Detachment of ciliary body—anatomical and physical considerations

Robert A. Moses

The scleral attachments of the ciliary body and choroid were found to be densest from the equator to the posterior pole, less dense at the ora serrata, and practically nonexistent under the ciliary body and between the ora and equator. The elasticity of the choroid is such that in the excised human eye about 2 mm. Hg pressure is necessary to distend the uvea against the sclera. The tensile strength of the choroid was found to be greater than 5 Gm. per centimeter. It was concluded that although the interciliary zonules are under stress in vivo the elastic behavior of the ciliary body could not be entirely attributed to these zonules. It is suggested that, since pressure in the suprachoroidal space is lower than intraocular pressure due to the elasticity of ciliary body and choroid, in the presence of ocular hypotony the suprachoroidal pressure may fall below atmospheric pressure, encouraging transudation into the space. The distribution of the transudate is explained by the distribution of the suprachoroidal lamellae.

Separation of the ciliary body and choroid from the sclera is a common sequel to severe ocular hypotony. Detachment of the choroid can be readily appreciated ophthalmoscopically, but separation of the ciliary body was recognized only in histological sections until Chandler and Mau-menee1 pointed to the fact that as a rule, in hypotonic eyes fluid is found anywhere over the ciliary body.

The present paper deals with some of the anatomical and physical features of the choroid and ciliary body which predispose to their separation from the sclera. Eye Bank eyes no more than 72 hours post mortem were used.

1. In the three eyes studied, the attachments of the uvea to the sclera by suprachoroidal lamellae were found to be very scant in the region of the ciliary body, somewhat more dense at the ora serrata, apparently absent from the ora to just posterior to the equator, and increasingly dense from there to the optic nerve. The relative distribution and predominant course of the lamellae are shown schematically in Fig. 1. These findings are similar to those of Salzmann.2

2. The gross elasticity of the choroid2 was confirmed in three eyes. In any section of the posterior segment the choroid retracted, exposing a rim of sclera. If the choroid was stretched out, it retracted again when released. The fact that the choroid retracts implies that even in the dead eye it is under tension.

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Fig. 1. Schematic cross section of eye. The uvea is separated from the sclera to show the distribution of supraciliary and suprachoroidal lamellae.

A definite tendency of the cut edge of sclera to roll inward was noted. This was partially relieved by breaking the suprachoroidal lamellae.

3. The tensile strength and elasticity of the choroid were measured.

A. A strip of the ocular coats was cut from anterior to posterior pole. The portion of sclera posterior to the equator was cut away. A suture was sewed into the cornea and the cut end of the choroid was placed between the jaws of a fixed, small clothespin-like plastic clamp. The corneal suture was attached to a spring balance (Fig. 2). As the spring balance was raised or lowered change of length of the choroidal strip was noted with the aid of a microscope on a micrometer stand. Measurements were made from the clamp to the posterior tip of a ciliary process.

When overstressed the strips tore, usually at the ora serrata. Seven eyes were used in this investigation.

B. Equatorial strips of choroid were similarly measured using a second, movable clamp to hold the upper end of the strip. Strips from five eyes were measured. The results are summarized in Table I. Although the stress-strain curves are not strictly linear, values for compliance and the related Young's modulus were computed from measurements in physiological range of tension.

4. The lamellae running from the postequatorial choroid to the sclera also demonstrated elasticity and an aggregate tensile strength of the same order as the choroid. A strip of ocular coats was cut in an anteroposterior direction. The cornea was clamped while a suture connected sclera to spring balance. The sclera was then divided anterior to the equator (Fig. 3). The breaking force of this preparation...
in two eyes was 5.5 and 7.0 Gm. per centimeter strip width. Tearing occurred at the ora serrata.

5. The effect of temperature on the elastic properties of the choroid was tested in one meridional preparation (eye No. 6, second strip in Table I). Comparing the more meaningful second stretching it was found that at

25°C, compliance was .20 mm./Gm or
M = 2.5 × 10^4 Gm./cm.²
33°C, compliance was .13 mm./Gm or
M = 3.7 × 10^4 Gm./cm.²

6. Separation of the ciliary body in vitro was demonstrated in three eyes. The eye was first injected with saline through a needle placed in the optic nerve in order to restore the normal turgor. The eye was then embedded in four per cent agar, frozen, and sawed in two in a meridional plane. The choroid and ciliary body were found to be closely applied to the sclera. The lens was removed from one half of the eye and both halves of the agar-embedded eye were allowed to thaw. In both halves the uvea separated in a characteristic fashion, remaining attached at the scleral spur, or a millimeter or two behind it if anterior ciliary vessels perforated at that

Table I

<table>
<thead>
<tr>
<th>Eye</th>
<th>Age</th>
<th>Days post mortem</th>
<th>Compliance (mm./Gm.)</th>
<th>Young’s modulus (Gm./cm.)</th>
<th>Breaking strain (Gm./cm.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Initial</td>
<td>Second</td>
<td>Initial</td>
</tr>
<tr>
<td>Meridional strips</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>3</td>
<td>.11</td>
<td>.15</td>
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<td>3</td>
<td>60</td>
<td>3</td>
<td>.22</td>
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<td>4</td>
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<td>3</td>
<td>.17</td>
<td>.17</td>
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<tr>
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<td>.10</td>
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<td>77</td>
<td>3</td>
<td>.17</td>
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<td>1.9 × 10^4</td>
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<td>7</td>
<td>27</td>
<td>1</td>
<td>.20</td>
<td>.20</td>
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<td>Equatorial strips</td>
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<td>.30</td>
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<td>27</td>
<td>1</td>
<td>.42</td>
<td>.42</td>
<td>1.2 × 10^4</td>
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<tr>
<td>Soft rubber</td>
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<td></td>
<td>.26</td>
<td>.26</td>
<td>1.9 × 10^4</td>
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</tbody>
</table>

*A calculated for choroidal strip 1 cm. wide and 1 cm. long.

†Young’s modulus, M = force × length / width × thickness × elongation. The thickness of the choroid is assumed to be .002 cm.
point, and just posterior to the equator, but forming a chord between these two points as seen in the cross section (Fig. 4). That the separation progressed entirely around the half eye forming a truncated cone could be shown by pressing anywhere on the pars plana with a blunt instrument and observing the dimpling produced and the appearance of fluid and bubbles in the separated area of the section. When the instrument was removed the anterior uvea again retracted from the sclera. The findings were the same in all three eyes.

7. The intraocular pressure necessary to distend the ciliary body against the sclera was found to be about 3 cm. H₂O (2 mm. Hg). This result was obtained by cutting a scleral window over the ciliary body in a cannulated eye. When the intraocular pressure was reduced below 3 cm. H₂O a drop of water in the window was seen to become concave as it sucked into the supraciliary space. The drop reappeared in its convex form when the pressure was raised. Two eyes were investigated in this manner with similar results in both eyes.

8. An attempt was made to assess the contribution of the interciliary zonules (Fig. 5) to the elasticity of the ciliary body.

It was found, however, that even in relatively fresh eyes the ciliary epithelium had autolyzed so that the internal limiting membrane and zonules pulled away rather readily. The detached membrane shortened and rolled inward, indicating its elasticity and that of the interciliary zonules.

In two fresh monkey anterior segments the ciliary body detached very markedly. When the lens was removed by cutting the suspensory zonules the detachment persisted (Fig. 6). Chymotrypsin did not relieve the separation, although the interciliary zonules were dissolved, so it is inferred that in the monkey other ciliary body structures are sufficiently under tension to maintain ciliary separation.

Comment

The choroid, like many other body tissues, appears to be an elastomer. That is, it does not obey Hooke's law precisely, but repeated stress-strain determinations on the same specimen show close...
Fig. 6. Meridional section of anterior segment of fresh monkey eye showing marked separation of the ciliary body.

ing hysteresis loops* (Fig. 7). Young’s modulus† was calculated only for rough comparison of results and is similar to that of soft rubber. Like other elastomers choroid shows a decreased compliance with rise of temperature. It has been shown that the dead choroid displays considerable tensile strength, more than 5 Gm. per centimeter. It was also found that about 3 cm. H₂O was necessary to distend the uvea against the sclera. van Alphen† measured the pressure in the suprachoroidal space by direct cannulation in living cat eyes and found values very similar to the present ones. Since in a sphere tension = \( \frac{1}{2} \) pressure \( \times \) radius, the tension in the distended choroid is

\[ \frac{1}{2} \times 3 \text{ Gm./cm.}^2 \times 1.1 \text{ cm.} = 1.6 \text{ Gm./cm.} \]

The ciliary muscle may contract 5.0 – 1.6 = 3.4 Gm./cm. in accommodation before damage to the choroid might be expected.

If the low compliance of 0.1 mm. per gram is assumed, it is readily calculated that the ora serrata may be moved forward 0.7 mm. before the minimal breaking strain of 5 Gm. per centimeter is reached. It is highly doubtful that the ora moves this much even in an extreme accommodation. It seems clear then that the choroid is strong enough to serve as an attachment of the ciliary muscle, and is not the extremely delicate structure Henderson‡ supposed.

The elasticity of the ciliary body and choroid suggests that when the intraocular pressure falls to atmospheric, as during a cataract extraction, the pressure in the suprachoroidal potential space falls to as much as 2 mm. Hg below atmospheric. It is not surprising that transudate appears in the space in many such cases. Hudson§ also pointed to the fact that the nearly spherical sclera tends to maintain its domed shape when intraocular pressure is dropped to atmospheric. Meller¶ and Ha-
gens pointed to the loss of elasticity of the sclera with age as a reason why choroidal separation is often seen with hypotony in older adults but not often in the young. Thus the thinness and elasticity of the rabbit’s sclera may account for the lack of choroidal separation on fistulization of the anterior chamber found by Capper and Leopold. That the choroidal detachment so formed tends to be limited posteriorly just behind the equator is dependent upon the fairly firm epichoroidal attachment to the sclera from this point to the optic nerve. The vortex veins tie the choroid to the sclera in the equatorial region, and combined detachments tend to occur in the vertical and horizontal planes between the vortices.

The strength of the epichoroidal lamellae was quite unsuspected. Even though each lamella is very fragile, when the lamellae are stressed in aggregate and in the direction imposed in life they are capable of withstanding considerable tension. The vortex veins, short posterior ciliary arteries, and nerves passing between sclera and choroid undoubtedly augment the epichoroidal lamellae in holding the posterior choroid to the sclera. The virtual absence of attachment of the ciliary body to the sclera except at the spur and at points of perforation of anterior ciliary vessels allows transudate (or in the case of cyclodialysis, aqueous) to become distributed throughout the supraciliary space.

A therapeutic implication of the present findings is that treatment of separation of the ciliary body and choroid might be aided by cycloplegic drugs since in relaxation of the ciliary muscle tension on the uvea should be minimal. Separation of the choroid and ciliary body seen in histological sections may be declared to have existed in vivo only if proteinaceous material can be demonstrated between uvea and sclera. However, the artificial detachment commonly seen in sections is very likely the result of tension already existing in the uvea and not the result of differential shrinkage caused by the fixative.

Combined detachment depends essentially on tension existing within the uvea, and not upon the pull of the suspensory ligament of the lens as was shown by production of detachment in the absence of the lens (sections 3, 4), although lens zonule traction probably augments the effect. The ciliary structures are also under tension, and, when intraocular pressure is reduced, tend to cause the ciliary body to curl inward.

In the foregoing, no reference was made to the fact that in the excised eye the choroid is not distended with blood and that the elastic relations might be altered by such distention. This is undoubtedly true. From geometrical considerations it is seen that in the blood-distended choroid the inner layer (Bruch’s membrane) will be under less tension. The tissue between the vessels, however, may be under greater tension when the choroid is filled with blood, since the collapsed vessels can be drawn out to obliterated circles (in cross section), the diameters of which are considerably longer than the diameters of vessels rounded by blood filling.

REFERENCES
6. Hudson, A. C.: Serous detachment of the choroid and ciliary body as an accompani-
Erratum

In the article, "Changes associated with the appearance of mature sugar cataracts," by Drs. Patterson and Bunting, in the April issue of this JOURNAL, page 167, Figs. 1 and 2 are reversed, so that the legend for Fig. 1 applies to Fig. 2 and vice versa. The footnote of Table I should have read as follows: *Corrected hydration index equals (wet weight in milligrams minus [milligrams of dulcitol per lens multiplied by 16.5]) divided by (the dry weight of the lens in milligrams minus milligrams of dulcitol per lens).