The phacoemulsification procedure. III.
Corneal complications

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Persistent corneal edema is one of the complications of phacoemulsification. Five patients underwent this procedure 6 to 8 months before keratoplasty was performed. In addition to bullous keratopathy, two corneas had corneal scarring due to probe overheating or corneal vascularization of the anterior chamber. Electron microscopy of corneal specimens showed that four cases had Fuchs’ dystrophy without warts and one had guttata. Endothelial cell destruction varied from lesions of small size (15 to 50 μ) to large abrasions. Cases with severe edema and vitreous adhesion showed retrocorneal membrane formation. Surgical trauma seemed to have precipitated decompensation of these dystrophic corneas.

In recent years, the surgery of cataracts has been drastically modified by the introduction of the phacoemulsification procedure. When initially described by Kelman,1 strict guidelines for its use, limitations, and contraindications were given. The generalized use of this procedure in the last few years and the appearance of less sophisticated instruments with similarly powered drive have raised the question of safety to the corneal endothelium and structures of the anterior segment of the eye. At least four potential problems can be identified with all these instruments: the heat generated by the ultrasonic tip, the effect of the irrigating solutions, the effect of the ultrasonic vibration, and the mechanical trauma to the corneal endothelium by instruments or lens nucleus. Temperature changes during the phacoemulsification procedure with the Cavitron-Kelman instrument were studied by Benolken and associates in 1974.2 They determined that as long as fluid was running through the ultrasonic needle, no adverse temperature changes should develop to affect the corneal tissue. Normal animal corneas studied after various stages of the phacoemulsification procedure with the Cavitron-Kelman unit3,4 showed that although irrigation and ultrasound could induce minimal and reversible corneal endothelial changes, the mechanical injury by the instruments introduced into the anterior chamber or manipulation of hard lens nucleus could induce severe cell or Descemet’s membrane changes. In healthy animal corneas, these changes recovered in 2 to 5 days following the procedure.4
Table I

<table>
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<th>Case</th>
<th>Description</th>
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<td>1, A. Ch. (65)</td>
<td>Bilateral phacoemulsification followed by corneal edema O.U. One year later, V.A. (O.D.) was 20/80 with soft contact lens. O.S. severe bullous keratopathy and glaucoma with stromal scarring in area of probe insertion. Anterior iris synechiae, lens remnant, and vitreous in anterior chamber (Fig. 1). V.A. (O.S.): hand motion. Following cyclocryotherapy, 7.5 mm. penetrating keratoplasty.</td>
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<td>2, J. W. (62)</td>
<td>Bullous keratopathy O.D. following phacoemulsification. Edema persisted 8 months later (Fig. 2, A). V.A.: finger counting. 7.5 mm. penetrating keratoplasty. Graft clear. No vitreous in A.C.</td>
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<td>3, N. G. (66)</td>
<td>Progressive corneal edema 6 months after phacoemulsification O.D. (Fig. 4, A). V.A.: hand motion. Mild glaucoma. 7.5 mm. penetrating keratoplasty. Graft clear, on antiglaucoma therapy. No vitreous in A.C.</td>
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<td>4, P. S. (59)</td>
<td>Corneal edema O.D. with stromal thickening and some folds in Descemet's membrane 8 months after phacoemulsification. Vitreous in A.C. IOP 28 mm. Hg. (O.S. clear cornea, with thickness of 0.57 mm., normal anterior chamber depth, and moderately advanced senile cataract.) 17.5 mm. penetrating keratoplasty O.D.</td>
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<td>5, R. P. (64)</td>
<td>Phacoemulsification O.S., July, 1975, followed by bullous keratopathy (Fig. 6, A). V.A.: poor hand motion. Thickened opaque cornea with anterior synechiae and scattered stroma. Organized material in pupillary area. IOP 14 mm. Hg. Suspicion of detached retina not confirmed by B-scan. ERG present, but subnormal. 7.5 mm. penetrating keratoplasty O.S. Organized vitreous in A.C., adherent to cornea. Retinal detachment was present.</td>
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O.U., both eyes; O.D., right eye; O.S., left eye; V.A., visual acuity; A.C., anterior chamber; IOP, intraocular pressure; ERG, electroretinogram.

Fig. 1. Appearance of the cornea of Patient 1. Bullous keratopathy, corneal scarring at 9 and 1 o'clock with stromal vascularization. Anterior synechiae and organized vitreous in anterior chamber.

The five cases here reported and studied from the histopathological point of view were patients referred for penetrating keratoplasty because of persistent corneal edema 6 months or more following phacoemulsification (Table I). The ultramicroscopic changes resembled those observed experimentally in rabbit and cat corneas, however, every cornea studied had evidence of Fuchs' endothelial dystrophy, with and without warts in Descemet's membrane.

Methods

Penetrating keratoplasties were 7.5 mm. in diameter. The excised corneal buttons were immediately fixed in cold 4 per cent glutaraldehyde for 24 to 48 hours. One third of the button was removed for transmission electron microscopy (TEM) or thin light microscopy sections. Tissues were then fixed in 1 per cent osmium tetroxide after distilled water rinse. Samples for scanning electron microscopy (SEM) were dehydrated in graded series of alcohol, and dried in a Bomar critical point apparatus. Specimens for TEM were also dehydrated in graded alcohols and embedded in Epon. Those sections were examined in a Zeiss EM9S microscope. Samples for SEM were examined in a Stereo-scan (Cambridge, England) microscope or in a Zeiss EM1 scanning microscope at 10 or 20 kv. Pictures were recorded on Polaroid P/N film.

Results

Light microscopy of 1 μ thick sections of plastic-embedded specimens showed abnormalities in Descemet's membrane of all five cases studied.

Case 1 showed moderately thick Descemet's membrane covered with single or multiple layers of fibroblast-looking, or flat endothelial cells. SEM showed large, abnormal endothelial cells with stretched junctions or forming a membrane two or more cells thick. Descemet's membrane in
some areas was devoid of cells or partially covered by fibroplastic or atrophic cells.

In Case 2, there were multiple areas of cell destruction measuring 20 to 80 μ, surrounded by cells of large size or with cytoplasmic filaments extending over bare Descemet's membrane (Fig. 2, b). There were areas of individual cell destruction, as well as large abrasions without Descemet's rupture (Fig. 2, c and d). Cytoplasmic cell expansions and filaments along the injury border suggested that the lesion was not a recent artifact. Descemet's membrane was thicker than normal, with a wavy surface covered by collagen fibrils and clumps of fibers of large spacing collagen (Fig. 3). Occasional lymphocytes were found between reduplicated endothelial cells.

Case 3 also had a Descemet's layer of abnormal thickness with multiple lacunae and a layer of fine and dense collagen fibrils between it and thin, single, or reduplicated endothelium. In other areas there were endothelial cell remnants or total absence of cells. SEM revealed multiple areas of endothelial degeneration or absence, which varied in size from 2 to 3 cells (Fig. 4, b) to a diameter of 40 to 50 μ. Occasional warts were observed under absent endothelium (Fig. 4, c). Areas of degeneration or destruction were covered by cell remnants (Fig. 4, d). Altered cell morphology suggested attempts to repair the injury.

Case 4 showed multiple scattered lesions which varied in size from a few to many cells (Fig. 5, a). They appeared as pockmarks under the low-power SEM; at higher

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**Fig. 2.** Case 2. a, Diffuse corneal edema, more pronounced in inferior nasal quadrant. b, Area of endothelial cell destruction comprising two or more cells. Adjacent endothelial cells vary in size from 9 to 30 μ. (SEM, ×200.) c, Another area of corneal button showing extensive loss of endothelium without rupture of Descemet's membrane (Des). Cell debris and large endothelial surround areas of damage. (SEM, ×200.) d, Endothelial cells at the edge of the injury are very thin and show cytoplasmic prolongation or filaments. (SEM, ×500.)
Fig. 3. Case 3. Electron microphotograph of Descemet's membrane with irregularly increased thickness. A layer of thin and coarse collagen separates the membrane from endothelial cells with increased endoplasmic reticulum and cytoplasmic filaments in the posterior aspect. (*x1,050.)

magnification, it could be observed that each lesion corresponded to a prominent wart (Fig. 5, b). Degenerating endothelial cells surrounded these excrescences, but in some areas there were fibroblast-like cells attached to abnormal endothelium and vitreous fibrils (Fig. 5, c). Epon-embedded 1 μ sections showed thick Descemet's membrane with multiple warts in some areas or wavy surface covered by fibroblastic cells (Fig. 5, d and e). Subendothelial fibrillar material was seen to be present on TEM.

Case 5 (Fig. 6, a) had a thick and wavy Descemet's layer covered by thin and large-spacing collagen. Endothelial cells were thin and reduplicated. SEM of the specimen showed large areas of bare Descemet's membrane lined by thin, large endothelial cells of abnormal shape (Fig. 6, b). Cells were reduplicated forming a retrocorneal membrane with apparent inclusion of vitreous fibrils between cells (Fig. 6, c). These fibrils appeared to adhere to, or form part of the surface of, Descemet's membrane (Fig. 6, d).

Comment

Cases 2, 3, and 4 show histological alterations which resemble those we have described in experimental eyes immediately after the phacoemulsification procedure. Cases 1 and 5 showed alterations similar to those found in corneas with chronic edema after cataract extraction. All cases showed alterations in Descemet's membrane compatible with Fuchs' dystrophy. It is our feeling that the surgical procedure caused enough endothelial cell disruption that permanent edema ensued. As demonstrated in our previous studies, the irrigating solutions used in this procedure
(Plasma-Lyte) as well as the ultrasound have little effect on the corneal endothelium, as long as these structures are healthy and the procedure is not very prolonged (perhaps it should not exceed 20 minutes of irrigation). Obviously, it is not known what effect these two factors have on abnormal corneal endothelium. Most surgeons are familiar with the situation of persistent corneal edema following an uncomplicated intracapsular cataract extraction in which little irrigation and anterior chamber manipulation was done. In an electron microscopic study of these corneas which underwent penetrating keratoplasty, it was evident that Fuchs' dystrophy without guttata was present and was probably undetected prior to cataract surgery. It is possible, therefore, that irrigating solutions and ultrasound may affect a dystrophic endothelial layer. However, the trauma induced by instrumentation in the anterior chamber or the trauma caused by the hard nucleus while it is being broken down in the an-

Fig. 4. Case 3. a, Bullous keratopathy, more pronounced centrally. b, Electron microphotograph of typical lesions involving a few to several cells. (SEM, x500.) c, Several necrotic endothelial cells partially covering two warts. (SEM, x1,000.) d, Endothelial cells have partially covered a defect centrally; however, in the inferior portion of the picture, two small lesions show Descemet's membrane covered by cell debris. (SEM, x500.)
Fig. 5. Case 4. a, Low-power microphotograph of endothelial surface showing multiple lesions of small size centrally. There are numerous warts in Descemet's membrane. Most of the lesions correspond to areas of prominent warts (arrow). (SEM, ×250.) b, High-power view of a portion of a showing a guttata formation (G) surrounded by dead or abnormal endothelium. (SEM, ×1,000.) c, Other areas of specimen possibly related to vitreous adhesion showed abnormal endothelial cells, guttata formations, and fibroblast-like cells. (SEM, ×1,000.) d, Cross-section of central portion of cornea showing prominent warts and abnormal endothelium. (PAS, ×400.) e, Another area of Descemet's membrane showed no warts, but thickened Descemet's covered by fibroblastic cells. (PAS, ×800.)

terior chamber is more important. These alterations appeared in our experimental corneas even though trauma had been unnoticed during the procedure, and it may explain the transient corneal edema we see after phacoemulsification. In Cases 2 and 3, the surgeons had reported uncomplicated procedures of short duration, but large abrasions found in the endothelial layer suggested that mechanical trauma had occurred. In addition, both cases showed multiple small-sized lesions scattered throughout the endothelium. Furthermore, they showed evidence of Fuchs' dystrophy without guttata. This condition described by Stocker is characterized by thickened Descemet's membrane because of deposition of fibrillary material and long-spacing collagen bundles under the endothelium.

It is assumed that adult human corneal endothelium does not heal by mitotic proliferation in the central cornea, but by cell spreading and migration. It is also known that with aging, corneal endothelial cells become larger and fewer in number. Decrease in cell population and increase in cell size is also found following intraocular surgical procedures. In eyes with corneal endothelial dystrophy, however, these cells fail to repair even small areas of damage which may develop following intraocular surgery. Some degree of endothelial repair is characterized by cytoplasmic expansions and filaments, reduplication...
of cells, and eventually, by their metaplasia to cells with fibroblastic appearance with increased production of collagen material. This was evident in Cases 1, 4, and 5 and, to a lesser degree, in the corneas of Cases 2 and 3.

It is possible that abnormal regeneration of Descemet's membrane may have followed endothelial damage during the cataract operation. However, those changes would not be so widespread as found here. The alterations found suggest a disease of several years and not a cell response of a few months or vitreous effect (in two cases the posterior capsule was intact). The presence of endothelial dystrophy in these eyes indicates the need for a more precise screening of corneas of eyes which may undergo phacoemulsification or any intracocular surgery. These studies should include a careful observation of Descemet's membrane to discard the possibility of dystrophy without warts. A prominent Descemet's membrane by slit-lamp examination, particularly if the central cornea measures over 0.56 mm., is a strong suggestion that the patient may have an abnormal endothelium. Cell population counting and cell pattern study with the specular microscope may provide additional in-

Fig. 6. Case 5. a, Bullous keratopathy with area of stromal scarring and vascularization at 12 o'clock. There is vitreous adhesion to the cornea and anterior synechiae. b, Low-power microphotograph showing large area of endothelial destruction with bare Descemet's membrane. (SEM, x250.) c, Several large endothelial cells with stretched-out junctions. Cells are arranged in multilayers. Vitreous strands are attached to areas of bare Descemet's (arrow). (SEM, x1,000.) d, Vitreous fibrils overlying two endothelial cells and forming part of abnormal Descemet's membrane. The surface of this membrane has a meshlike structure. (SEM, x5,000.)
formation to detect subclinical cases of endothelial dystrophy.

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REFERENCES