VASCULARIZATION OF THE OPTIC PATHWAY*

IV. OPTIC TRACT AND EXTERNAL GENICULATE BODY

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THE literature contains a diversity of opinions on the subject of the vascularization of the optic tract and the external geniculate body. This fact is explained partly by the numerous anomalies and the variable anatomy of the arterial circle of Willis and the vessels dependent on it; the arteries to the optic tract and to the geniculate body arise at random and without any discernible systematization from the posterior communicating artery, the anterior choroidal artery, and the posterior cerebral artery.

There exists no artery reserved specifically for the supply of the optic tract and the geniculate body as is the case with the retina and partially even with the optic nerve. The optic tract and the geniculate body are supplied by such arteries as happen to be in their immediate vicinity.

Technique of Examination

Examinations were made of 47 cerebral hemispheres from subjects aged 45 to 65 years, by three different techniques:

(1) Macroscopic examination by dissection of the vascular network with or without injection of Neoprene latex 572 and after fixation in a 10 per cent. formaldehyde solution.

(2) Stereoscopic examination of sections after injection of Indian ink (diluted to two-thirds) and fixation in a 10 per cent. formaldehyde solution. The sections, made with a razor-blade, varied in thickness from 0.1 to 0.5 mm., and were rendered transparent by alcohol dehydration and treatment with toluol.

(3) Microradiographic examination after injection of Thorotrast, by a technique previously described (François, Neetens, and Collette, 1955).

Results

I. INJECTION OF INDIAN INK INTO VARIOUS ARTERIES

The following diagrams (Fig. 1 *a-f*) show the degree of filling of the vascular system of the optic tract and external geniculate body according to the artery into which Indian ink was injected; for each injection the internal carotid artery was ligatured at the level of its site of section.

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FIG. 1.—Diagrams showing how injections into various arteries affect the optic tract (O.T.) and lateral geniculate body (L.G.B.)

Key to arteries:

1. Internal carotid	6. Posterior communicating (b) (d)
2. Anterior cerebral	7. Posterior cerebral (e)
3. Anterior communicating	8. Basilar
4. Middle cerebral (a)	9. Superior cerebellar (f)
5. Anterior choroidal (c) (d)	10. Posterior choroidal (e)
	11. Thalamo-geniculate (g)

Note: Internal carotid artery always ligatured at level of its site of section. Heavy black lines indicate positions of ligatures.

- (a) Injection into the middle cerebral artery (4) hardly filled the optic tract and did not fill the geniculate body at all.
- (b) Injection into the posterior communicating artery (6) was followed by moderate filling of the optic tract, but none of the geniculate body.
- (c) Injection into the anterior choroidal artery (5) was followed by moderate filling of the optic tract and very slight filling of the geniculate body.
- (d) *Simultaneous injections into the posterior communicating artery (6) and the anterior choroidal artery (5) caused complete filling of the vascular system of the optic tract, but only slight filling of that of the geniculate body.*
- (e) *Combined injection into the posterior cerebral artery (7) and the posterior choroidal arteries (10) caused no filling of the vascular system of the optic tract, but completely filled that of the geniculate body.*
- (f) and (g) Injections into the superior cerebellar artery (9) and the thalamo-geniculate artery (11) caused slight filling of the geniculate body in exceptional cases, but no filling of the optic tract.

II. EXAMINATION OF ARTERIES SUPPLYING OPTIC TRACT AND EXTERNAL GENICULATE BODY

The optic tract and external geniculate body are treated separately in this study, but this is not because the vascular systems of these two organs are absolutely and strictly separate, for certain arteries may well extend from one organ to the other. Although a certain type of vascularization may be regularly encountered, there are many individual variations in detail.

(1) Optic Tract.—Two arteries are involved in the supply of the optic tract: the anterior choroidal artery and the posterior communicating artery both of which are in its vicinity.

A characteristic feature is the fact that one of these arteries nearly always prevails over the other; in this respect the site of origin of the anterior choroidal artery is important. This artery does not always arise at the level of the internal carotid; in nearly 50 per cent. of cases (in 21 of 47 hemispheres), it arises from the middle cerebral artery, from which it detaches itself more or less laterally. If the site of origin is extremely lateral, this artery produces few collaterals, nearly all extending to the posterior part of the optic tract, and in this case the posterior communicating artery predominates. If the site of origin is nearer the sagittal plane, it produces many collaterals extending to both the anterior and posterior parts of the optic tract, and becomes the predominant artery.

It may therefore be stated (without generalization) that, macroscopically, the anterior half of the tract is entered mainly (in 55.4 per cent. of cases) by branches of both the posterior communicating artery and the anterior choroidal artery, while the posterior half of the tract is entered mainly by branches of the anterior choroidal artery.

Often, although not as a standing rule, the collaterals of the anterior choroidal artery enter the optic tract at its temporal side; those of the posterior communicating artery approach its nasal side but the majority pass over the tract to enter it on the temporal side.

It is often difficult to demonstrate the exact site at which all these collaterals penetrate into the interior of the optic tract; they may encircle the organ before penetrating it, sometimes producing fine anastomotic branches in their course. This is less frequently seen, however, than at the level of the optic nerve and chiasm.

No anastomoses have been observed between the anterior choroidal artery and the posterior communicating artery.

Deviations from the normal state are not infrequently observed, as in the following cases (Fig. 2):

FIG. 2.—(a) Anterior choroidal artery absent. (b) Communicating artery between middle cerebral and posterior communicating artery. (c) Deep communicating branch between middle cerebral and anterior choroidal artery. (d) Abnormal posterior communicating and posterior cerebral artery.

(a) In one hemisphere the anterior choroidal artery was absent, the supply of the optic tract depending entirely on the posterior communicating artery, which was of considerable width (Fig. 2a).

(b) In the contralateral hemisphere of the same case the posterior communicating artery was duplicated, one of its branches opening up into the middle cerebral artery (Fig. 2b).

(c) In two cases (*i.e.* in two hemispheres of different brains) there was a deep anastomosis (intratissular) between the middle cerebral artery and the anterior choroidal artery (Fig. 2c).

(d) In another case, the posterior communicating artery was especially important in that it replaced the posterior cerebral artery, and the circle of Willis was closed only by a thin anastomotic vessel between the posterior communicating artery and the basilar artery (Fig. 2d).

(2) External Geniculate Body.—There is a considerable supply of blood to the external geniculate body. It originates from an arachnoido-pial membrane, containing numerous anastomotic arterioles and localized beneath the organ. From this superficial arteriolar network are derived the supplying arteries which penetrate the geniculate body perpendicularly (Figs 3 and 4).

FIG. 3.—Transverse section of most superficial layers of external geniculate body, with arachnoido-pial membrane, containing arteriolar anastomotic network (a). Smaller arterioles plunging into neural tissue (b). Thorotrast. $\times 55$.

The formation of this network is based on the following arteries:

(a) *The anterior choroidal artery*, which extends collaterals to the optic tract and to the network supplying the external geniculate body and then terminates in the ventricular choroidal plexus.

FIG. 4.—Arachnoido-pial membrane containing arteriolar anastomotic network with superficial layers of external geniculate body. Indian ink. $\times 18$.

(b) *The posterior cerebral artery*, the terminal branches of which also open up into the choroidal plexus, which gives off three or four important branches to the above-mentioned network; these are the posterior choroidal arteries, of which we have been unable to find the three distinct groups that have been described (anterior, middle, and posterior). It may happen that there are only two posterior choroidal arteries or that the latter have a common origin.

On rare occasions we found recurrent branches leaving the choroidal plexus and extending to the external geniculate body.

In several cases it was possible to fill (albeit poorly) the external geniculate body by injecting Indian ink into a thalamo-geniculate artery, which forms no part of the superficial supply network.

In two hemispheres from two different brains the superior cerebellar artery was seen to extend a branch to the network. This branch was localized on the temporal side of the common oculomotor nerve, at the surface of the pons Varolii; it followed the inferior border of the posterior cerebral artery and encircled the pedunculus for a certain distance before starting ramifications into the network in question.

In summary, it may be stated that the anterior choroidal artery (to a smaller extent) and the posterior cerebral artery (to a very considerable extent) give off richly anastomosed branches of varying size to the external geniculate body, either directly or through the intermediary of the superficial supply network*.

The integrity of the superficial supply network is of paramount importance. Since it is composed of arterioles rather than capillaries, it is possible that, if one source of blood is suppressed, the supply may continue from another source, but exclusion of the posterior cerebral artery is nevertheless considerably more serious than that of the anterior choroidal artery. If, on the contrary, the network itself is partly or completely obstructed the supply of the external geniculate body is always impaired and may be completely cut off.

*According to Abbie (1933), the anterotemporal part of this network chiefly depends on the anterior choroidal artery, while the posteromedian part depends on the posterior cerebral artery. We have been unable to confirm this.

It is impossible to subdivide the vascular territories of organs as small as the optic tract or the geniculate body into parts dependent on one and parts dependent on another artery, especially because branches from the anterior choroidal and posterior communicating artery or from the posterior cerebral artery may extend to an identical site, so that the exclusion of one or the other does not necessarily render the site ischaemic. Also, when one part of the external geniculate body or optic tract is eliminated from a functional point of view, the causal lesion is generally localized at the level not of the large vessels, but of the intratissular capillary network itself.

This explains why functional deficiencies caused by circulatory disturbances may differ from case to case. For example, Steegmann and Roberts (1935) reported homonymous hemianopia following exclusion of the anterior choroidal artery, whereas Cooper (1953) observed no disturbances in vision in identical conditions; in certain forms of trembling Cooper excluded the anterior choroidal artery for therapeutic purposes (exclusion of the nucleus of Luys).

A study of the intratissular vascularization is still therefore more important than a study of the macroscopic vascularization.

III. INTIMATE VASCULARIZATION OF OPTIC TRACT AND EXTERNAL GENICULATE BODY

According to Fazio and Farina (1940), there exist in the optic tract polygonal capillary meshes of antero-posterior arrangement, all capillaries having the same size. According to Abbie (1933), all the branches to the external geniculate body, and even those arising from the perforating arteries running to the optic radiations, terminate in the cellular layers where each possesses its own vascularization.

(1) Optic Tract.—There is no axial vascular system similar to that of the optic nerve. Numerous arterioles are found, of which some supply only the optic tract, while others, less numerous, arise from the perforating arteries (Figs 5 and 6, opposite).

Several arterioles, after having perforated the organ, follow a slightly sloping course, which progressively assumes an antero-posterior direction but by a somewhat irregular path (Fig. 7, overleaf).

Others, penetrating perpendicularly to the surface of the organ, divide into branches running in all directions (Fig. 8, overleaf).

All these arterioles have collaterals which, before joining the capillary network, arrange themselves in an antero-posterior direction and then as a rule make a hairpin turn to reverse their direction. This pattern is characteristic of the optic tract, and the vascularization dependent on the anterior choroidal artery intermingles with that dependent on the posterior communicating artery in such a manner as to ensure that the optic tract has a double vascularization and is supplied by one source when the other is excluded.

The capillary network is arranged in an antero-posterior direction, its continuity being less systematic and more irregular than that of the optic

FIG. 5.—Optic tract. Antero-posterior section. Perforating artery (a), giving pre-capillary and capillary branches, arising perpendicularly from original vessel (b). Note special concentric arrangement of capillaries near perforating artery. Thorotrast. $\times 53$.

FIG. 6.—Optic tract. Antero-posterior section. Note concentric arrangement round perforating artery (a) as in Fig. 5. Indian ink. $\times 18$.

nerve. There are no long capillaries in a longitudinal direction, the antero-posterior continuity being ensured mainly by transverse capillaries.

In longitudinal sections the following features are seen (Fig. 7, overleaf):

- (a) Fairly large and irregular polygonal, often hexagonal, meshes.
- (b) These meshes alternate with others which are narrower, longer, and more fusiform.
- (c) At certain sites of intersection there are capillaries showing a circular or ellipsoid course from which emerge two transverse and two longitudinal capillaries; this pattern is characteristic of the optic tract (Fig. 8, overleaf).

FIG. 7.—Optic tract. Antero-posterior section. Slightly sloping course of arterioles (a). Hairpin curves of arterioles and precapillary vessels (b). Irregularly hexagonal capillary pattern (c), alternating with fusiform pattern (d). Thorotrast. $\times 55$.

FIG. 8.—Optic tract. Antero-posterior section. Arteriole, which penetrates perpendicularly (a), divides into branches running in all directions (b). Circular course of capillaries at sites of intersection (c). Thorotrast. $\times 55$.

Transverse sections show the following features:

- (a) The capillaries never form a complete ring round the nerve bundles.
- (b) The anastomotic capillaries assume an oblique direction.

The capillary network shows changes as it approaches the external geniculate body (Fig. 9):

- (a) The sites of intersection formed by capillaries with a circular (no longer ellipsoid) course become more numerous and smaller.
- (b) The antero-posterior capillaries are longer and more rectilinear.
- (c) The transverse capillaries assume a direction perpendicular to that of the longitudinal capillaries, so that the meshes thus formed become quadrangular.

FIG. 9.—Optic tract. Antero-posterior section towards external geniculate body. Note numerous sites of intersections with central round capillary pattern (a). Quadrangular meshes (b) and more rectilinear capillaries. Thorotrast. $\times 36.3$.

(2) External Geniculate Body.—Apart from the supplying vessels already described macroscopically, the external geniculate body also receives capillaries and precapillaries of the optic tract. It is so richly vascularized that, in sections, these vessels form a tight nucleus which can immediately be distinguished from the remainder of the brain (Fig. 10, overleaf).

The arterioles, which contribute to the supply of the external geniculate body, usually perforate this body before continuing to the optic radiation. Their course is slightly curved, showing an internal concavity; they are

FIG. 10.—External geniculate body with transition to optic radiations. Oblique frontal section. Tight vascular nucleus of external geniculate body (a). Start of optic radiation (b). Slightly curved, parallel arteries perforating external geniculate body (c). Relatively free space around arteries (d). Collateral branches close together (e). Arterioles discontinuing at various levels (f). Thorotrast. $\times 34$.

parallel and fairly large. The branches arising from them and extending to the external geniculate body are very close together, and often remain parallel until they become transformed into capillaries (Fig. 10). The arterioles exclusively supplying the external geniculate body discontinue at various levels. Round the large vessels there is a relatively narrow free space (Figs 10 and 11).

FIG. 11.—External geniculate body. Parasagittal section. Branching of small arterioles (a). Relatively narrow free space around arterioles (b). Indian ink. $\times 18$.

The *capillary network* of the external geniculate body, which is in anastomotic communication with other capillary networks, constitutes a more or less spherical and easily recognizable formation. It is composed of several layers of capillaries, of which two alternating types are distinguished (Figs 12, 13, 14, 15, overleaf):

(i) Some form serrated, round, or slightly ellipsoid meshes in clusters; these are characteristic of the cellular layers of the geniculate body; each group of nerve cells would seem to possess its own cluster of capillaries.

(ii) Others are more rectilinear, more widely spaced, and slightly larger, and originate partly from the optic tract. These are characteristic of the fascicular layers and are interconnected by transverse capillaries, thus forming a network analogous to that of the optic tract.

The capillary structure of the external geniculate body is a spatial reconstruction of that of the retina.

Although each cellular layer possesses individual vascularization, anastomoses occur between all the capillary networks, and the same network may be composed of different arterioles.

In one case a small cluster of capillaries was seen at the level of the optic radiation; this cluster was identical with those found at the level of the cellular layers of the external geniculate body, and had been injected with Indian ink simultaneously with the capillary network of the external geniculate body. It suggests that a cellular group may exist at the level of the optic radiation, which is normally devoid of cells.

Summary

(1) The optic tract is supplied by the anterior choroidal artery and the posterior communicating artery.

(2) In the interior of the optic tract the arterioles form hairpin turns; owing to these recurrent arterioles, each part of the tract receives a double vascularization.

(3) Because of this, exclusion of one of these two supplying arteries does not seem to cause permanent lesions.

(4) In longitudinal section the capillary network of the optic tract consists of hexagonal meshes alternating with fusiform meshes. Certain sites of intersection are formed by a circular capillary from which arise two transverse and two longitudinal capillaries.

(5) The external geniculate body is partly supplied by the anterior choroidal artery, but especially by the posterior cerebral artery; both contribute to the formation of an anastomotic network localized at the surface of the organ. From this network extend arterioles which terminate within the geniculate body, and others traverse it to continue towards the optic radiation.

(6) The capillary network of the geniculate body, showing features of the myelo-architecture, is particularly rich; there are two types of capillaries:

(b)

(a)

FIG. 12.—External geniculate body, superficial layers without arachnoido-pial membrane. Oblique transverse section. Greater and smaller arterioles continue further than the first cellular layer (a) or have their terminal ramifications (b) at that level. Thorotrast. $\times 36.3$.

(b)

FIG. 13.—External geniculate body. Frontal section. Note two types of capillaries: (a) Extremely serrated round meshes in clusters (cellular layer). (b) More rectilinear, more widely spaced, and slightly larger (fascicular layer). Thorotrast. $\times 38$.

FIG. 14.—External geniculate body. Thin oblique frontal section. Arterioles ending in different layers (a). Thorotrast. $\times 38$.

FIG. 15.—External geniculate body. Parasagittal section. Enlargement of cellular capillary pattern (a) in Fig. 14. Thorotrast. $\times 135$.

some accumulated in clusters, extending to the cellular layers, and others straighter and more widely spaced, extending to the fascicular layers.

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