OPHTHALMOLOGY
PRINCIPLES AND CONCEPTS

FRANK W. NEWELL

OPHTHALMOLOGY

Principles and Concepts

Frank W. Newell, M.D., M.Sc.(Ophth.), F.A.C.S.

Professor and Head, Section of Ophthalmology
The University of Chicago

172 Illustrations

The C. V. Mosby Company

St. Louis 1965

Printed in the United States of America

Library of Congress Catalog Card Number 65-15273

Distributed in Great Britain by Henry Kimpton, London

Preface

This is an introduction to ophthalmology intended for the student, both undergraduate and graduate. Its purpose is to integrate the basic disciplines both with ocular diseases and abnormalities and with the ocular manifestations of systemic disease.

The advance of medical science in recent years has uncovered a need for emphasis to be placed upon the mechanism of disease and the common denominators of the disease process rather than upon formal instruction in each of the classical clinical disciplines. The opportunities for review by the student have become increasingly limited, although he is expected to correlate the previous studies of college and medical school with the diagnosis and management of the patient for whom he is responsible. This is why I became convinced that a single text presenting briefly several of the basic sciences, the methods of examination, and the local and systemic diseases of the eye would be useful to the medical student.

This book was not written to prepare the student to practice ophthalmology but rather to provide him with a guide to the recognition of minor and serious ophthalmic disease and ocular signs of systemic disorders. Diseases of the eye are discussed without emphasis upon refraction, optics, biomicroscopy, and similar areas in which the nonspecialist rarely becomes involved. Systemic diseases are presented so as to emphasize the fundamental abnormality of the primary disease process rather than the involvement of a particular portion of the eye. Hopefully, the text has been prepared so that the student will be able to interpret intelligently the symptoms arising from abnormalities of the eye and will be able to carry out a meaningful examination.

In this day of specialization within ophthalmology, it is presumptuous for an individual to expect to prepare a book authoritative in all areas. However, it does not seem appropriate to require the lone student to become familiar with a topic so complicated that it may be explained adequately only by a number of experts. Additionally, it appeared likely that an individual author could more easily correlate the basic sciences with clinical topics.

Thanks are due to the many students who provided instruction through the years and to many individuals. Suzanne Fritsch Sanchez, Mary Leiva, and Bette Fain typed the original manuscript, which was put in its final form by Louise B. Searing. Tibor G. Farkas, M.D., Ph.D., was unusually helpful in finding omissions and in eliminating inaccuracies and discrepancies. Alex E. Krill, M.D., Marcel Frenkel, M.D., and J. Terry Ernest, M.D., were unfailingly helpful. Many colleagues were

kind enough to provide illustrations, which are acknowledged where they appear.

Publication of a book for students reveals for all to see the author's foibles, myopia, ignorance, and bias. It would be most appreciated if teachers and students using the book would advise me of errors, improper emphasis, and editorial nodding.

Frank W. Newell
Chicago, Illinois

Contents

Part IV

Systemic diseases and the eye

Part I

BASIC MECHANISMS

Chapter 1

Anatomy and embryology

Anatomy

To an unusual extent, the understanding of ocular functions and their modification in disease is dependent upon an appreciation of the anatomy of the eyeball, the surrounding structures, and the central vascular and nervous connections. Dissection of a fresh animal eye readily reveals the interrelationship of the intraocular tissues and the organization of the eyeball as a multichambered, nearly spherical structure. The surface anatomy is easily studied by direct inspection of a living subject, using a small penlight for illumination and a +15 diopter lens for magnification.

THE EYEBALL

The eyeball (Frontispiece) rests in the front half of the cavity of the orbit upon a fascial hammock surrounded by fat and connective tissue; only its anterior aspect is exposed. Attached to it and arising within the orbit are four rectus and two oblique muscles. These are innervated by the oculomotor (N III), trochlear (N IV), and abducens (N VI) cranial nerves that enter the orbit at its apex. The optic nerve connects the eye with the brain and leaves the apex of the orbit in the optic foramen, which also transmits the ophthalmic artery and the sympathetic innervation of the eye. The ophthalmic branch of the trigeminal nerve (N V), transmitting sensory impulses from the upper portion of the face and the eye, also enters the cranial cavity through the orbital apex. The exposed anterior one third of the eyeball consists of a central transparent portion, the cornea, and a surrounding opaque portion, the sclera. The sclera is covered with conjunctiva that is reflected onto the inner surface of the protective tissue curtains, the eyelids. Located in the upper outer portion of the bony orbit is the lacrimal gland.

The anterior pole of the eyeball is the center of curvature of the cornea. The posterior pole marks the center of the posterior curvature of the globe, and it is located to the temporal side of the optic nerve. The geometric axis is a line connecting these two poles. The equator encircles the eyeball midway between the two poles. (Fig. 1.)

The anteroposterior diameter of the normal eyeball is about 22 mm. to 27 mm. The circumference is between 69 mm. and 85 mm. In the average eye (24 mm. diameter), the equator is considered to be 16 mm. behind the junction of the cornea and the sclera, and the posterior pole is considered to be 32 mm. behind this junction. The anterior termination of the sensory retina is approximately 8 mm. posterior to the corneoscleral limbus.

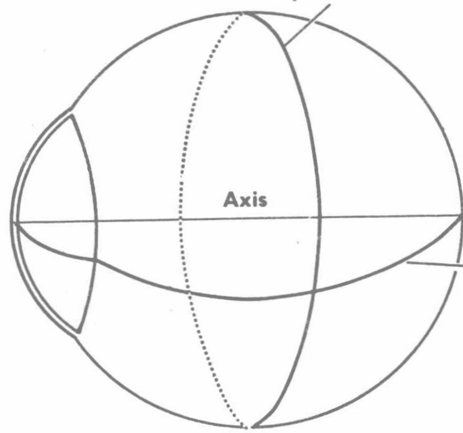

Fig. 1. The principal coordinates of the eye. The geometric axis does not correspond with the visual axis, which is a line connecting an object in space with the fovea.

The length of the eye cannot be directly measured during life. The normal emmetropic, or nearly emmetropic eye, measured by roentgen ray or ultrasonic methods, is between 22 mm. and 27 mm. long. As in other biologic measurements in man, the length varies about a mean with a normal (binomial) distribution, if refractive errors of more than 4 diopters hyperopia and 6 diopters myopia are excluded.

The globe has three main layers, each of which is further divided. The outer supporting coat is composed of the transparent cornea, the opaque sclera, and their junction, the corneoscleral sulcus or limbus. The middle vascular layer, or the uvea, consists of the choroid, the ciliary body, and the iris, which contains a central opening, the pupil. The inner layer consists of the photosensitive retina, which is composed of two parts, a light-sensitive nervous complex and a layer of pigment epithelium.

The lens is a transparent structure located immediately behind the iris and supported in position by a series of fine fibers, the zonule. These are attached to the ciliary body and the capsule of the lens.

Three chambers are described: (1) the vitreous cavity, (2) the posterior chamber, and (3) the anterior chamber. The *vitreous cavity,* by far the largest, is located behind the lens and zonule and is adjacent to the retina throughout. The *posterior chamber* is minute and is bounded by the lens and zonule behind and the iris in front. The *anterior chamber* separates the iris from the posterior surface of the cornea and communicates with the posterior chamber through the pupil. Anterior chamber aqueous humor enters the venous circulation through a filtration area. This is the trabecular meshwork that opens into the canal of Schlemm, an endothelium-lined channel that encircles the anterior chamber.

Outer coat of the eye

The outer coat of the eye consists of relatively tough fibrous tissues shaped as segments of two spheres: the sclera with a radius of curvature of about 13 mm. and the cornea with a radius of curvature of about 7.5+ mm. The white, opaque sclera constitutes the posterior five sixths of the globe, and the transparent cornea is fitted into a beveled opening in the anterior sclera to provide the anterior one sixth of the globe. The junction of the cornea and the sclera, the corneoscleral limbus, is an important functional and anatomic area.

Sclera. The sclera is a dense, fibrous, relatively avascular structure that comprises the posterior five sixths of the eyeball. Anteriorly it comprises the "white" of the eye, and here it is covered with Tenon's capsule and conjunctiva through which fine blood vessels can be seen. Posteriorly it is connected by loose, fine collagen fibers to the dense fascia bulbi (Tenon's capsule).

At a point 3 mm. medial to the posterior pole, the sclera is perforated by a 3 mm. opening, the posterior scleral foramen, through which the optic nerve exits from the eye. The scleral foramen is bridged by thin elastic fibers of the inner sclera that form a sievelike structure, the lamina cribrosa. The sclera is thickest in the region surrounding the optic nerve where the dural coverings of the nerve blend into the scleral fibers. The sclera is perforated by the long and short posterior ciliary arteries and nerves in the area surrounding the optic nerve.

The anterior scleral foramen is the beveled opening of the sclera into which the cornea fits. On its inner surface is the scleral spur to which the ciliary muscle is attached. About 4 mm. posterior to the equator, in the region between the rectus muscles, are the openings for the four vortex veins that are the collecting channels for choroidal veins. In the anterior segment, about 4 mm. posterior to the corneoscleral limbus, the anterior ciliary arteries and veins pierce the sclera. Occasionally a long posterior ciliary nerve loops through the sclera and is evident by a small pigmented dot 2 mm. to 4 mm. from the corneoscleral limbus.

Structure. Three ill-defined layers of the sclera are described: (1) the episclera, (2) the sclera proper, and (3) the lamina fusca. (Fig. 2.)

The *episclera* is the outermost superficial layer. It is composed of loosely intertwined fibrous tissue strands connected to Tenon's capsule. The episclera has a rich blood supply and may become violently congested in inflammation.

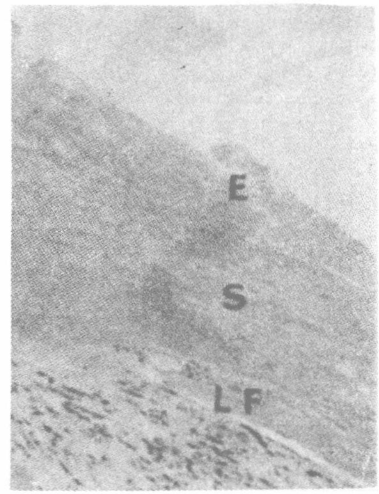

Fig. 2. Transverse section of sclera. **E,** Episclera. **S,** Sclera proper. **LF,** Lamina fusca. (Hematoxylin and eosin stain; ×38.)

The *sclera proper* consists of elastic fibers and typical collagen fibers with cross striations of 640 Å. The collagen fibers vary in diameter from 10 μ to 15 μ and are 100 μ to 150 μ long. They are arranged approximately parallel to the surface of the globe to form an interlacing basketlike weave. Their pattern differs at the area of insertion of the extraocular muscles and at the scleral foramen, apparently in response to mechanical stresses induced by traction of the muscles and the intraocular pressure. (Fig. 3.)

The *lamina fusca* is adjacent to the choroid, from which it derives a large number of melanocytes that give it a brown color. It contains more elastic tissue than the sclera proper. Delicate elastic fibers covered with endothelium with adjacent smooth muscle run between the lamina fusca and the choroid in the potential perichoroidal space.

Blood supply. Posterior to the insertion of the rectus muscles the blood supply of the sclera is sparse. It is provided by the

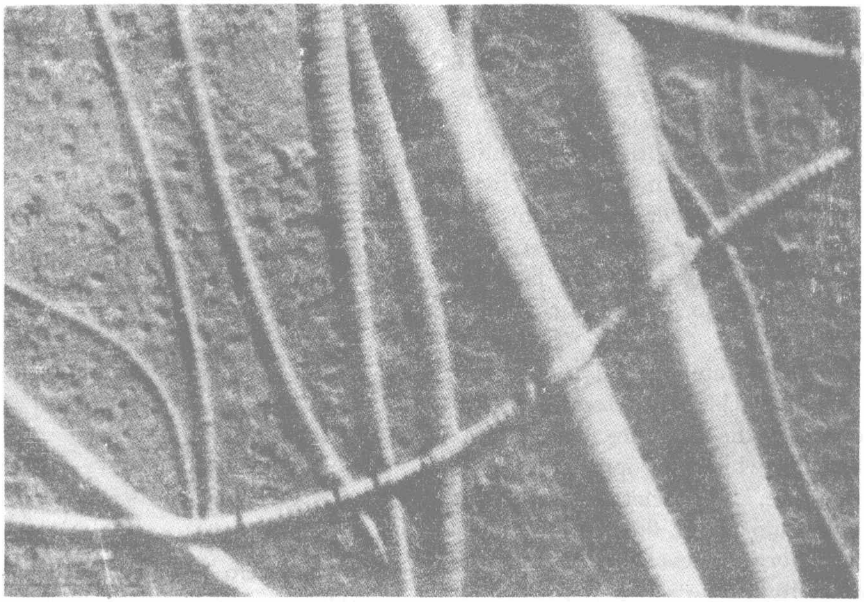

Fig. 3. Scleral fibrils mechanically dissociated. The fibrils vary markedly in diameter. (Electron photomicroscopy, ×28,000.) (Courtesy Prof. J. François, Ghent, Belgium.)

episcleral branches of the short and long posterior ciliary arteries.

Anterior to the insertion of the rectus muscles the anterior ciliary arteries form a dense episcleral plexus. It is these vessels that become congested in "ciliary injection."

Nerve supply. The sensory nerves supplying the sclera are branches of the short and long posterior ciliary nerves.

Cornea. The cornea is the transparent anterior one sixth of the eyeball. It is approximately circular in shape and fits, as a watch glass, into the beveled edge of the sclera. The corneal diameter is about 11.5 mm. Exact measurement of the diameter is difficult because the peripheral border is covered by conjunctiva at the corneoscleral limbus. The central optical portion of the cornea is only 0.5 mm. to 0.7 mm. thick and has nearly parallel anterior and posterior surfaces. Its peripheral portion thickens to about 1.0 mm. The radius of curvature of the anterior surface is slightly less than 8 mm., and the radius of curvature of the concave posterior surface is slightly more than 6 mm. The cornea is the chief refracting surface of the eye because it separates media of such different indexes of refraction as air and aqueous humor. Variations in curvature of different corneal meridians cause astigmatism.

Structure. The cornea (Fig. 4) is composed of five layers: (1) epithelium, (2) Bowman's membrane (continuous with the stroma), (3) substantia propria (stroma), (4) Descemet's membrane (the basement membrane of the endothelium), and (5) endothelium.

The *epithelium* covers the substantia propria anteriorly and is continuous with the epithelium of the conjunctiva. It consists of stratified squamous cells formed in the deepest basal layer and shed 4 to 8 days later from the superficial layer. The basal cells are columnar in shape and rest upon a delicate basement membrane 100 Å to 300 Å thick. This consists of a superficial lipid layer adherent to the

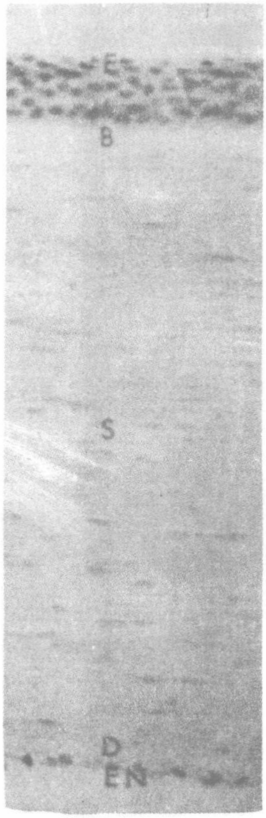

Fig. 4. Transverse section of the cornea. **E,** Epithelium, five to six cells thick; the basement membrane is not seen. **B,** Bowman's membrane, an anterior condensation of stroma. **S,** Stroma with lamellas and cells (keratocytes and wandering cells). **D,** Descemet's membrane. **EN,** Endothelial layer. (Hematoxylin and eosin stain; ×105.)

overlying cells and of a deeper reticular network that merges into the adjacent Bowman's membrane. With maturation, basal cells are pushed forward to form three layers of progressively flatter cells, called wing cells. The outermost squamous cells are two layers thick and consist of thin, flat cells that form the outer surface of the cornea and are attached to adjacent cells by desmosomes 500 Å to 1,500 Å thick. Because of these attachments, sheets of epithelial cells may be mechanically removed from the cornea.

The anterior corneal stroma is condensed into a homogeneous layer, *Bowman's membrane*. It is grossly evident as a brilliant, glistening membrane when epithelial cells are removed or when corneal sections are examined by light microscopy. Electron microscopy indicates Bowman's membrane to be continuous with the substantia propria and not a separate structure. It terminates abruptly at the corneal periphery and marks the inner margin of the corneoscleral limbus. Injuries to the epithelium quickly regenerate by sliding and proliferation of adjacent cells, and healing occurs without scarring. Damage to the substantia propria results in scar formation.

The *substantia propria* or stroma forms 90% of the cornea. It consists of cells and fine fibrils. The cells are long, flattened, compressed keratocytes or corneal corpuscles and correspond to fibroblasts in other tissues. In addition, there are flattened, wandering leukocytes. The fibrils are composed of collagen and are approximately of uniform thickness. The fibrils are covered with a dense layer of a mucopolysaccharide cement substance. They are collected into bundles that form some 100 to 200 corneal lamellas. The lamellas are arranged parallel to the corneal surface but crisscross at right angles to each other in alternate layers. (Fig. 5.)

The substantia propria is lined with *endothelium* continuous with that covering the iris. The endothelium is composed of a single layer of flat cells of irregular size, arranged on the inner surface of *Descemet's membrane*. This is a glassy membrane loosely attached to the back surface of the stroma and secreted by the endothelial cells. Descemet's membrane is composed of collagen fibrils embedded in a mucopolysaccharide matrix. Both the matrix and the fibrils differ from those found in the substantia propria. Descemet's membrane regenerates readily and,

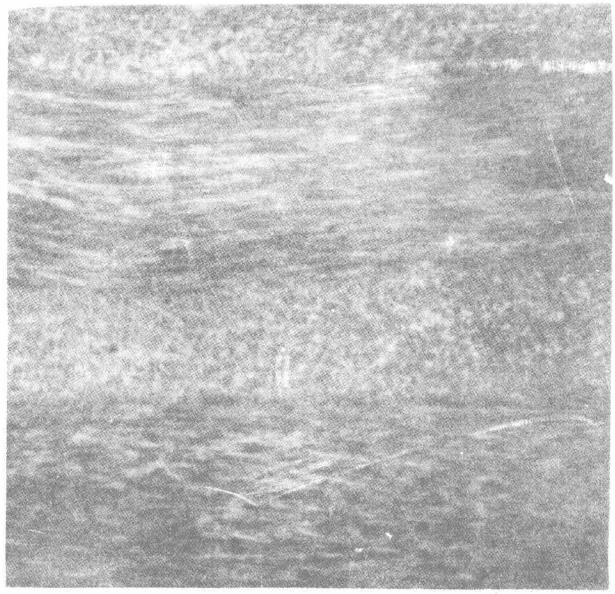

Fig. 5. Transverse section through the corneal stroma, showing several lamellas in which each of the collagen fibers is oriented parallel to each other and perpendicular to those in adjacent layers. (Electron photomicroscopy, ×10,230.) (From Jakus, M. A.: In Smelser, G. K., editor: The stucture of the eye, New York, 1961, The Academic Press.)

following injury, may form a double layer. At the periphery of the cornea it becomes fenestrated at the openings of the trabecular meshwork. Desmosomes have not been demonstrated in the endothelium lining the substantia propria, but adjacent cells are bound together by extensive interdigitation.

Blood supply. The central cornea is avascular, but the region of the corneoscleral limbus (Fig. 6) is generously supplied by conjunctival branches of the anterior ciliary arteries. These form a superficial marginal plexus that sends blood vessels at right angles toward the cornea. They give rise to two systems: branches forming terminal vascular loops at the corneoscleral limbus and recurrent branches that anastomose with posterior conjunctival arteries.

Nerve supply. The corneal nerves are entirely sensory, subserving the sensation of pain and possibly of touch. The nerve endings are either terminal beadlike thickenings or bare fibers in the epithelium or in the anterior stroma. Near the limbus, Krause's end-bulbs and endings for cold sensation are present. The nerves become medullated as they exit from the corneal periphery and pass to the semilunar ganglion by way of the long and short posterior ciliary nerves, branches of the ophthalmic division of the trigeminal nerve.

Corneoscleral limbus. The corneoscleral limbus, or junction, is a transitional zone 1 mm. to 2 mm. wide between the cornea proper and the sclera and conjunctiva. Its anterior margin is a line extending from the end of Bowman's membrane to the end of nonfenestrated Descemet's membrane. Its posterior margin is the corneoscleral junction through a plane drawn perpendicular to the scleral spur. The area is clinically important because it encompasses the trabecular meshwork and the canal of Schlemm, which forms the drainage system of the anterior chamber. In addition, surgical incision into the globe

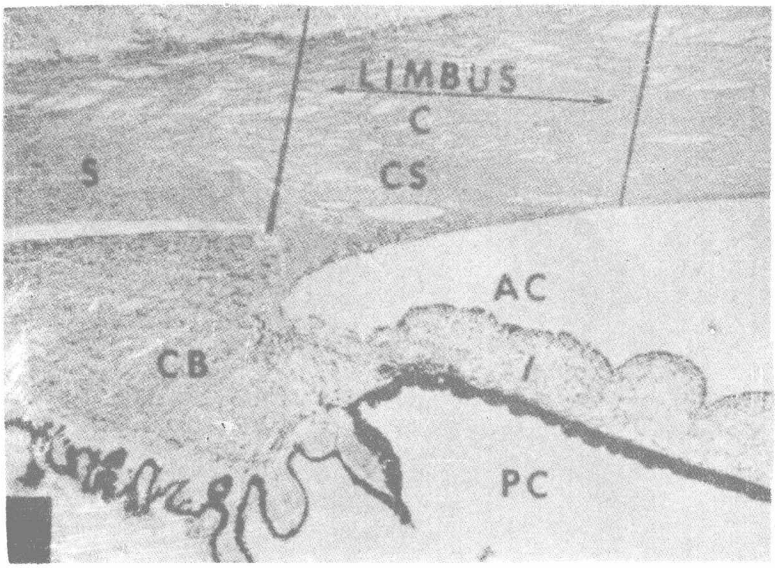

Fig. 6. The corneoscleral limbus. **AC,** Anterior chamber. **C,** Cornea. **CB,** Ciliary body. **CS,** Canal of Schlemm. **I,** Iris. **PC,** Posterior chamber. **S,** Sclera. The central margin of the corneoscleral limbus is a line drawn between the termination of Bowman's membrane and the point where Descemet's membrane becomes discontinuous. The posterior margin is a line drawn parallel to the central margin and passing through the scleral spur. (Hematoxylin and eosin stain; ×105.)

is usually at the limbus. The trabeculum can be seen clinically by using a gonioscope.

Structure. Basically the corneoscleral limbus is composed of but two layers: (1) the epithelium and (2) the stroma. Buried in its inner aspect is the trabecular meshwork that communicates between the anterior chamber and the canal of Schlemm.

In the limbal area the corneal *epithelium* thickens, and in some areas papelary formation may be seen. The corneal *stroma* looses its regular pattern, and the lamellas do not lie parallel to the corneal surface. Imperceptibly there is a gradual change from the regularly arranged corneal lamellas to the random distribution of the dense fibrous tissue of the sclera.

Trabecular meshwork. Surrounding the entire circumference of the anterior chamber is the trabecular meshwork, a pore-like structure through which aqueous humor percolates to the canal of Schlemm (Fig. 7). In cross section the trabeculum forms an obtuse triangle with a short base and two long sides. The apex of the triangle is at the anterior termination of the trabecular meshwork and forms the border ring of Schwalbe. The base of the triangle is in contact with the scleral spur and the free surface of the ciliary body. One long side is in contact with the cornea and the sclera and in communication with Schlemm's canal—this is described as the corneoscleral portion. The other long side communicates directly with the anterior chamber and is described as the uveal portion. The meshwork is arranged in sheets with round or oval openings between layers. An acid mucopolysaccharide coats the meshwork.

The trabecular meshwork is innervated by a plexus of delicate axons that ter-

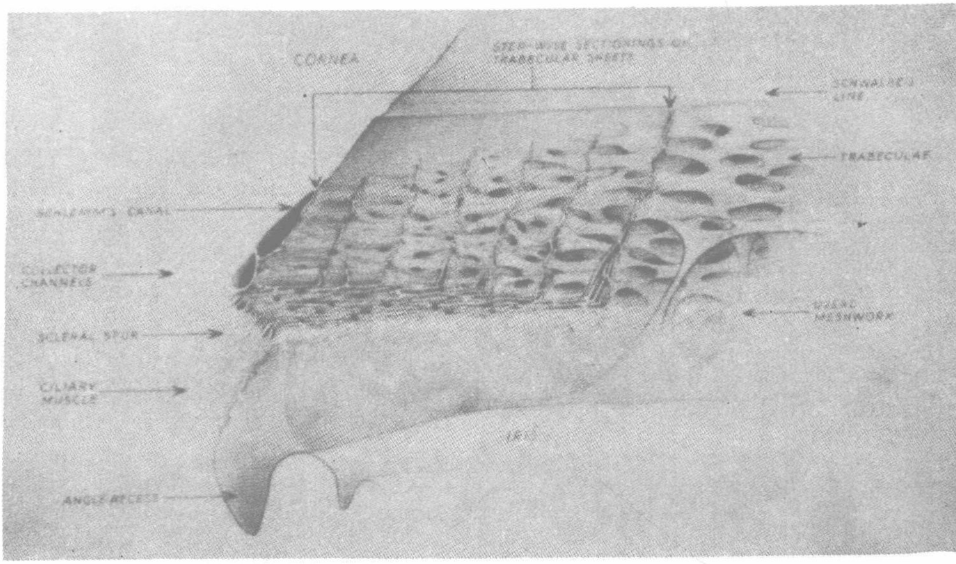

Fig. 7. Diagram of the trabecular meshwork, showing stepwise dissection of trabecular sheets from the anterior chamber to Schlemm's canal. (From Garron, L. K., and Feeney, M. L.: Arch. Ophth. **62**:966, 1959.)

minate without specialized endings within the endothelium of Schlemm's canal. The nerves arise from both divisions of the autonomic nervous system and from the trigeminal nerve. They may function in controlling the rate of flow of aqueous humor through the system.

Canal of Schlemm. The canal of Schlemm is an endothelium-lined channel, approximately oval in cross section, that surrounds the entire circumference of the anterior chamber. On its inner surface it communicates with the anterior chamber through the trabecular meshwork. Its outer wall is buried in the stroma of the corneoscleral sulcus. The endothelium contains numerous pores through which the aqueous humor percolates. The canal of Schlemm connects with the venous system through a system of 25 to 35 collector channels that anastomose to form a deep intrascleral plexus. This intrascleral plexus sends branches to the ciliary body and the anterior ciliary veins. The anterior ciliary veins may appear subconjunctivally as minute vessels containing clear aqueous, the aqueous veins.

Middle coat of the eye

The middle or uveal coat of the eyeball (from the Latin word *ūva* meaning grape) consists of the choroid, the ciliary body, and the iris. The choroid is a vascular layer providing the blood supply to that portion of the retina adjacent to it. The ciliary body secretes aqueous humor and contains the smooth muscle responsible for accommodation. The iris surrounds a central opening, the pupil, which controls the amount of light entering the eye.

The choroid is of mesodermal origin, whereas the epithelium of the ciliary body and the iris represents the anterior extremities of the primitive secondary optic vesicle. The dilatator and sphincter muscles of the iris arise from neural ectoderm, and the ciliary muscle arises from mesoderm.