Neonatal Lensectomy and Intraocular Lens Implantation: Effects in Rhesus Monkeys

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Purpose. To compare the effects of a lensectomy with and without intraocular lens (IOL) implantation on a neonatal rhesus monkey eye.

Methods. A lensectomy and anterior vitrectomy was performed on 75 monkeys during the first 16 days of life; 21 of these monkeys also had an IOL implanted into the posterior chamber. The eyes were examined at regular intervals using biomicroscopy, applanation tonometry, and ophthalmoscopy.

Results. The pseudophakic monkeys were studied until they were 92.5 ± 5.8 weeks of age and the aphakic monkeys until they were 80.4 ± 5.7 weeks of age. Pupillary membranes (100% versus 55.5%; \( P < 0.01 \)) and lens regeneration into the pupillary aperture (28.6% versus 5.6%; \( P = 0.02 \)) occurred more often in the pseudophakic than the aphakic eyes. As a result, the pseudophakic eyes required more reoperations than the aphakic eyes to keep the visual axis clear (\( P < 0.01 \)). There was not a significant difference in the incidence of ocular hypertension between the pseudophakic and aphakic eyes (9.5% versus 12.7%; \( P = 0.34 \)). Pupillary capture of the IOL optic occurred in 52% and haptic breakage in 33% of the pseudophakic eyes. All of the eyes with broken haptics had a prominent Soemmerring's ring varying in maximum thickness from 0.6 to 2 mm. Nine of the haptics from the seven eyes with broken IOLs had eroded into the iris, two into the ciliary body, and one into the anterior chamber.

Conclusions.Implanting an IOL into a neonatal monkey eye after a lensectomy and anterior vitrectomy increases the likelihood of a reoperation being necessary. Haptics frequently erode into the iris and ciliary body and may break because of stress placed on the optic-haptic junction by forward movement of the IOL. Invest Ophthalmol Vis Sci. 1995;36:300-310.

Cataract extraction coupled with the implantation of a posterior chamber intraocular lens (IOL) is now the standard treatment for visually significant cataracts in adults. In most series, at least 95% of eyes without other pre-existing ocular diseases are able to achieve 20/40 or better visual acuity after this procedure. While similar visual results can be achieved after cataract surgery coupled with the use of contact lenses or spectacles, IOLs are associated with fewer optical aberrations and do not require ongoing care. Although the complication rate is probably slightly higher after this procedure than cataract extraction alone, this difference is small. In contradistinction, IOLs have only rarely been implanted in the eyes of infants and no direct comparison has been made between cataract extraction with or without IOL implantation in infantile eyes. While a number of optical benefits could potentially be realized in an infant whose vision is corrected with an IOL in lieu of a contact lens or spectacles, the high rate of postoperative complications may limit their effectiveness. Features that increase the likelihood of complications developing after IOL implantation in infant eyes include: rapid ocular growth during the first year of life, an

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increased tendency for Soemmerring's rings to form, and a marked inflammatory response to surgery. 9

We developed a monkey model to compare the complications that arise after the surgical removal of a crystalline lens with and without the implantation of an IOL. The rhesus monkey was chosen as an animal model because of the close anatomic similarity of their eyes to human eyes.10 Unlike human eyes with congenital cataracts, which frequently have other abnormalities that may act as confounding variables, all of these eyes were otherwise normal. We report our results after treating a large series of monkeys with both these treatments.

MATERIALS AND METHODS

Animals

Seventy-five rhesus monkeys, ranging in age from 1 to 16 days, underwent a monocular lensectomy at the Yerkes Regional Primate Research Center between 1985 and 1992. The surgeries were all performed under sterile conditions while the monkeys were deeply anesthetized. An ocular examination was performed on each animal preoperatively including: biomicroscopy, application tonometry, and ophthalmoscopy to ensure that all of the eyes were normal. All procedures were performed in compliance with the ARVO Statement for the Use of Animals in Ophthalmic and Vision Research and approved by the Nonhuman Primate subcommittee of the Institutional Animal Care and Use Committee of Emory University.

Lensectomy

Fifty-four monkeys had their right crystalline lens removed using a pars plana approach without the insertion of an IOL. Forty of the lensectomies were performed when the monkeys were 0 to 6 days of age and 14 when they were 7 to 11 days of age (mean, 4.7 days). Three pediatric ophthalmologists (AF, HE, AG) performed the operations. After creating a conjunctival peritomy superiorly, a stab incision was made in the eye 2 mm posterior to the limbus. A vitreous cutting instrument (Ocutome II, Model 8000, Cooper Medical Sources Co., San Leandro, CA) equipped with an infusion sleeve was then introduced into the vitreous chamber. While the eye was being continually infused with a balanced salt solution (BSS Plus, Alcon Surgical, Fort Worth, TX) combined with 1 mg/ml of adrenaline chloride and 5 U/ml of low molecular weight heparin (Fragmin, Kabi Pharmacia, Stockholm, Sweden). Heparin was not added to the infusion solution during the primary surgery for the first nine monkeys undergoing IOL implantation because it was not appreciated at the onset of this study how much fibrin would accumulate in the anterior chamber of these eyes after IOL implantation. Heparin was subsequently added to the infusion solution to mitigate this complication. A can-opener anterior capsulotomy was then performed using a bent needle through the second incision and the lens was aspirated with an irrigation/aspiration cannula. Next, a 4 to 5 mm central opening was created in the posterior lens capsule with an automated vitreous cutting instrument (Ocutome II, Model 8000, Cooper Medical Sources Co., San Leandro, CA) through which an anterior vitrectomy was performed. We aspirated the lens with an irrigation/aspiration cannula instead of an Ocuteome because we achieved superior results in a pilot study using this technique. We performed a primary posterior capsulotomy because we found that if the posterior capsule was left intact it invariably opacified in 1 to 2 weeks and became so thickened that it could not be cut with the Ocuteome. After injecting sodium hyaluronate (Kabi Pharmacia Ophthalmics, Monrovia, CA) into the posterior chamber, the incision was enlarged to 5.5 mm, and an IOL was implanted in the posterior chamber. A monofocal, polyacrylamide surface-modified, one piece, all polymethylmethacrylate IOL (P327 UV, Storz Intraocular Lens Co., St. Louis, MO) with a diameter of 10 mm, a 5 mm biconvex optic and 30 diopters of power was implanted into the right eye of 11 monkeys and a diffractive multifocal one piece all polymethylmethacrylate IOL (3M Vision Care, Minneapolis, MN) with the same dimensions but 27 diopters of power and an add of 4 D was implanted into the right eye of 10 monkeys (Fig. 1). The limbal wound was then closed with interrupted 9-0 vicryl sutures. One milligram of dexamethasone sodium phosphate (Elkins-Sinn Inc., Cherry Hill, NJ) and 20 mg of gentamicin sulfate (Schering Pharma-
FIGURE 1. One piece all-poly(methylmethacrylate) IOLs used in the study (left, monofocal lens; right, diffractive multifocal lens). All of the haptics that broke did so at their junction with the lens optic (arrow).

Diaphragm phosphate and twenty milligrams of gentamicin sulfate were then injected subconjunctivally. Postoperatively, the pseudophakic eyes were treated for 2 weeks with topical antibiotics, corticosteroids, and 1% atropine sulfate.

Examinations Under Anesthesia
Ophthalmic examinations including biomicroscopy, applanation tonometry, and ophthalmoscopy were performed monthly until the monkeys were 6 months old and bimonthly thereafter using intramuscularly administered ketamine (0.1 mg/kg, Fort Dodge Laboratories, Fort Dodge, IA). These findings were recorded on standardized data collection sheets and then entered into a computerized data bank. Slit lamp photographs were taken of the anterior segments of the pseudophakic eyes during each examination under anesthesia as well.

Reoperations
Opacities involving the visual axis and interfering with retinoscopy were removed with an automated vitreous cutting instrument, a bent 23-gauge needle or a Q-switched YAG laser (Microruptor III, H. S. Meridian, Berne, Switzerland). YAG laser treatments were performed while the monkeys were in a supine position using a capsulotomy lens to focus the laser energy. A mean of 109 mJ of energy was used for each YAG laser membranectomy with a range of 37 to 345 mJ. Discisions with a bent needle were made through a limbal stab incision and then closed with a single 9-0 vicryl or 10-0 nylon suture. Surgical membranectomies were performed using a vitreous cutting instrument with an attached infusion sleeve introduced through a stab incision either at the limbus or through the pars plana. Tissue plasminogen activator (tPA, Genentech, San Francisco, CA) was injected into the anterior chamber of selected cases using a 30-gauge needle through the limbus. The tPA was prepared for intracocular injection by dissolving lyophilized tPA in sterile water to an initial concentration of 25 μg/100 μl. It was then diluted in sterile balanced saline solution to a concentration of 6 μg/100 μl and stored at −70°C.

Histopathology
Eight animals from the pseudophakic group were killed with a lethal injection of phenobarbital. Seven of these animals had a broken IOL haptic and one had glaucoma in its pseudophakic eye. The eyes were then enucleated and placed in 10% formaldehyde. Then they were bisected through the equator and the position of the IOL was inspected grossly. The eight fellow eyes were opened in a similar fashion. The eyes were then embedded in paraffin, sectioned, and stained with hematoxylin and eosin. Stepwise sections were examined to determine the position of each lens haptic. The maximal thickness of the Soemmerring's ring and the distance of the lens haptic from the ciliary sulcus was measured to the nearest 0.1 mm using a reticule placed in the eyepiece of the viewing microscope. The cornea, iris, trabecular meshwork, and posterior segment of each eye was also examined.

Electron microscopic examination was performed on a pupillary membrane removed from the anterior surface of an IOL 4 days after its implantation. The specimen was fixed in 2.5% glutaraldehyde and postfixed with 0.1M cacodylate buffer and 1% osmium tetroxide. After standard dehydration, the specimen was embedded in epoxy resin. Semithin 1.0 μm sections were cut and stained with uranyl acetate and lead citrate for transmission electron microscopy.

Statistical Methods
Kaplan-Meier curves were used to conduct life table analyses comparing the first occurrence of lens regeneration, the development of a pupillary membrane, and ocular hypertension among aphakic and pseudophakic monkeys. The statistical significance of the effect of IOL implantation on the occurrence of these complications were assessed using the generalized Savage and Wilcoxon x² test. Additionally, because most complications occurred very early in the follow-up period (that is, less than 1 month), we were able to use a risk ratio to evaluate the relative risk of the occurrence of these complications associated with IOL implantation. The statistical significance of the risk ratio was assessed with Pearson's chi-squared and Fisher's exact test when the data were sparse.
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FIGURE 2. Kaplan-Meier curves showing the cumulative incidence of pupillary membranes in the pseudophakic and aphakic groups. The difference between the two groups was significant using the Mantel-Cox and Breslow tests ($P < 0.01$).

We also assessed the impact of IOL implantation on the number of reoperations (that is, lensectomies and membranectomies) required using the Wilcoxon Rank Sum test. All statistical analyses were performed using the BMDP statistical program.

RESULTS

Clinical Findings

The aphakic monkeys were followed up for an average of 80.4 ± 5.7 weeks (mean ± SE) and the pseudophakic monkeys for 92.5 ± 5.8 weeks. The earliest complication seen in most monkeys was the formation of a pupillary membrane. Visually significant pupillary membranes developed in 56% of the aphakic eyes and 100% of the pseudophakic eyes (risk ratio = 1.83; $P < 0.01$; Fig. 2). The membranes developed within 2 weeks of surgery in 77% of the aphakic eyes and 80% of the pseudophakic eyes (range, 0 to 21 weeks). Pupillary membranes developed in 25 of the 40 (62%) aphakic monkeys who underwent a lensectomy during the first 6 days of life, but only 4 of 14 (29%) of the monkeys who underwent a lensectomy at 7 to 11 days of age (risk ratio = 1.44; $P = 0.03$). In the aphakic eyes, the membranes would typically contract resulting in occlusion of the pupil. In the nine pseudophakic eyes that did not have heparin in the infusion solution, a thick pupillary membrane developed on the anterior surface of the lens optic and a thin membrane on the posterior surface of the lens optic. Thin membranes developed on both surfaces of the lens optic in the 12 pseudophakic eyes that received heparin intraoperatively (Fig. 3A).

More membranectomies were required to clear the visual axis in the pseudophakic (median = 4; range 1 to 7) than the aphakic eyes (median = 1, range 0 to 2; $P < 0.01$; Fig. 4). In the aphakic eyes 7 membranectomies were performed using a YAG laser and 31 were performed surgically. In the pseudophakic eyes, 57 membranectomies were performed using a YAG laser and 14 were performed surgically. The only complication that occurred during or after the YAG laser treatments was transient bleeding of the iris. An attempt was made to lyse the pupillary membranes in four pseudophakic eyes by injecting tPA (4 to 9 μg) into the anterior chamber 1 to 2 days postoperatively. No observable effect on the fibrin membranes was noted after this treatment.

Lens regeneration into the pupillary aperture occurred more commonly in the pseudophakic (29%) than the aphakic eyes (6%; risk ratio = 5.2). Life table analysis showed a statistically significant difference in the rate of development of lens regeneration ($P = 0.02$) (Fig. 5). In the pseudophakic eyes, regenerating lens material began to extend into the pupillary aperture 7 to 54 weeks postoperatively compared to 12 to 46 weeks postoperatively in the aphakic eyes (Figs. 3B, 3D). It did not recur in any of the aphakic eyes after being aspirated once. A single reoperation was sufficient to remove the regenerating lens material in four pseudophakic eyes; however, one reoperation was necessary in one eye and six were required for one eye because of persistent lens regeneration. In each case, the lens regeneration recurred in the same sector of each eye.

The incidence of ocular hypertension was not statistically different between the aphakic (13%) and the pseudophakic eyes (10%; risk ratio = 1.3). Life table analysis showed no statistical difference in the rate of development of ocular hypertension ($P = 0.34$). Ocular hypertension developed 2 to 83 weeks postoperatively in the aphakic eyes and 20 to 136 weeks postoperatively in the pseudophakic eyes.

Three pseudophakic eyes developed hyphemas: one after the excision of a fibrin membrane with an automated vitreous cutting instrument, another after the injection of 9 μg of tPA into the anterior chamber, and the third after an uncomplicated lensectomy and IOL implantation. An anterior chamber washout was performed on two of these monkeys. The other hyphema cleared spontaneously. A vitreous hemorrhage developed postoperatively in one aphakic monkey, which cleared spontaneously.

Immobile pupils developed in all of the aphakic and pseudophakic monkeys. A wound dehiscence developed postoperatively in two of the pseudophakic monkeys. Pupillary capture of the lens optic occurred in 11 (52%) pseudophakic eyes. The IOLs broke in seven (33%) of the pseudophakic eyes. Pu-
pillary capture was present in each of the pseudophakic eyes in which the haptic broke. In each instance the IOL broke at the juncture of the lens optic with the haptic (Fig. 1). Both haptics broke in two eyes while one haptic broke in five eyes. The haptics broke 6 to 31 months after surgery. In each case the IOL became decentered or dislocated into the anterior chamber after the haptic or haptics broke (Figs. 3E, 3F).

No retinal detachments or abnormalities of the posterior segment developed in any of the aphakic or pseudophakic eyes.
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FIGURE 3. (Continued) (E) Pupillary capture and pigmented precipitates on a monofocal IOL 8 months after its implantation. (F) The same eye 7 months after breakage of the nasal haptic at the haptic–optic junction (arrow). The IOL was subluxed inferiorly and vibrated with ocular movement.

Histopathology

Examination of the anterior segments of the eight pseudophakic eyes showed the anterior surface of the iris leaflets to be adherent to the posterior surface of the cornea resulting in partial occlusion of the trabecular meshwork in two eyes, near complete occlusion in four eyes (Figs. 6A, 6B) and complete occlusion with iris bombe in the eye with ocular hypertension. Lens remnants were present in a Soemmerring’s ring configuration in all cases (Fig. 6). The maximum thickness of the Soemmerring’s ring ranged from 0.8 to 2.0 mm (Table 1). The posterior surface of the iris leaflets were adherent to the lens remnants in all cases.

FIGURE 4. Kaplan–Meier curves showing the cumulative incidence of lens regeneration into the pupillary opening in the pseudophakic and aphakic groups. The survival difference between the two groups was significant using the Mantel–Cox and Breslow tests ($P < 0.01$).

FIGURE 5. Histogram comparing the percentage of aphakic and pseudophakic eyes undergoing different numbers of membranectomies (surgical or YAG laser). The difference between the aphakic and pseudophakic eyes was significant using the Kruskal–Wallis test ($P < 0.01$).
FIGURE 6. Photomicrographs of hematoxylin and eosin stained sections through the anterior segments of pseudophakic eyes. (A) A negative impression of nasal haptic in the iris leaflet (asterisk). The trabecular meshwork (arrow) is occluded by the iris leaflet (RAG3). Original magnification X10. (B) Negative impression (asterisk) of the temporal haptic in the ciliary body from the same eye. The trabecular meshwork is also occluded and a large Soemmering's ring (SR) is pushing the iris anteriorly. Original magnification X10. (C) Soemmering's ring (SR) present in a pseudophakic eye from a monkey killed 21 months after IOL implantation. The IOL dissolved during the processing of the eye but a negative impression of one optic can be seen (arrow; RVF3). Original magnification X2. (D) The same eye at a higher magnification showing the impression of a haptic (asterisk) that had eroded through the iris into the anterior chamber. Original magnification, X10.

The Soemmering's ring in the aphakic eyes are described separately.11

Negative impressions of the lens haptics were observed in all eight pseudophakic eyes. In the seven eyes with broken IOL haptics, nine haptics had eroded into various parts of the iris leaflets, two into the ciliary body, and one through the iris to rest on the surface of the iris leaflet in the anterior chamber (Fig. 6). Only one haptic was positioned in the capsular bag and one in the ciliary sulcus. In the eye with ocular hypertension but intact haptics, one haptic was in the capsular bag and the other had eroded into the sclera. Varying degrees of fibrous tissue proliferation and foreign body giant cells were associated with the haptics.

<table>
<thead>
<tr>
<th>Monkey</th>
<th>Type of IOL</th>
<th>Time From IOL Implantation to Haptic Breakage (months)</th>
<th>Maximal Thickness of Soemmering's Ring (mm)</th>
<th>Location of Haptic Breakage(s)</th>
<th>Distance From Ciliary Sulcus (mm)</th>
<th>Location of Other Haptic</th>
<th>Distance From Ciliary Sulcus (mm)</th>
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<tr>
<td>RWF3</td>
<td>Monofocal</td>
<td>6</td>
<td>0.8</td>
<td>Both</td>
<td>Iris/iris</td>
<td>0/2.2</td>
<td>Caputal bag</td>
</tr>
<tr>
<td>REQ3</td>
<td>Multifocal</td>
<td>15</td>
<td>1.8</td>
<td>Inferior</td>
<td>Capsular bag</td>
<td>1.6</td>
<td>Ciliary body</td>
</tr>
<tr>
<td>RVF3</td>
<td>Monofocal</td>
<td>15</td>
<td>1.0</td>
<td>Nasal</td>
<td>Iris root</td>
<td>0.1</td>
<td>Anterior chamber</td>
</tr>
<tr>
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<td>24</td>
<td>1.8</td>
<td>Nasal</td>
<td>Iris</td>
<td>1.8</td>
<td>Iris</td>
</tr>
<tr>
<td>RNH3</td>
<td>Monofocal</td>
<td>27</td>
<td>2.0</td>
<td>Temporal</td>
<td>Iris</td>
<td>0</td>
<td>Iris root</td>
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<tr>
<td>RAG3</td>
<td>Monofocal</td>
<td>31</td>
<td>2.0</td>
<td>Both</td>
<td>Iris/ciliary body</td>
<td>0.4/0.8</td>
<td>Sulcus</td>
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<tr>
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<td>1.0</td>
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<td>Iris</td>
<td>2.0</td>
<td>Sulcus</td>
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</table>
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The haptics were 0 to 2.2 mm from the ciliary sulcus. The posterior segments of the eyes were histologically normal.

The pupillary membrane examined histopathologically comprised clusters of cells with spindle-shaped nuclei with bland chromatin and an extracellular matrix composed of strands of electron dense material with a 25-nm banding pattern (Fig. 7). Intracytoplasmic pigment granules were present in the cells. These cells were most consistent with iris melanocytes and the extracellular material with fibrin.

DISCUSSION

Using a nonhuman primate model, we found that implanting an IOL into a neonatal eye after a lensectomy doubled the incidence of pupillary membranes and increased the incidence of lens regeneration into the pupillary space by 500%, but did not affect the incidence of ocular hypertension. In addition, one or both haptics broke in seven of the pseudophakic eyes resulting in dislocation of the IOLs in these eyes. Visually significant pupillary membranes developed in 100% of the pseudophakic eyes, but only in 55% of the aphakic eyes. The one pupillary membrane studied histopathologically consisted of fibrin intermixed with probable iris melanocytes. More pupillary membranes may have developed in the pseudophakic than the aphakic eyes because: (1) the IOLs provided a scaffolding to which the fibrin could adhere; (2) more manipulation of the iris was required in the pseudophakic eyes; and (3) the presence of an IOL in the pseudophakic eye may have incited an ongoing inflammatory response. Adding heparin to the infusion solution reduced the severity but not the incidence of this complication.11 A YAG laser was found to be an effective means of opening these membranes; however, a mean of 2.6 sessions was needed to open each pupillary membrane. Multiple sessions were required to open these membranes both because an attempt was made to limit the amount of energy used per session as well as the difficulty of accurately focusing the laser after freeing inflammatory debris from the membranes into the anterior chamber. While these membranes could be opened surgically, this exposed these eyes to all of the risks associated with an intraocular procedure. Pupillary membranes have been reported to occur in 11 to 12%12-15 of children who undergo lensectomies and 13%13 of children who undergo IOL implantation. The lower incidence of this complication in children than infantile Rhesus monkeys is likely due to two factors: first, the younger age of the monkeys at the time of surgery; and second, the more pronounced inflammatory response of a nonhuman primate to surgery.14-18 The monkeys in our study ranged from 0 to 16 days of age whereas
the mean age of the children in the series reported by Keech and coworkers\textsuperscript{12} was 18 weeks and the youngest patient in the study by Hiles\textsuperscript{7} was 4 months of age. Keech et al\textsuperscript{12} noted a higher incidence of complications in children who underwent a lensectomy during the first 2 months of life (30\%) compared to children who underwent a lensectomy when 2 to 12 months of age (10\%). We even found a higher incidence of pupillary membranes in monkeys undergoing a lensectomy during the first compared to the second week of life. The higher incidence of pupillary membrane in the pseudophakic eyes is particularly noteworthy because these animals were on average 9.1 days older than the animals undergoing lensectomies only.

The intracameral injection of tPA was ineffective in lysing the pupillary membranes in the four eyes in which it was tried, despite the fact that similar doses have been reported to be effective in lysing intraocular fibrin in human eyes.\textsuperscript{16-19} While tPA has been reported to be an effective treatment for intraocular fibrin in several studies using a rabbit model,\textsuperscript{20-21} Ryan and Mizener\textsuperscript{22} reported only a transient decrease in intraocular fibrin in rabbit eyes after two injections of 12.5 \( \mu \)g of tPA. We may have been more successful in lysing the fibrin in these pupillary membranes with larger doses of tPA, but chose to limit the dose to 9 \( \mu \)g after a hyphema developed in one eye. Dabbs et al\textsuperscript{23} also reported intraocular bleeding as a common complication after the intracameral injection of tPA.

Lens regeneration into the pupillary space occurred in 28.6\% of the pseudophakic eyes but only 5.6\% of the aphakic eyes. Lens regeneration is known to arise from epithelial cells migrating from the anterior lens capsule to the equatorial bow region.\textsuperscript{24} All of the pseudophakic eyes studied histopathologically had a Soemmerring's ring, but only 29\% of the pseudophakic eyes had lens regeneration extending into the pupillary space. A Soemmerring's ring forms when the anterior capsular flap adheres to the posterior lens capsule creating a doughnut-shaped sac, which becomes filled with newly formed cortical fibers and metaphastic lens epithelial cells.\textsuperscript{25} The circumferential fusion of the posterior and anterior lens capsule is believed to act as a barrier to the migration of cortical fibers and epithelial cells into the pupillary space. Wasserman and coworkers\textsuperscript{26} observed radial tears in the anterior capsule of 86\% of postmortem eyes that had undergone can opener anterior capsulectomies during cataract surgery. Because all of the pseudophakic monkeys received can opener anterior capsulectomies, it is likely that a high percentage of these eyes had radial tears of the anterior lens capsule. These tears may have acted as a conduit for the regenerating lens material to migrate into the pupillary space. The frequency of this complication may have been reduced if the anterior capsulectomies would have been performed using a continuous curvilinear capsulorhexis technique. Lens regeneration into the pupillary space may have occurred less often in the aphakic eyes because the capsulectomies were performed using a vitreous cutting instrument, which would be less likely to produce radial tears, and more of the anterior lens capsule was removed in these eyes, which would reduce the number of residual lens epithelial cells available to generate new lens fibers. While lens regeneration into the pupillary space has been reported to occur in human infants after a lensectomy, its incidence is unknown.\textsuperscript{27}

The incidence of ocular hypertension was comparable between the aphakic and the pseudophakic eyes. The incidence of 9.5\% in the pseudophakic eyes and 12.7\% in the aphakic eyes is similar to the 6 to 11\% incidence of glaucoma that has been reported to occur in children who undergo a lensectomy.\textsuperscript{12,28} However, with a longer follow-up period, more of these eyes may have developed ocular hypertension. None of the fellow eyes developed ocular hypertension. Optic disc cupping was not observed in any of the monkeys with ocular hypertension but in all cases they were either killed shortly after it developed or they were treated with topical medications to lower it. In the one eye with ocular hypertension that was studied histopathologically, the trabecular meshwork was completely occluded by the iris leaflets. Lesser degrees of occlusion of the trabecular meshwork were observed in all of the other pseudophakic eyes studied histopathologically. Oclusion of the trabecular meshwork may have occurred secondary to postoperative inflammation or forward movement of the iris by the Soemmerring's ring.

One of the most serious complications that developed in seven of the pseudophakic eyes was breakage of one or both haptics. All of the eyes with broken haptics had pupillary capture and the IOL optics had been pushed forward into the anterior chamber. It is likely that the IOLs broke at the optic–haptic junction because of the stress they experienced as the optics were pushed forward into the pupillary space while the forward movement of the haptics was limited by the iris. In the seven eyes with broken haptics, ten haptics had been pushed forward, (nine into the iris and one into the anterior chamber), two had eroded horizontally into the ciliary body, one was in the ciliary sulcus, and one was still positioned in the capsular bag. In the eye studied histopathologically that did not have broken haptics, one haptic was still in the capsular bag, while the other had eroded horizontally into the sclera. An attempt was made at the time of surgery to place both haptics into the capsular bag, but this may not have occurred in all instances. In other instances, the haptics may have migrated out of the bag after having been positioned there at the time.
of surgery. It is unclear why some haptics migrated anteriorly while others migrated horizontally. While it is likely that the Soemmering's ring contributed to anterior migration of the lens haptics, in one eye studied histopathologically without haptic breakage, the maximal thickness of the Soemmerring's ring (1 mm) was similar to that in the eyes with broken haptics (0.8 to 2 mm). It is likely that haptic breakage could have been prevented by using an IOL with more flexible haptics. Alternatively, more accurate capsular bag placement after a continuous curvilinear capsulorhexis may have reduced the incidence of this complication. We are unaware of reports of haptic breakage after IOL implantation in children.

Intraocular lens implantation has been studied using an adult, but not a neonatal monkey model. Spångberg and coworkers14 implanted polymethylmethacrylate IOLs in 32 adult cynomolgus monkeys and noted a fibrinous reaction in the anterior chamber during the immediate postoperative period. One month later the fibrin had completely cleared from all but a few eyes. In the few eyes with residual fibrin, the fibrin had organized into single strands. Twenty-three of these monkeys were followed up for 1 year. After 1 year, the only complications noted were posterior synechiae in 25% of the eyes with heparin surface-modified IOLs and 75% of the eyes with non-surface-modified IOLs, pigmented precipitates on the lens optics of 5% of the eyes with heparin surfaced-modified IOLs and 50% of the eyes with non-surface-modified IOLs, and posterior capsular opacification in an unspecified number of eyes. Fagerholm and coworkers15 noted similar results after performing bilateral posterior chamber IOL implantation in eight adult cynomolgus monkeys. The more exaggerated inflammatory response that occurred in these adult monkey eyes compared to adult human eyes after IOL implantation may represent a species difference, or may reflect that none of these monkeys received topical corticosteroids postoperatively. We also observed a fibrinous reaction in the anterior chamber of neonatal monkey eyes after implanting IOLs using a similar surgical technique; however, unlike what has been reported with adult monkeys, the fibrin did not clear spontaneously in any of these eyes.

We conclude that IOL implantation in nonhuman primate eyes during infancy is associated with a higher complication rate than lensectomy alone. Several of these complications may be preventable by using a different surgical technique and a different type of IOL, but it is not clear if the potential visual benefits warrant the increased risks. We are currently in the process of assessing the visual outcome in these monkeys so the risk–benefit ratio can be more carefully evaluated.20

Key Words

lens regeneration, pupillary membrane, Soemmering's ring, pseudophakia, aphakia, intraocular lens

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