Optic Nerve Head Microvasculature of the Rabbit Eye

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Vascular luminal castings of rabbit eyes were microdissected and studied with scanning electron microscopy to elucidate the three-dimensional angioarchitecture of the optic nerve head. Using sequential microdissection, an incomplete arterial circle was identified as terminal branches of two to three short posterior ciliary arteries around the optic nerve head. Several recurrent branches from the arterial circle form a pial arterial network. This pial system supplies the optic nerve head microvasculature and receives numerous venules from them. The only large vessel to enter the optic nerve is a central retinal artery that has few branches within the optic nerve and provides several branches at the surface of the optic disc. Moderately numerous vessels connect the retinal and ciliary vascular layers within the optic nerve head. Few arterioles to the optic nerve head arise from the choroid; however, there are a small number of capillary and numerous venous connections between them. These results indicate that the principal blood supply of the rabbit optic nerve head is derived from the short posterior ciliary arteries by the arterial circle. The retinal arteries contribute to the surface vasculature of the optic nerve head. The pial system also plays a significant role in both supply and drainage of the rabbit optic nerve head.

We used a microvascular corrosion technique that replicates permanently the anatomic condition of vascular beds under the physiologic conditions at the time of plastic injection.1 We previously described the anterior uveal microvasculature in the eyes of primates, rabbits, and other mammals.2–6 These studies revealed constriction cuffs in arterioles supplying the ciliary process arterioles that may provide an anatomic basis for regional alterations in ciliary blood flow.7

The optic nerve head appears to be peculiarly susceptible to the vascular compromise that occurs in various disorders, including anterior ischemic optic neuropathy, cranial arteritis, and possibly, glaucoma. Disorders associated with peripheral vasospasm have been postulated to predispose the eye to glaucoma (eg, optic neuropathies).8–10 Anatomic and physiologic study of the microcirculation in this region has been limited by the complexity and multilaminate nature of its microvasculature.

Buoyed by the success of our studies of the rabbit anterior segment,11–13 we extended these corrosion-casting experiments to the rabbit optic nerve head. In connection with planned experimental studies of the rabbit optic nerve head vascular caliber changes in response to pharmacologic and physiologic stimuli, we first investigated the normal blood supply of the rabbit optic nerve head.

Materials and Methods

We used eight adult normal New Zealand white rabbits of either sex, weighing at least 2.5 kg. All experiments conformed to the ARVO Resolution on the Use of Animals in Research.

Castings of the ocular vasculature were obtained under controlled physiologic condition as described previously.1 We maintained the physiologic status of the animal up to the moment of injection, using a low-viscosity plastic (11 centipoise) at physiologic temperature (37°C) and injection pressure (100–120 mm Hg). The injection pressure was maintained until the plastic begins to polymerize (approximately 15 min). Two hours after injection, the eyes were enucleated, stored overnight in warm formalin to complete the polymerization, and then corroded in 6 mol/l potassium hydroxide. Castings were rinsed in running water and air dried. Whole globe vascular castings were hemisected at the equator, and the posterior segments were placed on large aluminum stubs, sputter coated with gold–palladium, and examined with a scanning electron microscope (Etec Autoscan, Hayward, CA).
Fig. 1. (A) Posterior view shows the optic nerve leaving the globe at an acute angle. ON: optic nerve, SPCA: short posterior ciliary artery, LPCA: long posterior ciliary artery, CH: choroid. Bar = 1.0 mm. (B) Lateral view shows the central retinal artery (CRA) entering the optic nerve about 2 mm posterior to the optic disk and giving off a pial branch (arrow). ON: optic nerve, SPCA: short posterior ciliary artery, CH: choroid. Bar = 0.10 mm.
Fig. 2. Anterior view shows the optic disk is situated superior to the macula (MA), and retinal vasculature confines itself to a pair of wing-shaped areas. Bar = 1.0 mm.

Fig. 3. Anterior view of inferior quadrant of the optic disk shows the cilioretinal artery (two arrows) supplying one wing of the retinal vasculature. Note no capillary connection between the optic disk and the choriocapillaris. CRA: central retinal artery, RV: retina vein, OD: optic disk, CH: choroid. Bar = 0.10 mm.
We viewed the optic nerve head castings from either the anterior or posterior aspect of the globe using sequential microdissection of each microlayer to determine the specific relationships of all vessels in the optic nerve head. For posterior dissections, an initial photograph of the posterior view of the optic nerve was taken, and the vessels of the pial system were removed. The specimen then was recoated and rephotographed. After removing some of the capillaries in the optic nerve, we examined and photographed previously inaccessible vessels and identified sites crucial to optic nerve head perfusion. From the anterior aspect, we excised the retinal vasculature at the edge of the optic nerve head and examined the vascular communications between the optic nerve head and the choroid. Finally, we sectioned the optic nerve castings longitudinally to investigate the relationships between the optic nerve head and retinal vasculature.

Results

General Vascular Anatomy of the Posterior Segment

Viewed posteriorly, the optic nerve leaves the globe at an acute angle in the ventral direction, remaining almost in contact with the sclera (Fig. 1A). The optic nerve head is situated superior to the posterior pole of the globe. There are several branches of the short posterior ciliary arteries between the optic nerve head and the posterior pole. Most supply the choroid; however, two or three branches usually form an incomplete arterial circle around the optic nerve head just before they reach the choroid. A central retinal artery enters the optic nerve ventrally about 2 mm posterior to the optic disc (Fig. 1B). Just as it penetrates the nerve, it regularly provides a branch to the pial system. The two long posterior ciliary arteries enter the globe along the horizontal meridian on the medial and lateral side and provide the many short branches to the choroid. Four venous vortices are located just anterior to the equatorial one in each quadrant.

The anterior view of the casting is shown in Figure 2. The rabbit optic nerve head is situated superior to the macula and has a deep broad physiologic cup. The retinal vasculature, supplied by the central retinal artery and drained by several veins, confines itself to a pair of wing shape areas that extend from the optic nerve head both medially and laterally. The rest of the retina is avascular. The retinal arterial branches usually are supplied by the central retinal artery; however, in 5 of 16 castings, one retinal arterial branch, which turns onto the retina at the margin of the optic cup and supplies one wing of the retinal vasculature, was identified as a direct branch from the short posterior ciliary artery (Fig. 3), corresponding to a cilioretinal artery in the human. The other wing of the retinal vasculature was supplied invariably by the central retinal artery in all castings.
We removed the pial system and some capillaries in the optic nerve substance to observe both the retinal artery and veins (Fig. 4). The central retinal artery usually provides few branches in the optic nerve. Two large retinal veins pass from lateral and medial wings of retinal vasculature to the optic nerve head; in addition, there are two small retinal veins. These retinal veins leave the optic nerve head independently and join the pial system.

Microvascular Anatomy of the Optic Nerve Head

The primate optic nerve head conventionally is divided into four lamellar portions from anterior to posterior as follows: nerve fiber layer, prelaminar, laminar, and retrolaminar region. Because the rabbit optic nerve head has almost no visible lamina cribrosa, we regarded the laminar region as the scleral level of the optic nerve head (i.e., just adjacent to the posterior portion of the choroid vasculature). Similarly, we considered the nerve fiber layer, prelaminar, and retrolaminar regions as the surface, prescleral, and retroscleral vascular lamellae of the optic nerve head, respectively.

The nerve fiber layer (surface): The retinal artery provides several direct branches to the surface vasculature of the optic nerve head, the venous drainage of which empties into the retinal veins (Fig. 5). This re-
region is continuous with the peripapillary retinal vasculature.

The prelaminar (prescleral) region: We found a small number of capillary connections between the choriocapillaris and this region of optic nerve head vasculature at the superior quadrant (Fig. 6A). Excision of the retinal vasculature at the edge of the optic disc also revealed a small number of capillary connections between the choriocapillaris and this region of the optic nerve head vasculature at the medial and lateral quadrants (Fig. 6B). A notable exception to this was the inferior quadrant of the optic nerve head, which had no connections to the choroid (Figs. 3, 6C). The optic nerve head was sectioned longitudinally from 12 to 6 o'clock. At the prelaminar region, we found a moderate number of capillary interconnections between the nerve fiber layer (surface) and the laminar (scleral) region in the optic nerve head (Fig. 7).

The laminar (scleral) and retrolaminar (retro-}

![Fig. 6. (A) Anterior view of the superior quadrant of the optic disk (OD) and the choroid (CH) showing a small number of capillary connections (arrow). Bar = 0.10 mm. (B) Lateral quadrant of the optic disk after excising the retinal vasculature at the edge of the optic disk (OD) and the choroid (CH), showing a small number of capillary connections (arrow). Bar = 0.10 mm. (C) Same region as in Figure 3 after removing the choriocapillaris, showing no choroidal vessel connection between the optic disk (OD) and the choroid (CD). Two arrows: cilioretinal artery. Bar = 0.40 mm.](downloaded from iovs.arvojournals.org on 02/14/2019)
Figures 8A–B show the posterior view of the optic nerve head vasculature (A) and its diagram (B). Three short posterior ciliary arteries form an incomplete arterial circle around the optic nerve head. Most efferent vessels from this circle pass to the choroid; however, several branches pass posteriorly, supplying the pial layer of the optic nerve sheath. These branches form a pial arterial network and nourish the retrolaminar (retroscleral) region of the optic nerve head capillaries. Similarly, numerous septal venules inside the optic nerve drain to the pial system. Some branches from the arterial circle penetrate the optic nerve head centripially and supply the laminar (scleral) region of the optic nerve head (Fig. 9A). Removing the pial system revealed that this arteriole from the arterial circle supplied the laminar region of the optic nerve head vasculature (Fig. 9B). The pial veins along the optic nerve head margin drain to the venous part of the peripapillary choroid (Fig. 10). The longitudinal section (12 to 6 o'clock) of the optic nerve head showed that the small vessels in the optic nerve head form a highly complex network with transverse and longitudinal anastomoses at the retro-laminar (retroscleral) and laminar (scleral) region (Fig. 11).

Discussion

The microvasculature of the optic nerve head has been studied in humans and nonhuman primates,14,15,29,31 sheep,32 dogs,33,34 cats,34,35 rats,36 and rabbits.15,16,37 These studies show that the short posterior ciliary arteries, the pial blood vessels, and the retinal arteries all are important sources of blood flow to the optic nerve head. Unfortunately, the precise anatomic sites of blood vessels that control the optic nerve head perfusion currently are unknown because of the inaccessibility of many blood vessels in this region of the eye. Our earlier understanding of the angioarchitecture of the rabbit optic nerve head was based on light microscopic studies of corrosion casts of neoprene latex preparations. Use of sequential microdissection allows us to view previously inaccessible vessels and identify potential vascular sites crucial to optic nerve head perfusion.

We depicted the normal three-dimensional angioarchitecture of the optic nerve head in the rabbit eye (Figs. 12A–B). The retinal arteries (central retinal artery and cilioretinal artery) contribute to the anterior part of the optic nerve head vasculature, corresponding to the surface nerve fiber layer in humans. The pial branches and centripetal branches from the arterial circle around the optic nerve head (short posterior ciliary arterial contribution) supply the posterior part of the optic nerve head vasculature, corresponding to the laminar and retrolaminar region in humans. There are a moderate number of capillary interconnections between the retinal contribution and short posterior ciliary arteries contribution at the prescleral region, corresponding to the prelaminar region in humans. We found a minor contribution from the choroid to the arterial blood supply of optic nerve head vasculature, except for a small number of capillary connections. Venous drainage of the optic nerve head is through the retinal veins (anterior part of the optic nerve head vasculature) and the choroidal and pial systems (posterior part of the optic nerve head vasculature). These results indicate that arterioles derived from the short posterior ciliary arteries through the arterial circle appear to be the most important sites for arterial perfusion of the optic nerve head. The retinal arteries contribute only to the surface of the optic nerve head vasculature. Regional vasoconstriction of any of these arterioles could cause regional ischemia of the optic nerve head and possibly nerve damage in various disease states.

Comparing these anatomic findings with those of similar studies in humans or primates may allow us to develop a rabbit animal model for studying the optic nerve head vasomotor changes in response to pharmacologic and physiologic stimuli. The surface nerve fiber layer in both rabbits and primates is supplied...
mainly by the retinal arterioles and is continuous with the peripapillary retinal vasculature. The prelaminar region in primates is supplied by vessels of ciliary origin, and it is still controversial whether these vessels are derived primarily from the peripapillary choroid or are direct branches from short posterior ciliary arteries. The prelaminar (prescleral) region in the rabbit is not supplied primarily by the peripapillary choroid. In addition, there are abundant anastomoses between capillary beds of the surface nerve fiber layer and the laminar region in primates, but rabbits have fewer capillary anastomoses between the retinal contribution and short posterior ciliary arterial contribution than do primates. The rabbit optic nerve has virtually no lamina cribrosa. However, rabbits have a dense vascular plexus in the laminar (scleral) region as do primates. This region is supplied by short posterior ciliaryarteries (SPCA) supply to an incomplete arterial circle around the optic nerve, which provides arterial branches to both the optic nerve head and the choroid. On the other hand, numerous venules inside the optic nerve drain to the pial veins. Bar = 0.20 mm.

Fig. 8. Posterior view of the optic nerve head (ONH) vasculature (A) and its diagram (B) show that short posterior ciliary arteries (SPCA) supply to an incomplete arterial circle around the optic nerve, which provides arterial branches to both the optic nerve head and the choroid. On the other hand, numerous venules inside the optic nerve drain to the pial veins. Bar = 0.20 mm.
Fig. 10. Posterior view shows pial veins along the optic nerve head margin draining to the venous part of the choroid (arrow head). ON: optic nerve, CH: choroid. Bar = 0.10 mm.

These considerations indicate that the rabbit optic nerve head vasculature has some similar feature with retinal artery contributes the blood supply of this region.14,22,23

In primates, studies disagree on whether the central arteries through the arterial circle in both rabbits and humans.14,17,19,22,23,28 The retrolaminar (retro-scleral) region in both rabbits and primates is supplied mainly by short posterior ciliary arteries.14,16,17,20–24,31

In primates, studies disagree on whether the central

Fig. 9. (A) Posterior view shows the branch (arrow) from the arterial circle penetrating the optic nerve head centripitally. Bar = 0.10 mm. (B) Posterior view after removal of the pial system showing the exact distribution of this branch (arrow). Bar = 0.10 mm.

Fig. 11. Longitudinal section of the optic nerve head showing a highly complex vessel network with transverse and longitudinal anastomoses. CRA: central retinal artery, RV retinal vein. Bar = 0.10 mm.
that of humans and other primates, but there are also differences. Despite these intraspecies differences, the establishment of a thorough baseline concept of optic nerve head microvasculature in a readily accessible mammalian model should permit additional studies of the regional vasomotor response to pharmacologic and physiologic stimuli.

Key words: optic nerve head, microvascular anatomy, vascular corrosion casting, physiologic injection of plastic, sequential microdissection

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References


