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The fiber system of the choroidocapillaris

Wolf Krebs and Ingeborg P. Krebs
Departments of Opthalmology, College of Physicians and Surgeons of Columbia University, and Manhattan Eye, Ear and Throat Hospital, New York, USA

Summary. In the central choroid of three cynomolgus monkeys *(Macaca irus)* and a baboon *(Papio anubis)* the shape of the choroidocapillary sinus is determined by a system of interstitial collagen fibers, the «fiber system of the choroidocapillaris». The inner leaflet of this system is Bruch's membrane. The outer leaflet consists of interwoven collagen bundles, covering the roof of the capillary sinus. Straight bundles of collagen fibers passing through connective tissue columns in the choroidocapillary sinus connect both leaflets. Forces created by changes in the arterial tone in the vascular stroma may be transmitted by the choroidocapillary fiber system to the elastic layer of Bruch's membrane.

Key words: Primates, Choroid, Choroidocapillaris, Bruch's membrane, Functional morphology, Fine structure

Introduction

The choroid of the eye is considered homologous to the leptomeninges of the brain (Shanthaveerappa and Bourne, 1965). It supplies the outermost layers of the retina with blood and plays a role in the uveoscleral outflow of occular fluids (Bill, 1985). The microscopic anatomy of the human choroid was described in great detail by Torczynski (1982). The structure of the choroidocapillaris received special attention. The reader will find a thorough review of the choroidal literature before 1980 in Torczynski's article.

In the choroid of baboon *(Papio anubis)* and cynomolgus monkey *(Macaca irus)*, we found an elaborate fiber system in the choroidocapillaris. It contains Bruch's membrane, the pericapillary collagen fibers described by Torczynski (1982), and a newly discovered outer fiber leaflet. The orderly arrangement of the fibers implies that the fiber system is a functionally important subunit of choroidal organization.

Offprint requests to: Wolf Krebs, Department of Opthalmology, Columbia University, 630 W. 168th Street, New York, N.Y. 10032, USA

Materials and methods

Eyes of three healthy male cynomolgus monkeys, four, eight and twenty years of age, and of one 15 year old baboon were obtained from experiments involving heart surgery which resulted in the euthanasia of the animals. The eyes were removed after the lethal injection of nembutal. An incision was made at the *limbus corneae* to ease the penetration of the fixative (2% glutaraldehyde and 2% formaldehyde in cacodylate buffer). The eyes were left in the fixative for 24 hours. This long fixation time prevented the detachment of the retina from the choroid. Small samples of choroid with the retina attached to it were excised of the following locations: *fovea centralis*, parafovea (2 mm from the foveolar center), and from the nasal sector at 30° excentricity. The specimens were postfixed with osmium tetroxide. They were embedded in epoxy resin such that some could be sectioned parallel to a plane tangential to the globe («tangential sections») and that other specimens could be cut radially. For further details see Krebs and Krebs (1987). Ultrathin sections were stained with uranyl acetate and lead citrate.

Results

Bruch's membrane was composed of elastic material between two sheaths of collagen fibrils. Its thickness was about 1 μm (Fig. 1). Viewed tangentially, the choroidocapillaris was a capillary sinus rather than a maze of capillaries (Fig. 2). The depth of the sinus, radial to the globe, was about 10 μm (Fig. 1). The endothelium was fenestrated throughout and covered by a continuous basal lamina (Figs. 1-3). The roof and floor of the sinus were connected to each other by columns which contained straight collagen bundles aligned parallel to

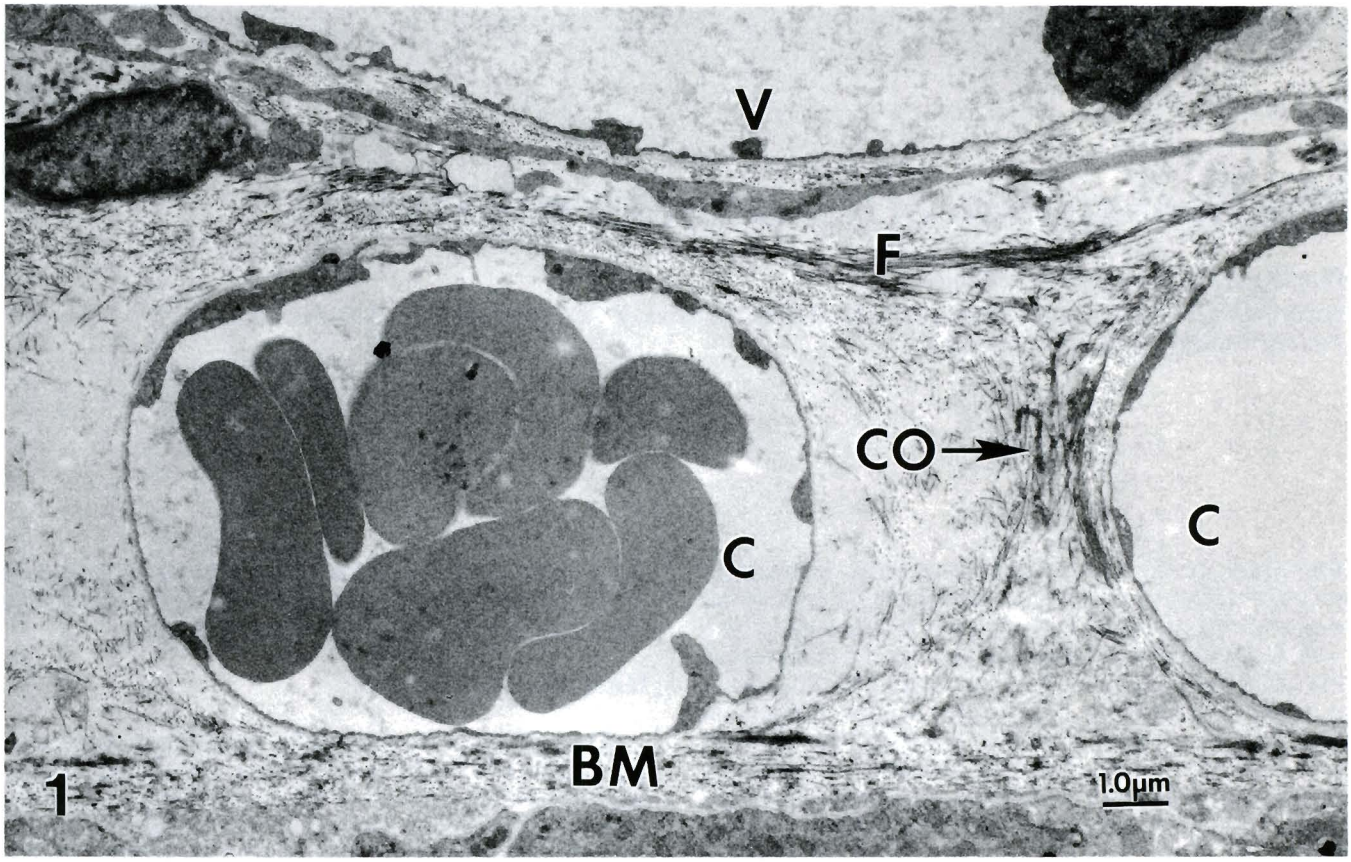

Fig. 1. Radial section through the foveal choroidocapillaris of the baboon. BM: Bruch's membrane; C: lumen of the choroidocapillaris; CO: connecting fibers in the columns of the choroidocapillary sinus; F: outer leaflet of the fiber system of the choroidocapillaris; V: vein. × 4,200

the length of the columns. The bundles were surrounded by loose collagen of variable orientation. The columns were covered by fenestrated endothelium (Fig. 3).

At the outer surface of the capillary sinus, opposite the side of Bruch's membrane, was an approximately 2 µm thick fiber layer (Figs. 1, 4). Very few fibroblasts were seen between the fibers of this layer. One to 2 µm thick straight interwoven bundles of fibrils ran parallel to the roof of the capillary sinus. The fibrils within the bundles were 20 to 30 nm in diameter and they showed a collagen specific cross striation (Fig. 4). Between these bundles were loose collagen fibrils with a diameter of 40 nm. Elastic material (not shown) was occasionally present between the fiber bundles. No nerves were seen in this layer.

Discussion

Torczynski (1982) has described that «collagen from Bruch's membrane extends down into the intervascular columns or septa (of the choroidocapillary sinus), and fibers in small bundles swirl outward and around the external wall of the subcapillary layer». Torczynski did not mention the straight fiber bundles passing through the columns of the choroidocapillaris (Figs. 1-3). Our sections reveal that these fibers actually connect Bruch's membrane with a distinct flat layer of interwoven fibers covering the surface of the capillary sinus opposite of Bruch's membrane. Thus, the capillary sinus is sandwiched between two leaflets of organized connective tissue fibers. The fibers of the outer leaflet are straight bundles crossing each other. They are composed of thin collagen fibrils, resembling reticular fibrils.

Figure 5 is the interpretation of our findings: collagen bundles, originating from Bruch's membrane (Krebs, 1982), pass through the connecting columns of the capillary sinus. These fibrils blend into an external fiber leaflet which covers the roof of the sinus. The backbone of the external fiber leaflet is a fabric-like sheath of interwoven straight bundles of thin collagen fibrils. The distance between Bruch's membrane and the external fiber leaflet is set by the length of the connecting fibers that pass through the columns of the choroidocapillary sinus. Therefore, an expansion of the sinus is limited, and roof and floor are flat endothelial sheaths. If there were no external forces to counteract the perfusion pressure, the sinus walls would be pressed outwards and the sinus would become balloon-like in shape.

Bruch's membrane is regarded as a separate entity of

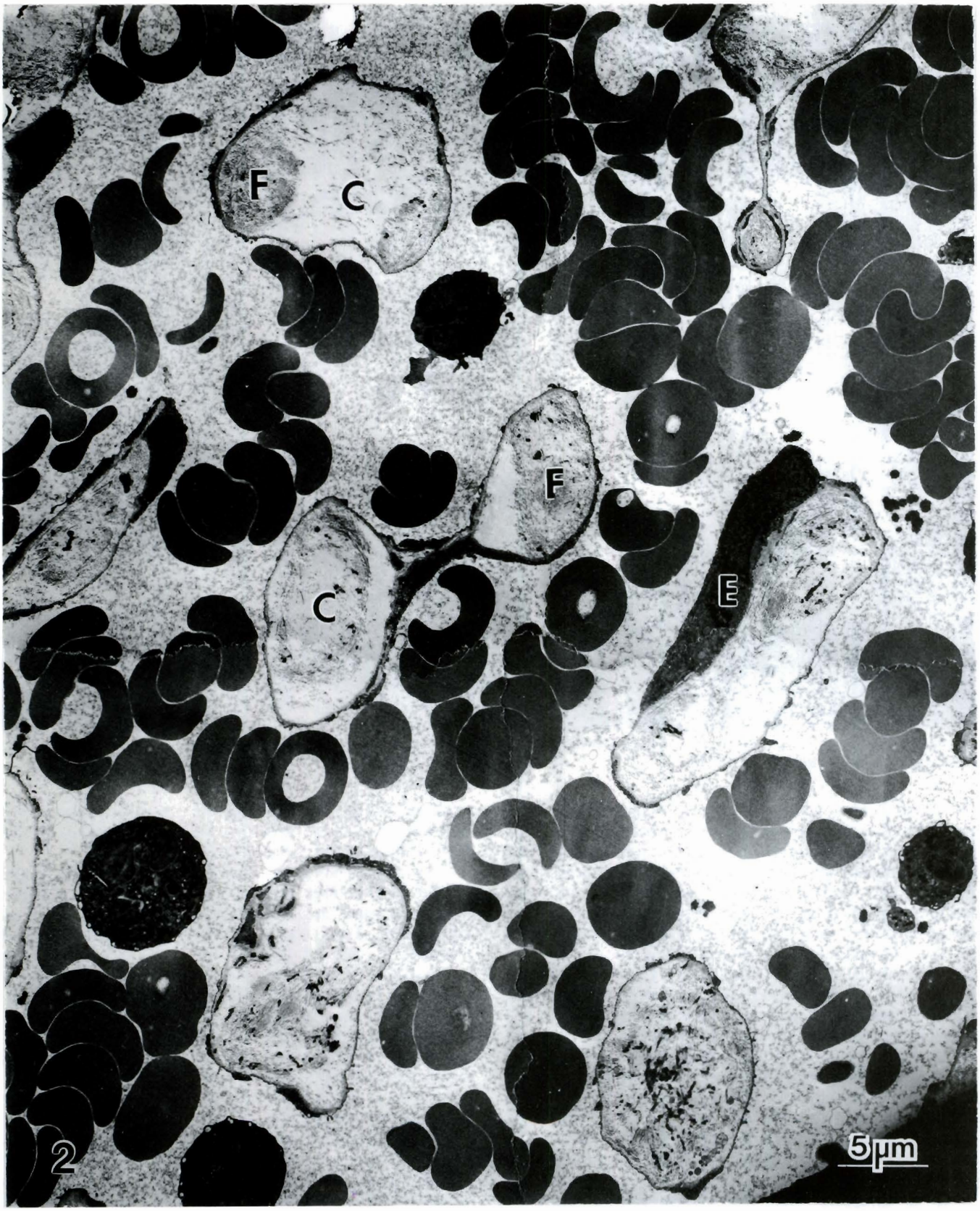

Fig. 2. Tangential section through the choroidocapillaris at 30° excentricity of a cynomolgus monkey. C: column connecting floor and roof of the choroidocapillary sinus; E: endothelial cell; F: collagen fibrils. × 3,150

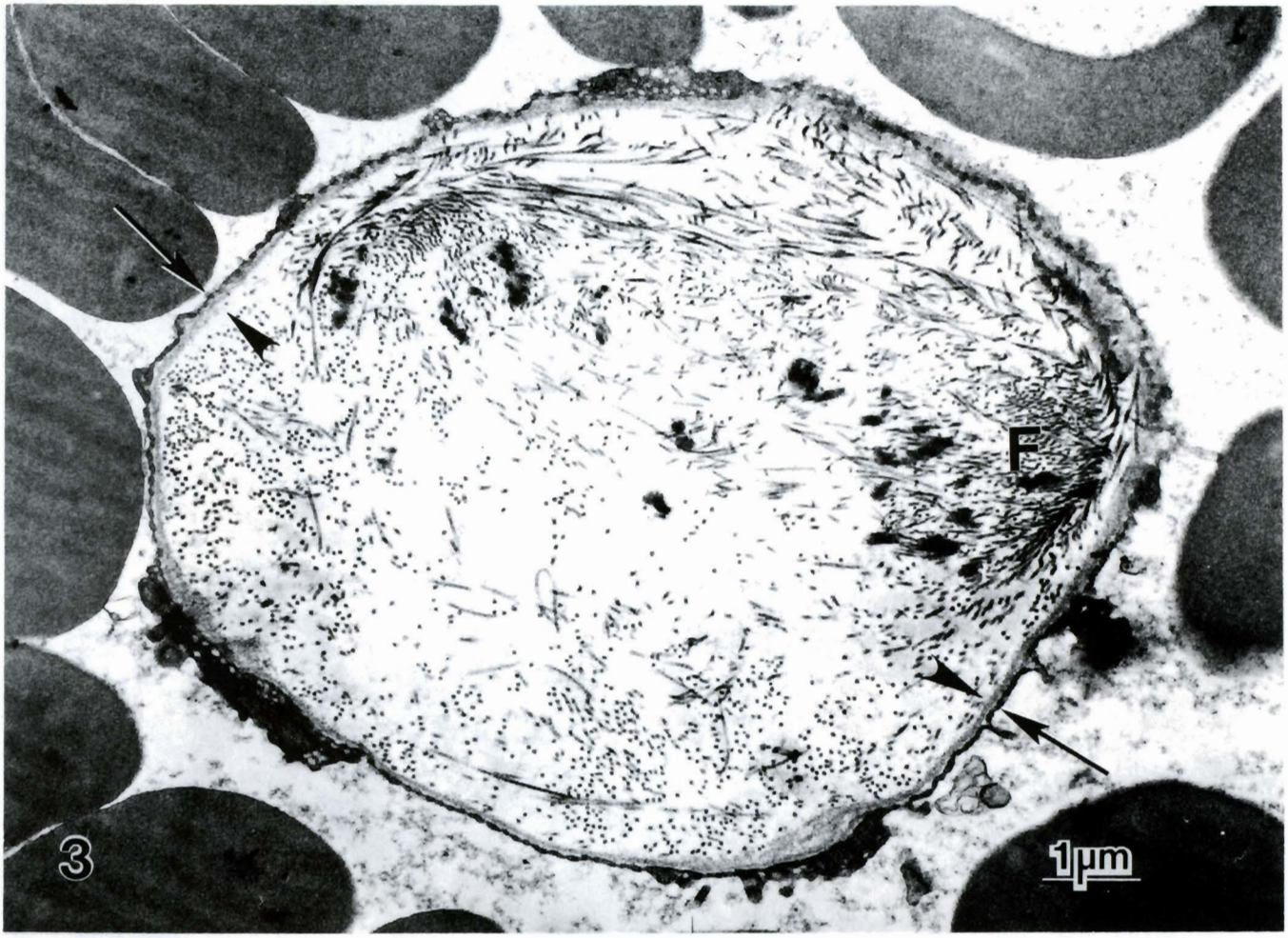

Fig. 3. A column of the choroidocapillaris; cynomolgus monkey at 30° excentricity. F: collagen fibrils; arrowhead: basal lamina of the endothelium; arrow: fenestrated endothelium. × 13,770

the choroid (Hogan et al., 1971). Now it turns out to be a part of a fiber system that provides mechanical strength to the choroidocapillaris. We suggest to name this system «fiber system of the choroidocapillaris» consisting of an inner leaflet —which is Bruch's membrane—, an outer leaflet, and connecting fibers that pass through the columns of the choroidocapillary sinus. The basal lamina of the choroidocapillary endothelium should not be considered part of Bruch's membrane (Krebs, 1982).

Emi et al. (1989) report that the hydrostatic pressure of the suprachoroid in cynomolgus monkey is 3.5 to 4.2 mm Hg lower than the normal intraocular pressure of about 15 mm Hg. With increasing intraocular pressure the pressure difference between choroid and vitreous increases (Emi et al., 1989). The retinal pigment epithelium must be the barrier that maintains this pressure difference since it contains a well developed system of occluding (tight) junctions (Hogan et al., 1971).

It is unlikely that the monolayered pigment epithelium could withstand the high pressure difference without being pressed against its substratum. The absorption of these forces is a suggested function of the fiber system of the choroidocapillaris.

The elastic layer of Bruch's membrane, the inner leaflet of the fiber system, produces an inward force which presses the membrane towards the pigment epithelium. Thus, the choroidocapillary sinus will not collapse in spite of the high pressure difference. The outer leaflet of the fiber system is anchored in the stroma vascularis by collagen fibrils (Fig. 5). Increasing vascular tone of the arteries creates an outward force, which results in an outward pull on the outer leaflet of the fiber system. Via the fibers in the columns of the capillary sinus, this pull will reduce the inward force created by the elastic layer of Bruch's membrane, relieving strain on the pigment epithelium. The rich innervation of the choroidal blood vessels suggests that their tone can be tuned precisely (Kurus, 1955; Wolter, 1960; Feeney and Hogan, 1961; Ruskell, 1971; Bergmanson, 1977). The system would be able to react to varying pressure differences between vitreous and choroid.

Fig. 4. Tangential section through the choroid of a cynomolgus monkey at 30° excentricity close to and external of, the choroidocapillaris, E: endothelium of the choroidocapillaris; F: collagen fibril bundles. × 3,150. The inlet depicts fibrils of the bundles at higher magnification to show the collagen-specific cross striation. × 102,500

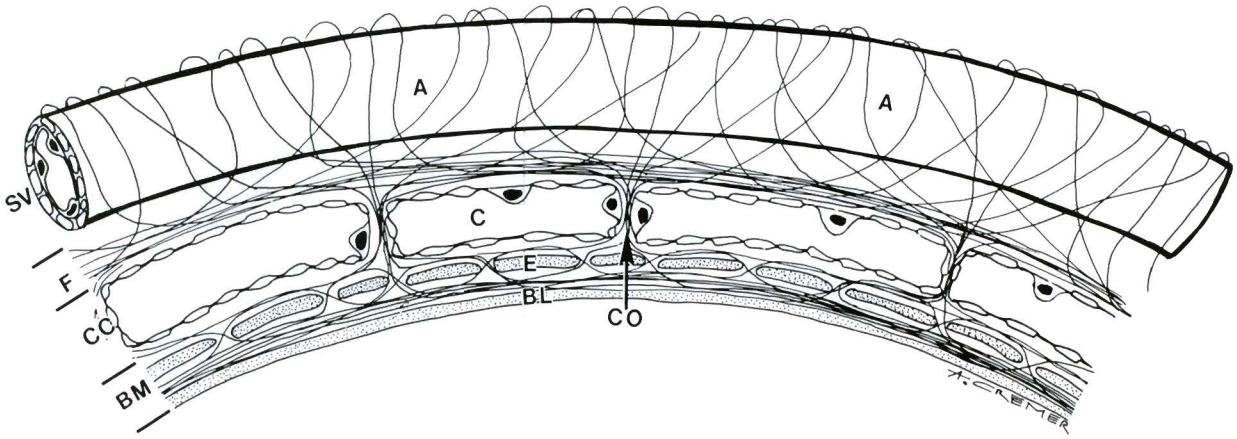

Fig. 5. Schematic presentation of the fiber system of the choroidocapillaris (not to scale). The stroma vascularis (SV) to which the fiber system is anchored, is symbolized by one large artery (A). F: the external leaflet of the fiber system; CO: connecting fiber; BM: Bruch's membrane, the inner leaflet of the fiber system; CC: the layer of the choroidocapillaris; E: eleastic layer of Bruch's membrane; BL: basilar lamina of the retinal pigment epithelium.

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