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MYOPIC AND HYPEROPIC HYDROGEL KERATOPHAKIA

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KEY WORDS

Alloplastic implants, astigmatism, cornea, hidrogel keratophakia, keratophakia, lamellar corneal surgery, myopia, refractive surgery.

ABSTRACT

Hidrogel keratophakia is an experimental form of refractive corneal surgery. In this preliminary study, significant myopic and hyperopic corrections were obtained in a non-human primate model. This technique is technically much simpler than previous forms of lamellar refractive surgery in which corneal lathing is required. In addition, a limitless supply of plastic lens material obviates the need for corneal donor tissue and quality controlled production of plastic lens material is possible in contrast to the production lathed corneal tissue. The surgical correction of almost any form of refractive error is feasible with this technique.

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INTRODUCTION

For several decades researchers and clinicians have experimented with a host of surgical techniques to permanently change the refractive power of the eye. Most surgeons have attempted to modify the anterior corneal curvature. The pioneering work of José Barraquer[1] forms the basis for all current approaches to lamellar refractive surgery. The approach of Barraquer, however, has had several drawbacks. The procedures he developed were technically complex; the visual recovery period was prolonged; the accuracy of correction is in the hand of many surgeons less than desirable; and donor tissue is required form some of these procedures.

In an attempt to overcome these problems, Werblin[2,5] developed a procedures called epikeratophakia. This modification of Barraquer's classical approach simplified the surgical technique, but still presented problems in the area of predictability of the optical correction, visual recovery, and the need for donor tissue. More recently research interest had been directed towards the use of higher water content hydrogels [6,10]. The stability and biological compatibility of these materials used in refractive surgery has been demostrated by several investigators [11,13]. In this paper work will be presented which demonstrates the feasibility of both myopic and hyperopic corrections utilizing high water content hydrogels. Several types of materials and desings have been used and complications resultant from poor lens design will be demostrated. This work does not analyze the critical area of predictability. It does, however, present preliminary data which will form the basis for further large scale experiments to study this critical problem.

MATERIAL AND METHODS

Surgery was performed on Macacus fasicularis and rhesus females (4.5-6.0 kg) under general anesthesia. Either freehand or microkeratome corneal sections were performed. The previously described modified Barraquer microkeratome enabled a precise anterior keratectomy[9]. Hydrogel implants were placed at 50% corneal depth and the wound closed with a single continuous 10-0 nylon suture which was removed after one to two weeks. A temporary tarsorrhaphy protected the cornea for one week postoperatively. One-half cc of gentamicin sulfate (80 mg / ml) and one-half cc of methyl prednisolone acetate suspension (80 mg / ml) were injected beneath the conjunctiva. In general, no other postoperative medications were given.

Hydrogel lenses* from several manufacturers were used in this study. All were of 70% or greater water content. These lenses measured 4.0 mm to 5.5 mm in diameter. A "thin" peripheral edge finish was requested from the manufacturer, however, this edge design varied tremendously depending on source. Extreme care was necessary in handling the lens material to prevent tearing or notching of the soft hydrogel.

The Haag-Streit 900 slit lamp was used for examination and pachometry measurements. The AO CLC ophthalmometer was used for keratometry with a +1.75 diopter lens to "extend" the scale of measurement. A Nikon FG camera with Haag-Streit adapter (Technical Enterprises, Gainesville, Florida) and a Zeiss photo slit lamp were used for photographic documentation.

RESULTS

Stable hyperopic corrections were obtained in eleven non-human primates, ranging between 4.7 diopters and 14.0 diopters (Table I). Fluctuations in corneal curvature noted for each animal on sequential observations are due primarily to variability in repeated instrument readings which are greater in the primate eye

TABLE I

HYPEROPIC LENS CORRECTIONS

Animal No.	Lens material	Time postoperatively					
		Pre-op	1 Mo	2 Mo	6 Mo	10-13 Mo	Δ
707 OD	Wisconsin***	54.7*	63.3	59.9	61.0	59.8	+ 5.1
694 OD	Wisconsin	56.0	58.7	59.0	61.4	**	+ 5.4
701 OD	Wisconsin	55.2	ND	70.8	66.6	68.3	+ 13.1
681 OD	Permalens	52.0	64.1	62.5	62.3	61.7	+ 9.7
769 OD	Sauflon	53.6	58.7	63.1	56.9	58.3	+ 4.7
697 OS	Wisconsin	54.8	71.8	70.8	72.6	68.8	14.0
425 OS	Sauflon	47.9	56.4	59.5	60.0	58.5	+ 10.6
353 OD	Wisconsin	57.2	62.9	63.5	63.0	ND	+ 5.8
346 OS	Florida***	58.7	67.3	69.4	69.7	ND	+ 11.0
348 OS	Florida	56.0	64.1	65.3	64.3	ND	+ 8.3
353 OS	Florida	59.0	63.4	64.3	ND	ND	+ 5.3

* Keratometric readings in diopters
** Cornea recovered for histopathology
*** Proprietary
ND-Not determined

* Several of the lens materials are proprietary in nature.

than seen clinically, because of a lack of fixation capability and a smaller critical optical surface. Nevertheless, no trend is seen during the year's observation period for either progressive increase or decrease in corneal curvature. The stability of these lenses within the stroma is demonstrated in (Table 2). The anterior and posterior corneal lamellae remained of constant thickness during the observation period. Again, fluctuations in monthly measurements were due to variability in reading with optical pachometry and do not indicate a trend to either progressive thinning or thickening of the anterior lamellae, posterior lamellae, or lens itself.

TABLE 2
HYPEROPIC LENS STABILITY

Animal No.	Pre OP	1 Mo	2 Mo	6 Mo	10-13 Mo
707 OD	ND	0.20* / 0.38** / 0.15***	0.23 / 0.41 / 0.10	0.23 / 0.39 / 0.13	0.23 / 0.43 / 0.09
694 OD	ND	0.26 / 0.30 / 0.13	0.23 / 0.24 / 0.22	0.23 / 0.30 / 0.17	+
701 OD	ND	0.28 / 0.13 / 0.26	0.18 / 0.32 / 0.21	0.20 / 0.29 / 0.28	0.18 / 0.27 / 0.22
681 OD	ND	0.23 / 0.24 / 0.16	0.24 / 0.24 / 0.15	0.24 / 0.22 / 0.15	0.26 / 0.26 / 0.15
769 OD	ND	0.27 / 0.24 / 0.22	0.26 / 0.26 / 0.08	0.30 / 0.16 / 0.07	0.30 / 0.16 / 0.12
697 OS	ND	0.25 / 0.29 / 0.17	0.32 / 0.32 / 0.16	0.28 / 0.29 / 0.14	0.24 / 0.31 / 0.12
425 OS	ND	0.30 / 0.20 / 0.15	0.30 / 0.20 / 0.18	0.27 / 0.21 / 0.17	0.30 / 0.18 / 0.12
353 OD	.36	0.16 / 0.42 / 0.17	0.20 / 0.39 / 0.20	0.21 / 0.43 / 0.09	ND
346 OS	.39	0.27 / 0.16 / 0.11	0.24 / 0.14 / 0.12	0.21 / 0.23 / 0.07	ND
348 OS	.39	0.23 / 0.13 / 0.19	0.22 / 0.12 / 0.18	0.22 / 0.20 / 0 / 16	ND
353 OS	.39	0.20 / 0.10 / 0.22	0.23 / 0.08 / 0.25	ND	ND

* Thickness in mm of anterior corneal lamellae overlying implant
** Thickness in mm of alloplastic implant
*** Thickness in mm of posterior corneal lamellae beneath implant
\+ Cornea recovered for histopathology
ND-Not determined

Many of the lens materials used were unique in design. However, two series of lens were from a single manufacture (Table 3). The "Wisconsin" lenses were quite thick centrally (Table 2). The "Florida" lenses were, in general, more uniform and were thin centrally (Table 2) with very thin edges. Because of the variability in lens design and because the curvature of the anterior and posterior lens surface was not verified preoperatively it is difficult to critically evaluate the relationship between lens power and change in corneal curvature (Table 3). However, with two exceptions (707 and 353) in general, there was a reasonable relationship between predicted lens power and observed changes in anterior corneal curvature.

TABLE 3
HYPEROPIC LENS

Animal No.	Predicted No.*	Obtained No.	Lens material**
697 OS	+ 19.2	+ 14.0	Wisconsin
701 OD	+ 16.9	+ 13.3	Wisconsin
707 OD	+ 16.5	+ 5.1	Wisconsin
353 OD	+ 7.9	+ 5.8	Wisconsin
694 OD	+ 4.7	+ 5.4	Wisconsin
346 OS	+ 17.5	+ 11.0	Florida
353 OS	+ 10.0	+ 5.3	Florida
348 OS	+ 7.75	+ 8.3	Florida

* Anterior lens curvature plus posterior lens curvature in diopters

** Proprietary

Only two myopic lenses were available for implantation (Table 4). Both significantly flattened the anterior corneal curvature of the primate eye. The position of these lenses in the corneal stroma was constant (Table 4) and the corneas looked remarkably clear throughout the observation period. The lenses were so thin centrally that no accuate pachometry measurement of central lens thickness could be made.

TABLE 4
MYOPIC LENS CORRECTIONS

Animal No.	Lens Material	Pre OP	1 Mo	2 Mo	8 Mo	Δ
337 OS	Florida	61.0*	53.4	52.1	**	8.9
347 OS	Florida	58.2	54.8	54.8	55.0	3.2

Animal	Pre Op	1 Mo	2 Mo	8 Mo
337 OS	0.45	0.22+ 0.25++	0.20 0.25	**
347 OS	0.41	0.20 0.24	0.23 0.22	ND

* Diopters

** Used for histopathology

\+ Thickness of anterior corneal lamellae in mm

++ Thickness of posterior corneal lamellae in mm

ND-Not determined

There was little change in corneal astigmatism as a result of the surgical procedure (Table 5). The freehand corneal dissection resulted in a larger increase

in astigmatism (1.3 diopters) than the microkeratome cuts (0.7 diopters); however, the number of animals is too small to draw any specific conclusion. One lens (353-OD) with poor edge design was complicated by progressive thinning and eventual extrusion of the implant. Large amounts of astigmatism were noted in this eye and the data were not included in this comparison. Two animals (425 and 701) had an irregular corneal surface secondary to scarring. It appeared that this was caused by a reaction to the suture material or lens material early in the observation period. Because of difficulities in judging astigmatism in these two animals, these data were also excluded.

TABLE 5

ASTIGMATISM AFTER INTRASTROMAL IMPLANT
FREEHAND RESSECTION-HYPEROPIC LENS

Animal No.	Pre Op	Δ	Pos Op	Δ
707 OD	54.7 x 53.1**	1.6	59.0 x 60.8	1.8
694 OD	55.8 x 54.8	1.0	59.5 x 63.0	3.5
701 OD	55.6 x 53.9	1.7	69.7 x 67.0*	2.7*
681 OD	51.5 x 50.6	0.9	60.0 x 62.5	2.5
769 OD	52.7 x 52.2	0.5	57.0 x 59.5	2.5
		Av 1.0 (4)		Av 2.3 (4)

MICROKERATOME SECTION-HYPEROPIC LENS

* Animal No.	Pre Op	Δ	Pos Op	Δ
697 OS	54.9 x 55.3	0.4	67.8 x 70.0	2.2
425 OS	49.9 x 49.9	0.0*	60.6 x 56.8*	3.8*
353 OD	57.8 x 56.5	1.3**	67.8 x 58.3**	9.5**
346 OS	59.0 x 58.3	0.7	67.8 x 72.0	4.2
348 OS	56.5 x 55.5	1.0	63.0 x 65.3	2.3
353 OS	60.0 x 57.2	2.8	62.0 x 65.3	3.3
			59.0 x 58.3	0.7*

MICROKERATOME SECTION-MYOPIC LENS

Animal No.	Pre Op	Δ	Pos Op	Δ
337 OS	60.0 x 62.0	2.0	52.8 x 51.5	1.3
347 OS	57.8 x 58.7	0.9	55.0 x 55.0	0.0
		AV 1.3 (6)		

* Scar on corneal surface

** Lens extruded over 10 months

+ Second surgical procedure performed to exchange lens

++ Keratometry readings in diopters

Av-Average

()-Number of observations

One of the major difficulties in evaluating the predictability of hydrogel keratophakia has been the lack of consistency in design of supplied lens materials. Ideally, the peripheral lens design should allow for a very smooth, thin edge as shown in figure 1. However, as can be seen in figure 2, when a very bulky lens with thick edges was implanted, progressive extruction of the lens material was noted, a process which in this instance took ten months. Clinically, the corneal stroma over the lower edge of the lens demonstrated progressive thinning. In time, an epithelial defect appeared, and eventual total dissolution occurred in that area. At no time was the eye inflammed during these events.

Another complication is demonstrated in figure 3. Inadvertantly, at the time of surgery, a lint-like foreign body was inserted with the hydrogel lens and caused a considerable amount of local stromal reaction. This area of corneal infiltrate eventually progressed to ulceration of the anterior corneal cap (Figure 3). Interestingly, again, no conjunctival or limbal reaction was seen at anytime during this process, which took approximately five months. After removal of the lens, the cornea healed without difficulty. A small irregular central scar resulted.

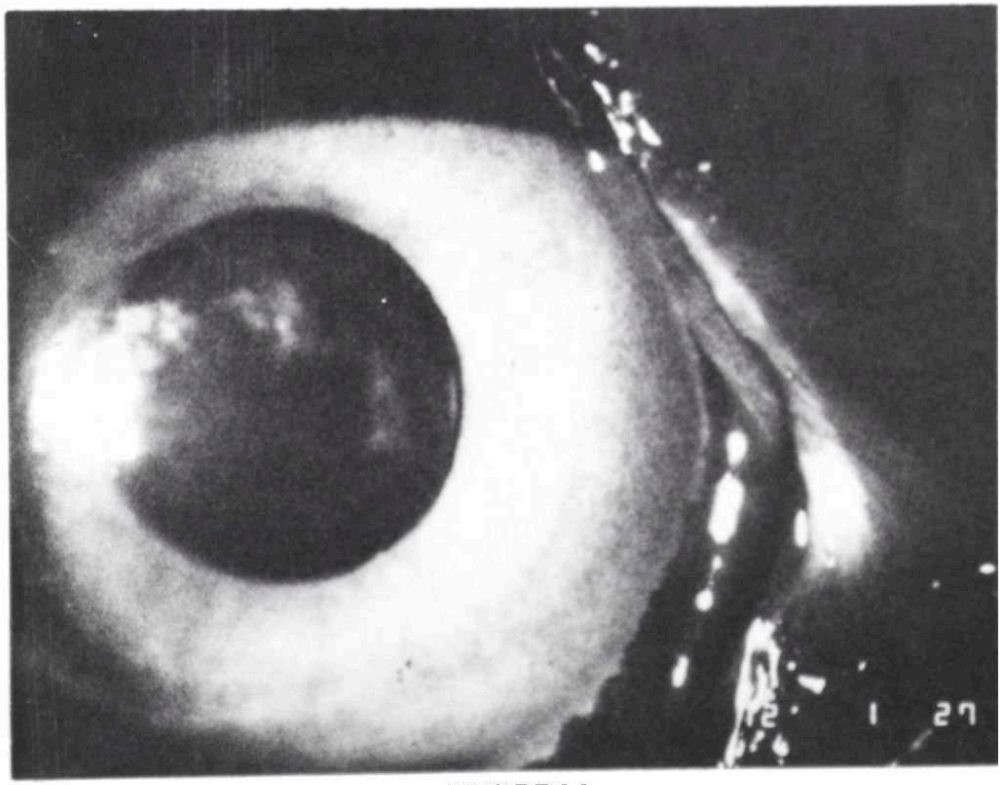

FIGURE 1A

Diffuse illumination of hydrogel implant six months post-operatively. The cornea is clear with no significant reaction to the lens material.

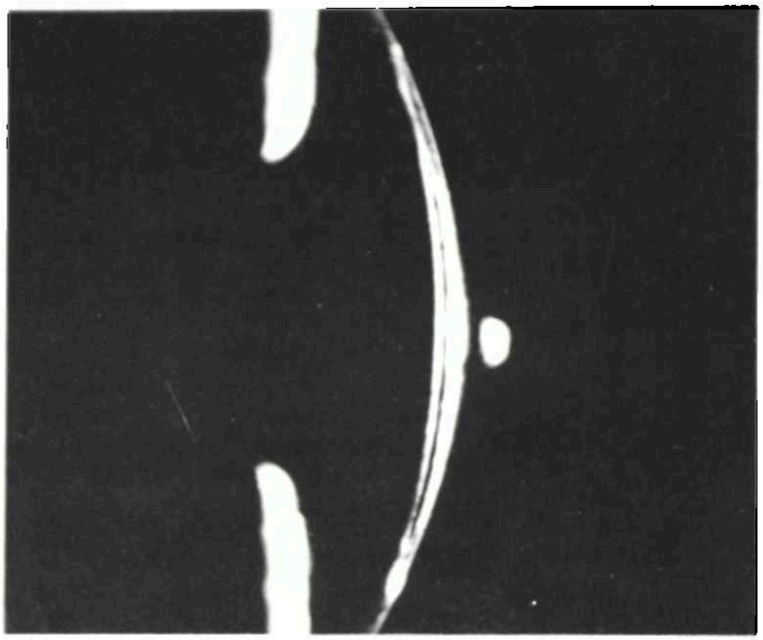

FIGURE 1B

Slit beam examination. The lens appears as an optically void area midway within the cornea. The lens is quite thin with fine tapered edges.

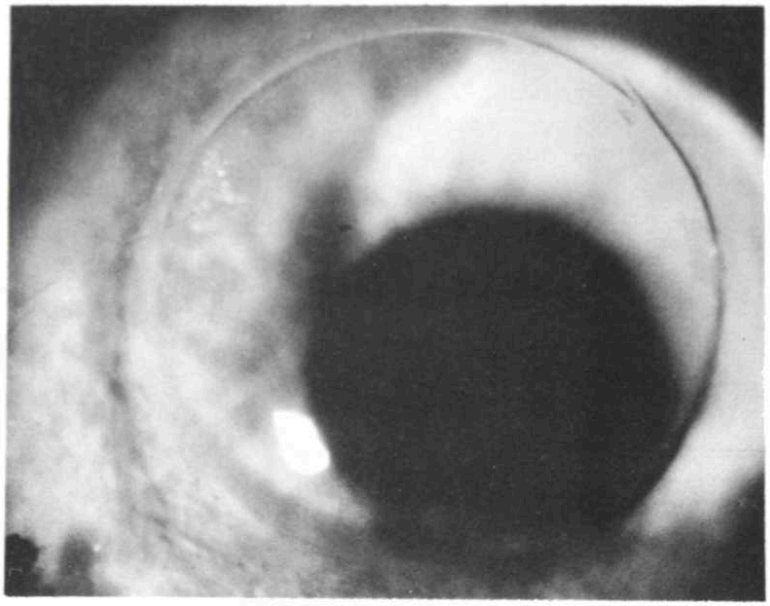

FIGURE 2A

Diffuse illumination of hydrogel implant five months postoperatively. Note the debris collected at edge of the implanted lens.

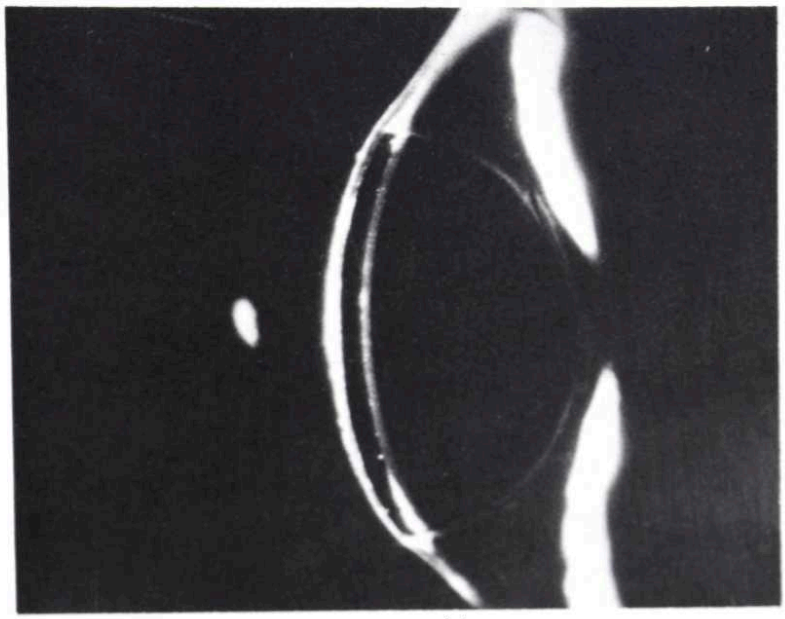

FIGURE 2B

Slit beam examination demonstrating extremely bulky lens with sharp thick edges.

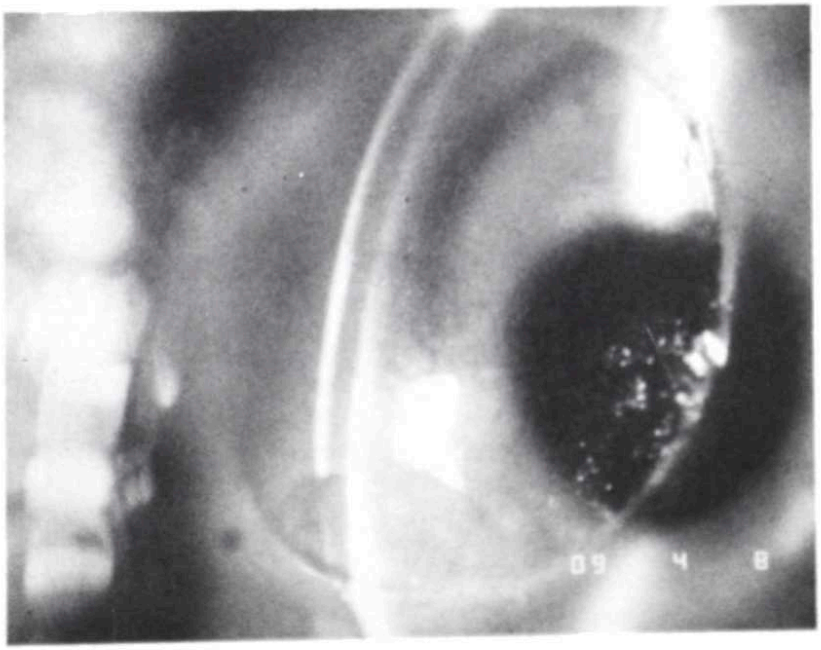

FIGURE 2C

Ten months postoperatively. The lower edge of the lens eroded through the anterior corneal cap. No reaction is seen about this area of erosion.

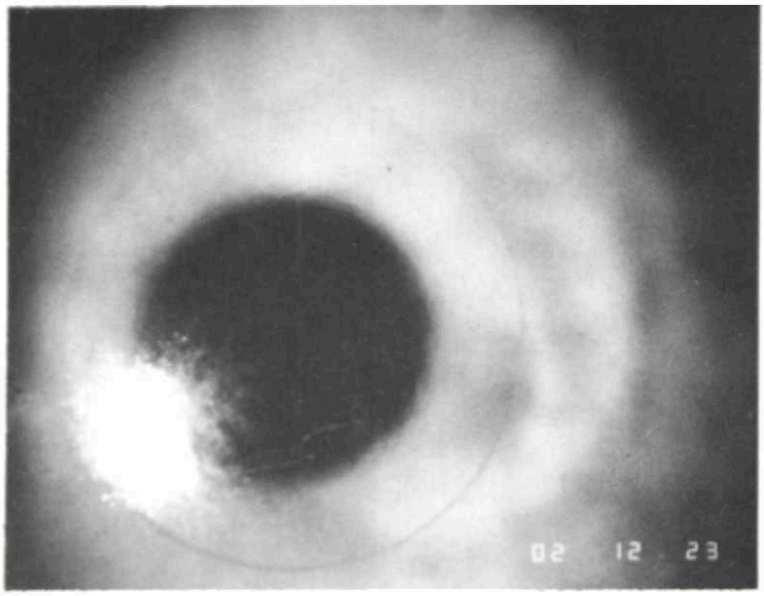

FIGURE 3A

Hydrogel implant in place in a non-human primate cornea. Note the thread-like particle of debris at the lower papillary border. Considerable reaction in the area of this foreign body caused eventual necrosis of the anterior corneal cap.

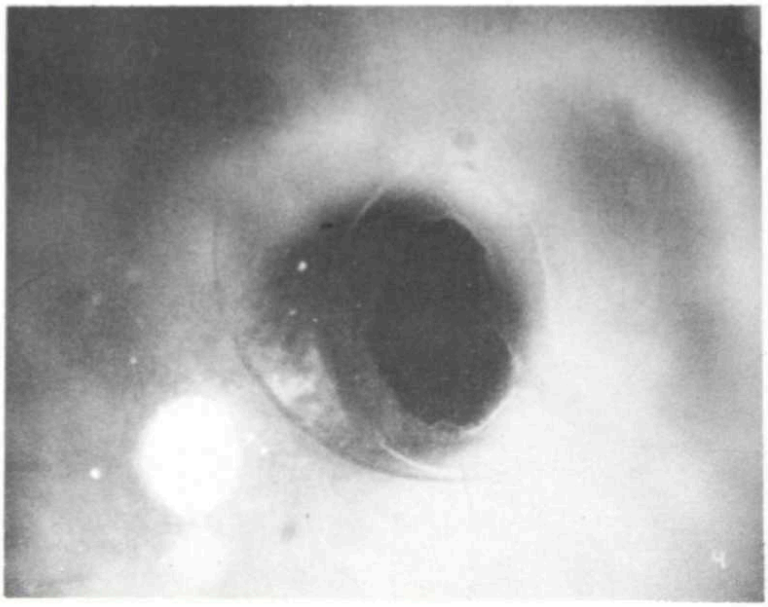

FIGURE 3B

Area of dissolution of the anterior corneal cap. overlying the implant decribed above. There was no peripheral vascular reaction to this process of progressive ulceration.

DISCUSSION

Hydrogel kertophakia is a new form of surgery which may resolve many of the difficulties inherent in earlier attempts at refractive surgery. Certainly, from the technical point of view it is far simpler than all of the procedures involving lathed corneal tissue. Obviously, the supply of materials would be not problem with alloplastic lenses. The ability to control the accuracy of the lens design supplied by manufacturers, is again far greater in the case of synthetic lens materials. It is clear from the data presented in this paper that both hyperopic and myopic corrections are feasible utilizing this surgical procedure. The consistency of the experimental results were, however, hampered by the fact that several different materials supplied by different manufacturers were utilized. It is obvious that the quality control of these particular lens materials was inadequate. As manufacturers become more accustomed to producing lenses for refractive surgery, this problem should be overcome.

The question of optical predictability, however, may be somewhat more complex with hydrogel implants than with other materials. Hydrogels are very flexible and conform to a corneal surface quite readily. Thus, the shape of the lens may be partially dependent on the shape of the corneal bed and not totally a function of the lens design. Also, the shape of the hydrogel lens is partially dependent on the local hydrostatic environment; the higher the water content of the lens, the more the intrastromal hydrostatic pressure will influence the lens configuration[14]. Thus, it is possible that there will never be a direct relationship between *in vitro* hydrogel lens design and *in vivo* lens configuration. However, it is probable that, given a high degree of accuracy of lens production, an empirical relationship between lens design and corneal configuration will be established.

The surgical technique of hydrogel keratophakia does not introduce a large amount of astigmatism. This has also been observed with previous forms of lamellar refractive surgery. The variability within the keratometry measurement as well as the difficulty in finding the small affected corneal of the non-human primate eye surface, contribute to the fluctuations seen in successive keratometric readings. However, given these difficulties, it is reassuring to find that significant iatrogenic astigmatic errors are avoided. Only larger studies will verify this clinical impression.

Synthetic materials used in hydrogel keratophakia can be produced with greater reliability than lathed corneal lenses used in other forms of refractive corneal surgery. Hydrogel lenses can be manufactured to precise tolerances and their power and optical qualities verified objetively prior to clinical use. This is in

marked contrast to lathed corneal lenses whose configuration is totally dependent upon an *in vivo* healing processes which occur weeks to months postoperatively. Thus, at the time of surgery there can be no objective evaluation of the power or configuration of these "biological" lenses.

It appears critical that lens design and quality control of lens production be carefully monitored. In this limited study, the desired lens configuration was characterized extremely thin, smooth edges. The progresive extrusion of the poorly designed, thick lens described above, demostrates that this configuration is undesirable. Lenses made of the identical material but with better lens design characteristics did not undergo this process of extrusion (Table I-707 OD, 694 OD, 701 OD, 697 OD, 353 OD). In general, it would appear that a lens thin both centrally and peripherally is the preferable configuration.

Foreign material introduced at the time of surgery can cause numerous refractile bodies at the lens-stromal interface. The optical consequences of this are open to conjecture. However, these materials can also be reactive and this reaction within the cornea can cause destruction of the corneal lamellae as demonstrated above. At the time of surgery, it can be difficult to identify all of these foreign materials. Thus, care must be exercised during this procedure to avoid this potentially serious complication. Considerations of laminar flow and/or careful aspiration/suctioning procedures with filtered irrigating solutions may be necessary.

This preliminary study demonstrates that myopic and hyperopic corrections are feasible with hydrogel corneal implants. The field of refractive surgery would be revolutionized by a technically simple form of surgery whose refractive outcome can be accurately predicted. To date, no surgical technique approaches this goal. For hydrogel keratophakia, only extensive preclinical testing in a controlled, experimental environment can generate the necessary data to answer this critical issue.

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