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COMMUNICATIONS

THE CENTRAL ARTERY OF THE RETINA*†

I. ORIGIN AND COURSE

BY

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THE central artery of the retina is of vital importance because it is the only source of blood supply to the retina. An exhaustive study of the literature reveals a striking lack of unanimity in the views held by various workers (Meyer, 1887; Magitot, 1908; Quain, 1909; Beauvieux and Ristitch, 1924; Whitnall, 1932; Wolff, 1939, 1954; Kershner, 1943; Duke-Elder, 1946; Sudakevitch, 1947; Traquair, 1949; François and Neetens, 1954, 1956; François, Neetens, and Collette, 1955; Wybar, 1956; Steele and Blunt, 1956). The origin and course of the central artery of the retina have not been studied in detail and the literature pertaining to those aspects is scanty. It was therefore considered desirable to investigate the subject more thoroughly.

Material

This study was carried out in 106 human orbits, eighty specimens being obtained from dissection room cadavers and 26 from fresh autopsies.

Methods

The central artery of the retina was studied in two ways, 100 specimens by dissection, and six by histological sections.

(A) Dissection Techniques

(*1*) *Injection with Neoprene Latex* (Type 571).—Three different techniques were used.

(*i*) 44 specimens were injected with latex *in situ* through the internal carotid 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 24–48 hrs to coagulate the latex. The roof of the orbit was then opened and all branches of the ophthalmic artery were carefully dissected. The mode of origin of the central artery was studied in detail. Then the eyeball, with the entire length of the optic nerve, and the ophthalmic artery, with its branches, were removed.

(*ii*) In twenty autopsy specimens the orbital contents (enclosed in orbital periosteum) were removed through the intra-cranial route as described by Ashton (1952). A metal

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cannula was inserted into the internal carotid artery. Both ends of the cavernous and intra-cranial portions of the internal carotid artery were ligated. Alternatively, the cannula was introduced directly into the ophthalmic artery and tied in. The specimens were irrigated and treated as described by Ashton (1952). Latex was then injected through the cannula and the specimens were transferred to a mixture of 4 per cent. acetic acid and 4 per cent. Formalin for about 24 hrs in order to coagulate the rubber and to fix the tissues (Smith and Henry, 1945). The central artery of the retina was then dissected.

When the central artery was not filled satisfactorily by these two techniques of injection, a direct injection into the artery was tried.

(*iii*) In the later stages of this study, in 36 specimens, a different technique was tried. They were treated as described in Technique (*ii*) as far as the stage of irrigation. After this they were dissected and the central artery exposed. The ophthalmic artery was ligated distal to the origin of the central retinal artery and the latex was injected through a cannula introduced into the ophthalmic artery at its point of origin. The advantage was that the injection into the central artery was under direct vision and its filling was seen clearly.

The specimens injected by the first and the third techniques were from ordinary dissection-room cadavers, and those injected by the second technique were fresh autopsy specimens. The extent of filling of the central artery by the various techniques is shown in Table I. In the five specimens which were distorted during maceration, no conclusion could be drawn regarding the extent of injection.

TABLE I

FILLING OF CENTRAL RETINAL ARTERY BY VARIOUS TECHNIQUES

Technique Used	Total No. of Specimens Examined	Central Retinal Artery Filled				Specimens Distorted during Maceration
		Completely	Only in intra-orbital and intra-vaginal parts	Only in intra-orbital part	Not at all	
(*i*)	44	18	7	12	5	2
(*ii*)	20	14	3	Nil	Nil	3
(*iii*)	36	30	2	4	Nil	Nil
Total	100	62	12	16	5	5

(2) *Maceration of Specimens.*—After removal of all extraneous tissues the specimens were macerated by the following two techniques:

(*i*) Fifty specimens were macerated in organic enzymes at 37° C. Each specimen was first placed in a solution of pepsin in N/10 HCl for 10 to 14 days; later it was carefully transferred to a solution of trypsin in 10 per cent. $NaHCO_3$ and incubated for another 10 to 14 days. The maceration was not allowed to proceed too far lest the specimen became distorted.

Later, this method was replaced by the following quicker method:

(*ii*) Fifty specimens were macerated in 20 per cent. HCl at 60 to 70° C. The maceration was adequate in about 12 hours. Another advantage was that the sheath of the optic nerve became gelatinous and semi-transparent, so that the blood vessels containing clotted blood or injected material could be clearly seen through, as they lay on the pia of the nerve or in the sheath of the nerve, even before the dissection of the sheath.

(3) *Dissection of Specimens.*—The origin and the intra-orbital part of the central artery were studied before maceration and the rest of the study was carried out after maceration. Dissection was carried out under a wide-field stereoscopic binocular dissection microscope with direct illumination from a high-power lamp with low-voltage filament. Distances were measured under the microscope with a graduated caliper. The specimens were fixed with pins on wax plates for dissection. The course and branches of the central artery of the retina were traced by careful dissection. The finer branches were seen only under high magnification ($\times 100$).

(B) Histological Studies

Six autopsy specimens of the region of the optic nerve containing the central artery of the retina were embedded in paraffin and serially sectioned. In two of these specimens (belonging to one person) all the clots were cleared out by the method of Ashton (1952). A 3 per cent. solution of prussian blue was injected into the central artery (Technique *iii*) before sectioning. Graphic reconstructions were made of these two specimens. The sections were stained with Heidenhain's modification of Mallory's azan technique. In the two specimens in which prussian blue was injected, a 1 per cent. solution of light green was used as a counter-stain, instead of orange G-aniline blue mixture, so that the colour of the prussian blue was not masked.

Observations

Ophthalmic Artery.—The origin of the central artery of the retina is closely related to the origin and course of the parent trunk, the ophthalmic artery. In 102 specimens of this series (100 latex-filled and two filled with prussian blue) the origin of the ophthalmic artery was seen to be as follows:

(*a*) In 96 specimens it arose from the internal carotid artery (Fig. 1, A, overleaf).

(*b*) In four specimens it arose from the internal carotid artery in the usual way, but the major contribution of blood to the ophthalmic artery came from the middle meningeal artery through a marked enlargement of the anastomosis between it and a recurrent meningeal branch of the lacrimal artery. In these cases the calibre of the artery between its origin from the internal carotid artery and the point of the origin of the lacrimal artery was much smaller than normal (Fig. 1, B, C, D, E, and Figs 2 and 3, overleaf).

(*c*) In two specimens the arrangement was the same as in (*b*), except that the trunk of origin from the internal carotid artery was obliterated in its intra-canalicular course. Thus the middle meningeal artery was the only source of blood supply to the ophthalmic artery (Fig. 1, F, and G).

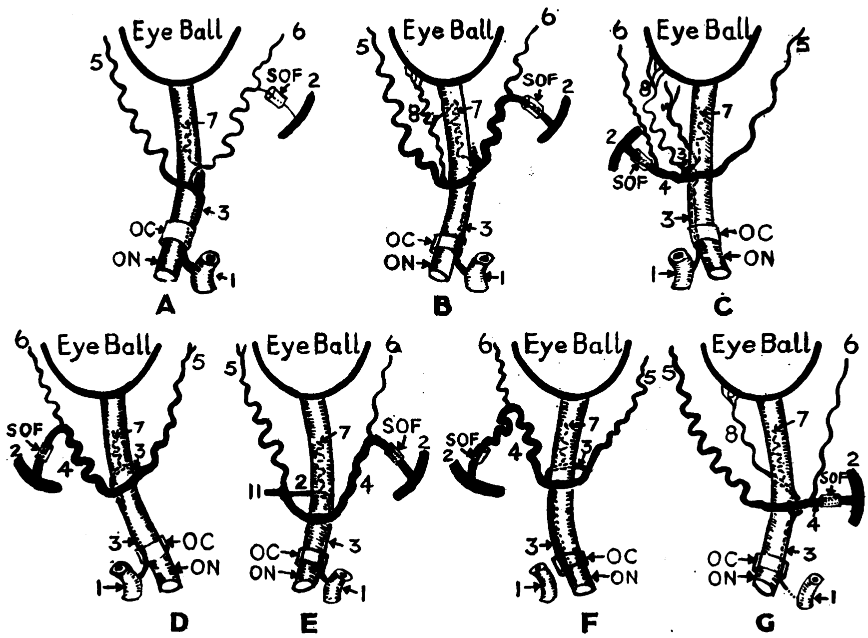
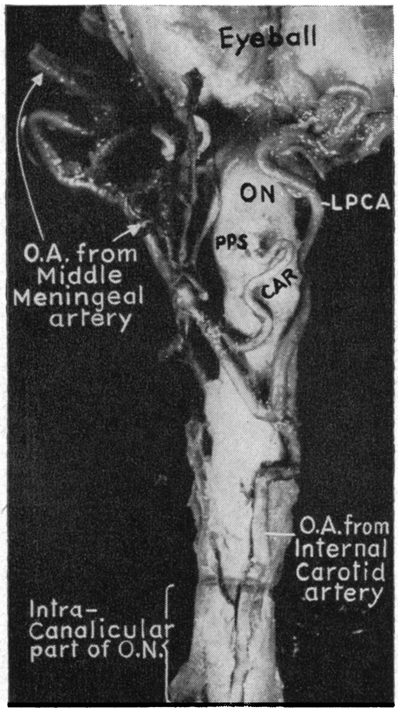


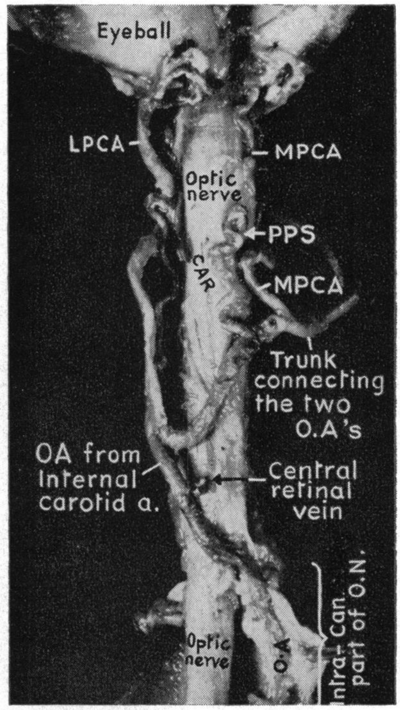
FIG. 1.—Variations in origin and course of ophthalmic artery.
(A) Normal pattern.
(B, C, D, E) The ophthalmic artery arises from the internal carotid artery as usual, but the major contribution comes from middle meningeal artery.
(F, G) The only source is the middle meningeal artery, as the connexion with the internal carotid artery is either absent (F) or obliterated (G).

(1) Internal carotid artery.
(2) Middle meningeal artery.
(3) Ophthalmic artery trunk from internal carotid artery.
(4) Ophthalmic artery trunk from middle meningeal artery.
(5) Terminal part of ophthalmic artery.
(6) Lacrimal artery.
(7) Central retinal artery.
(8) Medial posterior ciliary artery.
(9) Lateral posterior ciliary artery.
(10) Muscular artery to inferior oblique and inferior rectus.
(11) Ethmoidal artery.
ON = Optic nerve.
OC = Optic canal.
SOF = Superior orbital fissure.

To facilitate the description of the site of origin of the central artery in the following pages, the course of the ophthalmic artery has been divided into three parts: the first part lying along the infero-lateral aspect of the optic nerve; the second part passing over or under the optic nerve to go medially; and the third part lying medial to the optic nerve. The bend between the first and the second parts is termed the "angle" (Fig. 4, opposite).

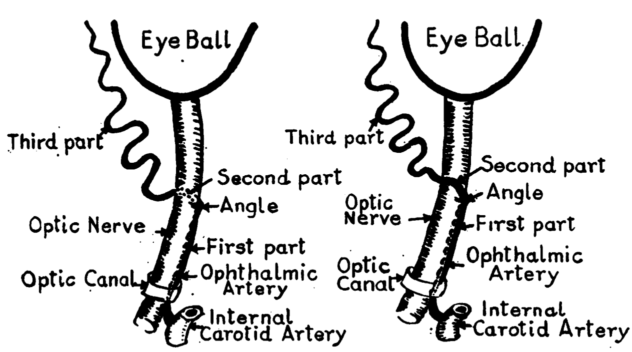
Number of Central Retinal Arteries in any One Specimen.—The literature contains no reference to the existence of more than one central artery of the retina in any one specimen. In two specimens of the present series, there are two central arteries, each arising independently from the ophthalmic artery.





FIGS 2 and 3.—Specimens illustrated in Fig. 1, D and 1, E as seen from below. The origin and intra-orbital course of the central retinal artery are also seen.

CAR = Central artery of retina
OA = Ophthalmic artery
LPCA = Lateral posterior ciliary artery
MPCA = Medial posterior ciliary artery
PPS = Point of piercing optic sheath
Intracan. = Intra-canalicular



A B

FIG. 4.—Course of ophthalmic artery. (A) The artery crosses UNDER the optic nerve; (B) the artery crosses OVER the optic nerve.

In one of these specimens, the two central retinal arteries run independently up to the optic disc, and pierce the sheath of the optic nerve at points 12 mm. and 5 mm. behind the eyeball on its lower lateral aspect. At the optic disc the two join to form a loop, from the summit of which arise terminal branches which follow the usual course (Fig. 5).

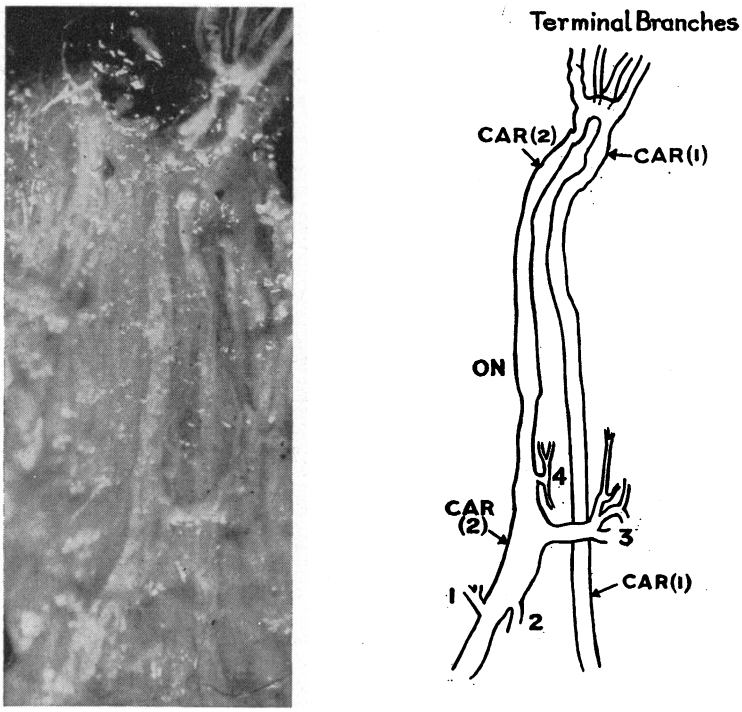


FIG. 5.—Two retinal arteries, CAR (1) and (2), of independent origin. The intraneural course and termination of the two arteries are shown as seen from above on splitting open the optic nerve and eyeball. Branches (1, 2, 3, 4) from the intraneural course of the smaller artery are also seen.

In the other specimen, the two arteries unite to form one trunk at the point of entry into the sheath of the optic nerve (Fig. 1, B).

Origin of the Central Artery of the Retina.—References to the origin of the central artery in the literature are scanty and incomplete, and there is no uniformity of opinion between different workers (Meyer, 1887; Magitot, 1908; Quain, 1909; Beauvieux and Ristitch, 1924; Whitnall, 1932; Wolff, 1939, 1954; Kershner, 1943; Duke-Elder, 1946; Sudakevitch, 1947; Traquair, 1949; Wybar, 1956; Steele and Blunt, 1956). The number of specimens reported has been too small for any definite conclusion to be reached. Sudakevitch (1947) reported findings from 103 specimens, and Beauvieux and Ristitch (1924), Wybar (1956), and Steele and Blunt (1956) examined twenty, seventeen, and thirty specimens respectively. A complete analysis of results has been presented only by Beauvieux and Ristitch (1924).

(A) *Source of Origin.*

(*i*) All the authors quoted above describe the ophthalmic artery, a branch of the internal carotid artery, as the source of origin of the central artery. This is true of 100 specimens (out of 102) in the present series, in which the ophthalmic artery arose from the internal carotid artery. (Fig. 1, A, B, C, D, E).

(*ii*) The central artery of the retina may at times, however, arise from an ophthalmic artery which itself arises from the middle meningeal artery (Traquair, 1949). Two such cases in which communication with the internal carotid artery was obliterated were seen in the present series (Fig. 1, F, G).

Our findings further indicate that, though the main source of blood supply to the ophthalmic artery may be the middle meningeal artery, yet is also often a small trunk connecting the internal carotid artery to the ophthalmic artery (Figs 1, B, C, D, E, 2, 3). The central artery of the retina may arise from this latter trunk. Four specimens out of the 100 included in (*i*) above were of this type.

Finally, it is possible for two central arteries to be present each with a different source, corresponding to the description in (*i*) and (*ii*) above. Out of the four specimens included in the above paragraph, one was of this type (Fig. 1, B).

(B) *Site, Order of Branching, and Mode of Origin* (Table II, overleaf)

(1) SITE OF ORIGIN

(*i*) Wolff (1939), Duke-Elder (1946), and Traquair (1949) state that the artery arises close to the optic canal *at the apex of the orbit*. Meyer (1887) and Kershner (1943) state it branches from the ophthalmic artery while the latter is still within the sheath of the optic nerve at the apex, but this site of origin was seen only in 1·78 per cent. of the present series and in them the central artery arose from the ophthalmic artery after the latter had emerged from the optic nerve sheath.

(*ii*) According to Sudakevitch (1947), the artery may arise anywhere along the *first part of the ophthalmic artery* and very rarely distal to this point. In the present series, this site of origin was seen in only 22·12 per cent. of cases.

(*iii*) The "*angle*" *of the ophthalmic artery* was the commonest site of origin in the present series (57·69 per cent.).

(*iv*) Sudakevitch (1947) stated that very rarely the artery might arise from the *second part of the ophthalmic artery*; no other worker has described such an origin, but in the present series this site was seen in 18·27 per cent. of cases.

TABLE II

SITE, ORDER, and MODE OF ORIGIN

Origin		Total Incidence	Ophthalmic Artery Crosses	
			Over Optic Nerve	Under Optic Nerve
Site	From first part of ophthalmic artery	22·12	20·20	1·92
	From angle of ophthalmic artery	57·69	51·92	5·77
	From second part of ophthalmic artery ..	18·27	4·81	13·46
	From third part of ophthalmic artery ..	1·92	—	—
Order	As first branch of ophthalmic artery	77·45	74·51	2·94
	As second branch of ophthalmic artery ..	18·63	2·94	15·69
	As third branch of ophthalmic artery	3·92	0·98	2·94
Mode	As independent branch	37·50	21·15	16·35
	With medial posterior ciliary artery	37·50	33·65	3·85
	With lateral posterior ciliary artery	11·54	11·54	Nil
	With MPCA LPCA and muscular arteries ..	1·92	1·92	Nil
	With MPCA and LPCA	4·81	4·81	Nil
	With MPCA and muscular artery	2·88	1·92	0·96
	With muscular artery	2·88	2·88	Nil
	With lacrimal artery and LPCA	0·96	0·96	Nil
Total Number of Specimens Examined		102	78·43 per cent.	21·57 per cent.

* In these specimens the ophthalmic artery arose from the middle meningeal artery.

(*v*) When the central artery arises from a branch of the *middle meningeal artery*, its site of origin is on the medial side of the optic nerve.

(2) ORDER OF BRANCHING FROM THE OPHTHALMIC ARTERY.—According to Meyer (1887), Whitnall (1932), Sudakevitch (1947), and Wybar (1956), the central artery arises as the first branch of the ophthalmic artery. Beauvieux and Ristitch (1924), however, described it as the first branch of the ophthalmic artery in only one out of their twenty specimens, and as the second branch in six specimens. In the present series the central retinal artery was the *first* branch in 77·45 per cent., the *second* in 18·63 per cent., and the *third* in 3·92 per cent. (Table II).

(3) MODE OF ORIGIN.—The artery may arise independently or in common with some other branch of the ophthalmic artery (Table II).

(*a*) Independent (Figs 2, 3, 14);

(*b*) In common with the medial posterior ciliary artery (MPCA) (Fig. 7).

(*c*) In common with the lateral posterior ciliary artery (LPCA) (Fig. 8).

(*d*) By a trunk common to the MPCA, LPCA, and muscular arteries.

(*e*) By a trunk common to the MPCA and LPCA.

(*f*) By a trunk common to the MPCA and muscular artery.
(*g*) In common with the muscular arteries.
(*h*) In common with the lacrimal artery and the LPCA.

Previous authors have made the following observations:

(*i*) According to Kershner (1943), Traquair (1949), and Wybar (1956), the artery arises as an independent branch.

(*ii*) Magitot (1908), Quain (1909), Wolff (1939), and Sudakevitch (1947) state that it usually arises in common with the medial posterior ciliary artery. Meyer (1887) and Wybar (1956) also describe such a mode of origin but do not give its relative frequency.

(*iii*) The central artery may also arise in common with the lateral posterior ciliary artery (Wybar, 1956), the posterior ciliary artery (PCA) (Soemmerring and Weber, cited by Beauvieux and Ristitch, 1924; Magitot, 1908; Kershner, 1943; Traquair, 1949); the posterior ethmoidal or lacrimal artery (Merckel, 1874); and the muscular arteries (Soemmerring and Weber, cited by Beauvieux and Ristitch, 1924; Sudakevitch, 1947).

In Table III, the findings of the present study are compared with those of other workers who have furnished details.

TABLE III

COMPARISON OF MODE OF ORIGIN WITH THAT SEEN BY OTHER AUTHORS

Author and Date	No. of Specimens	Independent Branch (per cent.)	With MPCA (per cent.)	With LPCA (per cent.)	With Any Other Branch of Ophthalmic Artery
Beauvieux and Ristitch (1924)	20	35	30	25	With Medial Posterior Ciliary Artery and Lateral Posterior Ciliary Artery in 5 per cent. With Short Posterior Ciliary Artery in 5 per cent.
Sudakevitch (1947)	103	19·3	Mostly	—	
Steele and Blunt (1956)	30	93·3	—	—	With PCA in 6·7 per cent.
Present Series (1960)	102	37·50	37·50	11·54	(*a*) With MPCA and LPCA in 4·81 per cent. (*b*) With MPCA, LPCA, and muscular artery in 1·92 per cent. (*c*) With MPCA and muscular artery in 2·88 per cent. (*d*) With muscular artery in 2·88 per cent. (*e*) With lacrimal and LPCA in 0·96 per cent.

An interesting fact that does not seem to have been noticed by the previous workers is that the crossing medially of the second part of the ophthalmic artery over or under the optic nerve affects the site, order, and mode of origin of the central retinal artery. Table II shows that, when the ophthalmic artery crosses over the optic nerve, the central artery commonly arises at the "angle" or first part of the former, as its first branch, either independently or in common with some other artery. On the other hand, when the ophthalmic artery crosses under the optic nerve, the central retinal artery usually arises from its second part, as a second or third branch, and nearly always independently.

Sudakevitch (1947), while stressing that the first part of the ophthalmic artery was the commonest site of origin of the central retinal artery, said that this site was of great importance from the haemodynamic point of view. The central artery of the retina receives its blood supply by the shortest route and almost in a direct line. According to him it is rare to find any site of origin other than this. He further stated that, whenever such a condition was present, nature provided anastomoses and accessory branches to compensate for the disadvantageous site of origin. In the present series, however, the central artery of the retina arose from the second part of the ophthalmic artery in 18·27 per cent. of cases, and no anastomoses and accessory branches were seen.

Course of the Central Artery of the Retina

No detailed description is available in the literature. For descriptive purposes the whole course of the central retinal artery may be divided into three distinct parts (Fig. 6, opposite):

(*1*) *Intra-orbital.*—This extends from the origin of the artery to its entry into the space between the optic nerve and the dural sheath.

(*2*) *Intravaginal.*—This lies in the space between the optic nerve and the dural sheath.

(*3*) *Intraneural.*—This lies within the substance of the optic nerve, and may be further subdivided into the *vertical* section and the *horizontal section.*

(*1*) *Intra-orbital.*—The central retinal artery is usually described as having a tortuous intra-orbital course and this was the case in most specimens in the present series (Figs 2, 3, 7, 8), but not in all. This tortuosity is particularly marked near the point of entry into the dural sheath and in this locality coils of the artery are usually fixed to each other by thin fibrous sheets.

(*i*) The intra-orbital part usually lies (in 90 per cent. of cases) free in fatty areolar tissue round the optic nerve, lightly adherent to the sheath of the nerve, as described by Wybar (1956).

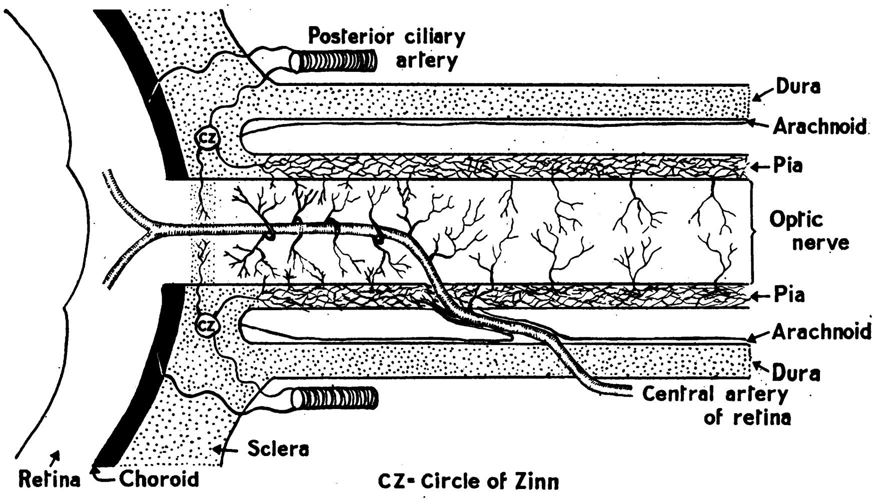
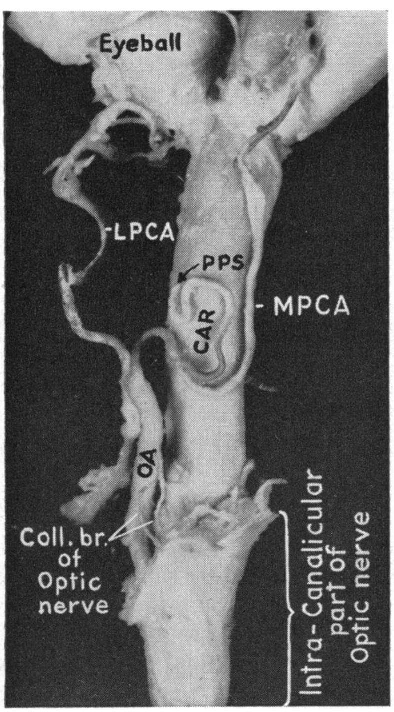
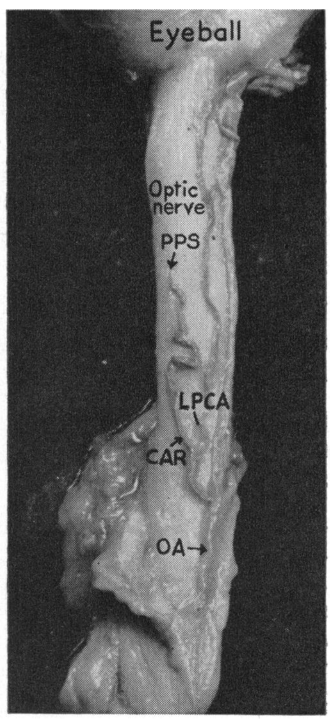


FIG. 6.—Schematic section of optic nerve and eyeball, showing the course and branches of the central retinal artery.





FIGS 7 and 8.—Origin and intra-orbital course of central retinal artery as seen from below. Coll. br. = Collateral branch.

(*ii*) Meyer (1887) and Magitot (1908) stated that the central retinal artery lay embedded in the folds of the dura beneath the optic nerve. This was true of only 6 per cent. of specimens in the present series.

(*iii*) In 4 per cent. of cases it was adherent only near the site of entry into the sheath for a millimetre or so, and was free more proximally. Beauvieux and Ristitch (1924) found the central retinal artery adhering to the dural sheath by vascular fascia for 1 or 2 mm. only.

At times the central retinal artery is surrounded in its intra-orbital course by a thick plexus of veins derived from the dural sheath and central retinal vein.

SITE OF PENETRATION OF THE DURAL SHEATH BY THE CENTRAL RETINAL ARTERY.—Previous authors have not agreed on the exact site of this penetration:

(*i*) Deyl (1896), Fry (1930), Wolff (1939), Kershner (1943), Duke-Elder (1946), Traquair (1949), and Steele and Blunt (1956) have stated that the dural sheath is pierced on the lower medial aspect of the optic nerve. According to Deyl (1896), during development, this is the site of the embryonic optic fissure where the mesenchyme invaginates the primary optic vesicle to form the vitreous, and it thus appears that the central retinal artery maintains its primitive position. This site was observed in 86·3 per cent. of the present series.

(*ii*) Contrary to this view, Vossius (1912) thought that the artery pierced the sheath on its lower lateral aspect, believing that during development the nerve and eyeball rotated through an angle of 90°. This site was observed in 12·7 per cent. of the present series.

(*iii*) Beauvieux and Ristitch (1924) found the site of penetration on the superior surface of the optic nerve in 20 per cent. of their specimens, but this site was not observed in the present series.

(*iv*) In 1 per cent. of the present series the site of penetration was observed on the lateral side of the optic nerve.

The distance of penetration of the sheath behind the eyeball has also been variously described by different authors (Table IV, opposite).

The distance from the eyeball in various cases in the present series is compared with those observed by Beauvieux and Ristitch (1924) in Table V (opposite), which shows that most commonly the dural sheath is pierced about 10 mm. from the eyeball.

After the artery has pierced the dural sheath of the optic nerve its course may be described as intravaginal. According to Beauvieux and Ristitch (1924), it pierces the sheath obliquely, running upwards and forwards within the sheath for about 1 mm. before entering the intravaginal space. Wolff (1939), on the other hand, stated that the artery pierced the sheath by turning vertically upwards so that it pierced the dura and the arachnoid as it entered the intravaginal space. In the present series the artery was invariably seen to traverse the sheath obliquely upwards and forwards, remaining within the substance of the sheath for 0·3 to 1·5 mm.

TABLE IV

DISTANCE BETWEEN EYEBALL AND SITE OF PENETRATION OF DURAL SHEATH BY CENTRAL RETINAL ARTERY

FINDINGS OF VARIOUS AUTHORS COMPARED

Authors	Date	Number of Specimens Examined	Distance from the Eyeball at which the Sheath of the Optic Nerve is pierced by the Central Retinal Artery (mm.)
Magitot	1908	—	5–9
Quain	1909	—	10–20
Vossius	1912	—	10–20
Beauvieux and Ristitch	1924	20	4–13
Whitnall	1932	—	5–15
Wolff	1939	—	10–15
Kershner	1943	—	10–15
Duke-Elder	1946	—	10–15
Traquair	1949	—	10–15
François and Neetens	1954	—	10–20
Wybar	1956	17	15
Steele and Blunt ..	1956	30	7–17
Present Series ..	1960	102	5–15·5

TABLE V

DISTANCE BETWEEN EYEBALL AND SITE OF PENETRATION OF DURAL SHEATH PRESENT SERIES COMPARED WITH PREVIOUS FINDINGS

Distance from the Eyeball at which the Dural Sheath is Pierced by the Central Retinal Artery (mm.)	Percentage of Specimens	
	Beauvieux and Ristitch (1924)	Present Series (1960)
4·0	5	Nil
5·0	Nil	0·97
6·0	5	0·97
7·0	Nil	4·85
7·5	Nil	2·91
8·0	10	9·71
8·5	Nil	3·88
9·0	10	14·56
9·5	Nil	10·68
10·0	30	19·42
10·5	Nil	6·79
11·0	20	7·77
11·5	Nil	2·91
12·0	5	5·82
12·5	Nil	1·94
13·0	15	Nil
13·5	Nil	2·91
14·0	Nil	2·91
15·5	Nil	0·97
Number of Specimens Examined	20	102

This oblique piercing of the sheath is well seen in serial transverse sections and reconstructions (Figs 9, 10, 11).

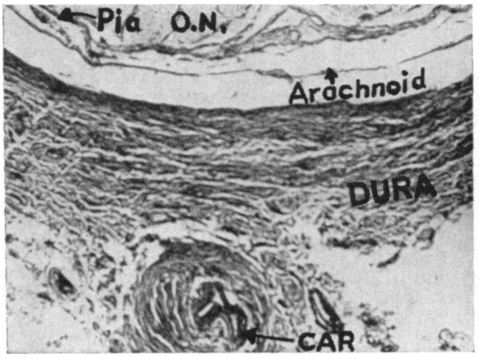


FIG. 9.—Central retinal artery lying outside the dural sheath and adherent to it. ×33.

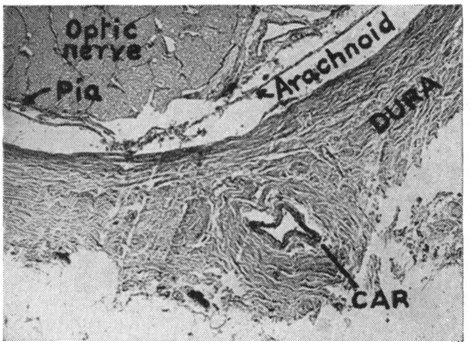


FIG. 10.—Central retinal artery piercing the sheath (Section 330μ anterior to Fig. 9). ×33.

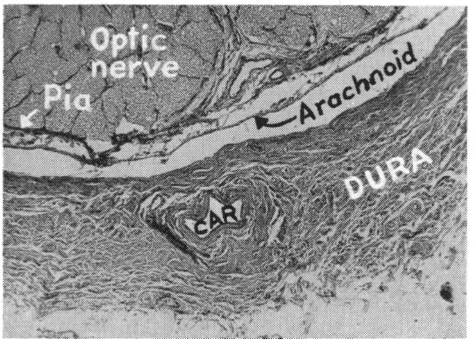


FIG. 11.—Central retinal artery lying within the substance of the sheath (Section 300μ anterior to Fig. 10). ×33.

The artery may very rarely run backwards within the substance of the sheath. Contrary to the view of Wolff (1939), it pierced only the dura and not the arachnoid as it entered the intravaginal space (Figs 12, 13).

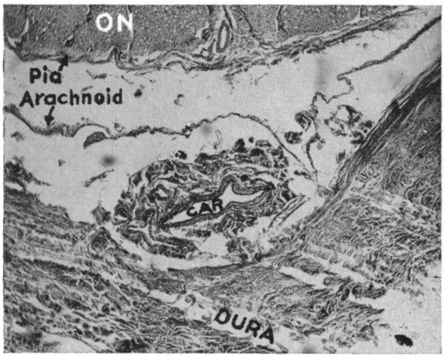


FIG. 12.—Central retinal artery in subdural space. × 61.

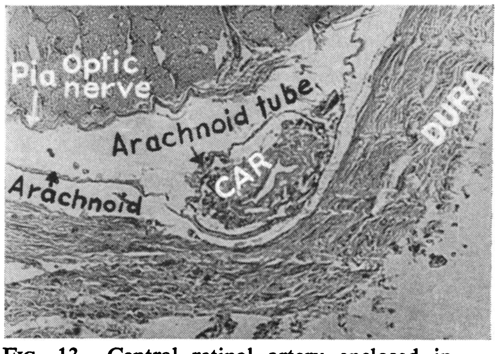


FIG. 13.—Central retinal artery enclosed in arachnoid tube (Section 250μ anterior to Fig. 12). × 38.

(2) *Intravaginal.*—That a distinct length of the central artery lies in the intravaginal space is unequivocally stated by Beauvieux and Ristitch (1924), Wolff (1939), Kershner (1943), and Traquair (1949), and has been confirmed by the present investigation (Fig. 14).

In the present series, the existence of distinct subarachnoid and subdural spaces is clearly seen in the reconstructions and serial sections. In its intravaginal course the artery usually runs forwards for a short distance in the subdural space (Fig. 12) and for a much greater distance in the subarachnoid space (Fig. 13). The artery carries a prolongation from the dura, and it also carries from the arachnoid a tube-like prolongation which surrounds it in the subarachnoid space (Fig. 13). The intravaginal part of the artery is usually 0·9 to 2·5 mm. long. The artery may be accompanied by the central retinal vein, but although this was described as invariable by Beauvieux and Ristitch (1924) and Kershner (1943) it was found in only eight out of fourteen of our specimens in which the vein could be studied. The artery may also be accompanied by a collateral branch according to Beauvieux and Ristitch (1924), but this is by no means constant.

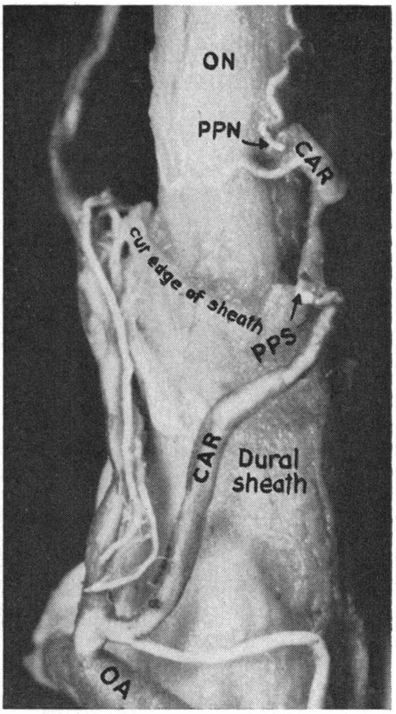


FIG. 14.—Origin, intra-orbital, and intravaginal course of central retinal artery as seen from below. Branches from the intravaginal part running on the pia are also seen.

PPN = Point of piercing optic nerve.

In 7·8 per cent. of the specimens a tortuous loop was formed by the artery in its intravaginal course and in such cases the intravaginal part is much longer than usual. In 1 per cent. the artery looped so it ran backwards.

(3) *Intraneural.*—All the authors who have studied this part of the central artery agree that when it enters the nerve it does not pierce the pia but the membrane is invaginated with it (Quain, 1909; Kershner, 1943; Duke-Elder, 1946; Traquair, 1949). According to Wolff (1939), the entering vessel is clothed by the entire thickness of the pia and for a short distance by some subarachnoid trabeculae as well. Thus the pial vessels are also invaginated into the optic nerve. Beauvieux and Ristitch (1924) have described a vascular fascia preceding these vessels into the centre of the optic nerve in the region just proximal to the point of entry of the central artery into the nerve.

In the present investigation, it was observed that the artery entered the optic nerve substance through a small depression situated on a well-defined fissure on the lower surface of the nerve (Fig. 15). A very clear fold of pia was seen to be invaginated by the artery into the nerve along the optic nerve fissure, and this pial invagination extended for a short distance posterior to the site of entry of the artery (Fig. 16). The site of entry of the nerve was always 1·2 to 3·5 mm., anterior to the site of penetration into the dural sheath, except in one specimen in which it was situated 4 mm. posteriorly.

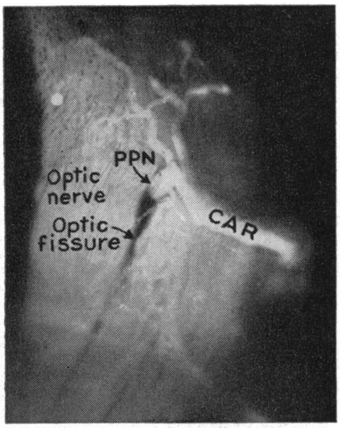


FIG. 15.—Intravaginal course of central retinal artery along with branches arising from this part as seen from below. The mode of penetration of the artery through a well-marked optic fissure is clearly seen.

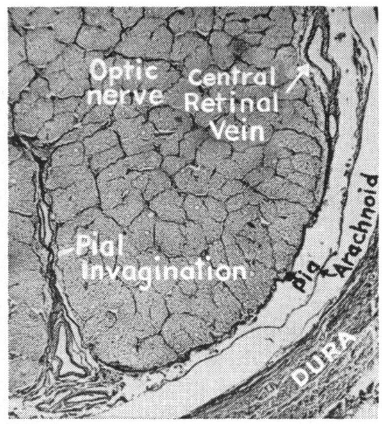


FIG. 16.—Transverse section of optic nerve, showing a fold of pia invaginated into the nerve and preceding the penetration of the artery into the nerve. The artery lies at its site of penetration (Section 1,240μ anterior to Fig. 13). × 38.

The intraneural part of the central retinal artery has two distinct sections —vertical and horizontal:

VERTICAL

(*i*) This section may run upwards and slightly forwards (89·06 per cent.) to reach the centre of the nerve. This agrees with the descriptions of Beauvieux and Ristitch (1924), Kershner (1943), and Duke-Elder (1946).

(*ii*) Wolff (1939), Traquair (1949), and Wybar (1956), however, described this section as running vertically upwards, but this was seen in only 7·8 per cent. of the present series.

(*iii*) In 3·13 per cent. (serial reconstructions) the artery ran upwards and backwards, and this course has not previously been described (Fig. 17, opposite).

The transition from the vertical to the horizontal was gradual, no sharp angle being formed at this point (Figs 6, 18). Wolff (1939), Duke-Elder (1946), and Wybar (1956) state that an angle of 90° is formed at the centre of the optic nerve.

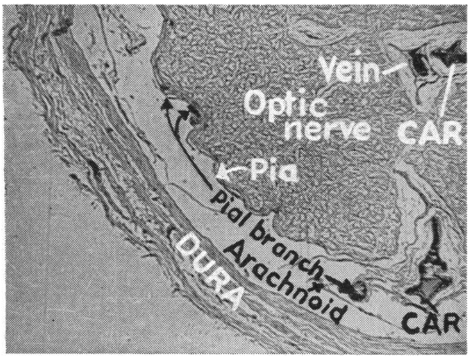


FIG. 17.—Transverse section of optic nerve after injection of 3 per cent. prussian blue into the central retinal artery, showing the mode of penetration of the artery into the nerve. The intraneural part of the central retinal vessel is also seen lying in the centre of the nerve as the artery in this case runs upwards and backwards in its vertical intraneural section. × 21.

HORIZONTAL

This section runs forwards in the centre of the optic nerve and passes through the centre of the lamina cribrosa to reach the optic disc, where it divides into its terminal branches (Fig. 19).

In its horizontal intraneural course the central retinal artery was found by Quain (1909) to run with the corresponding vein surrounded by fibrous and elastic tissue and accompanied by small parallel branches, the vein being longer than the artery. Magitot (1908) and Beauvieux and Ristitch (1924) found that the artery was surrounded in this part by vascular fascia which gradually diminished and came to an end just at the point of entry of the artery into the eyeball. In the serial sections studied in the present investigation it was observed that the artery was enclosed in a fibrous tissue envelope, which in turn was continuous with the fibrous septa of the optic nerve (Figs 20 and 21, overleaf). This agrees with the findings of Duke-Elder (1938). The artery was loose inside this envelope, the space surrounding being visible on dissection. No such space was seen around the central retinal vein,

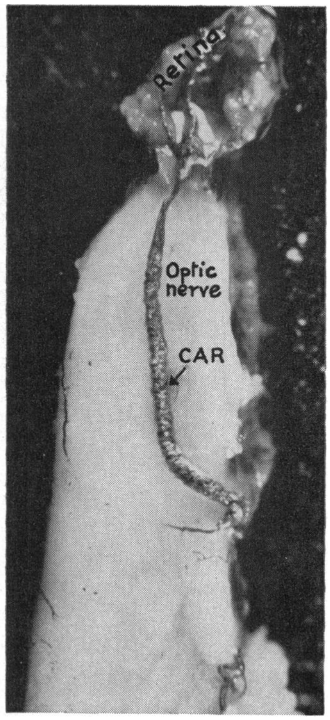


FIG. 18.—Intraneural course of central retinal artery as seen on splitting open the optic nerve along the optic fissure from below.

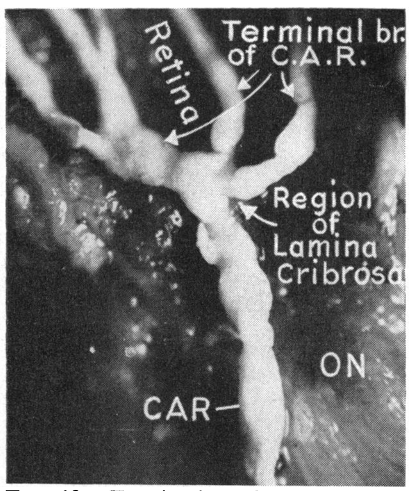


FIG. 19.—Termination of central retinal artery at optic disc as seen on splitting open the optic nerve and eyeball from below. Sacculations of terminal part of artery and its terminal branches are seen.

which lay beside the artery on the lateral side and was also enclosed in a fibrous envelope. The two vessels may lie in close apposition (Fig. 21) or they may be separated by fibrous tissue, and at places even nervous tissue may intervene.

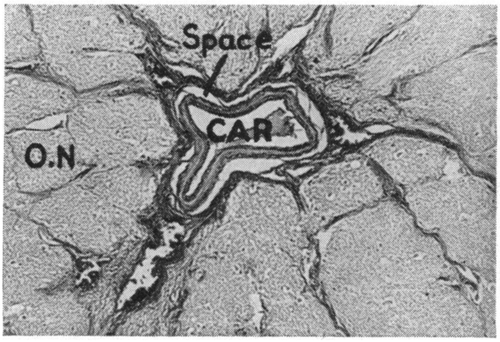


FIG. 20.—Transverse section of optic nerve showing central retinal artery in the centre of the nerve along with venous tributaries. The central retinal vein has not yet reached the centre. A space is seen around the artery (Section 3880μ anterior to Fig. 16). × 87.

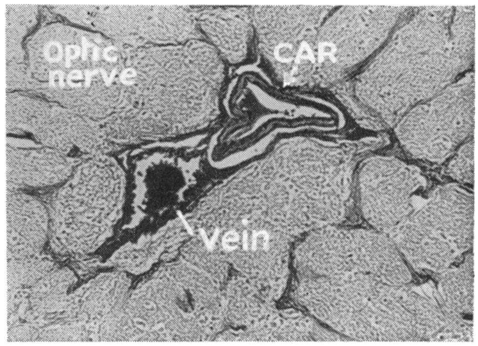


FIG. 21.—Transverse section of optic nerve, showing retinal vessels lying side by side in the centre of the nerve (Section 1930μ anterior to Fig. 19). × 87.

It was observed that it was not essential for the central retinal artery to travel in the centre of the optic nerve to reach the lamina cribrosa. In one specimen the vertical section was virtually absent, so that the artery ran straight to the centre of the lamina cribrosa from its point of penetration into the nerve; the vein, however, occupied the usual position at the centre. In the specimen with a duplicated central retinal artery, the two vessels lay side by side at the centre of the nerve (Fig. 5).

(*4*) *Bends of the Central Artery of the Retina.*—A study of the course of the central artery of the retina shows that between its origin and its termination at the optic disc it makes four main bends (Fig. 6):

(*i*) Where the artery pierces the dural sheath of the optic nerve.

(*ii*) Where having pierced the dural sheath, it runs within the intravaginal space.

(*iii*) Where the artery enters the optic nerve substance.

(*iv*) In the centre of the nerve between the vertical and the horizontal sections of the intraneural part of the artery.

Wolff (1939) and Traquair (1949) have described these bends; Wolff (1939) was of the opinion that they are all right-angled, but Traquair (1949) did not mention the angle. In the present investigation it was observed that all these bends made obtuse angles, the first and second being more obtuse than the third and fourth (Fig. 6). The second and the third bends were acute in the one specimen in which the intravaginal part of the artery ran backwards. The third and fourth bends were acute in two cases in which the vertical section ran upwards and backwards instead of following the usual direction upwards and forwards. When the intravaginal part of the artery was tortuous additional bends were present.

Summary

The origin and course of the central retinal artery was studied in 106 human orbits, 100 specimens by injection with liquid Neoprene latex and six by serial sectioning of the part of the optic nerve containing the central retinal artery. In two of the sectioned specimens 3 per cent. prussian blue was injected into the artery and graphic reconstructions were made.

In two specimens double central retinal arteries were present, which arose independently from the ophthalmic artery.

The central retinal artery may arise from the ophthalmic artery or very rarely from the middle meningeal artery. It may arise as the first, second, or third branch of the ophthalmic artery, from its first or second part, or from the angle between them. It may arise as an independent branch or in common with other branches of the ophthalmic artery. Its origin is closely related to the origin and course of the ophthalmic artery.

The course of the central retinal artery was studied in detail, and three distinct parts (intra-orbital, intravaginal, and intraneural) are described, and the different variations noted.

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