EXTERNAL AND GONIOSCOPIC VISIBILITY OF THE RING OF SCHWALBE AND THE TRABECULAR ZONE

AN INTERPRETATION OF THE POSTERIOR CORNEAL EMBRYOTOXON AND THE SO-CALLED CONGENITAL HYALINE MEMBRANES ON THE POSTERIOR CORNEAL SURFACE*

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INTRODUCTION

ABOUT two years ago our attention was drawn to glassy ring-like structures at the periphery of the posterior surface of the cornea. It soon became evident that these bands corresponded to the so-called posterior embryotoxon of the cornea (Embryotoxon corneae posterius, Axenfeld, 1), posterior marginal dysplasia of the cornea (Streiff, 2), congenital hyaline membranes on the posterior surface of the cornea (Mann, 3), or peripheral refractile postcorneal rim (Graves, 4). Once our interest in this subject was awakened, we gave close study to the limbus of all patients whom we saw during this period and performed a slit-lamp gonioscopic examination in those who presented to external slit-lamp study an unusual appearance of the limbus or of the periphery of the cornea.

These clinical investigations were followed by a careful study of 600 pathologic specimens of eyes, and this study in turn prompted us to extend our investigations to the chamber angle of the eyes of pigs, dogs, rabbits, and cattle and to the embryology of this region in man. Inevitably all this led us also to the problem of juvenile glaucoma.

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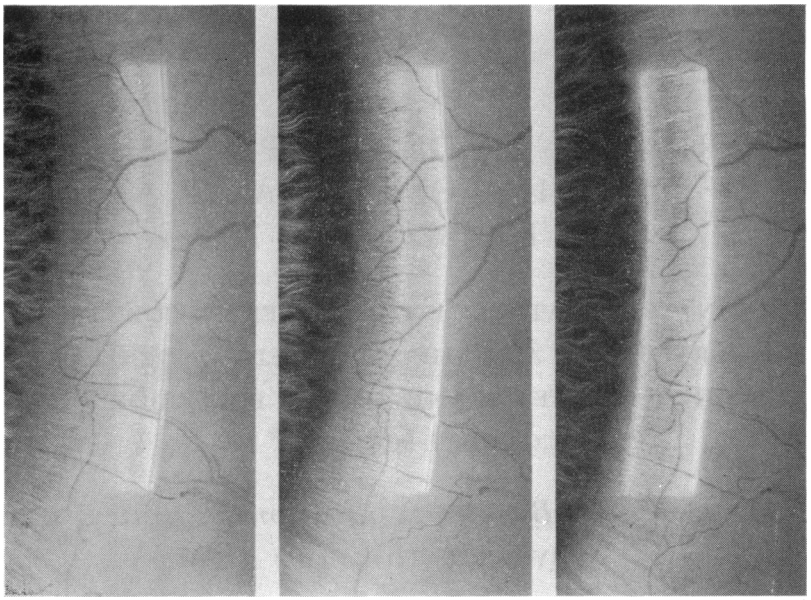
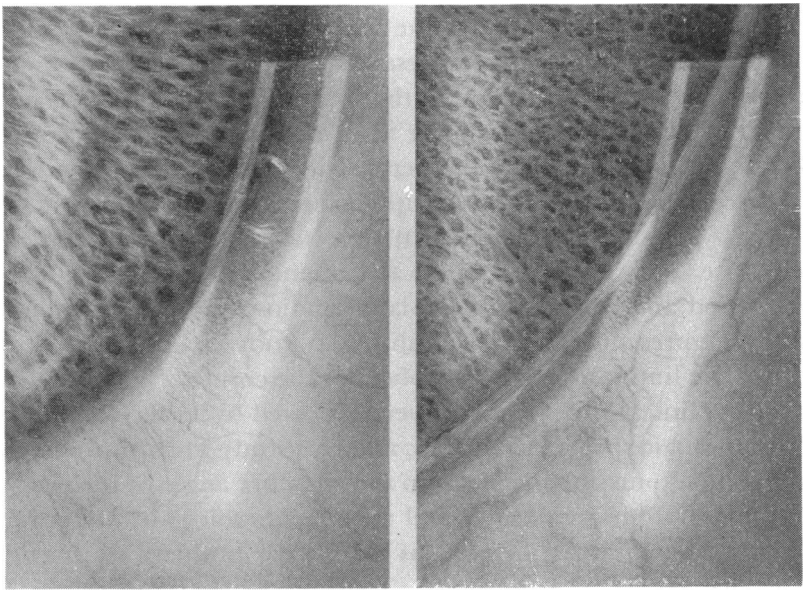


A B C

FIGURE 1. EXTERNAL APPEARANCE, UNDER SLIT-LAMP EXAMINATION, OF AVERAGE TRABECULAR BAND, TEMPORAL SIDE



A B

FIGURE 2. LEFT: WIDELY EXPOSED TRABECULAR BAND, WITHOUT PROMINENT BORDER, OF A TWENTY-ONE-YEAR-OLD GIRL. RIGHT: A SIMILAR BAND IN ANOTHER PATIENT

In the present paper the results of our clinical work will be presented. Its other aspects will be published elsewhere and will be mentioned here only insofar as necessary to support our evidence.

CLINICAL FINDINGS IN NORMAL EYES

Before discussing the embryotoxon, a description of the appearance of the normal limbal areas at slit-lamp examination will be given, insofar as it has a bearing on the subject under consideration.

When one focuses a very narrow slit beam on the sclera to the nasal or temporal side of the globe and slowly moves the beam toward the limbus, there will suddenly appear, when the beam is near the limbus but still in nontransparent tissue, a golden glow in the region of the chamber angle which is in its character comparable to the yellowish-golden appearance which is noted when observing ocular tissues in specular reflection (Fig. 1, left). As the beam is moved further corneaward on the limbus, one observes invariably, if the beam is carefully focused on the posterior corneal surface, a more or less translucent condensation of tissue which presents a fine regular or criss-cross striation (Fig. 1, center). In the majority of cases this band is perhaps one-third to one-half millimeter wide, in a few it is only a small fraction of a millimeter wide, and in others it may be more than one millimeter in width. Because of the vertical orientation of the slit beam and the width of the external scleral limbus in the upper and lower part of the corneal circumference, this band is best observed on the nasal and temporal sides.

Peripherally this band, as it appears to blend with the tissue of the scleral septum (Busacca, 5), has no discernible border and disappears behind the wedge of the external scleral limbus, but toward its corneal side it nearly always ends in a rather well-defined edge (Fig. 1C). As a rule this edge is nothing more than a line delimiting the band of relucent tissue. Occasionally it was seen to consist of a distinct whitish line, concentric with the limbus, clearly thickened, sometimes slightly wavy, and in the more pronounced cases obvious in focal illumination without the aid of magnification. It must be emphasized that this line appears whitish only in direct focal illumination against the darker iris. When

seen in retrograde illumination the line is always translucent and refractile.

The lower temporal portion of the left eye of a twenty-one-year-old girl who was seen in our clinic for refraction is pictured in Figure 2A. She had an unusually broad band of relucent tissue at the posterior corneal surface in the limbal area. This tissue feathered out to a thin, almost indistinguishable edge on the corneal side. It had no prominent border, except for a possible very slight indication in the upper temporal region. Just central to the edge of the relucent tissue there were in Descemet's membrane fine circular lines which appeared refractile by retro-illumination but were slightly relucent in direct illumination. Figure 2B contrasts the appearance noted in this patient with that in a patient in whom the relucent tissue, of which there is a similarly broad

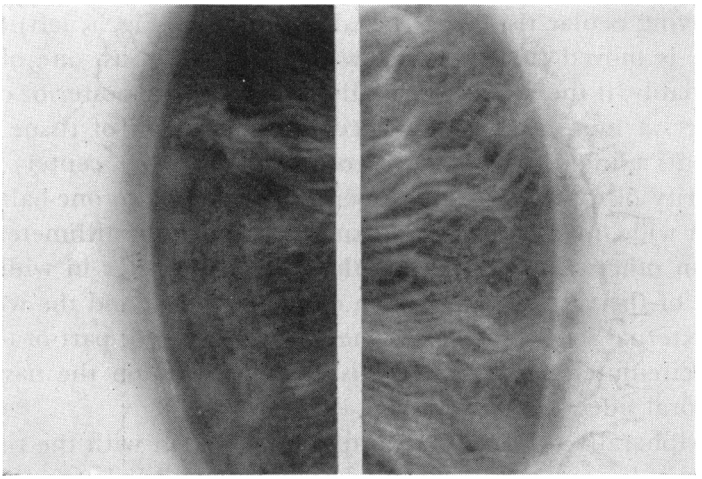


FIGURE 3. PROMINENT REFRACTILE LINE ON POSTERIOR CORNEAL SURFACE. LEFT: TEMPORAL QUADRANT OF RIGHT EYE. RIGHT: NASAL QUADRANT OF RIGHT EYE

expanse, is delimited by a distinct, whitish, somewhat prominent line.

This refractile line is seen in some patients only along a short stretch of the circumference, usually in the lower temporal or lower nasal periphery. It may extend along the greater part of the temporal or nasal periphery, or both (Fig. 3), and in some cases it

is continuous, leaving free only the region from 11:00 to 1:00 o'clock, where we have seen it externally only in exceptional cases. Short stretches of a prominent line are frequently noted, but more extensive lines are by no means rare. After seeing more than 30 patients with more or less extensive prominent lines, the pattern was so well established that we continued using gonioscopy only on eyes in which features of special interest warranted such examination.

When a prominent line is present, observation with the slit lamp creates the definite impression that the line constitutes the edge of a "hyaline" membrane adherent to the posterior corneal surface and extending into the chamber angle. The picture agrees with that of the entity described as posterior embryotoxon of the cornea, as posterior marginal dysplasia of the cornea, or as congenital hyaline membrane on the posterior surface of the cornea.

The similarity to this clinical entity was further enhanced by the frequent finding of small pigment dots on the prominent edge of the membrane or opacity, and of fine strands of iris tissue inserting on it which were occasionally visible with the slit lamp.

When the translucent band was pronounced, the corneas were usually a little smaller in the horizontal diameter than normal. The condition also occurs, however, in corneas of normal size, and we have even observed it in two cases of megalocornea. Often there was also some hypoplasia of the anterior mesodermal layer of the iris. This hypoplasia was as a rule mild, but was quite evident in certain patients. Most of our patients had gray or blue irises, but there were also some with dark-brown irises and we have seen the anomaly in two colored individuals. Most patients in our clinic are of Central European or Scandinavian stock; very few are colored. Studies on clinical material in which patients of Southern European stock or colored patients are prevalent are likely to show that the anomaly occurs with equal frequency in these patients. Biozzi and Lugli (6) were able to collect in a short period 16 cases in the Clinic in Bologna, Italy.

Aside from the hypoplasia of the iris, none of the eyes which we examined showed diseased conditions which could in any way be connected with the embryotoxon, except for a group of patients in whom an extreme development of this anomaly was found, to-

gether with iris atrophy and glaucoma. These cases will be discussed later on.

The question arose, What is the anatomic substratum of the opacity or membrane and of the prominent line seen at its edge? We expected and obtained an answer to this question from gonioscopic examination.

These examinations revealed that the structures of the chamber angle were well visualized and that they had their usual appearance. There definitely was no abnormal membrane of any kind covering the structures of the chamber angle or the periphery of the cornea. In the patient whose slit-lamp picture is reproduced in Figure 2A, the trabecular region was perfectly normal for a person of her age, although it appeared slightly broader than usual, especially in certain areas. The region of Schlemm's canal showed a normal gray appearance. Ahead of this region, still within the trabecular area, there was a whiter band which blended softly into another gray region just behind the anterior edge of the trabecular zone. In this patient no prominent line was visible anywhere. In those patients, however, who presented externally a prominent line, it was noted, when following the anterior border of the trabecular band, that along a greater or smaller portion of the angle the anterior border of this band became a prominent, pearly-white line. In some patients clumps of pigment were seen on this line and a certain number of iris processes inserted on or below the line. There were variations as to extent and prominence of the line and as to the amount of pigment, but the basic pattern was essentially the same in every one of the many cases which we have observed.

From our gonioscopic findings it was evident that what we had taken in the external slit-lamp examination of these patients to be a hyaline membrane was nothing else than the trabecular area, and that the prominent ring was the anterior border-ring of this area, or ring of Schwalbe.

We thereupon went back to an investigation of patients who did not show an embryotoxon, and were soon convinced that the trabecular region can be visualized externally with the slit lamp in every patient at the nasal and temporal portions of the limbus. The golden glow at the limbus is produced by illumination of the

trabecular region, and more peripherally of the scleral septum, in specular reflection, and the opacity seen in direct illumination and described at the beginning of this paper is, in fact, due to the visualization of the trabecular zone.

Because of the great uniformity of our findings it would not be worth while to discuss in detail the numerous patients with embryotoxon and otherwise normal eyes whom we have seen and the minor variations which were encountered. We shall restrict ourselves to a somewhat more extensive description of one case.

CASE 1. A twenty-nine-year-old schoolteacher requested a refraction because of eyestrain and headaches. He had no other complaints and there was no history of ocular disease. Examination produced no evidence of ocular anomalies except for the slit-lamp findings described below. *Intraocular pressure:* O.D. 17 mm. Hg (Schiötz), O.S. 15 mm. Hg (Schiötz). *Refraction:* O.D. +1.00 cyl. ax. 175° = 6/6 + 2; O.S. +.50 sph. +.50 cyl. ax. 170° = 6/6 + 6. *Visual fields:* normal.

The left cornea was slightly smaller than the right one, measuring 11 mm. in horizontal diameter against 12 mm. in the right eye (Fig. 4A). In the left eye there was noted at the periphery of the cornea extending from about 1:00 o'clock around the temporal, lower, and nasal circumference up to about 10:00 o'clock what appeared to be a hyaline membrane on the posterior surface of the cornea. This "membrane" was clearly visible in oblique illumination without magnification (Fig. 4B). Under slit-lamp illumination this membrane had a scalloped edge protruding into the anterior chamber (Figs. 4C and 4D). Clumps of pigment were seen on this edge and a few iris processes were noted inserting on it. The iris was grayish-brown and there was some hypoplasia of the anterior mesodermal layer. The limbal area of the right eye showed no particular anomaly (Fig. 4E).

In gonioscopic view (Fig. 4F) of the left eye, it was found that the ring seen externally with the slit lamp corresponded to a prominent, pearly-white line situated at the end of Descemet's membrane where one would expect to encounter the anterior border of the trabecular zone. Round and elongated pigment clumps were seen on the line and fine pigment granules were scattered over the trabecular area. When the sketch for the drawing of the lower quadrant of the chamber angle reproduced in Figure 4F was made, the canal of Schlemm happened to be filled with blood, thus giving an additional landmark for the identification of the structures of the chamber angle. The iris processes were seen inserting on the trabecular region and on the prominent line, some of them bridging the chamber angle. The scleral spur and the ciliary body band were readily seen and there was no indication whatever of a

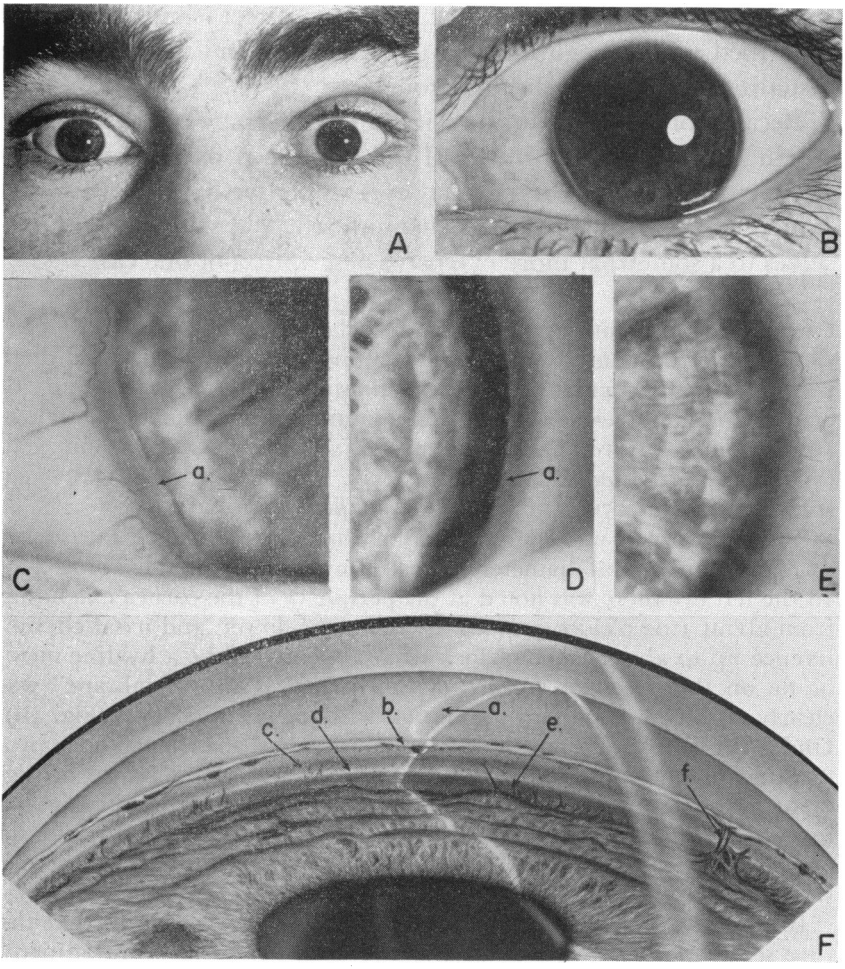


FIGURE 4. CASE 1

A. Photograph of patient's eyes, showing cornea of left eye to be smaller than cornea of right eye. B. Enlarged view of left eye, showing prominent bands nasally and temporally. C. Lower nasal quadrant of limbus of left eye, seen in direct illumination; note prominent ring (a). D. Temporal limbus of left eye with prominent ring (a) seen in sclerotic scatter. E. Nasal limbus, right eye, without prominent ring. F. Gonioscopic view of lower angle, left eye; (a) corneal wedge; (b) prominent anterior border-ring of Schwalbe, with pigment clumps; (c) blood-filled canal of Schlemm; (d) scleral spur; (e) ciliary body band; (f) bridging iris processes.

congenital or pathologic membrane overlying any of the structures of the chamber angle.

Clearly then, the thickened line seen with the slit lamp was the prominent anterior border ring of Schwalbe, and what was interpreted as a membrane on the posterior corneal surface was actually the trabecular band.

CLINICAL FINDINGS IN GLAUCOMATOUS EYES

While the majority of the eyes in which we noted by external slit-lamp study a prominent anterior border-ring of Schwalbe were clinically normal, except for an occasional hypoplasia of the anterior stromal layer of the iris, we have observed such a ring also in a number of eyes with glaucoma and other associated anomalies. Some of these cases will now be described.

CASE 2. A fifty-four-year-old white female, known to have had glaucoma for a number of years. The corneas of both eyes showed a membrane-like tissue with slightly prominent edge at the periphery of the posterior surface. The anterior chambers were deep. The iris was very

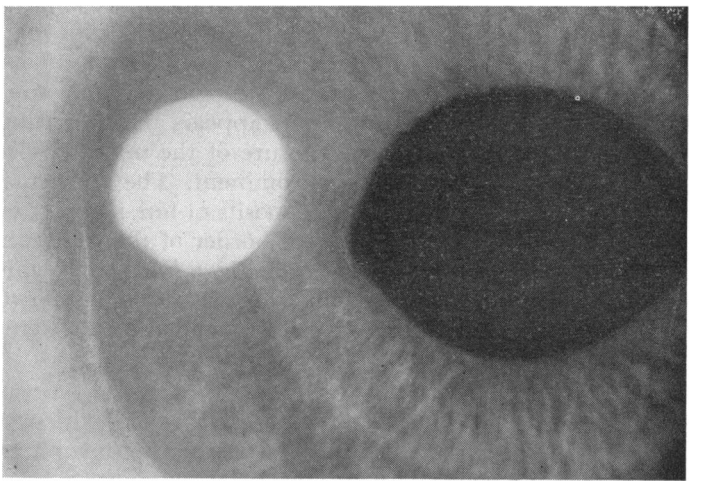


FIGURE 5. CASE 2. RIGHT EYE, SHOWING PROMINENT RING WITH ATROPHIC IRIS AND OVAL PUPIL

markedly atrophic, but without holes. The pupils (which were under the influence of pilocarpine when the patient was seen) were oval in shape (Fig. 5). The lenses and the vitreous were clear; both discs showed deep glaucomatous cupping and the visual fields an advanced deteriora-

tion, especially the field of the right eye. *Intraocular pressure:* O.D. 30 mm. Hg (Schiötz), O.S. 34 mm. Hg (Schiötz). *Visual acuity (with correction)*: O.D. 6/6 — 4, O.S. 6/6.

Gonioscopy showed the angles to be open; the findings were essentially the same in the different regions of the chamber angles. The view

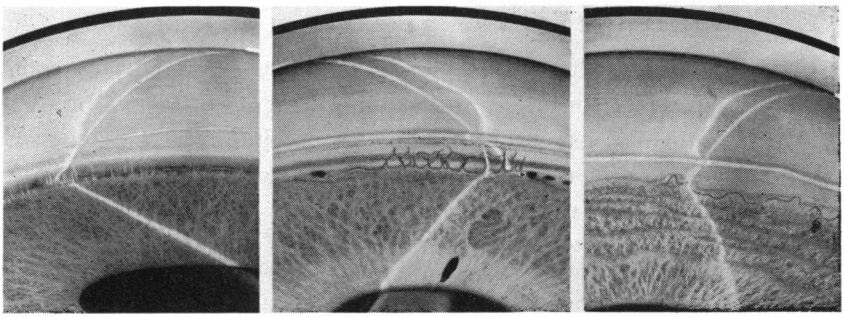


FIGURE 6. LEFT: CASE 2. LOWER ANGLE, RIGHT EYE. CENTER: CASE 3. LOWER ANGLE, RIGHT EYE. RIGHT: CASE 4. UPPER ANGLE, RIGHT EYE (REVERSED)

of the lower angle of the right eye is illustrated in Figure 6, left. As can be seen from this figure, the iris is atrophic. From its root many fine, almost transparent processes bridge the angle to the trabecular region. In the very apex of the angle at the root of the iris, and apparently close to the broad ciliary body band, there appears an undulating vessel which we take to be an abnormal exposure of the major circle of the iris. The scleral spur is moderately prominent. The trabecular zone varies in width and has in some areas deposits of fine pigment over the region of Schlemm's canal. The anterior border of the trabecular area is somewhat irregularly wavy and is marked by a fine pearly-white line.

The patient volunteered the information that her daughter (Case 3) and grandson (Case 4) "had eyes like hers," and the two were subsequently examined by us.

CASE 3. The daughter of the patient in Case 2, a woman thirty years of age, had no ocular complaints. With correction for her myopic astigmatism, she had a visual acuity of 6/6 in each eye. The media were clear, the fundi normal, as were the limits of the visual fields. *Intraocular pressure:* 20 mm. Hg (Schiötz) in each eye.

However, upon external examination, there was found to be a translucent band at the corneal periphery of both eyes, with a prominent edge on which pigment was noted. There were also some strands of iris tissue found inserting on the prominent ring: a particularly

dense group of such fibers was located at 7:00 o'clock in the right eye. The anterior layer of the iris was evenly atrophic in both eyes, with some prominent bands of iris tissue going radially.

The gonioscopic appearance of the lower quadrant of the right chamber angle can be seen from Figure 6, center. At the extreme basal margin of the moderately atrophic iris, patches of marked atrophy were found. At the root of the iris there was seen an undulating vessel connecting in one area with translucent, yellowish, bridging iris processes. On the temporal side the externally seen, dense group of iris processes bridging to the trabecular area was identified. This area appeared essentially normal in width and structure, but its anterior border was formed by a heavy, elevated white ring. Two lines of pigment were seen, a wide one over the region of Schlemm's canal and a very narrow one near the anterior border of the trabecular zone. It was of interest to note that no anterior ciliary vessels could be detected at the corneal margin of the limbus.

Case 4. The grandson, aged seven years, also showed in both eyes the translucent band on the posterior surface of the corneal periphery, ending in a prominent edge, and moderate iris atrophy. Otherwise the eyes appeared normal. *Uncorrected vision:* 6/9 in each eye. *Intraocular pressure:* O.D. 25 mm. Hg (Schiötz), O.S. 17-19 mm. Hg (Schiötz).

By gonioscopy (upper quadrant O.D., Fig. 6, right) the moderately atrophic iris showed occasional small areas of marked atrophy at its root, which had in the apex of the angle a translucent orange-yellow coloration. Within this yellow area, and extending in places onto the corneoscleral region, an abnormal vessel was seen. Neither the ciliary body band nor the scleral spur could be identified, and the area of Schlemm's canal did not have the normal gray color. In the optical section a double reflex similar to that described in normal trabecular regions by Busacca (5) indicated probably an unusual transparency of this area. Corresponding in position to the anterior border of the trabecular zone there was a white, heavy, elevated cord-like structure.

Thus these last three patients have a number of interesting anomalies in common. All three have an iris atrophy, which in the grandmother is associated with advanced glaucoma; all three have an abnormal vessel, probably an exposed major circle located at the apex of the angle, and present a line of Schwalbe of varying prominence. The grandmother and the mother show a number of coarse and fine iris processes bridging the angle of the anterior chamber, and each of the three offers other individual deviations from the usual appearance of the chamber angle.

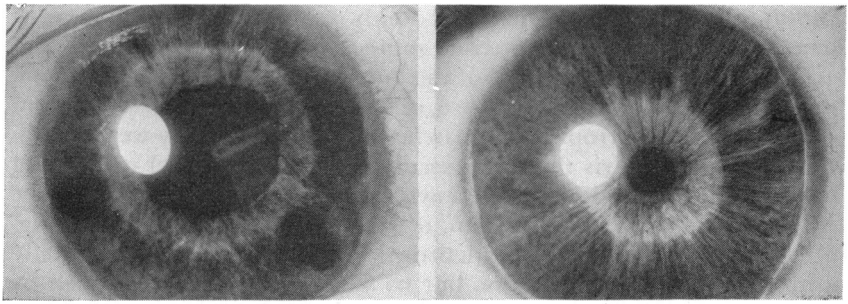


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FIGURE 7. LEFT: CASE 5. EXTERNAL VIEW OF RIGHT EYE, SHOWING PROMINENT RING AND MARKED IRIS ATROPHY, WITH HOLE FORMATION. RIGHT: CASE 6. SIMILAR VIEW

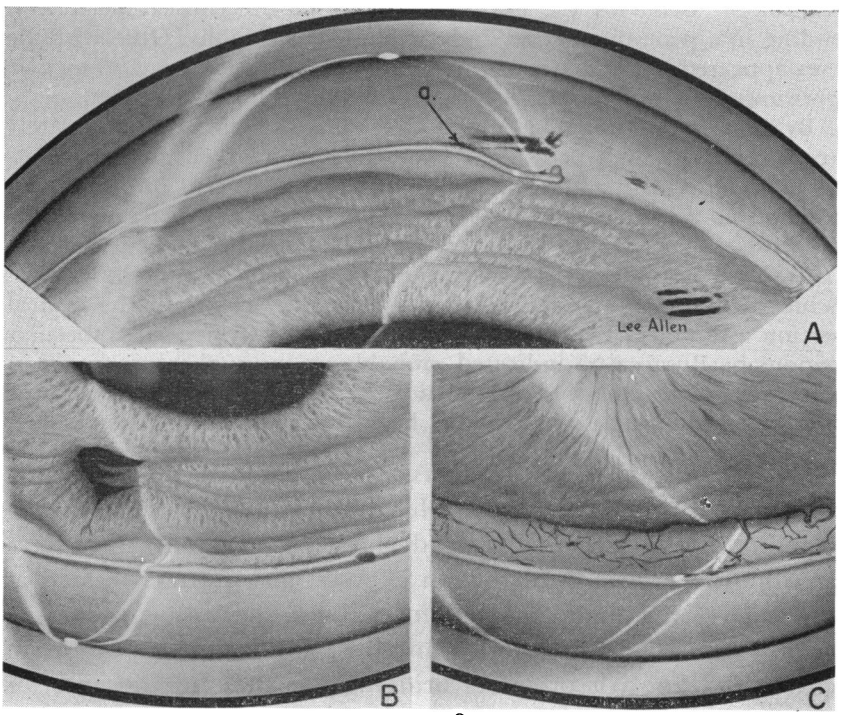

FIGURE 8

A. Case 5. Gonioscopic view of lower quadrant of right eye; (a) point at which ring of Schwalbe becomes detached. B. Case 5. Upper quadrant of chamber angle, left eye. C. Case 6. Upper quadrant of chamber angle, right eye.

Especially prominent rings were seen in the eyes of two brothers, both of whom had an essential iris atrophy and advanced glaucoma.

CASE 5. The older of two brothers with these rings, aged thirty-eight, presented externally the typical appearance of a very prominent ring and membrane-like formation at the posterior corneal circumference of each eye. In addition he had a very pronounced iris atrophy with hole formation (Fig. 7, left). The right eye had an intraocular pressure of 40 mm. Hg (Schiötz) and was blind. The pupil was large and there were incipient lenticular opacities and a deep glaucomatous cup of the optic disc with very large atrophic halo. The cornea and iris of the left eye had much the same appearance as in the right eye, but the pupil was normal in size and the lens clear. The disc showed some cupping, a nasal displacement of the vessels, and a glaucomatous halo. The intraocular pressure was 25 mm. Hg (Schiötz), the visual field showed an enlarged blind spot and a very pronounced constriction of the 1/1,200 isopter, but the vision was 6/6 + 4. The horizontal diameter of the right cornea was 9.5 mm., that of the left cornea 10.5 mm.

The results of the gonioscopic study of the eyes of this patient were especially noteworthy. In all views the iris appeared very atrophic, and in most views of both eyes the trabecular zone seemed whiter and broader than normal, with an undulating vessel appearing in that region and near the end of the corneal wedge in the upper and temporal quadrants of the right chamber angle. In the upper quadrant of the right eye the area of the anterior border of the trabecular band was occupied by a heavy white elevation. At 12:00 o'clock this elevation appeared as a sheet-like extension of the tissue peripheral to it, but to each side it took on a more strand-like character and actually seemed to separate from the cornea on the temporal side of the view. In this area, there was a broad peripheral anterior synechia.

In the lower quadrant of the right chamber angle (Fig. 8A) the atrophy of the iris with hole formation was very evident. No ciliary body band or scleral spur could be identified. A heavy, white, markedly elevated strand-like structure extended in what seemed to correspond to the region of Schwalbe's line from the temporal side to about 6:00 o'clock, where it suddenly separated from the overlying corneal tissue as a round strand and terminated at about the 5:30 o'clock position with a small translucent yellow ball near its free end. A patch of pigment was seen to lie on the corneal surface just anterior to this end. Nasally the white line was seen to recur in a position continuous with the line on the temporal side.

The upper quadrant of the left chamber angle (Fig. 8B) was of interest insofar as it showed very clearly the hole formation in the atrophic iris. It was similar to the other quadrants in that it presented throughout its entire extent a heavy, white cord-like strand in the position

where the ring of Schwalbe is expected to be found. Some pigment was seen on this ring and scattered upon the tissue posterior to it. This area of the chamber angle was furthermore remarkable in that the trabecular region was unusually transparent, as indicated by the two-fold reflex of the narrow beam of the slit lamp.

CASE 6. The younger of the two brothers, aged thirty-six, who also showed on external examination the typical ring and membrane-like formations on the posterior corneal surface (Fig. 7B), had considerable iris atrophy, but without hole formation. His eyes were otherwise essentially normal, except for baring of the blind spot and restriction of the 1/1,200 isopter and an increased intraocular pressure—O.D. 32 mm. Hg (Schiötz), O.S. 37 mm. Hg (Schiötz). *Vision:* O.D. +4.00 sph. +.75 cyl. ax. 180° = 6/6 — 1; O.S. + 1.00 sph. +.75 cyl. ax. 180° = 6/9.

The gonioscopic picture confirmed the iris atrophy. The ciliary band was not clearly visualized, nor was the scleral spur seen. The area of the canal of Schlemm could not be identified. In the upper quadrant of the chamber angle of the right eye (Fig. 8C), as well as in its lower quadrant, many irregularly formed iris processes extended forward onto and across the area expected to be occupied by the trabecular meshwork. The anterior margin of the supposed trabecular band was marked by an elevated, thick white strand on which inserted bridging iris fibers.

One abnormality found in this patient, in both the upper and lower quadrants, was that the slit beam demonstrating the corneal wedge in optical section extended across what was assumed to be the trabecular region to the iris root in the lower angle, and halfway to the iris root in the upper angle. It is particularly instructive to compare the relationship of the chamber angle structures to the corneal wedge of this patient with that in Case 7.

CASE 7. A thirty-seven-year-old white man, suffering from tuberculosis, and referred from a sanatorium because of eyestrain in reading, had a visual acuity of 6/6 in each eye, normal fields and normal intraocular pressure (O.D. 20 mm. Hg [Schiötz], O.S. 22 mm. Hg [Schiötz], after dilatation of pupils). He showed some thinning of the iris stroma, cerulean opacities of the lenses, and small punctate opacities of the cornea extending to limbus (white limbus girdle of Vogt). In addition, the external slit-lamp examination revealed what might be interpreted as a membrane or membrane-like formation at the periphery of the corneal endothelium around the entire limbus of both eyes (Fig. 9).

The most striking feature in the chamber angle (Fig. 10A) in each eye was a very opaque, elevated, cord-like band of tissue at the anterior margin of the trabecular zone. Posterior to this band the trabecular area had a smooth gray-tan color. The scleral spur and ciliary body band were not seen. Iris processes of varying lengths extended onto the

trabecular region and patches of pigment were seen lying on it and on the white border-line. The optical section had a peculiar angular break where the anterior corneal surface met the posterior surface of the limbus, but the corneal wedge had the usual nicely rounded form

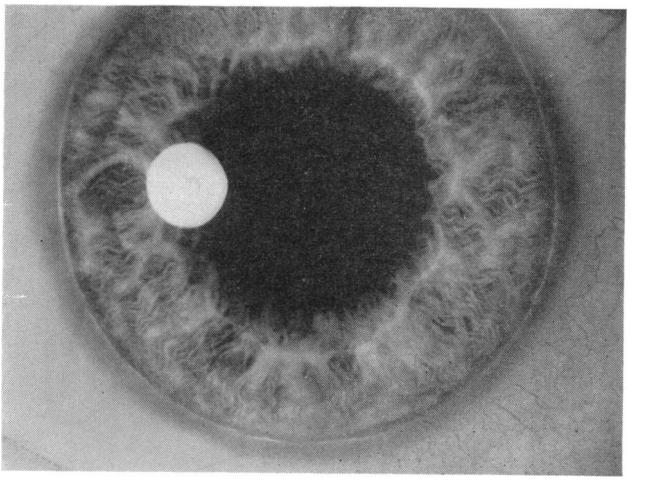

FIGURE 9. CASE 7. EXTERNAL VIEW, SHOWING PROMINENT RING WHICH IS EXTERNALLY VISIBLE AROUND ENTIRE LIMBUS

where it presumably coincided with the anterior border of the trabecular zone and the prominent ring of Schwalbe.

The shape of the corneal wedge in Case 7 was in marked contrast to the shape of the corneal wedge of the patient reported as Case 6 (Fig. 10B), in whom it formed an acute angle extending far beyond the prominent ring. Figures 10C and 10D show in a schematic cross section the situation which obtains in each of these two patients.

Regarding the family history of the patients in Cases 5 and 6, it must be added that they have an older sister, fifty years of age, who has always had eye trouble and who frequently sees an ophthalmologist. We did not have the opportunity to examine her, nor did we see the five-year-old son of the patient in Case 6, who, according to the report received from an ophthalmologist, has "a pronounced embryotoxon associated with glaucoma in one eye."

To complete this series of our observations we shall briefly mention three other cases.

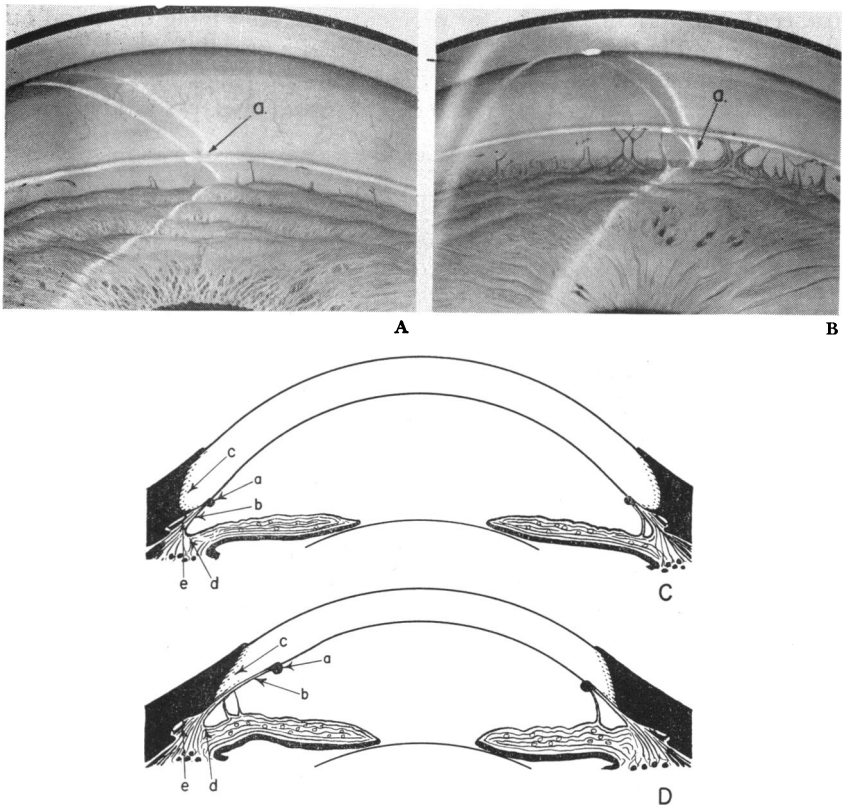

FIGURE 10

A. Case 7. Chamber angle; (a) end of corneal wedge. B. Case 6. Chamber angle; (a) end of corneal wedge. C. Schematic interpretation of the probable cross section of the chamber angle in Case 7, with cornea of relatively normal width; (a) normally located prominent ring of Schwalbe; (b) trabecular band of normal extent; (c) normally shaped corneoscleral junction and external scleral limbus. D. Schematic interpretation of the probable cross section of the chamber angle in Case 6, with a relative microcornea; (a) centrally located prominent ring of Schwalbe; (b) long, thin forward extension of uveal portion of trabecular meshwork; (c) abnormal corneal wedge forming an acute angle due to peculiar distribution of scleral tissue. Note forward position of iris root (D, d) in Case 6, and greater distance between apex of angle and Schlemm's canal (C, e) in Case 7.

CASE 8. The patient was an eighty-three-year-old man who had been under observation in our clinic since 1949 because of chronic simple glaucoma. On external slit-lamp examination he showed on the posterior corneal surface in each eye, parallel to the limbus, a line of pigment along with a band of refractile tissue, extending from this line peripherally into the angle. Just anterior to the place where the external limbus hid the corneal wedge, there could be seen in the lower

half of the corneal circumference a second smoother, denser line of pigment. From there out to the point where the corneal wedge was no longer visible the typical golden glow of the trabecular zone was observed. Gonioscopy confirmed the finding that the first pigment line was situated along the anterior border of the trabecular area. In gonioscopy, a third pigment band, not visible externally, was positively identified as a dense deposit over the area of Schlemm's canal.

CASE 9. This twenty-five-year-old white woman had been seen in our clinic since she was fourteen years of age because of congenital glaucoma. In the lower and temporal areas a line paralleling the limbus had been noted in each eye. The gonioscopic view of the lower quad-

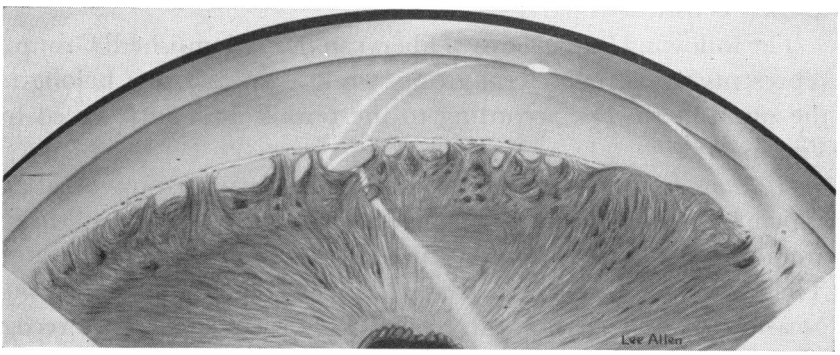

FIGURE 11. CASE 9. GONIOSCOPIC VIEW OF LOWER QUADRANT OF LEFT EYE
Corneal wedge disappears behind iris tissue.

rant of the left eye (Fig. 11) demonstrates massive iris processes similar to the heaviest band of pectinate ligament in certain lower animals, adhering to a prominent but narrow pearly-white line bordered on each side by pigment granules. The corneal wedge shows a behavior similar to that in Case 6, forming a very acute angle and reaching a plane apparently near the root of the iris.

CASE 10. A two-and-a-half-year-old girl presented large corneas (O.D. 12 mm., O.S. 13 mm. in horizontal diameter), a ring of tissue on the posterior surface of both corneas near the limbus, an atrophy of the iris, and an upward and outward displacement of her pupils. The intraocular pressure was O.D. 32 mm. Hg (Schiötz), O.S. 34 mm. Hg (Schiötz). Gonioscopy was not done.

MICROSCOPIC ANATOMY OF THE CHAMBER ANGLE

As was pointed out in the introduction to this paper a careful histologic study of the region of the chamber angle has been made in 600 eyes available to us in our collection of histologic specimens.

Of most of these eyes we had at our disposal a number of sections stained with hematoxylin-eosin and with the Held-van Gieson and Mallory stains. The result of these studies as they relate to the trabecular zone and its anterior border will now be summarized.

TRABECULAR MESHWORK

The elements of the trabecular meshwork are distributed in typical fashion, and its fibers can be divided into several groups on the basis of the course of the fibers and their relationship to adjacent tissues. The fibers of the various groups differ also with regard to their constituent parts.

The following four groups of fibers can be distinguished; Group 1 represents the corneoscleral group, while Groups 2 to 4 belong to the uveal meshwork according to the terminology introduced by Virchow (7).

1. *The corneoscleral group.* This is an outer group of fibers which have their anterior termination in the cornea, but which are possibly also related to the circular fibers of the scleral septum. These fibers generally run internally to Schlemm's canal, but occasionally will surround it, so that two or three layers are recognizable on its external surface and six to seven on its internal surface. In most cases these fibers appear to take a criss-cross direction. They are usually rather finer in texture than the other fibers of the trabeculum.

2. *Fibers of uveal meshwork relating to meridional fibers of the ciliary muscle.* This group has one terminal in the most posterior layers of the corneal stroma, frequently extending toward the center of the cornea well beyond the edge of Descemet's membrane (1/10 mm.). The posterior termination varies. Occasionally all fibers of this group seem to pass into the base of the scleral groove at the tip of the scleral spur, but just as frequently about 1/3 to 1/2 of the fibers continue past the tip of the spur to blend with the connective tissue surrounding the meridional fibers of the ciliary muscle. Even in the cases where all fibers seem to enter the tip of the spur, there appears to be some connection, either directly or indirectly by a fibrillary extension, through the spur with the ciliary muscle. There are approximately five layers of fibers in this group. These fibers take the most direct meridional course of any

of the trabecular fibers. In meridional sections of the eyes it is common to find one or more fibers shown nearly in its entire length. These fibers are usually somewhat thicker than the corneoscleral ones and their collagen and Descemet's layer are somewhat more distinctly seen.

3. Fibers of the uveal meshwork relating to the radial and circular fibers of the ciliary muscle. This next, more internal, group has its anterior termination just behind the edge of Descemet's membrane, at which point the fibers generally take a circular course. The posterior termination of these fibers is typically in the trabeculo-connective tissue surrounding the radial and circular fibers of the ciliary muscle. However, in the presence of an anomalously placed vessel, usually the major circle of the iris, some of the fibers may terminate by joining with the connective tissue surrounding the vessel. There are usually three to six layers of fibers in this group.

4. Fibers of the uveal meshwork relating to the root of the iris. This last group of fibers may or may not be present, and in our experience it is entirely absent in many eyes. When present it usually does not form a constant layer, but is represented by isolated fibers or groups of fibers scattered sparsely over the inner surface of Group 3. It may consist of collagen fibers with, or usually without, a Descemet's covering. The position of its anterior termination varies; it may be on the endothelial surface of the edge of Descemet's membrane, on the anterior border-ring of Schwalbe, if one is present, or on the internal surface of the fibers of Group 3, anywhere from the edge of Descemet's membrane to the apex of the angle. Its posterior termination is in the root of the iris and most frequently it appears to be continuous with the most superficial layers of the iris stroma. This group ordinarily is one fiber in thickness, and in the eyes in our pathologic collection is never more than two to three fibers thick at the level of the scleral spur. This group may lie in its entire course against the fibers of Group 3, or it may be separated from Group 3 in part of its course, forming a bridge. In the former case it has an endothelial and sometimes pigmented covering on its internal surface; if it bridges, there is endothelial covering with associated pigment on its entire surface.

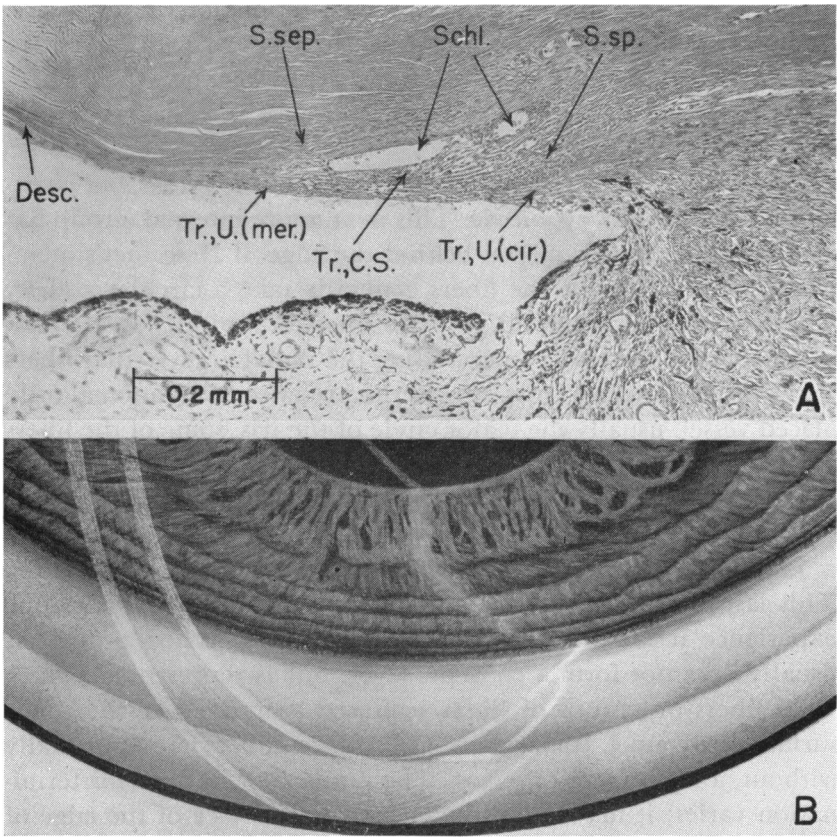

FIGURE 12

A. Histologic section of chamber angle of normal right eye of fifty-seven-year-old man. (Desc., Descemet's membrane; S. sep., scleral septum; Schl., canal of Schlemm; Tr., C.S., corneoscleral trabecular fibers; Tr., U. (mer.), fibers of the uveal meshwork related to the meridional ciliary muscle fibers; Tr., U. (cir.), fibers of the uveal meshwork related to the radial and circular ciliary muscle fibers; S. sp., scleral spur.) B. Gonioscopic drawing of the same region previous to enucleation.

With regard to the constitution of the trabecular fibers it must be briefly mentioned that these fibers contain a collagen core, a Descemet's layer, and a thin endothelial covering (Salzmann, 8). It has been stated that the trabecular fibers also contain a layer of elastic tissue. However, in our experience and judging by the observation of others (Anderson, 9), only the fibers of Groups 1 and 2 consistently contain elastic elements. Except in rare instances, the fibers of Groups 3 and 4 do not contain elastic material.

Figure 12A shows the histologic section of the chamber angle of a normal right eye, removed as part of an exenteration of the orbit because of carcinoma of the maxillary sinus extending into the orbit. The patient was a fifty-seven-year-old white man; the globe was clinically normal, the vision 6/9. The features of the chamber angle are clearly visible and are indicated in the illustration. The specimen is of particular interest since we had seen the eye gonioscopically prior to its removal (Fig. 12B).

THE ANTERIOR BORDER-RING OF SCHWALBE

The anterior border-ring of the trabecular area is commonly described (Schwalbe, 10; Salzmann, 8, and others) as a bundle of fibrillated connective fibers supported by elastic tissue, lying just beyond the edge of Descemet's membrane. This ring is clearly seen in preparations of the chamber angle of many animals (Fritz, 11), but in man it is as a rule not a densely packed group of fibers, but rather consists of fibers lying in fairly close proximity. In sagittal sections the fibers are cut across so that they are seen end on; they are seen to be separated by slight spaces. There is much variation in this group of fibers. One extreme, not further considered here, is represented by cases in which circular fibers comparable to those in the border-ring are found distributed over the inner surface of the trabeculum so that they do not constitute a ring. At the other extreme are the cases in which all the circular fibers are gathered into a ring which may be of such size that it forms an actual prominence extending into the anterior chamber.

When there is a prominent ring, it is made up of closely packed collagen fibers and may contain a greater or smaller amount of elastic tissue, indicated by small black-stained flecks when the Held-van Gieson stain is used. Occasionally we have noted a cell nucleus in the bundle, and more rarely still the inclusion of material appearing to stem from Descemet's membrane. With all stains the bundle takes the same deep stain as the scleral spur and the scleral septum, in contrast to the corneal tissue. The ring may appear as a single bundle or it may be divided into two distinctly recognizable portions. One of the two portions lies usually more internally than the other, and the internal portion tends to surround the other portion at its extremity directed toward the center

of the cornea. Ordinarily Descemet's membrane splits just as it reaches the ring, one portion going over the chamber side of the ring but thinning so as to be soon lost to view; the other portion follows a similar course on the corneal side of the ring. In some cases Descemet's membrane appears only on one side of the ring, either the internal side or the external. From the point where Descemet's membrane stops, the ring is covered only by a single layer of endothelium, identified by the isolated, thin, flat cell nuclei.

Such a prominent ring and its associated chamber angle are shown in Figure 13A. Figure 13B is a more magnified view of the

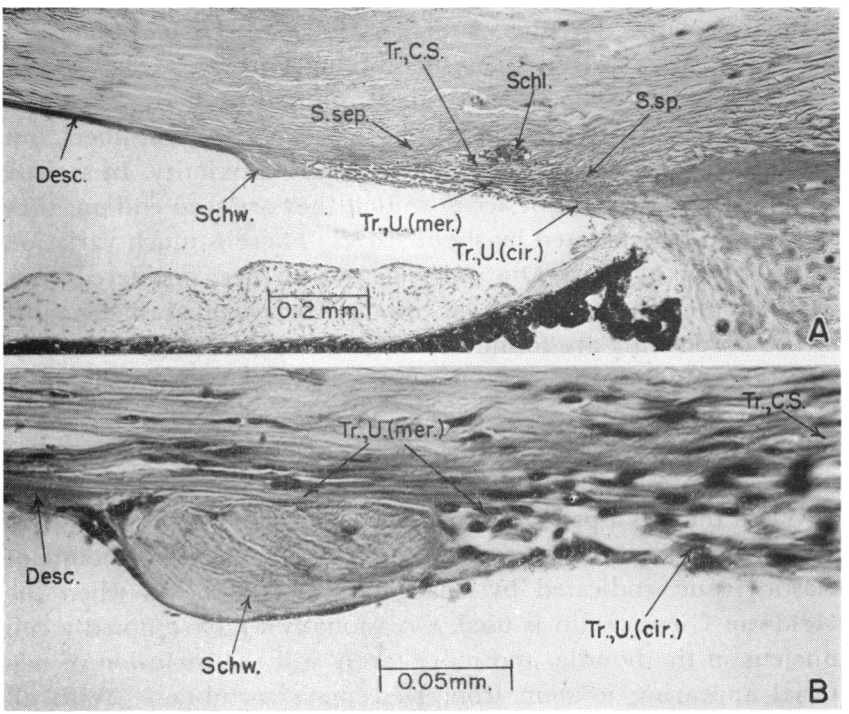

FIGURE 13

A. Histologic section of chamber angle of normal left eye of forty-six-year-old man. (Desc., Descemet's membrane; Schw., ring of Schwalbe; S. sep., scleral septum; Schl., Schlemm's canal; Tr., C.S., corneoscleral trabecular fibers; Tr., U. (mer.), uveal trabecular fibers related to the meridional ciliary muscle fibers; Tr., U. (cir.), uveal trabecular fibers related to the radial and circular ciliary muscle fibers; S. sp., scleral spur.) B. Photograph by oil immersion of another section of the same ring of Schwalbe as in A.

ring. In this ring the two portions which were mentioned before show up well; however, it contains only a small amount of elastic tissue.

Figures 13A and 13B (normal left eye of a forty-six-year-old man, enucleated because of epithelioma of lids and orbit), also show quite well the connections between the bundle of circular fibers and the trabecular fibers. These connections vary in different cases, but we were able to establish a certain pattern. On the corneal side, fibers belonging to the corneoscleral part of the trabecular fibers (Group 1) are seen which in our specimens were never incorporated into the ring. Internal to Group 1 are the fibers (Group 2) which are most closely associated with the tip of the

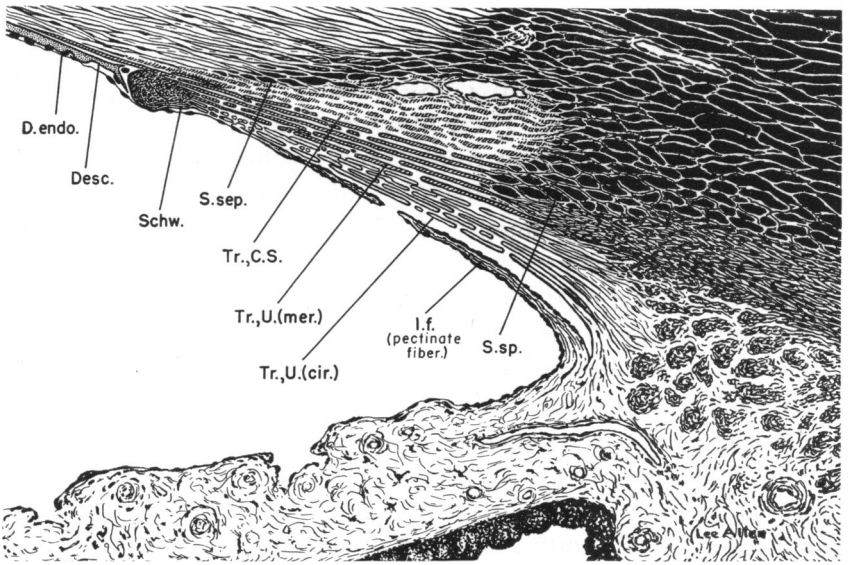

FIGURE 14. SEMISCHEMATIC REPRESENTATION OF THE CHAMBER ANGLE STRUCTURES AS THEY FREQUENTLY RELATE IN THE PRESENCE OF A PROMINENT RING OF SCHWALBE

(D. endo., Descemet's endothelium; Desc., Descemet's membrane; Schw., ring of Schwalbe bulging into anterior chamber; S. sep., scleral septum; Tr., C.S., corneoscleral trabecular fibers, relating to the spur and septum with a few fibers at corneal end wedging between septum and uveal trabecular meshwork; Tr., U. (mer.), uveal meshwork, one end relating to meridional ciliary muscle fibers and tip of spur, and other wedging between corneoscleral meshwork and Descemet's membrane, some fibers also entering ring of Schwalbe; I. f., iris fiber [iris process or pectinate strand], inconstant in presence, thickness, and extent upon trabeculum, sometimes bridging as atavistic pectinate fiber; S. sp., scleral spur.)

scleral spur and meridional fibers of the ciliary muscle. One or more of these may extend about 0.05 to 0.1 mm. beyond the ring, between the corneal stroma and Descemet's membrane. The remaining layers (reduced at this level to two or three in number) are incorporated into the ring. Occasionally a fiber enters the ring from the side adjacent to Descemet's membrane, but most of them enter it from the side toward the scleral spur and the meridional fibers of the ciliary muscle. On the chamber side of the ring, fibers are seen which have their origin toward the inner or anterior chamber aspect of the ring. They lie against its mass and are continuous with the trabecular fibers of Group 3 (those associated with the radial and circular fibers of the ciliary muscle). Trabecular fibers appearing to arise from the posterior part of the circumference of the ring may come to lie either in Group 2 or Group 3. Also associated in some manner with the ring are the less regular trabecular fibers of Group 4 (associated at their other insertion with the root of the iris). These fibers may have their origin on the inner surface of the ring or from its mass. When only one portion of the ring contains elastic fibers it is always the part from which the fibers of Group 2 emerge. At times the entire ring contains elastic elements, but in our sections these never extended into the inner uveal layers of the trabecular meshwork (Groups 3 and 4).

Our findings with regard to the various portions of the trabecular region when a prominent ring is seen in the section are summarized in a schematic drawing of the chamber angle (Fig. 14).

Among the 600 eyes which we examined we found 72 (or 15 percent) which showed a prominent ring. This is in surprisingly close agreement with our clinical observations with the slit lamp. We divided the 72 cases into four groups (+ to ++++) according to the degree of prominence, and noted a moderately prominent ring 11 times, a prominent ring 21 times, a very prominent ring 28 times, and an extremely prominent ring 12 times.

We rated the prominence of the ring in the eye of the next patient as being ++ (Fig. 15A). The right eye of this seventy-nine-year-old man was enucleated because of a tumor of the choroid. Prior to enucleation we saw a prominent ring at the periphery of his cornea in external slit-lamp examination and obtained a gonioscopic view. In the view of the upper angle reproduced in Figure

15B the pearly-white line is well visualized; it is more prominent in some regions than in others. At 12:00 o'clock there is an anomalous vessel at the root of the iris and there are two wide, abnormal, obliquely coursing vessels at the external corneoscleral limbus. The blunt, bulging displacement of the anterior line of the corneal

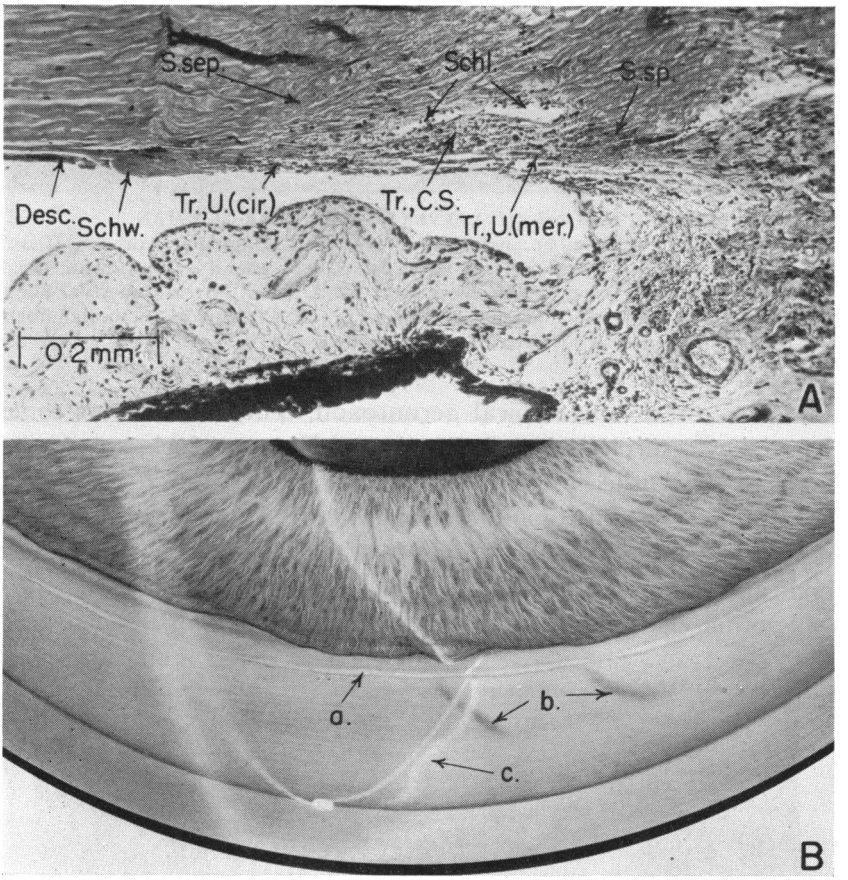

FIGURE 15. CASE OF A SEVENTY-NINE-YEAR-OLD MAN

A. Histologic section of upper chamber angle, right eye. (Desc., Descemet's membrane; Schw., ring of Schwalbe; S. sep., scleral septum; Schl., canal of Schlemm; Tr., C.S., corneoscleral meshwork; Tr., U. (mer.), uveal trabecular fibers related to the meridional ciliary muscle fibers; Tr., U. (cir.), uveal trabecular fibers related to the radial and circular ciliary muscle fibers; S. sp., scleral spur.) B. Gonioscopic view of same region previous to enucleation, showing narrowing of the angle due to ciliary body tumor; (a) moderately prominent ring of Schwalbe; (b) engorgement of two limbal vessels; (c) a typical gerontoxon.

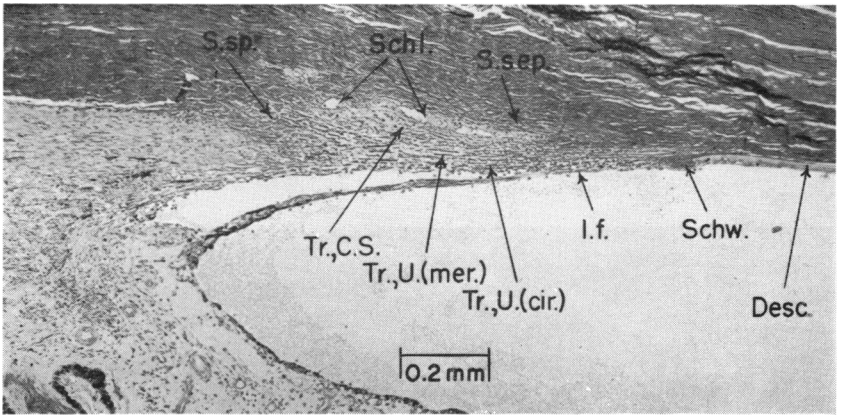

FIGURE 16. CASE OF A SEVENTY-FOUR-YEAR-OLD MAN
Histologic section of chamber angle of left eye, with bridging iris process. (Desc., Descemet's membrane; Schw., ring of Schwalbe; S. sep., scleral septum; Schl., canal of Schlemm; Tr., C.S., corneoscleral meshwork; Tr., U. (mer.), uveal trabecular fibers related to the meridional ciliary muscle fibers; Tr., U. (cir.), uveal trabecular fibers related to the radial and circular ciliary muscle fibers; S. sp., scleral spur.)

wedge is due to an atypical gerontoxon. The angle shows some narrowing, especially between 11:00 and 2:00 o'clock, where the iris root was pushed forward at a point corresponding to the site of the tumor. The histologic section (Fig. 15A) goes through this narrowed area of the angle; the forward displacement of ciliary body and iris root is clearly seen.

Another example of a prominent ring, but one of lesser degree

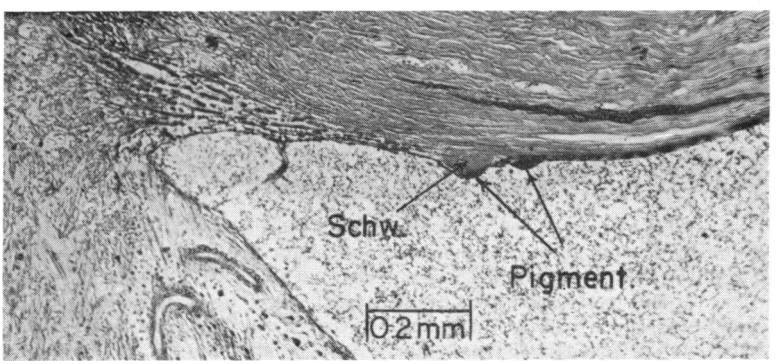

FIGURE 17. HISTOLOGIC SECTION OF THE CHAMBER ANGLE, WITH PIGMENT CLUMP ANTERIOR TO THE RING OF SCHWALBE

(+) is seen in Figure 16. This section (left eye of a seventy-four-year-old man, enucleated because of chronic iridocyclitis with secondary glaucoma following cataract extraction) shows an unusually long trabecular zone and also demonstrates the bridging of the trabecular fibers of Group 4, which has been discussed before. The fiber does not lie against the fibers of Groups 3 and 4 at the chamber angle, but rests against a loose meshwork with resulting open spaces, giving to the angle an appearance comparable to that seen in the eyes of some animals. As will be pointed out elsewhere, we consider this to be an atavistic formation. This bridging fiber which reaches the fibers of Group 3 midway up the trabecular area undoubtedly corresponds to the bridging iris processes which we observed gonioscopically.

The pigment seen so frequently on and around the prominent ring with the gonioscope is also to be found histologically, as can be seen from Figure 17, which represents the section of the chamber angle of a patient who had a chronic iridocyclitis and an iris bombé. The pigment is not of inflammatory origin.

EMBRYOLOGY OF THE TRABECULAR AREA AND OF THE PROMINENT RING

The results of our embryologic studies will be indicated here only in a few words.

We have been able to find in embryos as small as 91 mm. a differentiation of cells adequate to indicate broadly the grouping of the trabecular fibers which is to take place. At a point just beyond the end of Descemet's endothelium there were cells with large, round, granular nuclei which produce the trabecular fibers of the adult. The architecture of the corneoscleral trabecular fibers was already defined in a rudimentary way, whereas the layers internal to it were just beginning to appear grouped. In some embryos there was an excessive concentration of cell nuclei, in others they were fewer and they were more evenly distributed.

Evidence was gained that the chamber angle develops by a process of active cleavage and relative growth rather than by atrophy and resorption of mesodermal tissue. If this is correct, the cell concentrations which we have seen would not disappear, but would continue development and would either produce the normal

adult mass, or, being in excess and high concentration, would produce an excessive mass and prominence in whatever position they were laid down.

DISCUSSION

The accessibility of the trabecular region to external view depends on two or more factors: on the development of the sclera at the limbus, and on how far forward the trabecular region extends, and possibly on additional factors, so far undetermined, regarding a dysgenesis which might limit the extent of the posterior corneal stroma and Descemet's membrane. The relationship between cornea and sclera at the limbus is usually described as being such that the cornea fits like a watch glass into a groove formed by the sclera, so that the anterior edge of the scleral bevel extends farther forward than the posterior edge, thus effectively blocking the structures of the chamber angle to external view. This description undoubtedly fits the situation in many instances. We have seen, however, that it is not universally applicable. It is not rare to encounter, especially on the nasal and temporal sides, a narrow crescentic extension of the corneal tissue so that in these areas the outer scleral edge does not reach as far forward as in other parts of the limbus. This was noted and described by Kraupa (12), who stated that he had found it in many eyes and added that in this region the deep layers of the cornea were not clear, but that a striated grayish tissue extended into them. He considered this band to correspond to the posterior scleral wedge. It is of interest that Kraupa had seen this anomaly occasionally combined with other anomalies, one of which was corectopia. Kayser (13) has also reported a case of posterior embryotoxon in which the cornea extended in one eye much farther peripherally than is normally seen, so that he could survey the chamber angle freely. He gave no description of how it appeared, but Ascher (14) has reported a case of partial coloboma of the scleral limbus which permitted him to visualize Schlemm's canal by external examination. Thus far we have not been favored with finding such an extreme case and Ascher's case remains unique.

There can be no doubt that what these authors noted is essentially the same as what we have observed. The possibility, how-

ever, must be entertained that in certain instances the external visibility of the trabecular area is due not to a colobomatous formation of the sclera at the limbus, but rather to an abnormal forward extension of the trabecular zone relative to the limbus. Both gonioscopic and histologic findings point to this possibility.

It does not seem worth while to review here the whole literature on the posterior embryotoxon of the cornea, particularly since there exist able and relatively recent surveys of the subject (Streiff, 2; Paufique, Etienne, and Bonnet, 15; and others). A few remarks must, however, be made.

First, the embryotoxon is much more frequent than would appear from the literature. That it is by no means rare has already been emphasized by Graves (4) and Streiff (2), although the former did not recognize the identity of his finding with that of Axenfeld (1). Even the most complete surveys do not cover all cases in which such an appearance of the corneal margin is described. Leafing through the ophthalmic journals, one finds here and there a reference to what is undoubtedly a formation belonging to this group in papers which are not necessarily related to the subject, as for instance in Botteri's report (16) of an unusual case of polycoria. However, even if all reported cases were collected their number would still be small compared to the frequency with which the transparent bands are seen when looked for.

It should furthermore be noted that Axenfeld (1), in his original description of the embryotoxon corneae posterius, described the fine strands of iris tissue which insert into the whitish ring on the posterior corneal surface, bridging the normally deep chamber angle, and suggested that the whole formation might possibly be termed a rudimentary pectinate ligament in man. It should be emphasized that Axenfeld's view is much more correct than that of older and newer authors who insist on speaking of "goniosynechias" (Remky, 17; Paufique, *et al.*, 15; Šakić, 18; and others). The strands of iris tissue and iris processes extending from the iris root to the anterior border-ring, sometimes lying flat, at other times bridging the angle, are not synechias, even if they are closely packed (Fig. 11), but abnormal iris tissue which we considered to be an atavistic formation, as has been stated above.

The translucent bands on the posterior corneal surface have also been described as hyaline membranes (Mann, 3), and they do indeed frequently impress one as such on external slit-lamp examination. However, closer inspection not only reveals the ground-glass, striated appearance of these structures, but gonioscopic and histologic examination has definitely established that there are no abnormal membranes of any kind corresponding to the externally seen bands. At least the first two cases reported by Ida Mann doubtless belong in the group of cases discussed here, and it would, therefore, seem desirable to drop the designation "congenital hyaline membranes on the posterior surface of the cornea," since such membranes seem not to exist in the limbal region as congenital anomalies. In a recent paper Franceschetti and Rickli (19) have reported a case of eccentric lenticonus in which they had noted externally, and later also histologically (20), an embryotoxon as an incidental finding. The histologic section shows a beautiful example of the trabecular region and the prominent ring of Schwalbe, but we cannot agree with the interpretation given by the authors, who speak of a membrane on the posterior corneal surface in this area.

A. A. Knapp (21) reported in 1930 a case of corectopia with embryotoxon, and mentioned in his paper that Troncoso had studied the case with the gonioscope. However, the description given by Knapp is insufficient to permit conclusions as to the appearance of the chamber angle. The same is true of the description given by Paufique, Etienne, and Bonnet (15). The first and thus far only competent description of the chamber angle of a case with embryotoxon has been given by Busacca and Pinticart (22). These authors saw a case of embryotoxon with hypoplasia of the iris and slight corectopia. Gonioscopically they found an irregular enlargement of the trabecular zone and, in the region where the embryotoxon existed, a slight prominence of the anterior white limiting line (in Busacca's terminology; the anterior border-ring of Schwalbe in the terminology we use). They believed, however, in accordance with Busacca's interpretation of the anterior border-ring, that the pearly-white prominent line is made up of a thickening of the scleral septum, not of the border of Descemet's membrane. We agree that it is not a thickening of the border of Descemet's mem-

brane, but will state below our reason why we do not think that the prominent ring consists of scleral tissue.

As regards the anatomic substratum, Saba (23) expressed the idea that the prominent ring might be formed by irregular, abnormally developed sclerocorneal trabecular fibers. Biozzi and Lugli (6), although not recognizing that they were dealing with the posterior corneal embryotoxon, brought up the possibility that the prominent line was the anterior border-ring of Schwalbe and the opacity extending into the chamber angle was the corneoscleral trabecular zone, both visible at slit-lamp examination because of a more central location than is usual. Bloch's suggestion (24) that the prominent ring is nothing else than an atypically located branch of Schlemm's canal is not supported by any evidence. It is not quite clear what position Streiff (2) takes with regard to the anatomic substratum of the structures under discussion. He does not express himself concerning the band of relucent tissue, but definitely states at one place that the prominent line is the anterior border-ring of Schwalbe. He goes on to say, however, that normally the anterior part of the scleral meshwork is bounded by the anterior border-ring of Schwalbe, and that if it is bordered by a prominent line of hyaline aspect, we are then dealing with a posterior marginal dysplasia of the cornea.

Streiff (2) is also one of the few who have published a description of a histologic section of one of these prominent rings. In his description he speaks again of a hyaline spur protruding into the anterior chamber. This description is not correct in that the prominence is not hyaline, but differs in its staining characteristics from hyaline material. It is made up of collagen fibers and a greater or smaller amount of elastic material. This has been seen by Fritz (11), who was the first to note and depict such a prominent ring, and by Seefelder (25), who discussed them in 1910.

The prominence was positively identified as the ring of Schwalbe by A. Fuchs (26), who gave an excellent description of it. Fuchs noted that the thickness of the ring showed wide variations in the same eye and was entirely absent over short stretches of the chamber angle. In one of his eyes the area of a section of the ring varied from 570 $m\mu^2$ to 6,018 $m\mu^2$, where it was present, but at one point it had the exceptionally large area of 11,092 $m\mu^2$. It is furthermore of

interest to note that Fuchs observed, as we did, that the ring may consist of two parts which are as a rule so closely packed together that they actually form a single ring. In other areas of the same eye the two parts may, however, be completely separated. Fuchs also described radial fibers which entered the ring or passed behind it, but apparently did not consider them to be part of the uveal trabeculum as we do.

Otherwise, no one appears to have paid particular attention to the prominence, which surely must have been seen relatively frequently, until Loewenstein, in 1948 (27), again called attention to it. He did attempt to bring the prominence into connection with Schwalbe's ring, but came to the conclusion that this gonioscopic landmark was due to thickening and bulging of the corneal tissue toward the anterior chamber and that the "knoblike prominence" had nothing to do with it. In 1950, Loewenstein returned to the subject (28) and published a number of histologic sections of prominent rings. He changed his position somewhat in that he now considered both a white line at the border of the trabecular zone and the prominent rings to be representative of the ring of Schwalbe, but explained both as swelling of posterior corneal lamellas by aqueous entering the cornea at a gap between the end of Descemet's membrane and the trabecular zone. There is no reason to accept Loewenstein's explanation, as there is no evidence to support his claims that there is a gap in this region, that aqueous enters at this point, or that the closely packed circular fibers of the ring are swollen corneal lamellas. The case of mustard-gas injury to the cornea with swelling of the corneal lamellas which Loewenstein cites as evidence shows, on the contrary, that the prominence does not partake of the swelling. It is, in fact, additional support for our observation that the prominent ring is singularly immune from morbid processes surrounding it. Even in eyes with signs of severe inflammation or extensive infiltration with malignant cells in the surroundings of the ring, we have never found inflammatory or malignant cells within it.

As to the material making up the prominent ring, we think it doubtful that it is scleral in origin and that the prominence seen gonioscopically is a bulge in the scleral septum. While the circular fibers take the same stain as the scleral septum and scleral spur, and

even stain a little more darkly, the anterior layers of the group of trabecular fibers relating to the meridional position of the ciliary muscle (Group 2) insert between the scleral system and the ring in so positive a fashion that they form a regular wedge, so that there can not be an actual connection between septum and ring (Fig. 14). Also, the trabecular fibers of Group 3, relating to the circular and radial ciliary muscle fibers, are continuous with the fibers within the ring, suggesting that its fibers belong to the trabecular system.

We have indicated our views of the genesis of the prominent ring of Schwalbe in an earlier section of this paper and shall elaborate them in a subsequent paper on the basis of comparative anatomic and embryologic studies. We must, however, mention here briefly that, in general, there exist two thoughts with regard to the origin of the anomaly; one is that it is due to abnormally prolonged contact of the corneal periphery with mesodermal tissue during development, the other that it is the result of inadequate resorption of mesodermal tissue in the formation of the anterior chamber (Thier, 29; Remky, 17; Mann, 3; Rieger, 30; Hagedoorn, 31; and others). The thoughts are closely connected, and derive from the attempt at explaining hyaline membranes, hyaline rings, or corneal opacities assumed to exist on the basis of clinical observation. Since there actually are no such membranes or opacities in these cases, the theories thus far expressed miss the mark.

Although he too was seeking an explanation for "opacification of peripheral areas of Descemet's membrane," Thier (29) nevertheless came to an interesting conclusion in the case he reported. He had seen a twenty-two-year-old female patient with unilateral embryotoxon and marked hypoplasia of the iris stroma and thread-like adhesions of iris tissue to the prominent ring in the affected eye. He rejected in this case the hypothesis that the iris anomaly was explained by excessive resorption of iris tissue, but suggested that a mechanical transposition of the anterior stromal leaf had taken place; what was missing in the pupillary region was present in excess in the periphery.

The question of the genesis of the prominent ring is of importance in that a ring is often found in eyes in which there are other congenital anomalies, such as hypoplasia of the iris stroma, corectopia, polycoria, extensive remnants of the pupillary membrane,

and so on. The association of the prominent ring with these anomalies is too frequent to be purely coincidental, and Streiff (2) is doubtless correct in bringing all these anomalies under one heading, classifying them into three grades: (1) a prominent ring in essentially normal eyes; (2) a prominent ring in eyes with other congenital anomalies of mild degree; and (3) a prominent ring associated with congenital anomalies which must be looked upon as malformations. Consequently, the elucidation of the genesis of the prominent ring would also shed light on the genesis of other malformations.

An evaluation of the connection between the prominent ring and glaucoma is more difficult than the evaluation of its connection with other congenital anomalies. We have seen a number of patients in whom the combination with glaucoma existed, and the follow-up of these cases showed that the management of the glaucoma was very difficult. Other authors have also reported on patients with glaucoma and prominent ring. However, the number of patients who have a prominent ring and no glaucoma is very much larger, and in all cases with glaucoma the iris atrophy was severe and there were other associated anomalies. The case of Šakić (18) is interesting in this respect, since the patient had a bilateral glaucoma, but iris atrophy and a prominent ring were found only in the left eye. We consider it doubtful, therefore, that the ring as such is responsible for the glaucoma, and think rather that where it exists it is due to associated abnormalities of iris and chamber angle.

There can be no doubt that broad trabecular areas with prominent rings are not only congenital but also familial. Rieger (30), Biozzi and Lugli (6), Ascher (14), Theodore (32), Braendstrup (33), and Falls (34) have all reported its familial occurrence, and we have seen it not only in the families reported in this paper, but in its uncomplicated form in other families not specifically mentioned here.

A few words must, finally, be said regarding the incidence and the terminology. We have found that the trabecular zone is visible in external slit-lamp examination in almost everyone, and that a broad trabecular zone with a prominent thickened edge is seen in about 15 percent of all patients. We found it just as frequently

in our histologic material, namely in 72 out of 600 sectioned eyes which we examined. Streiff (2) puts the clinical incidence higher, namely at 20 to 30 percent, but he has seen it only rarely in sections, having made no systematic search. Why such seasoned pathologists as Seefelder (25) and Loewenstein (27), who doubtless had access to a large number of specimens, found the prominence to be such a rarity in the sections, we do not know.

As to the terminology, we have already stated that the term "congenital hyaline membranes on the posterior corneal surface" is inadequate and should be discarded. The term "embryotoxon" is meaningless once the nature of the condition is understood, and is ambiguous insofar as it has been used by some authors interchangeably for the prominent ring and the faint ring-like opacity formed by the trabecular region. The expression "posterior marginal dysplasia of the cornea" suggested by Streiff (2) is not quite correct, since we are not actually dealing with a corneal dysplasia, and is even less correct when it is used to include the more severe mesodermal abnormalities of iris and chamber angle. In this respect the designation "dysgenesis mesodermalis corneae et iridis" of Rieger (30), or, if one accepts Hagedoorn's criticism (31), "dysgenesis mesostromalis corneae et iridis," would seem to be preferable, although they might seem somewhat formidable names for the frequently seen simple form of a prominent ring. We are aware that severe abnormalities may be associated with it and that the trabecular zone may be abnormally wide and the ring very prominent, but we have no single term to offer to cover all abnormalities. We suggest that these structures be called what they actually are: the trabecular zone and a prominent line of Schwalbe.

SUMMARY

1. The trabecular region is visible at the periphery of the posterior corneal surface in almost every person in external slit-lamp examination, appearing in broad direct focal illumination as a band of grayish, translucent tissue showing fine criss-cross or regular striations. This band considerably differs in width in different individuals and in different regions of the limbus. This same tissue appears to have a "golden glow" when studied with a very narrow slit-lamp beam.

2. In about 15 percent of all patients examined, the trabecular region ended corneaward in a more or less prominent whitish line, often bearing clumps of pigment.

3. This line was identified by gonioscopy as a prominent anterior border-ring of Schwalbe.

4. A prominent anterior border-ring is often associated with mild to severe hypoplasia of the anterior stromal layer of the iris and other congenital anomalies, such as corectopia and polycoria. It is congenital and familial.

5. A prominent ring may be associated with glaucoma, but it is our impression that the ring itself is not causally related to the glaucoma.

6. Histologic studies of the trabecular region are presented. Among 600 sectioned eyes a promient anterior border-ring was seen 72 times and its histologic features are reported.

7. With regard to the genesis of the prominent ring, it is our conclusion from embryologic investigations that it is due to an excessive laying down of cells and excessive relative growth, not to a lack of resorption of mesodermal tissue. Abnormal iris processes bridging from the iris root to the trabecular meshwork and prominent ring are an atavistic formation.

8. "Congenital hyaline membranes at the posterior corneal surface," as applied to the formations described in this paper, do not exist and this term should be dropped. The term "embryotoxon" is ambiguous and superfluous; "posterior marginal dysplasia of the cornea" is not an entirely correct designation; "dysgenesis mesodermalis [or mesostromalis] corneae et iridis" is better, but we suggest that the structures under consideration should simply be referred to as "trabecular zone" and "prominent anterior border-ring of Schwalbe."

REFERENCES

1. Axenfeld, Th., Embryotoxon corneae posterius, Ber. Dtsch. Ophth. Ges., Heidelberg, 1920, pp. 301-2.
2. Streiff, E. B., Dysplasie marginale postérieure de la cornée (Embryotoxon corneae posterius, Axenfeld) dans le cadre des malformations irido-cornéennes, Ophthalmologica, 118:815-27 (Oct./Nov.), 1949.
3. Mann, Ida, On congenital hyaline membranes on the posterior surface of the cornea, Br. J. Ophth., 17:449-60 (Aug.), 1933.
4. Graves, B., Certain clinical features of the normal limbus, Br. J. Ophth., 18:369-87 (July), 1934.

5. Busacca, A. Eléments de gonioscopie normale, pathologique et expérimentale. Tipografia Rossolillo, São Paulo, 1945.
6. Biozzi, G., and L. Lugli, Ringförmige, periphere Verdickung in der Gegend der Descemet. (Ein neuer Spaltlampenbefund), v. Graefe's Arch. f. Ophth., 134: 287-90, 1935.
7. Virchow, H. Mikroskopische Anatomie der äusseren Augenhaut und des Lidapparates. Graefe-Saemisch, Handb. d. ges. Augenh. 2nd ed., Vol. I., pt. 1, chapter II. Wilhelm Engelmann, Leipzig, 1910.
8. Salzmann, M. The Anatomy and Histology of the Human Eyeball in Its Normal State; Its Development and Senescence. Translated by Dr. E. V. L. Brown. Chicago, 1912.
9. Anderson, J. Ringland. Hydrophthalmia or Congenital Glaucoma: Its Causes, Treatment and Outlook. Cambridge University Press, 1939.
10. Schwalbe, G. Lehrbuch der Anatomie der Sinnesorgane. Edward Besold, Erlangen, 1887.
11. Fritz, W., Über die Membrana Descemeti und das Ligamentum pectinatum iridis bei den Säugetieren und dem Menschen, Sitzungsber. d. mathem.-naturw. Kl. d. K. Akad. d. Wissensch., 115: Abt. III, No. VII, pp. 485-568. Wien, 1906.
12. Kraupa, E., Fehlen des Lederhautbandes in Sichelform als Abweichung vom gewöhnlichen Verhalten der Hornhaut-Lederhautgrenze, Klin. Mbl. Augenh., 64: 698-700, 1920.
13. Kayser, B., Über Embryotoxon corneae posterius nebst einem Befund von persistierenden Resten der Membrana capsulo-pupillaris lentis, Klin. Mbl. Augenh., 68:82-86, 1922.
14. Ascher, K. W., Partial coloboma of the scleral-limbus zone with visible Schlemm's canal, Am. J. Ophth., 24:615-19 (June), 1941.
15. Paufique, L., R. Etienne, and J. L. Bonnet, L'embryotoxon postérieur de la cornée, Ann. d'Ocul., 183:81-101 (Feb.), 1950.
16. Botteri, A., Ein besonderer Fall von Polykorie, Klin. Mbl. Augenh., 64:106, 1920.
17. Remky, E., Embryotoxon corneae posterius (Axenfeld), Klin. Mbl. Augenh., 78: 512-15, 1927.
18. Šakić, D., Un Cas de dysgenesis mesodermalis corneae et iridis (Rieger), Ophthalmologica, 123:31-39, 1952.
19. Franceschetti, A., and J. H. Rickli, Lenticône postérieur ayant simulé une néoformation kystique, Bull. et Mém. Soc. Franç. d'Opht., 64:168-75, 1951.
20. Franceschetti, A., and J. H. Rickli, Posterior (eccentric) lenticonus. Report of first case, with clinical and histological findings, Arch. Ophth., 51:499-508 (April), 1954.
21. Knapp, A. A., A case of corectopia, Am. J. Ophth., 13:141-42, 1930.
22. Busacca, A., and E. Pinticart de W., Etude gonioscopique d'un cas d'embryotoxon corneae posterius, Ophthalmologica, 115:283-90 (May), 1948.
23. Saba, V. Rara malformazione del limbo corneale in soggetto idrocephalico, Am. di. ottalm. e clin. ocul, Vol. 55, Nos. 5/6, pp. 446-52, 1927.
24. Bloch, F., Embryotoxon corneae posterius Axenfeld. Review of the literature and report of a case, Arch. Ophth., 18:68-72 (July), 1937.
25. Seefelder, R., Das Verhalten der Kammerbucht und ihres Gerüstwerkes bis zur Geburt. Graefe-Saemisch, Handb. d. ges. Augenh., 2nd ed., Vol. I, Part 1, Appendix to Chapter II. Wilhelm Engelmann, Leipzig, 1910.
26. Fuchs, A., Über die Festigkeit der Hornhaut und den Grenzring von Schwalbe, Z. f. Augenheilk., 67:129-40. 1929.
27. Loewenstein, A., Some aspects of the anterior drainage system of the human eye, Tr. Ophth. Soc. U. K., 68:485-501, 1948.
28. Loewenstein, A., "Knob" at the periphery of Descemet's membrane, Br. J. Ophth., 34:246-50 (April), 1950.
29. Thier, A., Angeborene Entwicklungsstörung des Irisvorderblattes im Zusammen-

hang mit ringförmiger peripherer Hornhauttrübung, Arch. f. Augenheilk., 89: 137-44, 1921.
30. Rieger, H., Beiträge zur Kenntniss seltener Missbildungen der Iris, II: Über Hypoplasie und Entrundung der Pupille, v. Graefe's Arch. f. Ophth., 133:602-35, 1935.
31. Hagedoorn, A., Congenital anomalies of the anterior segment of the eye, Arch. Ophth., 17:223-27 (Feb.), 1937.
32. Theodore, F. H., Congenital opacities of the cornea, Arch. Ophth., 31:138-43 (Feb.), 1944.
33. Braendstrup, J. M., Posterior embryotoxon in three generations. (Anomaly of development in the anterior chamber of the eye with annular opacity and membrane before the chamber angle), Acta Ophthalm., 26:495-507, 1948.
34. Falls, H. F., A gene producing various defects of the anterior segment of the eye, with a pedigree of a family, Am. J. Ophth., 32:41 (June, Part II), 1949.

DISCUSSION

DR. ROBERT N. SHAFFER. It is a privilege to be asked to discuss this excellent paper. The painstaking correlation of biomicroscopic, gonioscopic, and microscopic anatomy will be of great value in the future to all who are interested in pathologic changes of the chamber angle. When the eye physician finds such a case, it becomes a matter of real importance to determine whether the finding is an abnormal development or merely a variation of the normal.

It is probable that the prominent anterior border ring of Schwalbe and the unusually visible trabecular area reported in the first part of this paper are variations of a normal pattern and not to be considered as pathologic formations. However, there must be transition forms which will challenge the diagnostic skill of the eye physician.

It is a well-known fact that the full-blown syndrome of Axenfeld presents an extremely varied picture of disturbed development of the mesodermal elements of the iris and chamber angle. Falls reports one family pedigree of four generations exhibiting varied combinations of the following anomalies: embryotoxon, corneal opacities, corectopia, pseudopolycoria, slit-pupil, iridotasis, dyscoria, ectopia pupillae, ectopia lentis, anterior polar cataract, and congenital glaucoma. As in the cases reported in this paper, there is a definite dominant pattern to the heredity. Therefore, even though the patient under consideration may have a benign type of malformation, it is the duty of the physician to check other members of the family for more serious complications. The children should be examined repeatedly, as the glaucoma associated with this syndrome is usually delayed in onset—a so-called juvenile glaucoma. Affected members of families having such a genetic pattern should be strongly warned of the dangers of passing on the defect to succeeding generations.

If the syndrome of Axenfeld frequently produces a juvenile glaucoma which is based upon faulty angle development, it must also merge in the younger age group with the true congenital infantile glaucomas.

In this group of cases, angle studies, especially by Maumenee, also fail to show abnormal hyaline membranes or mesodermal reticulum filling the angle. In the microscopic sections, the iris inserts quite high on the uveal portion of the trabecular area. This high insertion is not the whole story of the etiology of congenital glaucoma, however, as Schlemm's canal can be filled in almost all cases, and can be seen above the insertion point of the iris, as has been pointed out, especially by Scheie. It would seem that there must be a relative impermeability of the trabecular area in these cases. In their studies on glaucomatous cases, have the essayists been able to determine any qualitative or quantitative difference in the physical structure of the trabeculum of a normal eye and that of an eye with either congenital or juvenile glaucoma?

In addition to congratulating Doctors Burian and Braley on their excellent presentation of the subject matter, it would be remiss not to commend Mr. Lee Allen for the magnificent angle drawings which we have all enjoyed.

DR. HAROLD F. FALLS. This extremely worth-while presentation merits our most careful attention.

A rather significant percentage of my patients, subjected to routine biomicroscopic study, exhibit this prominence of the temporal (and elsewhere) termination of the ring of Schwalbe. It is not uncommon to observe this mild entity occurring in the eyes of close relatives; in fact, I had the opportunity of seeing the trait bilaterally in the eyes of a chronic simple glaucomatous individual and his normal twelve-year-old daughter the day before I left for this trip.

The authors are correct in insisting that the descriptive word "embryotoxon" is basically meaningless. I sincerely trust that the writers will be able to present us with a more satisfactory terminology.

A rather severe manifestation of this entity has been frequently reported, at least in the European literature, under the name "Axenfeld's syndrome." This syndrome includes a wide range of anterior ocular segment anomalies: dyscoria, pseudo and true polycoria, corectopia, iridotasis, iris dehiscences, prominence of the iris sphincter, aplasia of the mesodermal leaf of the iris, ectropion uveae, as well as congenital corneal opacification or edema. The above features vary greatly in degree of expressivity among the affected individuals. That this developmental aberration can be determined by different gene mechanisms is suggested by the fact that features of Axenfeld's syndrome have been exhibited in both autosomal dominant and sex-linked recessive patterns of transmission.

Hydrophthalmos is, in my experience, a much different entity both clinically and genetically. Its genetic determination is due to an autosomal recessive gene having a heightened incidence in the male sex. I

have not been able to demonstrate anomalies of development of the iris or Schwalbe's ring in the eyes of the parents of hydrophthalmic children.

DR. HERMANN M. BURIAN. I wish to thank Dr. Shaffer for his very kind words, and Dr. Falls for his most illuminating discussion. Both added a great deal to what we have presented. I would like to say that I am not altogether familiar with the "syndrome of Axenfeld." I only know from the original page-and-a-half report of Axenfeld's that he described the line which we have shown and called it embryotoxon corneae posterius. Among his cases there was nothing but the very simplest form. The association with more severe anomalies came up later, but I am sure if anyone wishes to give Axenfeld credit by calling it the "syndrome of Axenfeld" that will be nice. I have never heard of it.

I wish to say, regarding the pictures which Dr. Shaffer showed, that he has no reason to apologize for them—on the contrary! Having tried with considerably less success than he has had to photograph the chamber angle, I must say they are wonderful. I wish we could do as well.

As to the matter of hydrophthalmos and the anterior chamber, anticipating what we expect to describe in another place, I would like to say that the anterior chamber does not open in normal development by a resorption of mesoderm, but rather by cleavage, by the formation of a cleft in the mesoderm, and that instead of being resorbed, actually the mesoderm seems to grow. If such a cleft does not take place, and the relative growth of the structures does not occur normally, other pictures may form, such as those of hydrophthalmos which Dr. Shaffer showed. Evidence for what I have said now will be presented at another place. To what extent the hydrophthalmos is to be separated genetically from the things we have described I would not presume to say. I certainly take Dr. Falls' word for it. It seems to us in looking over our histologic slides that these may well be tied together from the morphologic standpoint.

As for hyaline formations in the chamber angle, we are aware of their existence, and have them in our collection. They are the result of the secretion or, at any rate, the product of the endothelial covering of the anterior chamber, as shown by Reese and others. These membranes are a secondary formation; they are not congenital hyaline membranes.

As to the nature of the trabecular zone in glaucoma in children or adults, this is a subject into which we have not gone, because it is somewhat removed from our immediate purpose here. However, we are of course aware of the sclerosing and other processes in the trabecular area which were yesterday so beautifully shown by Dr. Theobald in the slides which she projected in one of her discussions.

I believe this covers the points which were brought up, and I will again take the opportunity to thank the discussers.