the existence of this arterial ring based upon sections obtained from man and monkey. Although there are reports demonstrating a well-developed arterial circle of Zinn in the guinea pig and a thin vascular ring in the macaque monkey with the use of the same low-viscosity plastic we have used, no investigation was made in these reports in detail concerning the arterial nature of the ring vessels. In fact, we originally undertook this research firmly believing that the venous ring was in fact the arterial circle of Zinn. Ujiie and Hanyuda showed a structure of peripapillary choroid, i.e., arteriole-arteriole (A-A) anastomosis at the edge of the choriocapillaries, in macaque monkey. They thought that the architecture corresponded to the arterial circle of Zinn. The vessels composing the anastomosis shown by them are too small in size and too much anterior in its position to estimate it the arterial circle of Zinn. And we consider that their peripapillary choroid A-A anastomosis is quite different structure from the venous ring shown in the present study.

We believe that a complete circle corresponding to the circle of Zinn is lacking in rat eye and that the incomplete arterial circle which was reported in the eye of primates as the circle of Zinn may be similar vascular structure to the afferent branches of the SPCA toward the optic nerve as we found in the present study.

We believe that since the veins which enter the venous ring run parallel with the SPCA and LPCA as described above, and following the custom of calling parallel veins and arteries by the same name, that these vessels should be called the short and long posterior ciliary veins. But judging from the similarities in size and structure, it is perhaps better to refer to them collectively as the short posterior ciliary veins. In an investigation of vascular casts using neoprene latex injected intravenously, Araki demonstrated the existence of ciliary veins not previously mentioned by others which he identified together with the ciliary artery which pierces the sclera wall in vivo in the vicinity of the optic nerve. He did not make mention of a venous ringlike structure, but as seen in his detailed figures (his Figs. 1 and 2), a ringlike structure is clearly visible.

Such findings indicate that the venous ring which we have detected is not a structure unique to the rat. We believe that the short posterior ciliary veins discussed above and this venous ring collectively comprise the posterior ciliary vein. It is thought that the role of this vein is not, as previously held, the drainage of the sclera and optic nerve, but rather is the major drainage pathway of the posterior half of the choroid.

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Key words: choroidal circulatory system, venous ring, posterior ciliary vein, arterial circle of Zinn, angioarchitecture, vascular cast, posterior choroid

REFERENCES

Axial lengths and refractive errors in kittens reared with an optically induced anisometropia. EARL L. SMITH, III, GREGORY W. MAGUIRE, AND JON T. WATSON.

An anisometropia was simulated in kittens during the critical period of development by securing a high-
powered negative lens in front of one eye. Refractive error measurements obtained with an objective infrared optometer indicated that the deprived eyes of the anisometropic kittens were significantly more myopic than the normal eyes. A-scan ultrasonography showed that these differences in refractive error were correlated with an increase in the axial dimensions of the deprived eyes. The results of this experiment demonstrate that form deprivation associated with a habitually defocused retinal image produces an experimental myopia which is similar in nature to the refractive error changes produced by lid fusion and corneal opacification.

Alterations in axial length and refractive error have been produced in the developing eyes of both cats and monkeys by neonatal lid closure. There is, however, some disagreement among investigators concerning the exact nature of the alterations caused by lid suturing. For example, some investigators have found that lid fusion consistently resulted in a relative myopia which could be attributed to an increase in the axial dimensions of the deprived eye, whereas other investigators have found that neonatal lid fusion causes alterations in refractive error and axial length which were not always in the direction of increased myopia. The reason for these inconsistencies is not obvious, although it has been suggested that the type of procedure used to achieve lid closure could possibly influence the final refractive state of the eye. In this regard it has been demonstrated that abnormal lid tension and elevated temperature in conjunction with elevated intraocular pressure can cause alterations in refractive error. Therefore it is possible that differences in the technique used to fuse the lids may have resulted in unequal mechanical and/or thermal effects on the eye and thus may have contributed to these somewhat conflicting results.

In a series of experiments designed to eliminate some of the confounding factors associated with lid fusion and to help elucidate the crucial factors involved in the development of myopia following lid suturing, Raviola and Wiesel and Wiesel and Raviola demonstrated that lid fusion and total light deprivation, per se, were not sufficient or necessary factors in the development of experimental myopia. But more important, they found that visual stimulation and presumably the abnormal visual inputs produced by their rearing procedures somehow triggered the elongation of the eyeball. The rearing procedures they used (lid suturing and corneal opacification) severely deprived the treated eyes of form vision and reduced the amount of light reaching the eye by 0.5 to 1.2 log units. Although it has been suggested that clear retinal images are necessary for the proper regulation of eyeball growth, the effects of form deprivation without the possible confounding effects of light attenuation have not been previously investigated. Studying the effects of form deprivation on the eye of the kitten in the absence of any light deprivation would be especially interesting, since it has been suggested that the differences in the magnitude of the refractive error changes produced by lid fusion in cats and monkeys are related to the differences in the light-attenuating characteristics of their eyelids. The fused lids of monkeys only attenuate light by approximately 0.5 log units, whereas the fused lids of cats attenuate light by about 4 log units. Thus the relatively smaller changes in refractive error observed in lid-sutured kittens may simply reflect inadequate light stimulation.

In the present study the role of a clear retinal image in the process of emmetropization was investigated by rearing kittens with an optically induced anisometropia. With this rearing strategy, the effects of form deprivation on refractive error could be evaluated without either the possible confounding effects of light deprivation or the potential mechanical and thermal effects of lid closure.

Methods. Nine kittens born in an isolated colony were reared from the time of eye opening until 28 days of age in a light-free environment. Beginning on the twenty-ninth day, the kittens received 2 to 3 hr of visual experience each day while wearing goggles which held either zero-powered lenses over both eyes (one kitten) or a zero-powered lens over the left eye and a high-powered negative spherical lens in front of the right eye (eight kittens). The goggles were made of lightweight plastic and elastic fabric and held the lenses, which were 25 mm in diameter, securely to the head at a vertex distance of approximately 12 mm. For the eight lens-reared kittens, the dioptic power of the negative lens was constant for a given animal, but the dioptic powers varied between −10 and −16 D for the group. Viewing through the minus lenses optically simulated a large hypermetropic refractive error and thus assuming that the refractive errors of the two eyes were equal at 4 weeks of age, mimicked a large anisometropia. This assumption is partially supported by the fact that normal kittens, 45 days of age or older, do not demonstrate significant interocular differences in ocular dimensions. The kitten which was fitted with goggles which held...
zero-powered lenses over both eyes and two additional kittens which were reared in a normally lighted environment served as controls.

When the kittens had reached 12 weeks of age, the refractive status of each eye was determined with an objective infrared optometer (Bausch & Lomb Ophthalmetron) and the axial lengths were measured by A-scan ultrasonography (Kretztechnik, 7200 MA). To obtain the measurements, the kittens were anesthetized with ketamine hydrochloride (40 mg/kg; Ketaset, 100 nig/nil), a drop of 10% phenylephrine hydrochloride (Efricel) was instilled in each eye to retract the nictitating membrane and 2 drops of 1% cyclopentolate hydrochloride (Cyclogyl) was topically applied to in-duce mydriasis and to paralyze accommodation. When the pupils were fully dilated, the optometer was repositioned and refocused between measurements. For axial length determinations, several drops of a topical anesthetic (proparacaine hydrochloride, 0.5%; Alcaine) were placed in direct contact with the geometrical center of the cornea with care being taken not to indent the surface. The position of the probe was adjusted to maximize the echoes from the posterior lens and the retina. Since the probe was in direct contact with the cornea, the distance between the crystal artifact and the echo from the retina was considered to represent the axial length of the eye. The axial lengths were measured directly from the scale of the echograph display to the nearest half unit (assuming a constant velocity for sound of 1530 m/sec, 0.5 U represents 0.38 mm). It should be noted that in general a more accurate assessment of ocular dimensions, especially those of the anterior chamber, can be obtained when the ultrasound probe is separated from the cornea by a fluid medium. Nevertheless, the direct contact approach utilized in this study provided consistent results for repeated measures, and thus we felt that the procedure was adequate for assessing the relative differences in the overall axial length of the two eyes of a given animal.

**Results.** The optometer provided in graphic form a direct reading of the refractive error (assuming a 13 mm spectacle plane) for essentially every meridian of the eye. A basic spectacle correction, in minus cylinder notation, was derived for each acceptable reading; readings distorted by obvious movement artifacts were disregarded. The mean refractive errors and the axial lengths for the right and left eyes are shown in Table I for each animal.

For the control kittens, there was very little difference between the refractive errors of the two eyes. The mean refractive errors (expressed as the mean spherical equivalent correcting lens) for the left and right eyes of the normal animals were +0.92 and +0.83 D, respectively. In comparison, the mean refractive errors for the normal and deprived eyes of the lens-reared kittens were substantially different. The mean refractive status of the normal left eyes of the anisometropic kittens (+1.06 D) was similar to that of the control animals, whereas the mean refractive error for the deprived right eyes (−1.12 D) was significantly more myopic (p = 0.005; Mann-Whitney-Wilcoxon). In fact, for all eight anisometropic kittens, the spherical equivalent refractive error of the deprived eye was always more myopic (or less hyperopic) than the normal left eye. This difference be-

### Table I

<table>
<thead>
<tr>
<th>Animal No.</th>
<th>Rearing condition</th>
<th>Refractive error</th>
<th>Axial length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OS</td>
<td>OD</td>
</tr>
<tr>
<td>1</td>
<td>Light-reared control</td>
<td>+2.00 − 0.50 × 180</td>
<td>+1.50 − 0.50 × 180</td>
</tr>
<tr>
<td>2</td>
<td>Light-reared control</td>
<td>+0.50 − 1.00 × 180</td>
<td>+0.50 − 1.00 × 180</td>
</tr>
<tr>
<td>3</td>
<td>Blank control</td>
<td>+1.75 − 1.50 × 160</td>
<td>+1.75 − 1.00 × 175</td>
</tr>
<tr>
<td>4</td>
<td>−10 D OD</td>
<td>+2.25 − 1.00 × 165</td>
<td>−2.00 − 1.50 × 005</td>
</tr>
<tr>
<td>5</td>
<td>−10 D OD</td>
<td>+3.75 − 1.75 × 140</td>
<td>+0.25 − 1.00 × 35</td>
</tr>
<tr>
<td>6</td>
<td>−10 D OD</td>
<td>+2.25 − 1.25 × 20</td>
<td>+1.00 − 0.75 × 180</td>
</tr>
<tr>
<td>7</td>
<td>−11 D OD</td>
<td>+2.00 − 0.50 × 20</td>
<td>+2.00 − 2.00 × 160</td>
</tr>
<tr>
<td>8</td>
<td>−12 D OD</td>
<td>+3.12 − 1.12 × 90</td>
<td>−0.25 − 1.75 × 180</td>
</tr>
<tr>
<td>9</td>
<td>−14 D OD</td>
<td>+2.75 − 1.75 × 10</td>
<td>−1.12 − 1.50 × 170</td>
</tr>
<tr>
<td>10</td>
<td>−15 D OD</td>
<td>−1.62 − 2.00 × 25</td>
<td>−3.25 − 0.50 × 165</td>
</tr>
<tr>
<td>11</td>
<td>−16 D OD</td>
<td>+1.00 − 2.50 × 115</td>
<td>−0.50 − 1.50 × 165</td>
</tr>
</tbody>
</table>
The dioptic difference between the spherical equivalent refractive errors for the two eyes of each kitten (left eye refractive correction-right eye refractive correction) plotted as a function of the rearing condition. The range of refractive error differences for the control animals is marked by the dashed lines. All the experimental kittens demonstrated larger differences in refractive error than the controls, and in every case the deprived right eye was more myopic than the normal left eye.

Although no differences between the axial dimensions of the two eyes were noted for the control kittens, differences between the axial lengths of the two eyes were observed in five of the eight anisometropic kittens. In every case where a difference in axial length was measured, the deprived right eye always had the longer axial length. The mean axial length for the normal left eyes (17.3 mm) is in good agreement with estimates reported by other investigators for kittens 12 weeks of age and is shorter than the mean axial length for the deprived eyes (18.07 mm) (p = 0.082; Mann-Whitney-Wilcoxon). In general, the lens-reared kittens which demonstrated the larger differences in refractive error also demonstrated the larger differences in axial length (correlation coefficient = 0.81). However, for individual animals the magnitude of the difference in refractive error could not always be reliably predicted from
the axial length measurements (e.g., compare animals 4 and 10). For the anisometropic animals as a group, there was no significant correlation between either the differences in refractive error or axial length and the dioptric power of the lenses used to optically induce the anisometropia.

**Discussion.** The results of these experiments indicate that when the retinal image presented to one eye of a developing kitten is habitually defocused, the eye receiving the blurred image will become relatively more myopic than the normal eye. This change in refractive error can be attributed primarily to a change in the axial length of the eye, although changes in refractive index or curvature cannot be ruled out. In this respect, these alterations are very similar to the refractive error changes noted by previous investigators in the form-deprived eyes of animals which had undergone either lid fusion or corneal opacification. However, since form deprivation was produced optically in the present study, the potential mechanical and thermal changes associated with lid closure and the light-attenuating effects of corneal opacification can be ruled out as crucial factors in the pathogenesis of the experimental myopia. Instead, our results suggest that the blurred retinal image was the key factor in the development of these refractive anomalies.

The fact that form deprivation in the absence of light deprivation leads to myopia implies that the central retina, most likely the area centralis which is highly susceptible to a defocused image, is somehow involved in the process of emmetropization. It has been suggested that the coordinated growth between the optical components and axial dimensions of the eye require visual feedback for proper regulation. The mechanism by which visual feedback modifies eyeball growth is not known; however, the effects of altered pupil size can be eliminated in the present study since both eyes of the anisometropic kittens received the same amount of light, and the pupils were equal in size. Raviola and Wiesel reached a similar conclusion in their study of the effects of dark-rearing on experimental myopia.

The rearing procedures used in this study provide a promising approach for the development of a clinically relevant animal model of myopia. The optical procedures utilized produced changes in refractive error which were consistent across all the subjects and which were similar in magnitude to the refractive error changes observed in lid-sutured cats. In addition to eliminating the potential confounding factors associated with other techniques, this rearing procedure is advantageous because the amount of form deprivation can be easily controlled and since the ocular media are unobstructed, changes in both refractive status and axial length can be monitored throughout development.

Since the differences in refractive error noted in this study were essentially equal to the changes observed in lid-sutured cats, it can be argued that the reduced retinal illumination levels associated with lid suture do not substantially affect the degree of myopia induced by form deprivation. And therefore the differences in the magnitude of myopia produced by lid closure in cats and monkeys cannot be attributed to differences in the optical density of the lids. However, it must be kept in mind that in the present study, the lens-reared kittens received substantially less visual experience than lid-sutured kittens maintained on a normal light-dark cycle.

A somewhat surprising finding in the present study was the prevalence of astigmatism in both the normal and anisometropic kittens. Although previous investigators studying experimental myopia in kittens have not mentioned a high incidence of astigmatism, the magnitude of the astigmatism observed in this study is in good agreement with estimates calculated from the mean difference in curvature between the two principal meridians in the central region of the kitten’s cornea. Because the mean astigmatic correction is significant in magnitude, it is important to take into consideration the degree of astigmatism when trying to assess the effects of any rearing strategy on refractive error.

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**Key words:** anisometropia, myopia, axial length, kittens, refractive error, form deprivation

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