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THE OPHTHALMIC ARTERY
II. INTRA-ORBITAL COURSE*

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Material

THIS study was carried out in 61 human orbits obtained from 38 dissection-room cadavers. In 23 cadavers both the orbits were examined, and in the remaining fifteen only one side was studied. With the exception of three cadavers of children aged 4, 11, and 12 years, the specimens were from old persons.

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 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 was carefully studied within the orbit.

Observations

COURSE

For descriptive purposes the intra-orbital course of the ophthalmic artery has been divided into three parts (Singh and Dass, 1960).

(1) *The first part* extends from the point of entrance of the ophthalmic artery into the orbit to the point where the artery bends to become the second part. This part usually runs along the infero-lateral aspect of the optic nerve.

(2) *The second part* crosses over or under the optic nerve running in a medial direction from the infero-lateral to the supero-medial aspect of the nerve.

(3) *The third part* extends from the point at which the second part bends at the supero-medial aspect of the optic nerve to its termination. It lies medial to the nerve.

In two places the ophthalmic artery bends to change direction: one is seen at the junction of the first and the second parts and is designated the "Angle" in the text (Sudakevitch, 1947; Hayreh, 1958; Hayreh and Dass, 1959;

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Singh and Dass, 1960), and the second is seen between the second and third parts and is designated the "Bend" to differentiate it from the former (Fig. 1).

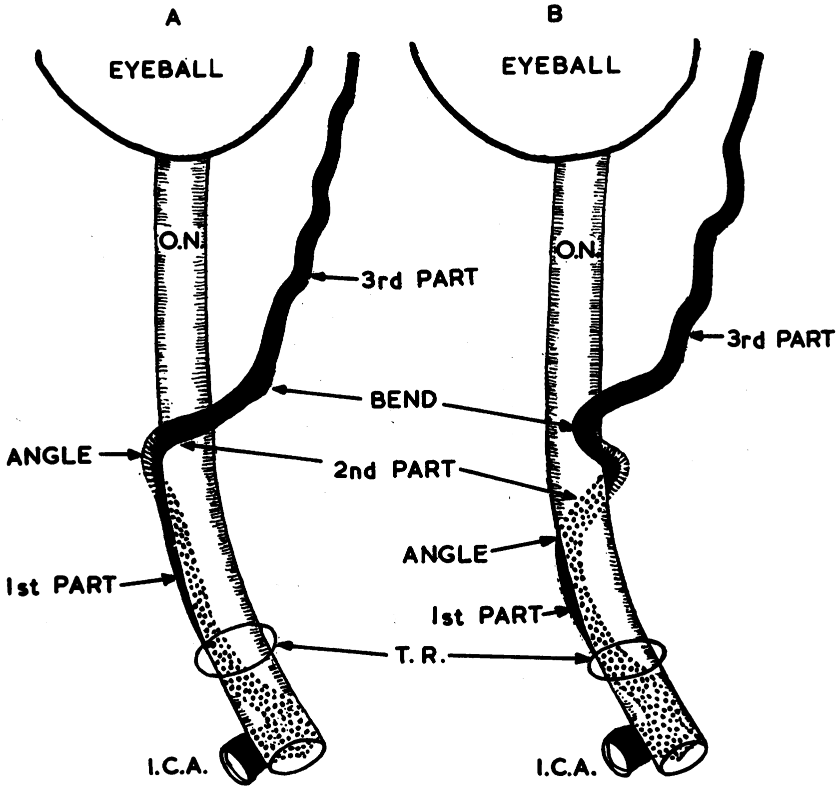
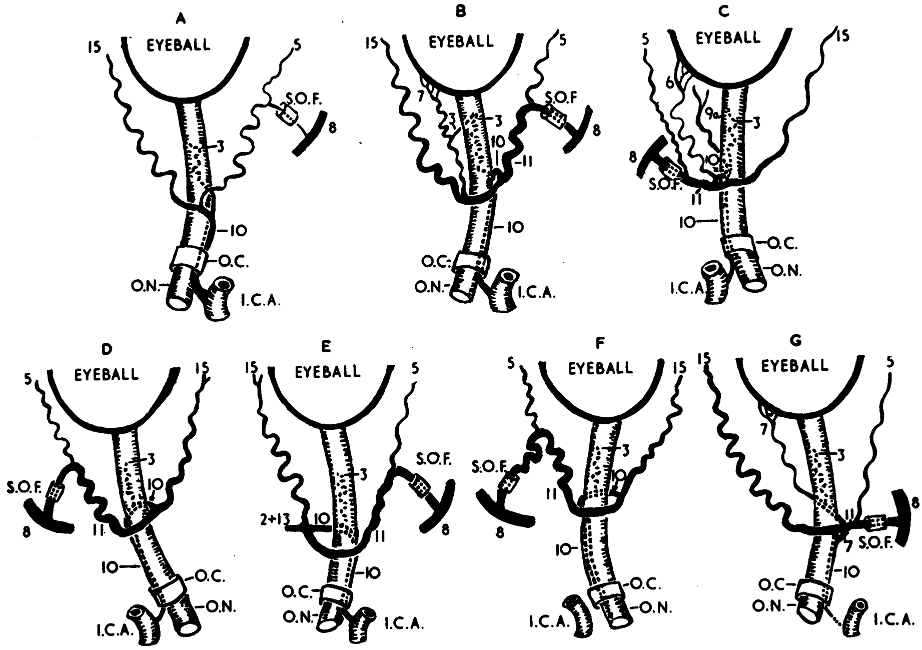


FIG. 1.—Course of ophthalmic artery. (A) The ophthalmic artery crosses OVER the optic nerve. (B) The ophthalmic artery crosses UNDER the optic nerve. I.C.A. = Internal carotid artery. O.N. = Optic nerve. T.R. = Tendinous ring.

First Part.—In 58 specimens the ophthalmic artery entered the orbit through the optic canal. In another two specimens the intra-canalicular and intra-cranial part of the artery was either absent or degenerated (Fig. 2–F, G, opposite).

At the apex of the orbit the artery lay under the lateral (55 specimens), central (1 specimen), or medial (4 specimens) part of the optic nerve. In one specimen the artery entered the orbit through the superior orbital fissure.

The first part of the ophthalmic artery ran along the infero-lateral aspect of the optic nerve in 51 specimens and along the infero-medial aspect in one (Fig. 3–I, overleaf). In three it ran forwards and upwards on the lateral side of the optic nerve. In four specimens it entered the orbit at the infero-medial aspect of the optic nerve, but then formed a tortuous loop or bend under the nerve near the apex of the orbit and so came to lie along the infero-lateral aspect of the nerve, and ran the rest of its course along this aspect.



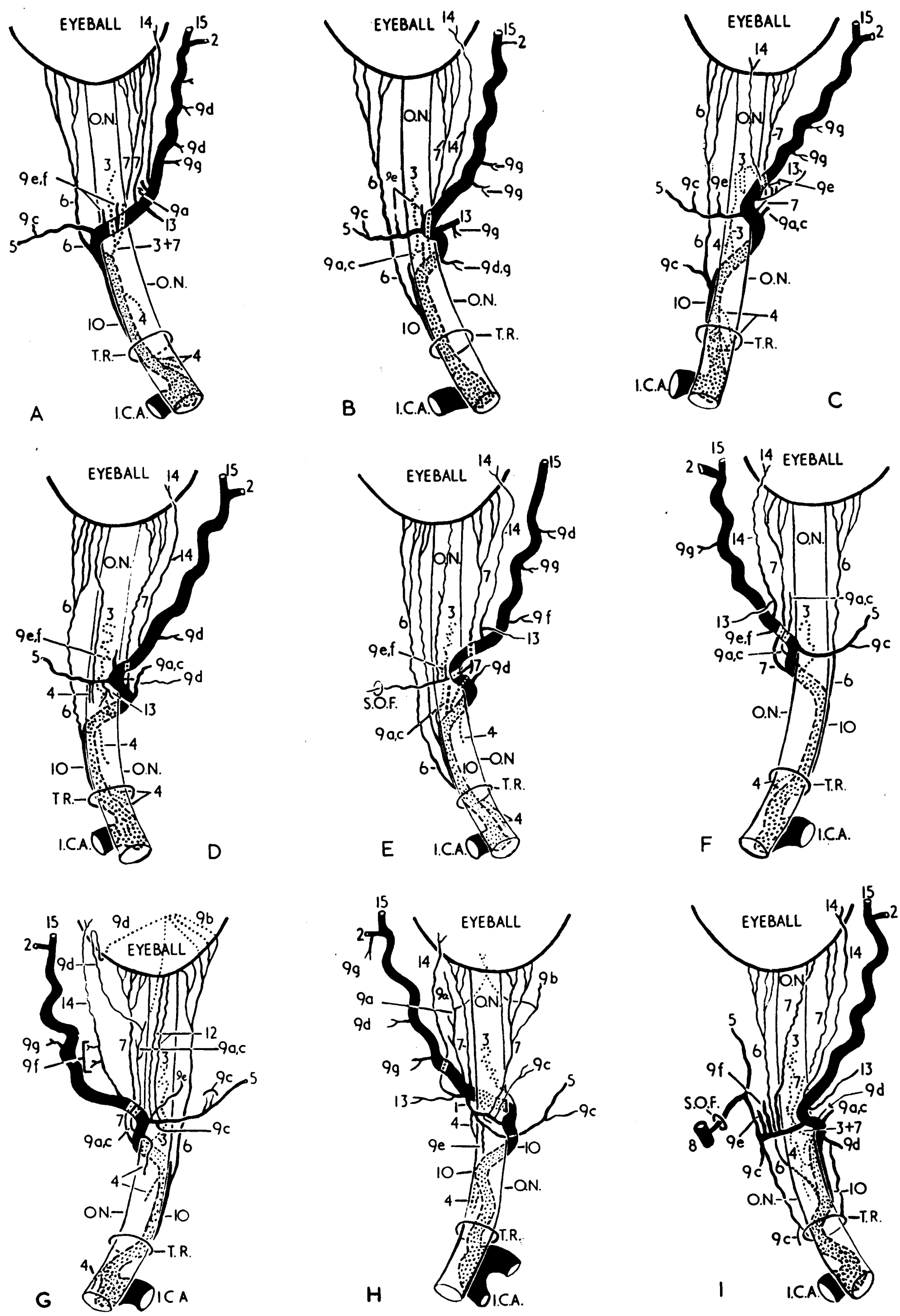
KEY TO FIG. 2

2. Anterior ethmoid artery.
3. Central retinal artery.
5. Lacrimal artery.
6. Lateral posterior ciliary artery.
7. Medial posterior ciliary artery.
8. Middle meningeal artery.
9a. Muscular artery to medial and inferior recti and inferior oblique.
10. Ophthalmic artery trunk from internal carotid artery.
11. Ophthalmic artery trunk from middle meningeal artery.
13. Posterior ethmoid artery.
15. Main continuation of ophthalmic artery.
I.C.A. = Internal carotid artery.
O.C. = Optic canal.
O.N. = Optic nerve.
S.O.F. = Superior orbital fissure.

FIG. 2.—Variations in origin and intra-orbital course of ophthalmic artery. (A) Normal. (B, C, D, E) The ophthalmic artery arises from the internal carotid artery as usual, but the major contribution comes from the middle meningeal artery. (F, G) The only source is the middle meningeal artery, as the connexion with the internal carotid artery is either absent (F) or obliterated (G).

Similarly, in another specimen, it entered the orbit under the centre of the nerve and then came to lie along its infero-lateral aspect. In still another instance, having entered the orbit at the infero-lateral aspect of the optic nerve, it ran forwards and medially under the nerve to reach its infero-medial aspect at the angle (Fig. 3–K). The first part of the ophthalmic artery usually lay in very close relationship with the optic nerve, free in the fat of the orbit and attached to the nerve only by fat and very loose connective tissue. In rare cases it was firmly fixed to the optic nerve, particularly in its proximal part. In five specimens this part of the ophthalmic artery showed a slight tortuosity.

The first part of the ophthalmic artery was of small calibre in six specimens where the main source (in four specimens) or the only source (in two specimens) of the blood supply to the orbit came from the middle meningeal artery (Fig. 2).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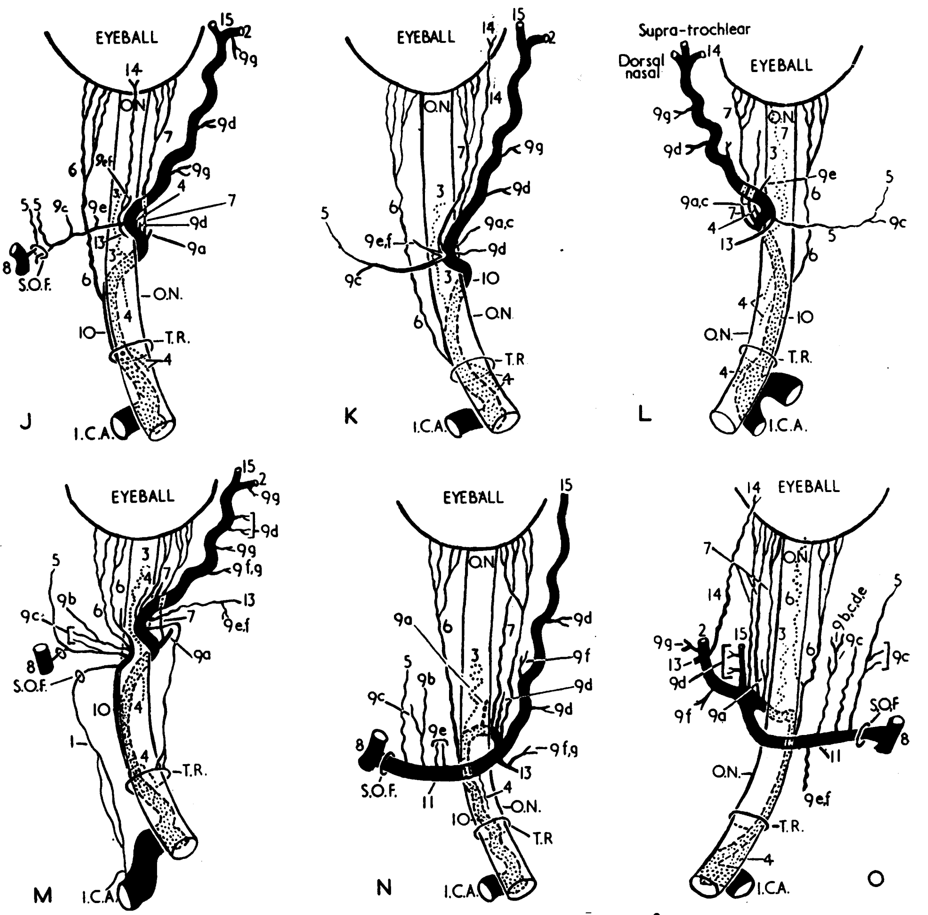
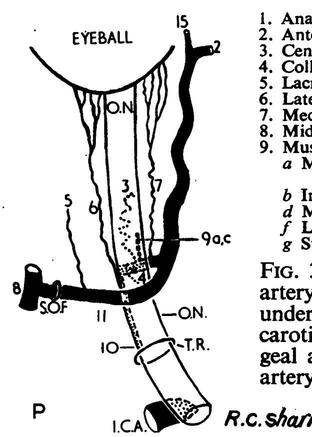




KEY TO FIG. 3

1. Anastomotic channel.
2. Anterior ethmoid.
3. Central retinal.
4. Collateral branch.
5. Lacrimal.
6. Lateral posterior ciliary.
7. Medial posterior ciliary.
8. Middle meningeal.
9. Muscular arteries to:
   a Medial and inferior recti and inferior oblique.
   b Inferior rectus. *c* Lateral rectus.
   d Medial rectus. *e* Superior rectus.
   f Levator palpebrae superioris.
   g Superior oblique.
10. Ophthalmic artery trunk from internal carotid (I.C.A.).
11. Ophthalmic artery trunk from middle meningeal (8).
12. Posterior ciliary.
13. Posterior ethmoid.
14. Supra-orbital.
15. Main continuation of ophthalmic artery.

I.C.A. = Internal carotid artery.
O.N. = Optic nerve.
S.O.F. = Superior orbital fissure.
T.R. = Tendinous ring.

FIG. 3.—Variations in origin, course, and branches of ophthalmic artery. (A) Usual pattern. (B) to (P) Ophthalmic artery crosses under optic nerve. (N, O) Ophthalmic artery arises from internal carotid as usual, the major contribution comes from middle meningeal artery. (P) The only source of blood is the middle meningeal artery, as the connexion with the internal carotid artery is absent. Because of incomplete injection of this specimen, the small branches could not be traced. N, O, and P are the details of Fig. 2D, 2E, and 2F respectively.

"Angle".—This was constantly present and was usually well defined. It usually lay at the infero-lateral aspect of the optic nerve (56 specimens), but was situated at the supero-lateral aspect in three and at the infero-medial aspect in two (Fig. 3–I, K).

The angle was measured in eighty specimens: it was acute in three, right-angled in 32; and obtuse (generally 120° to 135°, maximum 170°) in 45. It was noticed that the wider the angle, the less commonly was it seen, so that angles of 160°–170° were very rare. In three children the angles on each side were about 120° and 135°, 120° and 150°, and 135° and 135° respectively.

The angle on the two sides of the same individual was seldom the same and a wide difference was often seen, the angle on the left being usually greater than that on the right. The angle was usually well defined, but might at times be rounded off and ill defined. It did not adhere to the sheath of the optic nerve but was attached to the latter only by very loose connective tissue.

Second Part.—The second part of the ophthalmic artery crossed medially over the optic nerve in 82·6 per cent. of 161 specimens, and under in 17·4 per cent. The latter group includes two specimens (1·24 per cent.) in which the ophthalmic artery had no chance of crossing under the nerve because the angle was situated at the infero-medial border of the optic nerve instead of at the infero-lateral border (Fig. 3–I, K).

In 64 individuals (*i.e.* in 128 orbits), the crossing of the ophthalmic artery over or under the optic nerve was studied in both orbits. In 70·3 per cent. it crossed *over* on both sides, in 4·7 per cent. it crossed *under* on both sides, and in 25·0 per cent. it crossed *over* on one side and *under* on the other. In the remaining 33 specimens only one side was studied.

Although the second part wound closely round the optic nerve it was only loosely attached to the dural sheath. The direction in which the second part of the ophthalmic artery ran depended upon the size of the angle and on whether it crossed over or under the optic nerve.

"Bend".—This was usually clear enough but was not as well-defined as the "angle".

Third Part.—This ran medial to the optic nerve but was not intimately related to it. After the bend, the ophthalmic artery ran forwards above the medial rectus and under the superior oblique to reach the medial wall of the orbit close to the anterior ethmoid foramen. This was usually the only part of the ophthalmic artery which showed marked tortuosity in the majority of the specimens. It was usually anchored to the medial wall of the orbit by the short stout trunk of the anterior ethmoid artery, and then ran forwards close against the medial wall, passed below the trochlea, and then generally ran upwards and forwards to lie nearly midway between the medial palpebral ligament and the orbital margin. A tortuous loop formation was sometimes seen just proximal to the termination of the artery.

In one specimen the artery passed over the superior oblique to reach the anterior ethmoid foramen and continued as the anterior ethmoid artery. In this specimen the normal course of the ophthalmic artery beyond this point was represented by the continuation forwards of a very small trunk arising at the point where the ophthalmic artery bent to enter the anterior ethmoid foramen.

Termination.—The artery normally terminated at the supero-medial angle of the orbital opening, but in four specimens (including both sides in one individual) it terminated at the anterior ethmoid artery, and the normal course of the ophthalmic artery was very much reduced in size beyond this point. In two more specimens the anterior ethmoid artery was bigger than the main continuation, and in ten the anterior ethmoid artery and the main continuation were the same size. Thus, in about 25 per cent. of the specimens, the main part of the ophthalmic artery finished near the foramen where the anterior ethmoid artery arose, and was reduced in size beyond this point.

The terminal branches as seen in our 59 specimens (including those in which it terminated in the anterior ethmoid artery and a small branch represented the normal continuation) were as follows:

Terminal Branches	Percent. of Cases
Supra-trochlear and dorsal nasal	83·0
Supra-trochlear and supra-orbital	3·4
Supra-orbital, dorsal nasal, and supra-trochlear	3·4 (Fig. 3-L)
Supra-trochlear and superior medial palpebral	1·7
Supra-trochlear as main continuation	5·1
Supra-trochlear and dorsal nasal in common with inferior medial palpebral	1·7
Inferior medial palpebral as main continuation	1·7

Size

The trunk of the ophthalmic artery was reduced in size in those specimens in which the blood supply to the orbit derived totally (two specimens, Fig. 2–F, G) or mainly (four specimens, Fig. 2–B, C, D, E) from the middle meningeal artery. In these six specimens, the normal anastomotic channel connecting the ophthalmic artery with the anterior division of the middle meningeal artery (*i.e.* the lacrimal artery and its recurrent meningeal branch) with the orbital branch of the anterior division of the middle meningeal artery (passing through the superior orbital fissure or through a special foramen in the greater wing of the sphenoid) became very prominent and replaced the normal channel from the internal carotid artery beyond that point. In all these specimens the part of the normal ophthalmic artery, from the internal carotid artery up to the point where the lacrimal artery joined it, was very much reduced in size. The part involved varied depending on whether the artery crossed over or under the optic nerve. In three specimens (Fig. 2–B, C, G), in which the ophthalmic artery crossed *over* the optic nerve, the reduced part extended from the origin up to the supero-lateral margin of the optic nerve, where the lacrimal artery took its origin. In the other three specimens (Fig. 2–D, E, F; Fig. 3–N, O, P), in which the ophthalmic artery crossed *under* the optic nerve, the reduced part extended up to the bend. In one specimen, however, the second part was bigger than the first part, but smaller than the trunk from the middle meningeal artery (Fig. 2–E; Fig. 3–O).

Discussion

Course of the Ophthalmic Artery.—Having passed through the optic canal, the ophthalmic artery usually lies infero-lateral to the optic nerve until it crosses *over* or *under* the nerve to proceed in a medial direction. According to Meyer (1887), the artery in so doing makes a spiral turn, which may be more or less pronounced depending upon whether it enters the optic canal more medially or more laterally. This well-formed spiral was described as an anomaly by Zuckerkandl (1876).

Wood Jones (1949) illustrated the first part of the ophthalmic artery as lying lateral to the lateral rectus and later bending up to cross over the optic nerve by passing between the superior and lateral recti. No such course was seen in the present series.

In the present series a tortuous loop in the first part was seen in five specimens; in four of these the artery entered the orbit under the medial part of the nerve and in the other under the centre.

The ophthalmic artery in the present series usually crossed *over* the optic nerve. According to von Haller (1781), this crossing is either gradual or abrupt. The fact that the ophthalmic artery quite often crosses under the optic nerve has been noted by many workers (Mayer, 1777; Zinn, 1780; von Haller, 1781; Blandin, 1834; Theile, 1841; Sömmerring, 1841; Arnold, 1847; Luschka, 1865; Zuckerkandl, 1876; Meyer, 1887; Quain, 1892; Adachi, 1928; Sudakevitch, 1947; Wolff, 1954; Hayreh, 1958; Hayreh and Dass, 1959; Singh and Dass, 1960). Table I (opposite) shows that the actual incidence of crossing *under* the optic nerve is very variously described by various authors.

Sudakevitch (1947) has further added that when the artery crosses under the nerve, this usually occurs in one eye only in any individual, a fact which has been confirmed in the present investigation. The ophthalmic artery crossed under the optic nerve unilaterally in 25 per cent. of the specimens and bilaterally in 4·7 per cent., whereas in the rest (70·3 per cent.) it crossed over the nerve bilaterally.

Theile (1841), Arnold (1847), and Luschka (1865) have further stated that some times the artery runs on the medial side of the optic nerve from the start,

TABLE I

INCIDENCE OF CROSSING *UNDER* THE OPTIC NERVE OF THE SECOND PART OF THE OPHTHALMIC ARTERY, FINDINGS OF VARIOUS AUTHORS COMPARED

Author	Date	No. of Specimens Examined	Percentage Incidence
Zuckerkandl	1876	20	15·0
Meyer	1887	20	10·0
Quain	1892	—	15·0
Adachi	1928	—	6·5
Sudakevitch	1947	103	13·6
Wolff	1954	—	15·0
Hollinshead	1954	—	15·0
Johnston, Davies, and Davies	1958	—	15·0
Hayreh	1958	70	27·1
Singh and Dass	1960	102	21·6
Present Series	1962	161	17·4

so that no crossing takes place under the nerve. Zuckerkandl (1876) saw this in two out of twenty specimens, and Meyer (1887) in one out of twenty specimens, and one such specimen was seen in the present series.

Meyer (1887), discussing the two anomalous courses of the ophthalmic artery described above (*i.e.* lying under the optic nerve or entirely medial to it), stated that these were the most important deviations from the normal in the intra-orbital part of the artery. He emphasized that these two variations though essentially different were identical genetically, as they were due to the abnormal development of the anastomoses between the branches arising from the proximal and distal parts of the ophthalmic artery and situated on the medial or inferior aspects of the dura mater of the nerve. The real trunk either degenerated and presented only as an anastomosis over the optic nerve (in one of his three specimens: Fig. 4–D, overleaf) or disappeared completely (in the other two: Fig. 4–C, E). Thus, according to Meyer, the anomaly depended upon the site of origin and course of the anastomosing branches, of which he described two kinds:

(*i*) On the inferior and medial surfaces of the dural sheath of the nerve, Meyer found branches running forwards from the proximal part and backwards from the distal part (Fig. 4–F). Although they were always present, their number varied greatly. Zinn (1780) and von Haller (1781) described similar branches. They may anastomose with each other, as already mentioned, and may form the abnormal ophthalmic artery. Meyer (1887) saw such a condition in one specimen of his series. Zinn (1780) mentioned that they could even anastomose with exactly similar branches arising from the internal carotid artery through the optic canal.

These collateral branches running on the dural sheath of the nerve were constantly seen in the specimens of the present series but were very indefinite in their number and arrangement. They nearly always ran backwards.

The branches arising from the proximal part arose from the ophthalmic artery as it lay in the subdural space intra-cranially, or at the apex of the orbit, or within the dural sheath in the optic canal, the last being the most common. They always ran backwards under the nerve without exception. They were very small and usually varied in number from one to three.

The number of branches from the distal part was usually one to three, but sometimes more. They mostly ran on the superior surface of the nerve, rarely on the inferior and medial aspects, and still more rarely on the lateral aspect. They commonly arose from the second part, and less commonly from the third part near the bend, or from one of the branches arising near this site, *e.g.* the muscular, medial posterior ciliary, and lacrimal arteries. They also arose from the central retinal artery. These branches mostly ran backwards and very rarely forwards.

No significant difference was seen in the collateral branches in specimens in which the ophthalmic artery crossed over or under the nerve. No anastomoses were seen between the proximal and distal branches, because all were very small in size and all ran backwards rather than towards each other as described by Meyer (1887). Moreover, the collateral branches of the proximal branches were all situated on the inferior surface, while most of the distal branches were on the superior surface and very few on the inferior surface. It was not possible to imagine that these could anastomose with one another and replace the original ophthalmic artery so frequently as to explain why the artery crossed under the nerve or occupied a medial position.

(*ii*) The other type of anastomosis described by Meyer occurred between the muscular branches arising proximally in common with the central retinal artery and medial posterior ciliary artery (in two out of his twenty specimens) and those arising more distally from the ophthalmic artery when it runs medial to the optic nerve. Though Meyer was not able to prove definite anastomoses between these two sets of muscular branches, he postulated their existence, and if such anastomoses do occur this would explain the course of the ophthalmic artery under the nerve.

A casual look at the various figures illustrating the course of the ophthalmic artery *under* the optic nerve as seen in the present series (Fig. 3–B to P) gives a strong impression that this might occur, but a detailed consideration of the site, order, and mode of origin of the branches from the first, second, and proximal sections of the third part of the ophthalmic artery and great rarity of anastomoses, do not support Meyer's hypothesis.

In seven specimens of the present series, anastomoses were seen between the proximal and the distal parts of the ophthalmic artery.

Table II (opposite) shows that, contrary to Meyer's opinion, the proximal branches were not always muscular arteries arising in common with the central retinal artery and the medial posterior ciliary artery but were very variable. Similarly the distal branches forming the anastomoses were also very variable; they were muscular in four specimens and muscular arising in common with the medial posterior ciliary artery in two.

The criterion used by Meyer to decide which of the two anastomoses described was responsible for the abnormal course of the ophthalmic artery

TABLE II

ANASTOMOSES BETWEEN PROXIMAL AND DISTAL PARTS OF THE OPHTHALMIC ARTERY

Serial No.	Ophthalmic Artery Crossed Over/Under Optic Nerve	Anastomosis Over/Under Optic Nerve	Anastomosing Branch			
			Proximal		Distal	
			Name of Branch	Site of Origin	Name of Branch	Site of Origin
1	Under (Fig. 3 H)	Under	To inferior rectus from lateral posterior ciliary artery	First part near angle	Muscular branch to medial and inferior recti and inferior oblique	At bend
		Over	Trunk giving branches to lateral rectus, lateral posterior ciliary, and lacrimal arteries, to inferior and superior recti, and two collateral branches over the nerve running backwards	First part near angle	Main ophthalmic artery trunk	At bend
2	Under (Fig. 3 G)	Under	Branch on sclera from lateral posterior ciliary artery	At angle	Branch to inferior rectus from muscular branch supplying medial, inferior, and lateral recti and inferior oblique	Second part near bend
3	Over	Under	Central retinal artery	First part near apex of orbit	Medial posterior ciliary artery, arising in common with muscular branch to medial and inferior recti and inferior oblique	Bend
4	Over	Under	Central retinal artery, arising in common with branch to inferior rectus and inferior oblique	At angle	Muscular branch to inferior and medial recti and inferior oblique, arising in common with medial posterior ciliary artery	Third part
5	Over	Under	Central retinal artery with medial posterior ciliary artery and muscular branch to lateral, inferior, and medial recti, and inferior oblique	At angle	Inferior medial palpebral artery	At orbital opening
6	Over	Under	Trunk dividing into lateral posterior ciliary, lacrimal, and muscular arteries (to lateral, superior, and inferior recti, inferior oblique, and levator palpebrae superioris)	Second part near angle	Muscular branch to medial and inferior recti	Third part
		Over	Muscular branch to superior rectus, levator palpebrae superioris, inferior rectus, and inferior oblique, arising in common with lateral posterior ciliary and lacrimal arteries	Second part near angle	Main ophthalmic artery trunk after having given out muscular branch to medial and inferior recti	Third part
7	Over	Under	Branch to lateral rectus from lacrimal artery	Second part lateral to nerve	Muscular branch to medial and inferior recti and inferior oblique	Third part

was the order in which the branches arose from the ophthalmic artery. When this is due to the abnormal development of anastomoses between the branches to the dural sheath of the nerve (*vide supra*), any imaginable arrangement of branches is possible, because their points of origin from the ophthalmic artery show no definite pattern. On the other hand, if the abnormal course of the ophthalmic artery is due to anastomoses between the muscular arteries, then the central retinal artery should be the first branch, followed by the small posterior ciliary artery, and then by the small muscular trunk. This order of branching was seen in none of the fifteen specimens of the present series in which the ophthalmic artery crossed under the optic nerve (Fig. 3–B to P). The lateral posterior ciliary artery was nearly always the first branch, except in two specimens in which it arose in common with the lacrimal artery. The central retinal artery was the second branch in thirteen specimens and arose in common with medial posterior ciliary artery in the other two. The third branch was the muscular artery running to the inferomedial group of muscles in nine specimens, the medial posterior ciliary artery in four, and the muscular artery arising in common with the medial posterior ciliary artery in the other two. The fourth branch was the medial posterior ciliary artery in ten specimens, the muscular artery in four, and the lacrimal artery in one. These findings all discount Meyer's hypothesis.

The pattern of branches in those cases in which the ophthalmic artery crossed *over and under* the optic nerve was quite different in the present series, and will be discussed at length in a subsequent communication (Hayreh, 1962). If the ophthalmic artery crossing under the optic nerve was formed just by an enlargement of the normal anastomotic channels under the nerve, as mentioned by Meyer (1887), then the pattern of branching should be similar in the two types of case and not so very different.

Both Meyer (1887) and Sudakevitch (1947) explained the various anomalies in the course of the ophthalmic artery by constructing a schematic location of segments of atrophy or under-development of the main trunk of the ophthalmic artery. Meyer's chief basis in locating these atrophic segments was the variation of the lacrimal and supra-orbital arteries, as shown in Fig. 4 (overleaf).

Meyer described three possible locations of the atrophic segments of the artery:

(*a*) Proximal to the lacrimal artery (X in Fig. 4–C);

(*b*) Between the lacrimal and supra-orbital arteries (Y in Fig. 4–E);

(*c*) Distal to the supra-orbital artery (Z in Fig. 4–B).

According to him even two atrophic segments may be present in the same specimen—one proximal and other distal to the lacrimal artery (X and Y in Fig. 4–E)—and he has surmised the possibility that all the three segments may be atrophic in some cases, although, he did not actually see such a specimen. Meyer made no mention of the cause of this atrophy or of the age at which it might appear. Sudakevitch (1947) observed the condition in a very young patient and concluded that the atrophy might occur in embryonic life or soon thereafter. In the present series also the ophthalmic artery crossing under the optic nerve was seen in two children aged 4 and 12 years (Fig. 3–M and I respectively). But this may also result from the changes with age described by Sudakevitch, through an intra-cranial interruption of the ophthalmic artery on the basis of osseo-vascular correlation discussed in our previous paper (Hayreh and Dass, 1962).

In contrast to Meyer, Sudakevitch's basis in locating the atrophic segments of the ophthalmic artery trunk was the variation in the origin of the posterior ciliary arteries and the central retinal artery. He stated that, if the atrophy involved the ophthalmic artery at a point between the optic foramen and the angle, there was a variation in the origin of the posterior ciliary arteries which, according to him, normally arose in this section.

The findings of the present series do not agree with these findings of Meyer and Sudakevitch. Normally, when the ophthalmic artery crossed *over* the optic nerve, there was no branch at all from the first part in 60·9 per cent. of the specimens, in the remaining specimens the following branches were seen:

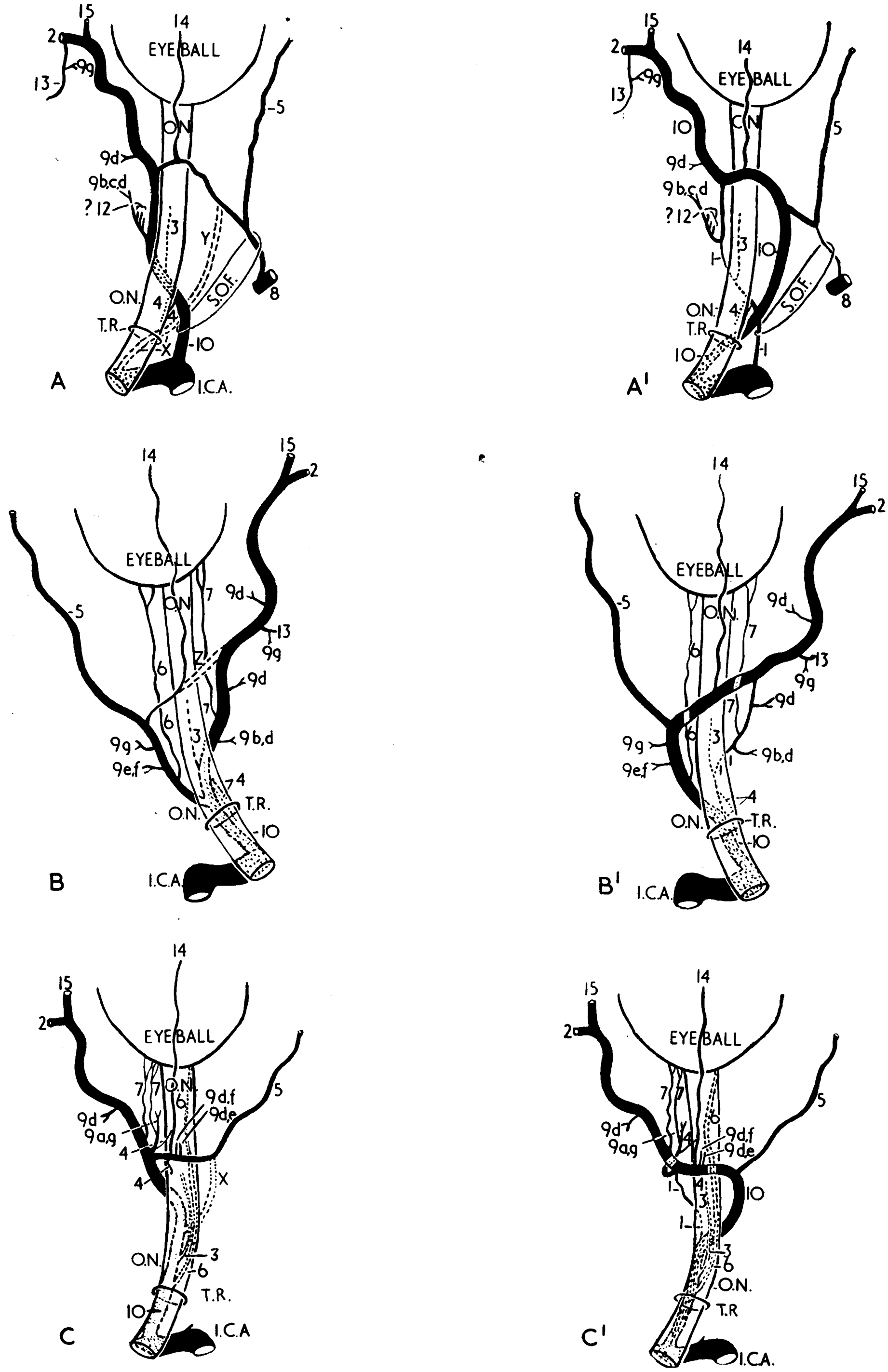
(*i*) *Only One Branch.*—Central retinal artery 6·5 per cent.; medial posterior ciliary artery 2·2 per cent.; central retinal artery arising in common with the medial posterior ciliary artery 17·4 per cent., and in common with the lateral posterior ciliary artery in 4·4 per cent.

(*ii*) *Two Branches.*—Central retinal artery and lateral posterior ciliary artery, arising independently, 2·2 per cent.; central retinal artery arising in common with the medial posterior ciliary artery and an independent lateral posterior ciliary artery 2·2 per cent.; central retinal artery and recurrent meningeal branch to the middle cranial fossa (representing the lacrimal artery), arising independently, 2·2 per cent.

(*iii*) *Three Branches.*—Central retinal artery, lateral posterior ciliary artery, and lacrimal artery, arising independently, 2·2 per cent.

In contrast to the above arrangement, when the ophthalmic artery crossed *under* the optic nerve, there was no branch from the first part in 33·3 per cent. of the specimens and in the remaining 66·6 per cent. the lateral posterior ciliary artery was the first branch. Other branches which also arose from this part were the medial posterior ciliary artery, 6·6 per cent.; the central retinal artery arising in common with medial posterior ciliary artery, 6·6 per cent.; the lacrimal artery arising in common with lateral posterior ciliary and muscular arteries (Fig. 3–M) in 6·6 per cent. These findings make it clear that explanation of Sudakevitch (1947) is not quite correct.

The ophthalmic artery may be crossing over the optic nerve as usual, but the trunk may be very much diminished in size. To compensate for this, the anastomosing trunk between the middle meningeal and the lacrimal arteries along with the portion of the lacrimal artery from its origin up to its union with this anastomotic trunk may enlarge to form the main (Fig. 2–B, C) or the only (Fig. 2–G) feeding trunk for supplying the orbit. In a similar case reported by Priman and Christie (1959), the origin of the lacrimal



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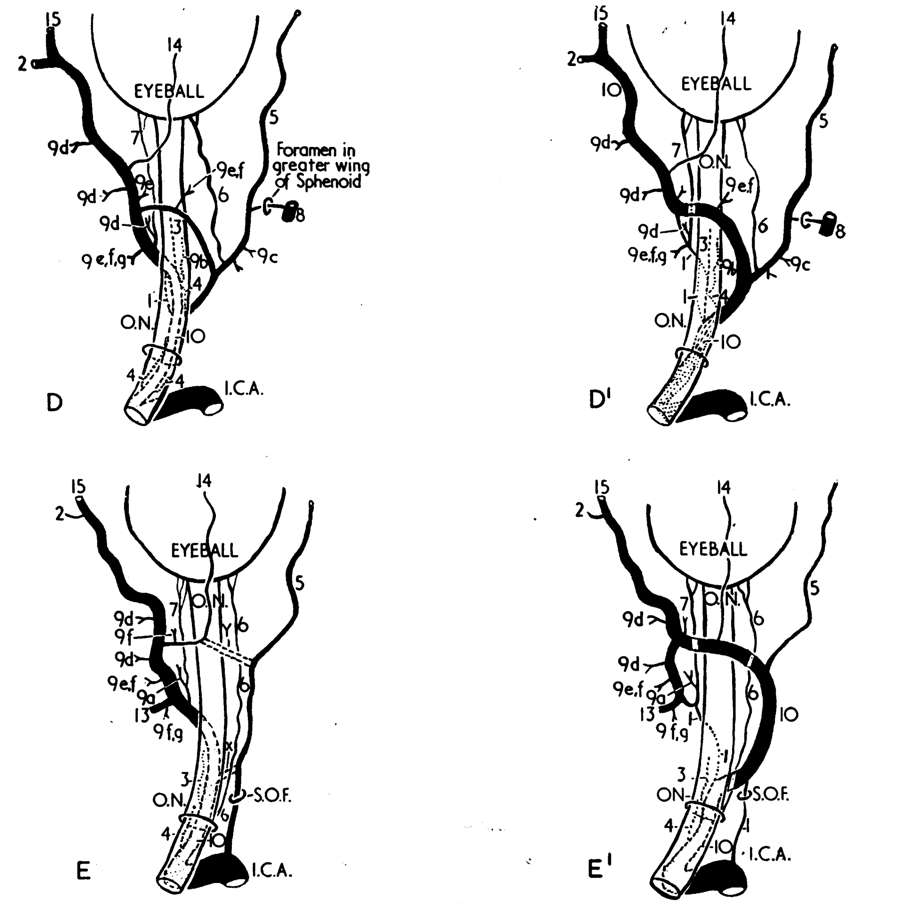

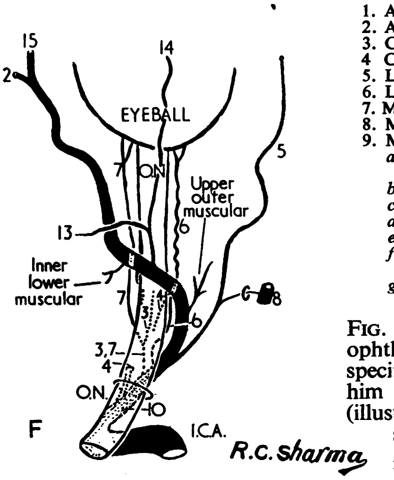

KEY TO FIG. 4

1. Anastomotic channel.
2. Anterior ethmoid.
3. Central retinal.
4 Collateral branch.
5. Lacrimal.
6. Lateral posterior ciliary.
7. Medial posterior ciliary.
8. Middle meningeal.
9. Muscular arteries to:
   a. Medial and inferior recti and inferior oblique.
   b Inferior rectus.
   c Lateral rectus.
   d Medial rectus.
   e Superior rectus.
   f Levator palpebrae superioris.
   g Superior oblique.
10. Ophthalmic artery trunk from internal carotid (I.C.A.).
11. Ophthalmic artery trunk from middle meningeal (8).
12. Posterior ciliary.
13. Posterior ethmoid.
14. Supra-orbital.
15. Main continuation of ophthalmic artery.

I.C.A. = Internal carotid artery.
O.N. = Optic nerve.
S.O.F. = Superior orbital fissure.
T. R. = Tendinous ring.

FIG. 4.—Variations in course and branches of the ophthalmic artery as seen by Meyer (1887). The specimens illustrated in A and B were not included by him in his series of twenty specimens, but the three (illustrated in C, D, and E) were included in his own series. (F) Normal pattern as seen by Meyer. A, B, C, D, and E show actual findings, and A′, B′, C′, D′ and E′ show Meyer's hypothetical reconstructions of normal courses corresponding to the actual cases. X, Y, and Z represent segments of atrophy of the actual ophthalmic artery.

artery was situated medial to the nerve; hence the second part of the normal ophthalmic artery and the enlarged trunk of the lacrimal artery both crossed over the optic nerve, the latter lying in front of the former. The condition was thus basically similar to that in our first two cases mentioned above. This subject of an anomalous ophthalmic artery arising from the middle meningeal artery has been discussed at length in our previous communication (Hayreh and Dass, 1962).

Other abnormalities in the course followed by the two trunks of the ophthalmic artery, *i.e.* one arising from the middle meningeal and the other from the internal carotid, are to be found in the literature:

There may be no communication between the two trunks. A case was reported by Chanmugam (1936), in which the trunk from the middle meningeal followed the usual course of the ophthalmic trunk, while that from the internal carotid supplied only the central retinal artery and the ciliary arteries. No such case was seen in the present series.

The trunk from the internal carotid may be completely absent and represented by a fibrous cord, as in the two specimens described by Musgrove (1893). In these cases the segment of the ophthalmic artery extending from its origin to the point of origin of the central retinal artery degenerated and formed a fibrous cord; the central artery of the retina arose medial to the optic nerve by a trunk common to it and the ciliary artery, and the muscular arteries arose from the trunk arising from the middle meningeal artery. The intra-orbital part of the trunk from the internal carotid was never absent in the specimens in present series, though in two the intra-cranial and intra-canalicular parts were either fibrous or absent (Fig. 2–F, G).

According to Meyer (1887) the ophthalmic artery may cross over the superior oblique muscle instead of taking its usual course below it, so that the artery is closely related to the roof of the orbit. Such a condition was also seen in one specimen of the present series.

None of the hypothetical solutions put forward by Meyer (1887) and Sudakevitch (1947) to explain abnormalities in the course of the ophthalmic artery (*vide supra*) seems to be satisfactory.

When the ophthalmic artery crossed *under* the optic nerve (Fig. 3–B to P), it seemed that a segment of the normal ophthalmic artery extending from the angle to the point of origin of the lacrimal artery was missing. When the ophthalmic artery crossed over the optic nerve, the lacrimal artery* arose from the first part in one specimen, at the angle in seven specimens, lateral to the optic nerve in twelve, supero-lateral to nerve in 25, and superior to the optic nerve in one specimen. On the other hand, when the ophthalmic artery crossed *under* the optic nerve, in 80 per cent. of specimens the lacrimal artery arising from the bend lay in the position of the original ophthalmic artery over the nerve (Fig. 3). The lacrimal arose from the angle in common

* Where the lacrimal arose from the middle meningeal, its point of origin from the ophthalmic artery was represented by one of its branches, *e.g.* a branch to the lateral rectus, or the recurrent meningeal artery, etc.

with the lateral posterior ciliary artery (Fig. 3–M) in 6·7 per cent., and from the first part in common with the lateral posterior ciliary artery, and with the muscular artery to the lateral and inferior recti in another 6·7 per cent. (Fig. 3–H); in the remainder there was nothing to represent the lacrimal artery (Fig. 3–E). In Fig. 3–M, the part of the normal ophthalmic artery between the origin of the lacrimal artery and the bend was missing. In Fig. 3–H, the anastomosing trunk connecting the first part with the bend gave rise to the lacrimal artery, and this anastomotic trunk may be regarded as the original trunk which had been very much reduced.

Out of the specimens in which the ophthalmic artery crossed *under* the optic nerve in the present series, no supra-orbital artery was seen in three (Fig. 3–M, N, P). According to Meyer's hypothesis, the atrophic segments (X, Y, Z) are located according to variations in the lacrimal and supra-orbital artery (*vide supra*). In the first specimen (Fig. 3–M), the absence of the supra-orbital artery can be explained on the basis of the presence of the atrophic segments Y and Z, but in the other two (Fig. 3–N and P) its absence cannot be explained in this way. Moreover, the atrophic segment 'Z' was not seen in this series except in the specimen mentioned above. Hence Meyer's speculations do not seem to be correct.

The formation of the abnormal trunk of the ophthalmic artery under the nerve from the anastomoses and from the mere atrophy of a segment of the normal ophthalmic artery, as explained by Meyer (1887) and Sudakevitch (1947), cannot be applied to the adult pattern of the artery for the following reasons:

(1) It was extremely rare to find an anastomotic channel connecting the first part or the angle with the bend or the third part normally.

(2) The medial posterior ciliary artery or the central retinal artery with the muscular artery arose from the proximal part of the ophthalmic artery so rarely that it could not explain the frequent occurrence of the ophthalmic artery under the optic nerve.

(3) The collateral branches from the proximal and distal parts of the ophthalmic artery were very small in size; they were all directed backwards and their arrangement was very indefinite.

(4) The pattern of origin of the branches from the first part, angle, bend, and initial portion of the third part was absolutely different and more or less characteristic in the two cases, whereas the pattern should have been nearly similar if it had been merely a question of forming the abnormal trunk from the anastomoses of normally existing branches.

Therefore the explanation of the abnormal course does not seem to lie in the normal adult pattern of branching, or in the existence of anastomoses or in atrophy of a segment of the ophthalmic artery trunk leading to the enlargement of the anastomoses, but it may lie in the abnormal differentiation of the vascular pattern during embryonic life. This needs further investigation.

During the development of the arteries three stages are usually seen:

(*i*) The formation of a diffuse capillary plexus;

(*ii*) The retiform stage;

(*iii*) The formation of the definitive single stem (Clark, 1958).

During the formation of the definitive arterial stem from the diffuse capillary plexus, some channels become enlarged and clearly defined while the others may disappear altogether. The factors controlling the selection and differentiation of the final vascular pattern may be divided into two groups—morphogenetic and mechanical. Roux (1878) postulated three stages in the developmental history of the vascular system: the first depends entirely on genetic factors; then comes a transitional stage in which hereditary formation is gradually supplemented by adaptational factors; finally, the differentiation of the vessels is controlled by haemodynamic factors. The various abnormalities in the course of the ophthalmic artery may thus be developmental in origin; the differentiation of this abnormal vascular pattern from the diffuse vascular capillaries may be due to some morphogenetic or mechanical influence.

Angle of the Ophthalmic Artery.—This has been described only by Sudakevitch (1947), though von Haller (1781) mentioned that the ophthalmic artery crossed over the nerve, in some cases gradually and in others more abruptly. Sudakevitch (1947) stated that it was nearly always present, but was very rarely absent when the ophthalmic artery was situated below and medial to the optic nerve, and that it varied in size even on the two sides of the same individual, a fact confirmed in the present series.

One point requires clarification before discussing the degree of angulation. Sudakevitch measured the angle between the second part of the ophthalmic artery and the optic nerve distal to the angle, and not between the first and second parts of the ophthalmic artery as it should be. This has proved rather confusing because the angle is in fact formed by the first and second parts and not by the nerve and the second part; the result is that the acute angle mentioned by Sudakevitch corresponds to our obtuse angle and *vice versa.*

Sudakevitch describes the angle as acute (our obtuse) in childhood and adolescence, at right-angles between 24 and 40 years, and obtuse (our acute) thereafter. He further states that his 'acute' (childhood) angle may rarely persist into old age but had never been seen by him after 65 years of age. In explaining the mechanism of this change in angle with age, he says that the angle, being firmly fixed to the sheath of the optic nerve, cannot straighten every time the pulse wave passes over it. Thus it changes from obtuse to acute with age, and this change, according to him, results from two constant but opposed factors—one working in a distal, and the other in a proximal direction. The angle being in a fixed place, the change with age is caused by the lateral action of a force usually directed antero-posteriorly, and this force comes from the supra-orbital and posterior ciliary arteries, probably mainly through the medial posterior ciliary artery. He found that when the order of the origin of the branches of the ophthalmic artery was unusual* (*i.e.* medial posterior ciliary artery and at times central retinal artery arising from the second part of the ophthalmic artery), the angle showed an earlier and more pronounced change from obtuse to acute. In these cases the blood wave first goes sharply round, sometimes even with a reverse direction of blood flow, to reach the second part to supply the blood to the medial posterior ciliary artery. Thus the correlation of the force is upset, the ophthalmic artery trunk inclines more and more towards the side of the weaker force, and this increases the angle of deflection of the pulse wave.

This is how Sudakevitch explained the change in angulation of the ophthalmic artery, by increasing age and by an unusual pattern of branching. He stressed the fact that the definite order of branching of the posterior ciliary arteries was very important from the haemodynamic point of view.

In the present series, the angle was constantly present and usually well-defined. It was obtuse in 56·25 per cent., right-angled in 40 per cent., and acute in 3·75 per cent. The individuals on whom this study was carried out were mainly past middle age, some being very old. Our findings do not agree with those of Sudakevitch, according to whom the angle in this age group should be acute and not obtuse. Moreover, we did not find the angle fixed to the optic nerve as pointed out by him; it was quite free, being attached to the nerve only by a very loose connective tissue. The factors determining the degree of angulation seem to be rather obscure and no relationship could be made out between the degree of angulation and the pattern of branches.

Termination of the Ophthalmic Artery.—Sudakevitch (1947) found that in 4·8 per cent. of his specimens the ophthalmic artery suddenly terminated medial to the optic nerve at the junction of the second and third parts giving off two or three lateral branches which left the trunk at an angle, even sometimes at right-angles. No such example was seen in the present series.

In 6·79 per cent. of his specimens he found the ophthalmic artery dividing medial to the optic nerve into two or three branches, out of which the weakest went forwards representing the usual ophthalmic trunk and the more powerful followed the route of the posterior ethmoid artery. One such example was seen in the present series (Fig. 3–O).

* The usual order being central retinal artery with medial posterior ciliary artery first, lateral posterior ciliary artery second, and the lacrimal artery third.

In 5·77 per cent. of his specimens, the ophthalmic artery followed the route of the posterior ethmoid artery (4·8 per cent. crossed *over* the nerve, and 0·97 per cent. crossed *under*).

Merkel (1874) also described the termination of the ophthalmic artery in the posterior ethmoid artery.

In the present series the ophthalmic artery terminated in the anterior ethmoid artery in 6·6 per cent., the anterior ethmoid was bigger than the main continuation of the ophthalmic in 3·3 per cent., and the ophthalmic bifurcated into two nearly equal trunks at the level of the anterior ethmoid in 16·4 per cent. In none of our specimens did the ophthalmic artery terminate in the posterior ethmoid artery; it was always present distal to the anterior ethmoid artery though it was much diminished in cases in which it terminated in the anterior ethmoid.

No anomalous termination of the ophthalmic artery (apart from the above) is described in the literature. The artery is said to terminate in the supratrochlear and dorsal nasal arteries.

The terminal branches, as seen in 59 specimens of the present series, are given on page 171.

Summary

A detailed study of the intra-orbital course and mode of termination of the ophthalmic artery was carried out in 61 human orbits after injection with liquid Neoprene latex, and certain variations from the normal were noted. This part of the artery is sub-divided into the first, second, and third parts, which lie infero-lateral, over or under, and medial to the optic nerve respectively. The genesis of the second part of the artery lying under the nerve is discussed in detail. Contrary to previous views on this subject, it is suggested that this abnormal vascular pattern may be due to abnormal differentiation from the diffuse vascular capillaries during the embryonic stage of development. Variations in the "angle" between the first and second parts of the artery are discussed.

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REFERENCES

ADACHI, B. (1928). "Das Arteriensystem der Japaner", vol. 1. Kyoto. (*Cited by* Priman and Christie, 1959).

ARNOLD, F. (1847). "Handbuch der Anatomie des Menschen", vol. 2, pt 1, p. 465. Herder'sche Verlags-handlung, Freiburg im Breisgau. (*Cited by* Meyer, 1887).

BLANDIN, P. F. (1834). "Traité d'anatomie topographique", 2nd ed., p. 147. Germer-Baillière, Paris.

CHANMUGAM, P. K. (1936). *J. Anat.* (*Lond.*), **70**, 580.

CLARK, W. E. LE GROS (1958). "The Tissues of the Body", 4th ed., p. 208. Clarendon Press, Oxford.

HALLER, A. VON (1781). "Iconum anatomicarum corporis humani", fasc. 7, pp. 38, 39. Vandenhoeck, Göttingen. (*Cited by* Meyer, 1887).
HAYREH, S. S. (1958). "A Study of the Central Artery of the Retina in Human Beings in its Intraorbital and Intra-neural Course". Thesis, Panjab University.
——— (1962). *Brit. J. Ophthal.*, **46**, 208.
——— and DASS, R. (1959). "Acta XVIII Conc. Ophthal. 1958, Belgica", vol. 2, p. 1345. Imprimerie Médicale et Scientifique, Bruxelles.
——— ——— (1962). *Brit. J. Ophthal.*, **46**, 65.
HOLLINSHEAD, W. H. (1954). "Anatomy for Surgeons", vol. 1, p. 158. Hoeber, New York.
JOHNSTON, T. B., DAVIES, D. V., and DAVIES, F. (1958). "Gray's Anatomy", 32nd ed., p. 757. Longmans, Green, London.
LUSCHKA, H. (1865). "Die Anatomie der Glieder des Menschen", vol. 3, pt. 2, p. 494. Tübingen. (*Cited by* Meyer, 1887).
MAYER, J. C. A. (1777). "Anatomische Beschreibung der Blutgefässe des menschlichen Körpers", p. 69. Berlin and Leipzig. (*Cited by* Meyer, 1887).
MERKEL, F. (1874). *In* "Graefe-Saemisch Handbuch der gesammten Augenheilkunde", vol. 1, p. 103. Engelmann, Leipzig.
MEYER, F. (1887). *Morph. Jb.*, **12**, 414.
MUSGROVE, J. (1893). *J. Anat. Physiol.* (*Lond.*), **27**, 279.
PRIMAN, J., and CHRISTIE, D. H. (1959). *Anat. Rec.*, **134**, 87.
QUAIN, R. (1892). *See* Thane (1892).
ROUX, W. (1878). "Über die Verzweigungen der Blutgefäße des Menschen", 12, Z. Naturwiss. (*Cited by* Clark, 1958).
SINGH, S., and DASS, R. (1960). *Brit. J. Ophthal.*, **44**, 193.
SÖMMERRING, S. T. (1841). "Vom Bau des menschlichen Körpers", vol. 3, pt. 2, p. 90, "Lehre von den Muskeln und Gefässen". (*Cited by* Meyer, 1887).
SUDAKEVITCH, T. (1947). *Brit. J. Ophthal.*, **31**, 738.
THANE, G. D. (1892). *In* "Quain's Elements of Anatomy", 10th ed., ed. E. A. Schäfer and G. D. Thane, vol. 2, pt. 2, p. 408. Longmans, Green, London.
THEILE, R. *See* Sömmerring (1841).
WHITNALL, S. E. (1932). "The Anatomy of the Human Orbit", 2nd ed., p. 303. Oxford University Press, London.
WOLFF, E. (1954). "The Anatomy of the Eye and Orbit", 4th ed., p. 370. Lewis, London.
WOOD JONES, F. (1949). "Buchanan's Manual of Anatomy", 8th ed., p. 1175. Baillière, Tindall and Cox, London.
ZINN, J. G. (1780). "Descriptio anatomica oculi humani", 2nd ed., ed. H. A. Wrisberg, pp. 194, 195. Vandenhoeck, Göttingen. (*Cited by* Meyer, 1887).
ZUCKERKANDL, E. (1876). *Med. Jb.* (*Wien*), p. 343.

CORRECTION

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