A STUDY OF THE CHOROIDAL CIRCULATION OF THE EYE IN MAN

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In a monograph on the circulation and nutrition of the eye, Leber (1903) presented a detailed account of the gross anatomy of the choroidal vessels, and little further has been added to his description since that time. More recently, however, Ashton (1952) has introduced a new technique whereby the choroidal vessels may be studied in casts prepared by the intravascular injection of Neoprene latex. This procedure represents a distinct advance on dye-injection methods, because the cohesive and elastic qualities of Neoprene permit dissection of individual vessels from the main vascular mass, a particular advantage in the study of such a tissue as the choroid wherein the vascular structure is dense and complicated; this technique has, therefore, been followed in the present investigation.

Some features of the normal choroidal circulation, as demonstrated in cast preparations, have already been described (Ashton, 1952), but this paper is particularly concerned with the equatorial anastomoses between the anterior and posterior arterial groups, with the distribution of the choroidal arteries in relation to the important question of a segmental blood supply, with the formation of the main venous channels and with the zonal peculiarities of the chorio-capillaris.

MATERIAL AND METHODS

(1) *Intravascular injection of Neoprene latex*

The human eye and the contents of the orbit, including the cavernous portion of the internal carotid artery, were removed in one mass by an intracranial approach at post-mortem. The ophthalmic artery, identified in the fresh specimen as it leaves the internal carotid artery, was irrigated through a glass cannula with tapwater for 60 min.; any large superficial vessels being ligated to prevent leakage and so allow thorough irrigation of the vessels of the eye. The specimen was then placed in a refrigerator for 12 hr. to promote haemolysis of any remaining blood clots, and finally irrigated with water.

Neoprene latex 572, diluted if necessary with water, was injected into the ophthalmic artery from a Woulff's bottle under a pressure of 5–10 lb., using an electric pump. Since Neoprene coagulates very rapidly, it is essential to start the injection at a high pressure, and this was achieved by releasing the clamps on the rubber tube on the cannula side of the Woulff's bottle a few seconds after switching on the pump, and by reducing the intra-ocular pressure before injection by a central corneal puncture wound.

The injected eye was fixed in 10% formol saline and after removal of the cornea, lens, vitreous and retina, the uvea was carefully removed from the globe by cutting the vascular and nervous connexions which linked it to the sclera. The uvea was then bleached in 2% potassium permanganate for 30–60 min., followed by washing in oxalic acid.

The intact choroid was floated into a glass hemisphere, designed to resemble the scleral cup in size and shape, and on withdrawing the fluid the choroid lined its inner surface. The choroid was examined with a wide-field stereoscopic microscope either by looking directly into the sphere, in which case the chorio-capillaris was clearly visible, or by observing through the under-surface of the sphere so that an unobstructed view was obtained of the larger choroidal vessels (Pl. 1, fig. 1).

The choroid was examined in greater detail by mounting it flat on a slide after cutting it radially in several places, but most of the observations described in this paper are based on an examination of individual vessels which were dissected under water from the main mass of the choroid with fine forceps, using a wide-field stereoscopic microscope (magnification × 9 to × 35) and direct illumination from a high-power low-voltage filament lamp.

(2) *Occlusion of a single short posterior ciliary artery prior to intravascular injection*

After the final irrigation described above, a weak solution of methylene blue was injected into the ophthalmic artery. The orbital tissues immediately behind the globe were prised apart until a short posterior ciliary artery lying near the optic nerve was exposed. The vessel was then ligated and severed between the ligatures. Neoprene, or indian ink, was injected into the ophthalmic artery and the uvea examined as previously described.

(3) *Injection of a single short posterior ciliary artery*

Around the central end of one short posterior ciliary artery, identified as described above, a ligature was placed to retract the artery and keep it taut during the insertion of a fine glass cannula through a small cut in the vessel wall. Indian ink was injected into the vessel, and the uvea subsequently examined as before.

RESULTS AND DISCUSSION

The following observations all relate to the examination of twenty-seven human eyes which, as far as could be assessed, were normal in all respects.

The arteries of the choroid

The choroid is supplied by two arterial systems; the more posterior part by six to eight short posterior ciliary arteries which divide into many branches as they pierce the sclera around the optic nerve, and the more anterior part by the recurrent arteries which arise within the ciliary body from the major arterial circle of the iris (Pl. 1, fig. 2), from the long posterior ciliary arteries (Pl. 1, fig. 3), and from the anterior ciliary arteries (Pl. 1, fig. 4). The two systems approach one another at the equator of the eye, where they anastomose either through an intervening capillary network (Pl. 2, figs. 5, 6) or not uncommonly by direct continuity (Pl. 1, figs. 2–4; Pl. 2, figs. 6–8). When the anastomosis is a direct one the two arterial components may be recognized by the direction of their branches; those of the posterior system pointing forwards and those of the anterior one pointing backwards. This free communication of the anterior and posterior blood supplies at the equator is contrary to the conception that the equatorial part of the choroid is an area of poor vascularity; a view put forward by Leber (1903), who considered that any intervening anastomosis is insufficient to allow the posterior system to maintain the circulation in the anterior part of the eye in the absence of a recurrent system.

In addition to the branches of the short posterior ciliary arteries which anastomose with the recurrent choroidal arteries at the equator, there are many branches running forwards in narrow sectors of the choroid, which terminate in arteriolar-capillary networks at some point between the peripapillary region and the equator. The short posterior ciliary arteries are not connected with one another by arterial branches except in the most posterior part of the choroid, so that to a certain extent they have the appearance of end-arteries. If they are true anatomical end-arteries, however, it would follow that occlusion of a single short posterior ciliary artery, prior to the injection of the eye by way of the ophthalmic artery, should result in a filling defect in the appropriate sector of the choroid. Although this occurred in three eyes (two injected with Neoprene and one with indian ink), in four other eyes (two injected with Neoprene and two with indian ink) there was complete filling of the choroid. Furthermore, more than two-thirds of the choroid, ciliary body and major arterial circle of the iris became filled in two eyes which were injected with indian ink through a single short posterior ciliary artery.

From an anatomical point of view the short posterior ciliary arteries cannot, therefore, be regarded as true end-arteries, because each one is in communication with the anterior uveal circulation, including the major arterial circle of the iris, through the free anastomosis between the two circulations at the equator, and consequently in communication with the other sectors of the choroid through the recurrent choroidal arteries. Furthermore, the chorio-capillaris, which forms a continuous series of capillary tubes on the inner surface of the choroid, provides another channel of communication between adjacent arteries. These findings are contrary to any conception of a rigid segmentation of the choroidal arteries, despite the occurrence of a sectorial filling defect in three out of seven eyes in which a single short posterior ciliary artery was occluded prior to the injection of the ophthalmic artery. It seems likely that the occurrence of such a filling defect is largely an expression of the success of the intravascular injection technique. The injection material will pass initially into the arteriolar-capillary network in that part of the choroid supplied by the patent vessels, but, provided the injection is continued beyond this point, the zone dependent on the occluded vessel becomes filled by the alternative pathways.

The veins of the choroid

The four main vortex veins in the region of the equator of the eye are formed by the junction of venous tributaries which converge towards them from neighbouring parts of the choroid. Occasionally a subsidiary vortex vein is formed which leaves the globe independently of the main venous exits (Pl. 3, fig. 9). Some of the venous tributaries pass directly forwards from their origin in the chorio-capillaris to the nearest vortex vein, but others pass backwards towards the peripapillary region before sweeping round to join the main vessels (Pl. 3, fig. 9). This results in a well-marked concentration of venules in the posterior part of the choroid.

Kiss & Orbán (1951) demonstrated swellings (bulbiculi) in the walls of the choroidal venules which they believe to be the site of arterio-venous anastomoses through which the choroidal circulation is controlled. Ashton (1952), however, showed that the bulbiculi occur simply as a result of compression of the venule by the overlying arteriole, and that they are not the site of any arterio-venous communication. This view is confirmed in this further study in which no evidence has been found of any direct arterio-venous anastomoses in any part of the choroid.

The capillaries of the choroid

The capillaries, which form a single layer on the inner surface of the choroid, are not uniform in calibre throughout the chorio-capillaris. Posteriorly, they are smaller with a closer intercapillary network and anteriorly they become wider with a more open network (Pl. 3, fig. 10). The capillaries are, therefore, more dense in that part of the choroid which lies under the macula as compared with capillaries in a more peripheral part of the choroid, but there is no detectable structural difference between the chorio-capillaris underlying the macula as compared with any other part of the chorio-capillaris situated at an equivalent distance from the optic disc. It would appear, therefore, that the density and calibre of the capillaries within the chorio-capillaris are purely an expression of the distance of the capillaries from the optic disc, and that there is no evidence to support the generally accepted belief of Leber (1903), and Nettleship (1903), that the chorio-capillaris which supplies the macular region has distinctive anatomical features.

SUMMARY

1. The technique is described for the preparation of casts of the choroidal vessels of the eye by intravascular injection of Neoprene, the cohesive and elastic properties of which permitted the study of individual vessels dissected from the main vascular mass.

2. The meeting place of the posterior choroidal circulation (short posterior ciliary arteries) and anterior choroidal circulation (recurrent branches from the major arterial circle of the iris, long posterior ciliary artery and anterior ciliary artery) may be marked by an intervening capillary network, but many of the vessels in the anastomosing circulations are in direct continuity with one another.

3. The short posterior ciliary arteries are segmentally arranged, and each branch supplies a localized zone of the choroid with an arteriolar-capillary network, but there is no anatomical evidence for the conception that the short posterior ciliary arteries are true end-arteries.

4. No arterio-venous anastomoses have been found in any part of the choroid, although these have been postulated by other workers.

5. The size and density of the vessels in the chorio-capillaris vary in different regions of the choroid according to their distance from the optic disc, but there is no evidence for the view that the chorio-capillaris underlying the macula has distinctive anatomical features.

I should like to thank Dr Norman Ashton for introducing me to the technique of Neoprene injection and for his encouragement and advice throughout this investigation. I am indebted to Messrs G. Knight and A. McNeil and to the Medical Illustration Department at the Institute of Ophthalmology for their help in the preparation of the casts and the photographs.

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EXPLANATION OF PLATES

Abbreviations: A, cut end of anterior ciliary artery; *E*, equator; *L*, cut end of long posterior ciliary artery; *M*, major arterial circle of iris; *O*, region of optic disc; *R*, recurrent choroidal artery; *S*, short posterior ciliary artery; *V*, venule; *VO*, vortex vein; *VS*, subsidiary vortex vein.

PLATE 1

Fig. 1. Neoprene cast of the intact choroid mounted in a glass sphere and viewed from without—larger arteries and veins nearest camera. × 4.

Fig. 2. Neoprene cast of a strip of uvea showing, above, a recurrent choroidal artery arising from the major arterial circle of the iris, and, below, the terminal parts of several short posterior ciliary arterial branches. Note the direct continuity of the two arterial systems at the equator although in places there is an intervening capillary network. (Dissected specimen.) × 8.

Fig. 3. Neoprene cast of a strip of uvea showing, above, three recurrent choroidal arteries arising from a long posterior ciliary artery, and, below, the terminal parts of several short posterior ciliary arterial branches. Note the direct continuity of the two arterial systems at the equator although in places there is an intervening capillary network. (Dissected specimen.) × 10.

Fig. 4. Neoprene cast of a strip of uvea showing, above, a recurrent choroidal artery, arising from an anterior ciliary artery, and below, the terminal parts of several short posterior ciliary arterial branches. Note the direct continuity of the two arterial systems at the equator although in places there is an intervening capillary network. (Dissected specimen.) × 8.

PLATE 2

Fig. 5. Neoprene cast of the terminal parts of a recurrent choroidal artery, above, and of a short posterior ciliary arterial branch, below, showing an intervening capillary network at the equator. (Dissected specimen.) × 19.

Fig. 6. Neoprene cast of the terminal parts of three recurrent choroidal arteries, above, and of two short posterior ciliary arterial branches, below, showing at the equator an intervening capillary network between the two systems on the right, and direct continuity of the systems on the left. (Dissected specimen.) × 16.

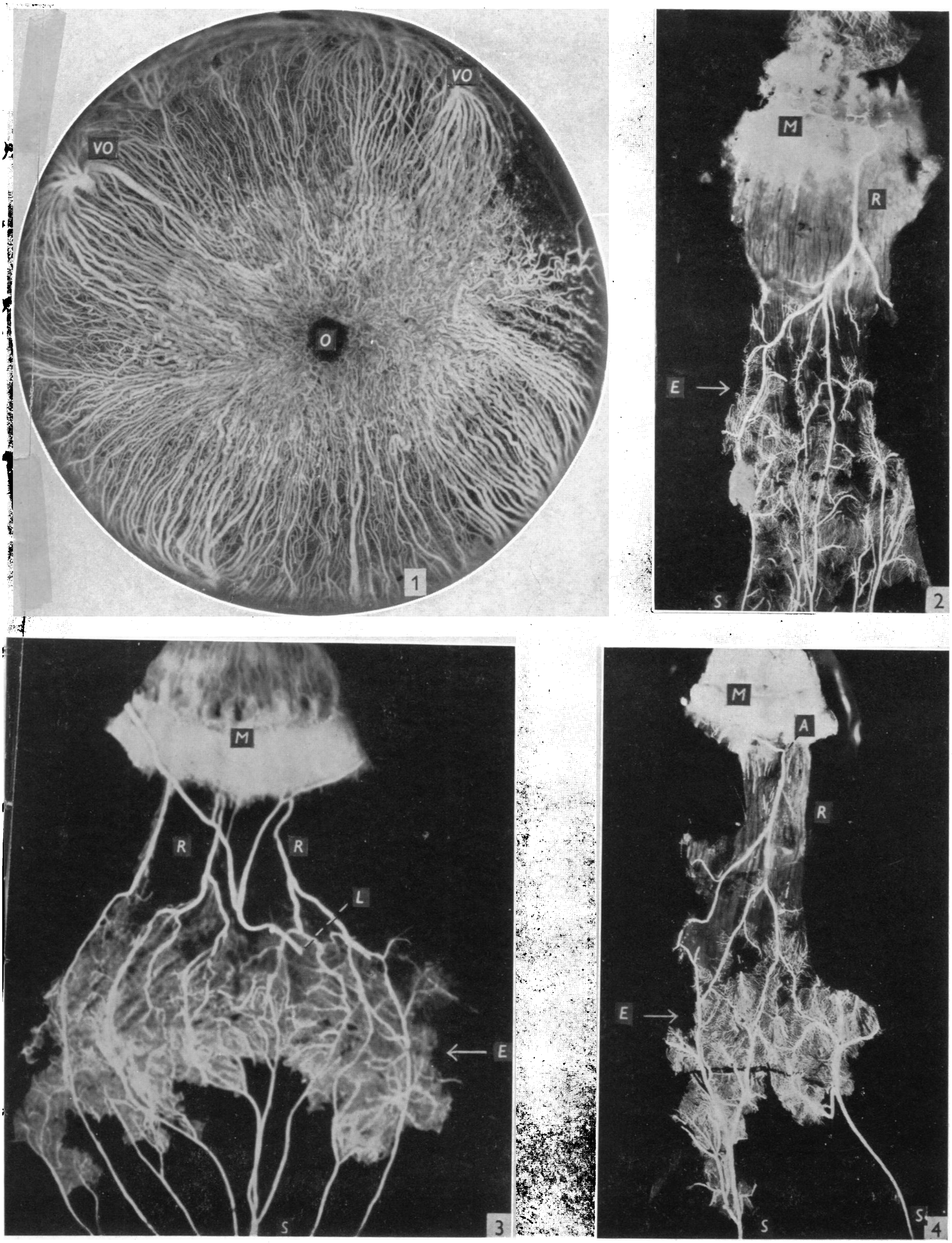
Fig. 7. Neoprene cast of the terminal parts of a recurrent choroidal artery, above, and of a short posterior ciliary arterial branch, below, showing direct continuity of the two arterial systems at the equator. Note the opposing directions of the branches of the two arteries. (Dissected specimen.) × 14.

Fig. 8. Neoprene cast of the terminal parts of two recurrent choroidal arteries, above, and of a short posterior ciliary arterial branch, below, showing the direct continuity of the two arterial systems at the equator. (Dissected specimen.) × 19.

PLATE 3

Fig. 9. Neoprene cast of the choroidal veins showing two main and one subsidiary vortex vein system. Note the sweeping round of certain venules in the peripapillary region as they run to the vortex veins. (Dissected specimen.) × 6.

Fig. 10. Neoprene cast of the chorio-capillaris showing the increase in calibre of the capillaries and decrease in density of the intercapillary meshwork in passing from the posterior to the anterior parts of the choroid, that is, from areas marked 1 to 4. (Dissected specimen.) × 5 and × 24.



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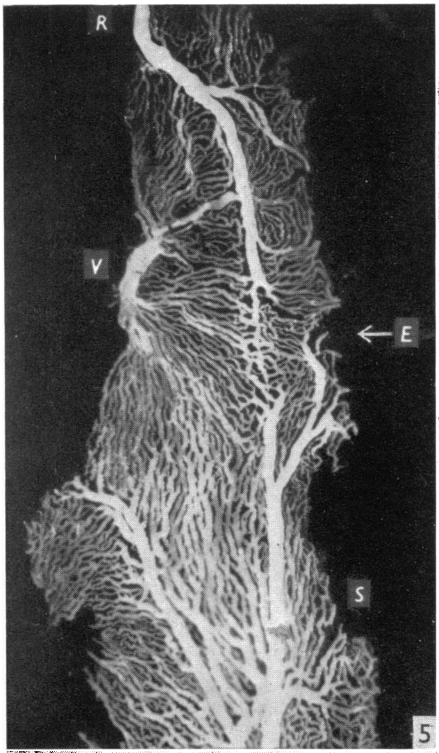

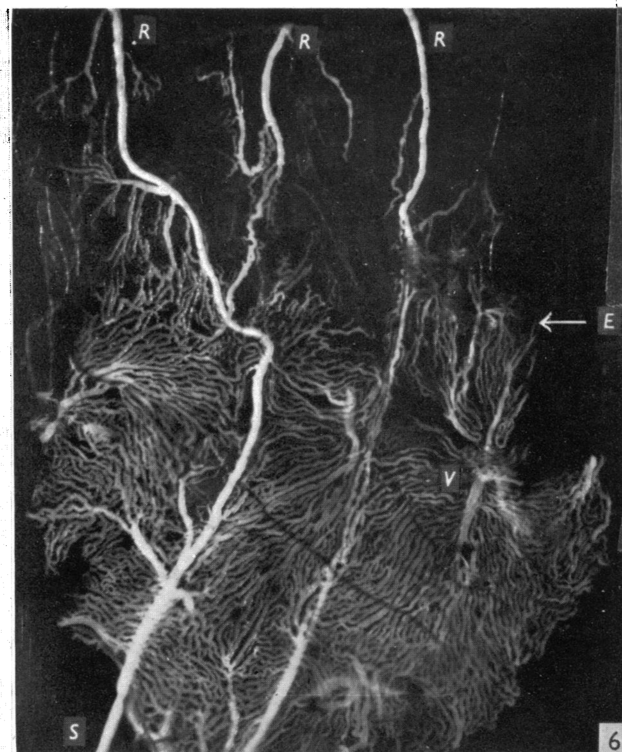

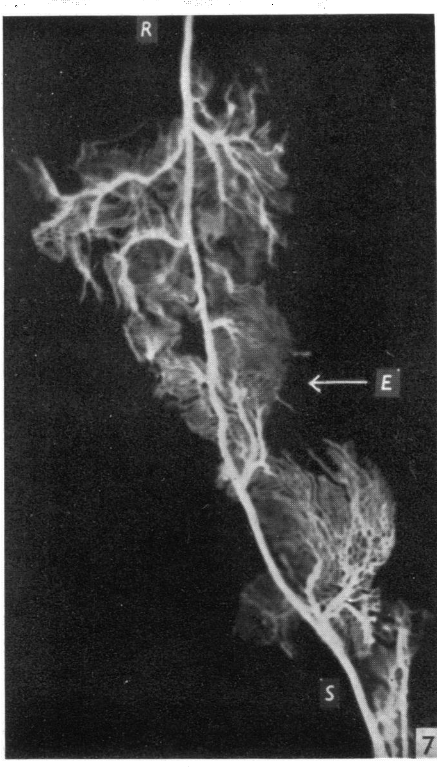

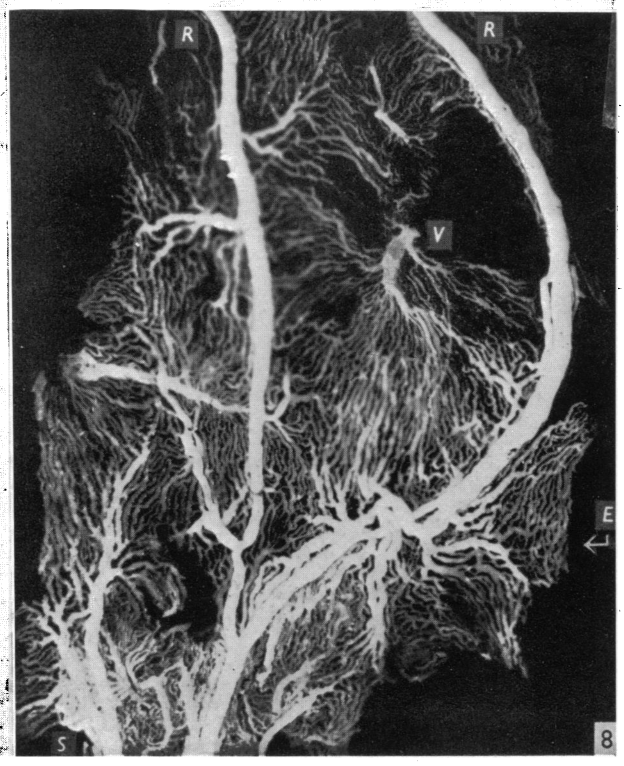

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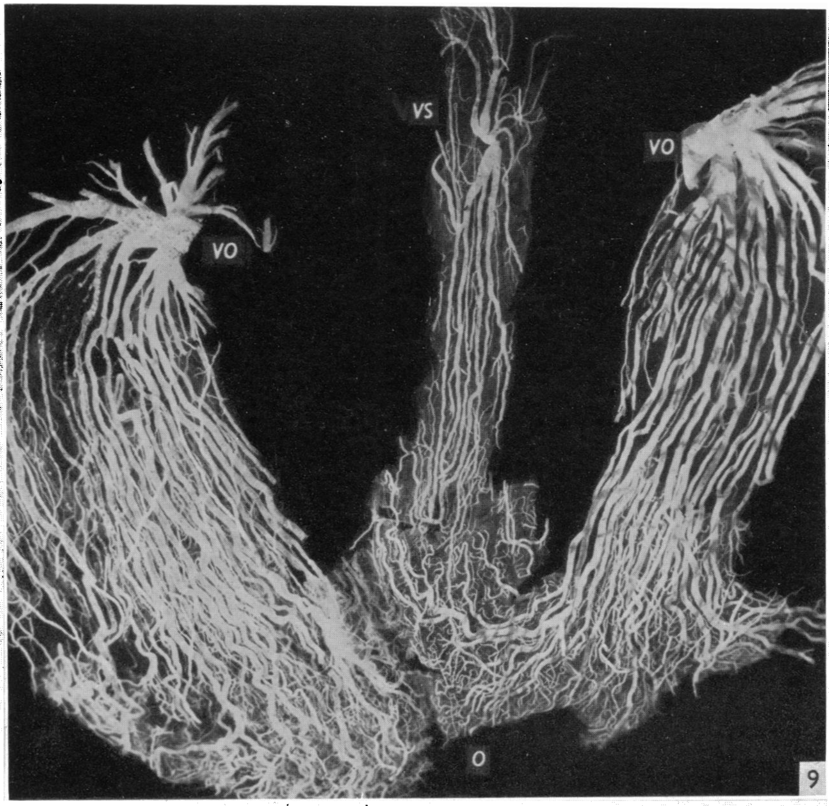

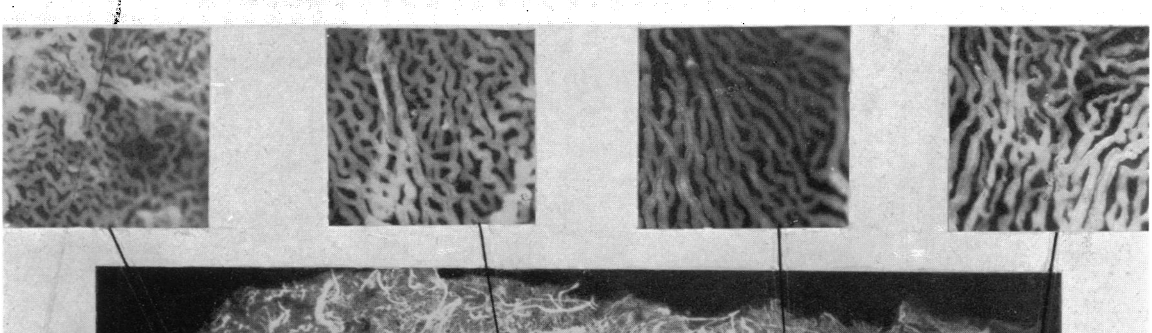

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