while the superior looked like a small branch from it. The inferior was invariably bigger than the superior, and was at times as big as the main continuation of the ophthalmic artery.

**SITE OF ORIGIN.**—They invariably arose under the trochlea and were close together when they arose separately. At the site of origin of these branches, the ophthalmic artery usually made a bend to run up to its bifurcation. The superior arose as a terminal branch of the ophthalmic artery in two specimens; in one the ophthalmic artery crossed *over* the optic nerve and in the other it crossed *under*. The inferior represented the main continuation of the ophthalmic artery in one specimen in which the ophthalmic artery crossed *over* the optic nerve.

**COURSE.**—They pass above and below the medial palpebral ligament to enter the upper and lower eyelids respectively, where they anastomose with corresponding lateral palpebral arteries to form arterial arches.

TABLE XIX  
MODE OF ORIGIN OF MEDIAL PALPEBRAL ARTERIES AS SEEN IN  
PRESENT SERIES (PERCENTAGES)

Mode of Origin		Ophthalmic Artery Crossed	
		<i>Over</i> Optic Nerve	<i>Under</i> Optic Nerve
Superior Medial Palpebral	Independent branch	60.5	53.8
	With inferior medial palpebral	25.6	38.5
	With supra-trochlear	4.7	Nil
	Absent	9.3	7.7
Inferior Medial Palpebral	Independent branch	72.1	61.5
	With superior medial palpebral	25.6	38.5
	With dorsal nasal	2.3	Nil
	Absent	Nil	Nil
Total Number of Specimens Studied		43	13

BRANCHES.—Whitnall (1932), Duke-Elder (1932), and Johnston and others (1958) found that each divided into a large marginal and a small peripheral branch lying along the two corresponding margins of the tarsus in the lids, thus forming two arterial arches in each lid, the marginal arch being 3 mm. from the margin of the lid. The peripheral branch in the lower lid has been described as inconstant. The arterial arch in front of the upper margin of the tarsus in the upper eyelid was called the "arcus tarsus superior" by Wolff (1954). Besides their anastomoses with the lateral palpebral branches of the lacrimal, they also anastomose freely with the surrounding arteries, and supply the lids and lacrimal apparatus. According to Whitnall (1932) and Duke-Elder (1932), the superior supplies the caruncle and lacrimal sac while the inferior supplies the naso-lacrimal duct.

In the present series, the superior passed above the medial palpebral ligament to enter the upper eyelid. This branch, besides supplying the upper lid, sometimes supplied the lacrimal sac, nose, and levator also. In the lid it usually anastomosed with the lateral palpebral branch of the lacrimal or rarely with the lacrimal itself. The inferior passed downwards behind the medial palpebral ligament to enter the lower lid. Besides supplying the lower lid it invariably gave off a branch to the lacrimal sac which usually arose where the artery turned from its initial vertical course to run horizontally in the lower lid. At times branches were given off to the upper lid, medial wall, and floor of the orbit and rarely to the naso-lacrimal duct and the nose. This artery anastomosed with the corresponding lateral palpebral branches and less commonly with the infra-orbital, lacrimal, or muscular branches.

Within the eyelids these arteries run between the orbicularis oculi and the tarsus, and the major branch usually runs along the free margin of the lid.

### Supra-trochlear Artery

The supra-trochlear or frontal artery has been described as one of the terminal divisions of the ophthalmic artery (Table I).

In the present series also it was one of the terminal branches, except in two specimens (in one the ophthalmic artery crossed *over* the optic nerve and in the other it crossed *under*) in which it was not a terminal branch



but arose from the third part of the ophthalmic artery near its termination. In two specimens in which it was a terminal branch (and in which the ophthalmic artery crossed *over* the optic nerve) it represented the main continuation of the ophthalmic artery. The artery was usually the larger of the two terminal branches, but at times it was equal to the other, and rarely it was smaller.

It pierces the orbital septum to enter the scalp (Whitnall, 1932; Duke-Elder, 1932; Schaeffer, 1953; Wolff, 1954; Hollinshead, 1954), but may arise anterior to the septum (Hollinshead, 1954). It terminates in the scalp where it anastomoses with the surrounding arteries, but in two specimens (Table XIX) it gave off superior medial palpebral branches.

#### **Dorsal Nasal (or Nasal) Artery.**

This has been described as the other terminal branch of the ophthalmic artery (Table I), and usually fulfilled this role in the present series. When the ophthalmic artery crossed *over* the optic nerve, it was a terminal branch in forty specimens, arose from the distal part of the third part of the ophthalmic artery under or distal to the trochlea in two cases, and was absent in the remaining two. When the ophthalmic artery crossed *under* the optic nerve, it was a terminal branch in twelve specimens, arose from the third part in one, and was absent in two. In one specimen of the former series it appeared to be a main continuation of the ophthalmic artery on the face. It was usually the smaller of the two terminal branches, but was sometimes bigger than or equal to the other.

It pierces the orbital septum above the medial palpebral ligament to enter the face (Whitnall, 1932; Duke-Elder, 1932; Schaeffer, 1953; Hollinshead, 1954; Wolff, 1954; Johnston and others, 1958), and runs on to the root of the nose and establishes, in addition to other anastomoses, an important anastomosis with the angular branch of the facial artery. This has been said to replace at times the facial artery (Quain, 1892; Whitnall, 1932; Wolff, 1954). According to Johnston and others (1958), it divides into two at the root of the nose—one branch anastomosing with the terminal branch of the facial artery while the other runs on the dorsum of the nose to anastomose with the other side. The dorsal nasal has also been said to give off a branch to the lacrimal sac.

In the present series the dorsal nasal supplied the scalp and forehead near the midline, and rarely the lacrimal sac, and in one specimen it gave rise to the inferior medial palpebral artery (Table XIX).

#### **Additional Branches**

Besides the named branches described above, the ophthalmic artery also gives out certain small irregular branches which have been described by various workers from time to time.

*Small Meningeal Arteries.*—These have been described as arising from the ophthalmic artery and passing through the superior orbital fissure by Duke-Elder (1932), Brash (1951), Wolff (1954), Bedrossian (1958), and Johnston and others (1958). They may be the branches of the lacrimal (Quain, 1892), and may anastomose with similar branches from the internal carotid (Quain, 1892; Brash, 1951; Wolff, 1954; Bedrossian, 1958), or from the middle and accessory meningeals (Brash, 1951; Johnston and others, 1958). Duke-Elder (1932) mentioned only one such branch and called it the anterior meningeal; Johnston and others (1958) also mentioned one which they called the meningeal artery; Quain (1892) thought that there might be one or two such branches.

In the present series one such meningeal branch was seen in only about one-eighth of the specimens, in all of which the ophthalmic artery crossed *over* the optic nerve, and in most of which the normal lacrimal artery was missing. This branch arose in each case from the proximal part of the ophthalmic artery.

The recurrent meningeal branch from the lacrimal, which was present in the majority of the specimens, has already been described.

*Branches Supplying the Loose Areolar Tissue lying Medial to the Eyeball.*—These were seen in most of the specimens of the present series. They arose from the third part of the ophthalmic artery, usually in close proximity to the anterior ethmoid; they varied in number from one to three and were mostly small.

*Periosteal Branches.*—Less frequently one to four branches to the anterior part of the medial wall of the orbit were seen arising from the third part of the ophthalmic artery close to the trochlea of the superior oblique. They sometimes supplied the lacrimal sac and occasionally even entered the nasal cavity.

### Summary

A study of the branches of the ophthalmic artery has been carried out in 59 human orbits. Their site, order, mode of origin, and distribution have been investigated. Though no "normal pattern" of these branches can be given because of their extreme variability, a characteristic distinction was observed when the ophthalmic artery crossed *over* or *under* the optic nerve in the second part of its course. These two groups have been dealt with separately throughout in order to reveal their separate entity.

When the ophthalmic artery crossed *over* the optic nerve, the various branches were collateral to the optic nerve, central retinal artery with the medial posterior ciliary, lateral posterior ciliary, lacrimal, muscular to superior rectus and/or levator palpebrae superioris, posterior ethmoid, supra-orbital, medial posterior ciliary, medial muscular, muscular to superior oblique and medial rectus, to areolar tissue medial to the eyeball, anterior ethmoid, medial palpebral, and terminal (supra-trochlear and dorsal nasal) in that order from the proximal to the distal parts of the ophthalmic artery.

When the ophthalmic artery crossed *under* the optic nerve, there were the collateral branches to the optic nerve, lateral posterior ciliary, central

retinal, medial muscular, medial posterior ciliary, lacrimal, muscular to superior rectus and levator, posterior ethmoid, supra-orbital, muscular to superior oblique and medial rectus, anterior ethmoid, to areolar tissue medial to the eyeball, medial palpebral, and terminal (supra-trochlear and dorsal nasal) respectively.

The branches were distributed along the course of the ophthalmic artery, but most of them were usually crowded together at two points—where the ophthalmic artery bent from the first to the second part and from the second to the third part. A detailed description of each branch of the ophthalmic artery is given and the findings are discussed and compared with those of previous authors.

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## CORRECTIONS

In the February issue (*Brit. J. Ophthalm.* (1962), **46**, 97), the reference to Barkow (1866) should read Taf. 17, Fig. 3, *not* Taf. 18.

In the March issue (*Brit. J. Ophthalm.* (1962), **46**, 185), the reference to Hayreh (1962) should read p. 212, *not* p. 208.