EXCIMER LASER PHOTOTHERAPEUTIC KERATECTOMY IN EYES WITH ANTERIOR CORNEAL DYSTROPHIES: PREOPERATIVE AND POSTOPERATIVE ULTRASOUND BIOMICROSCOPIC EXAMINATION AND SHORT-TERM CLINICAL OUTCOMES WITH AND WITHOUT AN ANTIHYPEROPIA TREATMENT

BY *Christopher J. Rapuano MD*

ABSTRACT

Purpose: To evaluate the use of high-frequency ultrasound biomicroscopy (UBM) in determining the depth of corneal pathology in eyes undergoing excimer laser phototherapeutic keratectomy (PTK) for primary or recurrent anterior stromal corneal dystrophies. Corneal clarity, visual acuity and refractive changes in eyes with and without an antihyperopia treatment were also analyzed.

Methods: Twenty eyes of 14 patients with anterior stromal corneal dystrophies were treated with PTK. Eyes were evaluated preoperatively and 6 to 8 weeks postoperatively with slit-lamp biomicroscopy, manifest refraction, keratometry, computerized corneal topography, ultrasound pachymetry, and UBM.

Results: Nineteen of 20 corneas (95%) had greatly improved corneal clarity after PTK. Mean uncorrected Snellen vision improved from 20/102 to 20/69 and best corrected vision improved from 20/62 to 20/38. Nine eyes (45%) improved 2 or more lines of uncorrected vision, and 13 eyes (65%) improved 2 or more lines of best corrected vision. Mean change in spherical equivalent was just –0.92 diopters (D); however, the range was large (–13 to +3.88 D). UBM measurement of central corneal pathology did not correlate with the actual PTK ablation depth (P = .07). The amount of antihyperopia treatment did not correlate with changes in manifest refraction spherical equivalent, keratometry, or computerized corneal topography readings, but did correlate with length of time until corneal reepithelialization after PTK (P = .003).

Conclusions: PTK resulted in improvements in corneal clarity and visual acuity in most patients with superficial corneal stromal dystrophies. UBM was not an effective tool to accurately measure the depth of corneal pathology preoperatively. The combined approach of minimizing ablation depth and selective use of an antihyperopia treatment resulted in minimal mean change in spherical equivalent; however, the range was large. PTK is a very good minimally invasive technique to improve vision in eyes with anterior stromal corneal dystrophies.

Trans Am Ophthalmol Soc 2003;101:365-394

INTRODUCTION

The excimer laser has been used since the late 1980s to reshape the anterior corneal curvature in a procedure known as photorefractive keratectomy (PRK), initially for myopia and later for astigmatism and hyperopia.[1] In this surgery, the epithelium is removed and the laser is applied to ablate a specific amount of Bowman's membrane and stroma. The excimer laser can also be used to remove superficial corneal pathology in a procedure termed phototherapeutic keratectomy (PTK). Unlike PRK and PTK, laser-assisted in-situ keratomileusis (LASIK) is a procedure where a thin flap of corneal tissue, including epithelium, Bowman's membrane, and stroma, is fashioned, and the excimer laser is used to reshape the stroma under the hinged flap. Afterward the flap is repositioned on the corneal surface without sutures.[2] The excimer laser clinically used in ophthalmology utilizes 193-nm wavelength ultraviolet light to break molecular bonds in the cornea to remove tiny amounts of tissue. One pulse of excimer laser light removes approximately 0.25 µm of tissue, depending on the specific laser system.[3,4] Excimer laser PRK and LASIK are approved by the US Food and Drug Administration (FDA) to treat mild to high degrees of myopia and mild to moderate degrees of hyperopia and astigmatism.

When excimer laser PTK was approved by the FDA in 1995 for clinical use in eyes with corneal pathology, many ophthalmologists thought that this procedure would eliminate the need for a significant number of corneal transplants in the United States. While excimer laser PTK is excellent for certain types of corneal pathology, it is not

From the Cornea Service, Wills Eye Hospital, and Jefferson Medical College of Thomas Jefferson University, Philadelphia, Pa. This study was supported in part by a grant from the Lions Eye Bank of Delaware Valley.

the panacea many physicians believed it would be. The concept behind PTK is to use the excimer laser to remove superficial corneal opacities and/or to smooth the corneal surface. This procedure is potentially applicable to a large number of patients, including those with anterior corneal dystrophies, anterior corneal scars, and superficial corneal irregularities. Over the past 7 years, we have learned a great deal about when excimer laser PTK is effective and when it is not.

Excimer laser PTK is an FDA-approved procedure to treat anterior corneal pathology affecting visual function, including symptoms of pain and/or decreased vision.[5] It is specifically indicated for conditions such as anterior corneal dystrophies, including anterior basement membrane dystrophy, dystrophies of Bowman's membrane, and granular and lattice dystrophies. It is also FDA-approved to treat anterior stromal scars occurring after corneal ulcers, ethylenediaminetetraacetic acid (EDTA) chelation of band keratopathy, trauma, or surgery (eg, pterygium surgery). Elevated lesions, such as Salzmann's nodular degeneration, can also be treated but are often more easily and effectively improved with superficial keratectomy. FDA indications state that the bulk of the pathology should be in the anterior 33% of the cornea. Additionally, not more than one third of the cornea should be removed and at least 250 µm of tissue should remain at the end of surgery. Consequently, contraindications to PTK include patients with deep corneal pathology or thin corneas. Caution should be taken in patients with potential healing abnormalities such as patients with keratitis sicca, neurotrophic corneas (eg, after herpes simplex or herpes zoster keratitis), exposure keratopathy, collagen vascular disorders (eg, rheumatoid arthritis), and diabetes mellitus. Eyes with a history of herpes simplex keratitis are at risk for recurrence of herpes after PTK.

Generally, the best candidates for excimer laser PTK are patients with corneal opacities in the anterior 10% to 20% of the cornea without significant irregularity or thinning. Eyes with localized elevated lesions are also good candidates for this procedure. Complications of PTK include infectious keratitis, corneal haze, and corneal scarring. In addition, opacities and dystrophies can recur after PTK, and induced refractive error, most typically hyperopia, but also myopia and astigmatism, is common. While one of the goals of the procedure is to decrease corneal irregularity, it is not unusual for PTK to cause worsened irregular astigmatism. Patients should understand that PTK is often being performed in lieu of a more invasive procedure such as lamellar or penetrating keratoplasty. Occasionally, PTK is unsuccessful and corneal grafting is required to improve vision.

PTK PROCEDURE

The exact procedure used to perform PTK depends greatly on the specific corneal pathology being treated.[5-11] There are three general techniques employed to treat most corneas. The three approaches are used to treat (1) relatively smooth central anterior stromal opacities (eg, Reis-Bücklers' or granular dystrophies), (2) elevated corneal lesions (eg, Salzmann's nodular degeneration), and (3) recurrent erosions, most commonly associated with anterior basement membrane dystrophy. Often, more than one of these techniques is used in an eye.

PTK for Stromal Opacities

Eyes with anterior stromal opacities, such as corneal dystrophies of Bowman's membrane (eg, Reis-Bücklers' dystrophy) and anterior stromal dystrophies (eg, lattice and granular dystrophies, recurrent dystrophies in a graft), generally respond well to PTK. In most of these cases, the epithelial layer is relatively smooth. Often the superficial stromal opacities extend anteriorly into the posterior aspect of the epithelium. In these cases, the epithelium acts as a smoothing or masking agent. Here, removing the epithelium manually actually creates a more irregular surface in many eyes. Therefore, the epithelium is preferably removed with the excimer laser. Laser epithelial removal potentially creates as smooth a surface in the stroma as existed in the epithelium. A large-diameter ablation zone (eg, 6 to 7 mm) is centered over the entrance pupil, and the ablation is performed through the epithelium and Bowman's membrane and into the stroma. Preoperatively, an estimate of the depth of the pathology needs to be determined, typically using a combination of slit-lamp biomicroscopy and ultrasound pachymetry. Only a percentage of this depth (eg, 50% to 75%) should be programmed into the laser system computer for initial delivery. When this amount of ablation has been performed, the patient is brought to a slit lamp and examined. Generally, more ablation is then required to remove the majority of the corneal pathology to improve the patient's symptoms. Not all of the opacity needs to be removed to significantly improve vision. This "ablate and check" technique is essential to remove only the amount of opacity necessary to improve symptoms, but not any additional tissue, which would increase the risks of significant refractive change and corneal haze or scar.

PTK for Elevated Lesions

Elevated opacities, most commonly Salzmann's nodular degeneration lesions and keratoconus nodules, are often treatable with mechanical superficial keratectomy using a blade. Those lesions not amenable to removal with a blade, generally because of some stromal involvement, can be treated with PTK. In these eyes, the epithelium is removed manually only from the elevated portion of the lesion and left in place adjacent to the lesion. A small-

diameter ablation zone (eg, 1 to 2 mm) is used to "shave" down the lesion. Ideally, the lesion is ablated to the level of the surrounding stroma, resulting in a smooth cornea. When there are areas of cornea that do not require ablation in close proximity to more elevated areas, the areas not requiring ablation can be coated with a masking agent to protect them. Different viscosities of masking agents can be employed for different lesions.[12] Most surgeons use a variety of thinner viscosity and thicker viscosity preservative-free tears as masking agents. Once the elevated area is relatively smooth, a larger-diameter ablation zone (eg, 4 to 6 mm) can be used to smooth the entire area. In the future, BioMask (Maverick Technologies, Inc, Clearwater, Fla), a material derived from porcine type I collagen, has the potential to be an effective masking agent to aid in the treatment of corneal irregularities with PTK.[13,14]

PTK in Thin Corneas

When corneal opacities associated with corneal thinning (eg, corneal ulcer scars) are being treated, it is difficult to create a smooth corneal surface without causing a large area of significant corneal thinning. Masking agents are often necessary to produce even a somewhat smooth surface. When required, such lesions can be treated, but the resulting corneal flattening, which can be dramatic, must then be managed, often with a rigid gas permeable contact lens.

PTK for Recurrent Erosions

The third technique is used to treat recurrent erosions, most commonly associated with anterior basement membrane dystrophy. Most eyes with recurrent erosions can be managed with medical therapy such as lubrication, hypertonic agents, and bandage soft contact lenses. With failure of medical management, surgical options are available, including anterior stromal puncture, diamond burr polishing of Bowman's membrane, and excimer laser PTK. When PTK is used, the entire area of loose epithelium is removed, and the cornea is treated to ablate 5 to 6 µm of Bowman's membrane. Care should be taken to remove all areas of loose epithelium and then to treat all of the exposed Bowman's membrane to prevent recurrences outside the treated area.

PTK-Induced Refractive Error

One of the most frustrating aspects of PTK surgery is induced refractive error. Most of the time ablations are performed centrally, causing central corneal thinning and flattening, resulting in induced hyperopia. When peripheral ablations are performed, induced myopia may occur. Induced astigmatism is not uncommon, because corneal opacities are often not uniform and are difficult to completely smooth out with current techniques, even with the use of masking agents. During the early PTK experience, hyperopic shifts of 5 to 15 D were routinely induced.[15-19] As more procedures were performed and patients were followed for longer periods of time, surgeons realized that deep ablations were responsible for this hyperopic shift. Techniques were developed, including the "ablate and check" procedure discussed earlier, to combat this adverse effect. Additionally, an antihyperopia ablation was proposed to decrease corneal flattening and induced hyperopia.[15,16] The effectiveness of these modalities is uncertain. One problem is that precisely how much tissue needs to be removed in any given patient is not known preoperatively. Also, exactly how much hyperopia is induced per amount of tissue removed during PTK is unknown, as is the best method to counteract induced hyperopia.

STUDY GOALS

This study evaluated methods to objectively measure depth of pathology preoperatively and prevent significant hyperopic shift in eyes with relatively superficial corneal stromal dystrophies undergoing excimer laser PTK. Specifically, ultrasound biomicroscopic analysis of the cornea was performed preoperatively to determine whether it was an effective technique to predict the exact depth of excimer laser PTK ablation required to remove the majority of the corneal opacity. Additionally, varying degrees of antihyperopia treatment were applied to different corneas after PTK, and the refractive effects were studied. The first hypothesis is that ultrasound biomicroscopy is an effective tool to determine depth of corneal pathology. The second hypothesis is that greater degrees of antihyperopia treatment would cause less hyperopic shift.

PTK PUBLISHED RESULTS

PTK Case Reports

One of the first reports of the clinical use of PTK was a case of successful removal of a corneal nodule in a patient with keratoconus, which allowed the patient to resume comfortable contact lens wear.[20] Since that time, PTK has been used to treat many different corneal conditions. Others have also used PTK to successfully remove keratoconus nodules in contact lens–intolerant patients.[21] PTK has been used to remove primary amyloidosis from the cornea,[22] band keratopathy,[23] corneal scarring from trachoma,[24] shield ulcers and plaques in vernal keratoconjunctivitis,[25] subepithelial cryoglobulin deposits,[26] corneal scarring during recurrent pterygium surgery,[27] corneal fibrosis after radial keratotomy,[28] corneal scarring after presumed infection after PRK,[29] corneal scarring in an epikeratophakia lenticule,[30] and subepithelial scarring in a child with Rothmund-Thomson syndrome.[31] It has also been used to treat painful bullous keratopathy[32,33] (Table I).

TABLE I: REFERENCES FOR CASE REPORTS AND SERIES OF PTK FOR CORNEAL PATHOLOGY

CORNEAL PATHOLOGY	1-4 CASES	5-10 CASES	> 10 CASES
Amyloidosis	11, 22		
Band keratopathy	7, 9, 15, 17	18, 34	11, 23, 36, 44
Climatic droplet keratopathy			45
Corneal scar after bacterial/ unspecified infection	29, 35, 41	15, 17, 34	18, 43
Corneal scar after radial keratotomy		28	
Corneal scar after trauma	17, 34, 35	15, 18, 41, 43	
Corneal scar after viral infection	34, 35, 71	15	18
Corneal scar in an epikeratophiakia lenticule	30		
Corneal scar in Rothmund-Thomson syndrome	31		
Corneal scar related to pterygium surgery	7, 15, 35, 38, 39, 40	18, 43	34, 44, 27
Corneal scar, unspecified	7, 37, 39, 40	9, 16, 36	11, 42, 44
Keratoconus nodule	15, 20, 39, 40	18, 21, 44	
Painful bullous keratopathy	11		32, 33
Recurrent erosions	7, 15, 34, 35, 38, 39, 40, 43, 48	9	18, 46, 47, 49, 50, 52, 53, 54, 55, 56
Salzmann's nodular degeneration	7, 9, 16, 35, 38, 39, 43	15, 40, 42	44
Stevens Johnson syndrome	18		
Subepithelial cryoglobulin deposits	26		
Subepithelial infiltrates after viral keratoconjunctivitis	81		
Thygeson's superficial punctate keratopathy	11		
Trachoma scar	24		
Vernal/atopic keratoconjunctivitis scar	17, 25		

Series for a Variety of Corneal Disease

A multitude of series of PTK results have been published over the past decade (Table I). The first large series reported on 33 eyes of 33 patients with a wide variety of corneal diseases, including corneal scarring from trauma, infection, herpes simplex virus, Salzmann's nodular degeneration, band keratopathy, granular dystrophy, and pterygium scars.[15] Best corrected vision improved in approximately half of the eyes, but vision worsened in 15%. A significant hyperopic shift was noted in 50% of eyes, especially at the beginning of the study, before the investigators combined their central treatment with a peripheral antihyperopia treatment.

A second large series was published the following year. Stark and associates[16] reported on 27 eyes after PTK done for a variety of corneal conditions, including primary and recurrent lattice dystrophy, primary and recurrent granular dystrophy, and corneal scarring. They found that 78% had a functional improvement in vision. However, there was a large amount of induced hyperopia in many eyes. Using their initial standard ablation, they found 5.7 D of induced hyperopia at 3 months and 5.9 D of induced hyperopia at 24 months. Because of this large amount of hyperopic shift seen in their early patients, they modified the laser ablation in later eyes and noted 7.1 D of induced hyperopia at 3 months, but it had declined to 2.7 D at 6 months. At 3 months postoperatively there was an association between depth of ablation and degree of induced hyperopia. No eye treated with 85 µm of stromal ablation had 9 D or more of induced hyperopia. The investigators concluded that "the central flattening of the cornea appears to be the principal undesirable effect of phototherapeutic keratectomy."

The largest early study was by Fagerholm and coworkers,[18] who reported on 166 eyes treated for anterior corneal abnormalities, including recurrent erosions, postinfectious keratitis scarring, corneal dystrophies, and herpes simplex keratitis scars. Because of the diversity of corneal pathology in their study, they set individual goals of treatment for each patient; they reportedly achieved their goal in 84% of eyes. They, too, found that the major complication was induced hyperopia. Regression analysis revealed that the number of pulses (ie, depth of ablation) was correlated with degree of hyperopic shift.

Another study of PTK for a variety of corneal conditions found success in 14 of 18 eyes (78%).[17] Mean manifest spherical refraction became more hyperopic by approximately 7 D at 1 month and 6.5 D at 3 months postoperatively. Hersh and colleagues[7] performed PTK on 12 eyes of 11 patients with various corneal diseases. They noted symptomatic improvement in 11 of 12 eyes; however, a hyperopic shift was found in 8 of 12 eyes

(mean, +5.4 D in these 8 eyes at 1 to 4 months). Hersh and colleagues[9] later reported PTK results for 28 eyes of 26 patients with diverse corneal pathology. Mean hyperopic shift was +1.4 D, but was greater for deeper ablations. The investigators described different ablation strategies to most effectively treat different pathologies while minimizing untoward side effects, especially hyperopic shift. They concluded that blending the peripheral treatment and minimizing total ablation depth are important to not excessively flatten the cornea.

Tuunanen and Tervo[34] achieved a 50% success rate in treating 39 eyes of 38 patients with a variety of corneal pathology. Eyes with corneal dystrophies and band keratopathy had better success rates than eyes with corneal scars. Mean hyperopic shift was 1.79 D at 6 months. Rao and coworkers[35] reported PTK results for 11 eyes of 10 patients, primarily for scars and Salzmann's nodular degeneration. Best corrected vision improved 2 or more lines in 6 of the 10 eyes treated to improve vision. A hyperopic shift was seen in 5 eyes (mean, +3.25 D) and a myopic shift was seen in 2 eyes (-2.25 D, -5.0 D). Hyperopic shifts were seen primarily in those eyes treated with deeper central ablations, while myopic shifts were seen in the two eyes with pterygium scars that received peripheral ablations.

Amano and associates[36] reported results of PTK for 31 eyes of 26 patients, most with band keratopathy, granular dystrophy, and scars. Eyes with granular dystrophy showed much greater improvement in best corrected vision than eyes with band keratopathy. About half of the eyes had a hyperopic shift greater than +1.0 D at 1 and 2 years. Kasetsuwan and coworkers[37] performed PTK on 17 eyes of 10 patients, almost all of which had lattice or Reis-Bücklers' dystrophy. All but two eyes underwent stromal ablations of greater than or equal to 80 µm. Even though they performed midperipheral antihyperopia ablations, all eyes with both preoperative and postoperative refractions available for analysis had hyperopic shifts. The investigators concluded that the severe degree of pathology, at least partly due to lack of corneal donors for corneal transplantation, required deeper than average ablations, causing greater corneal flattening. Interestingly, they believe PTK to be an excellent alternative for some patients awaiting corneal transplantation (which is typically 4 to 6 years in Thailand).

Rapuano and colleagues reported several studies evaluating results of PTK in the treatment of anterior corneal pathology.[38-40] In the largest study,[40] there were 28 eyes of 24 patients, primarily with granular dystrophy, dystrophies of Bowman's membrane, Salzmann's nodular degeneration, recurrent erosions, and keratoconus nodules. With a mean follow-up time of 22 months, the preoperative goal was achieved in 22 eyes (78.5%) and one eye (3.5%) was worse. Mean hyperopic shift was 2.13 D (range, 7.75 D flatter to 6.5 D steeper). Five eyes (18%) developed recurrences of their pathology during the follow-up period.

Migden and associates reported their results of PTK in 22 eyes of 21 patients with corneal scars.[41] Vision improved in 50% and 39% of eyes at 1 month and 3 months, respectively. The results were better in traumatic scars than in postinfectious scars. At 3 months, 44% had a hyperopic shift greater than 2 D. Another report of PTK on 48 eyes of 45 patients for a variety of corneal conditions noted a success rate of approximately 70% to 75%.[42] The investigators found a hyperopic shift of 3.1 D at 3 months. Starr and colleagues[43] found good clinical results of PTK in 45 eyes of 45 patients with a diverse group of corneal pathology, with approximately 50% enjoying improved vision. With an average depth of stromal treatment of 132 µm, they found a mean hyperopic shift of 2.81 D at last follow-up. However, for eyes treated with greater than 180 µm of stromal ablation, the hyperopic shift was 5.39 D. There was a nonstatistically significant trend toward ablation depth being correlated with degree of hyperopic shift. They noted much more hyperopic shift with stromal ablations greater than 100 µm than with stromal ablations less than 100 µm.

The Summit Technology (Waltham, Mass) multicenter study reviewed the results of PTK in 232 eyes of 211 patients.[44] The investigators reported improved vision in 45% at 1 year. Depending on follow-up time, they found a hyperopic shift in 40% to 50% of eyes. This shift was seen in all types of pathology treated except anterior basement membrane dystrophy, where minimal tissue was removed. Foster and associates[11] reported on PTK in 252 eyes of 216 patients. Most eyes had recurrent erosions (41%), corneal scars after pterygium surgery (34%), and band keratopathy (12%). Ninety-one percent of eyes with recurrent erosions were symptom-free at a minimum of 12 months follow-up, and all eyes with band keratopathy were pain-free. PTK corneal smoothing after pterygium surgery did not appear to greatly improve clinical results. The investigators concluded that hyperopic shift and induction of severe irregular astigmatism can be avoided by using a large ablation zone (eg, 8-mm diameter) and minimizing the depth of ablation.

A large study evaluated the success in the smooth and irregular varieties of climatic droplet keratopathy.[45] The investigators found better corneal clarity and improved visual acuity results in the smooth climatic keratopathy eyes than the irregular climatic keratopathy eyes. They also found higher rates of delayed reepithelialization (>14 days) and bacterial keratitis in the irregular climatic keratopathy eyes compared with the smooth variety. They noted a statistically significant hyperopic shift at 3 months, which was stable at 6 and 12 months.

PTK for Anterior Basement Membrane Dystrophy and Recurrent Erosion Syndrome

There are many effective medical and surgical treatments for anterior basement membrane dystrophy and recurrent erosion syndrome, but they do not work well in all situations. Excimer laser PTK can also be quite successful. Sridhar and colleagues[46] retrospectively compared the results of PTK and diamond burr polishing of Bowman's membrane in patients with recurrent erosions and anterior basement membrane dystrophy. Fifteen eyes underwent PTK and were followed for a mean of 17.6 months. Twenty-seven eyes underwent diamond burr polishing of Bowman's membrane and were followed for a mean of 6.7 months. The success rates were 73% in the PTK group and 89% in the diamond burr group. The investigators found no statistically significant difference in haze, recurrences, or change in vision between the two treatment groups and concluded that diamond burr treatment was as effective as PTK and generally less costly and more convenient for the patient and the surgeon.

Dausch and colleagues[47] reported on PTK for traumatic recurrent erosions not responding to conventional treatment in 74 eyes of 73 patients. They ablated epithelium with the laser in some cases and removed it manually in others. Their goal was to ablate just into Bowman's membrane. With a minimal follow-up of 6 months and a mean follow-up of 21.1 months, they found that 74% of eyes remained symptom-free at last follow-up. Recurrences occurred from 1 to 22 months (mean, 8.4 months) after PTK. Their impression was that their treatment did not induce a notable hyperopic shift. In a series of three eyes with recalcitrant recurrent erosions, John and coworkers[48] debrided the loose epithelium and ablated Bowman's membrane. They did not find any recurrent painful episodes for the 18 months duration of their study. Lohmann and associates[49] also debrided loose epithelium before PTK ablation in 31 eyes of 24 patients with traumatic and anterior basement membrane dystrophy–related recurrent erosions. With a follow-up of 3 to 12 months, they found no recurrent erosions in 30 eyes (97%). Additionally, no corneal haze and no significant change in refraction were found. Bernauer and colleagues[50] and Orndahl and Fagerholm[51] also noted good success in treating 15 eyes and 17 eyes, respectively.

In another study, PTK in 23 eyes of 23 patients with recalcitrant recurrent erosions was successful in 83% with 12 to 60 months of follow-up (mean, 38 months).[52] There was no significant change in refraction. Ho and associates[53] performed PTK on 35 eyes of 32 patients with recurrent corneal erosions not responding to conventional therapy. Approximately half had an anterior corneal dystrophy and half had previous corneal trauma. With a mean follow-up of 12 months (range, 0-56 months), 74% were pain-free after PTK. The results were slightly better in eyes with post-traumatic erosions compared with dystrophy-related erosions. No refraction changed by greater than 1 D. Minimal haze was noted in three eyes. Cavanaugh and coworkers[54] reported on 48 eyes of 43 consecutive patients with anterior basement membrane dystrophy and recalcitrant recurrent erosions who underwent PTK treatment. Of the 36 eyes with 12 months of follow-up, 5 (14%) required an additional PTK treatment for recurrence or erosions. One eye required a third treatment. All recurrences occurred within 6 months of the PTK. There was a statistically significant correlation between number of laser pulses applied and induced hyperopic shift.

Jain and Austin[55] reported PTK results for 77 eyes of 68 patients with recurrent erosions refractory to other forms of treatment. Fifty-two percent were related to trauma, 31% were related to anterior basement membrane dystrophy, and 17% were idiopathic. In the trauma group, 67.5% were pain-free, while 10% required a second PTK. In the corneal dystrophy cases, only 1 eye (4%) required a second treatment. In the idiopathic cases, 1 eye (8%) required a retreatment. Interestingly, the investigators combined PTK for recurrent erosions with PRK for refractive error in 6 patients. In this small group, they found no recurrences of erosions and a satisfactory refractive outcome, such that no patient required additional surgery. Kremer and Blumenthal[56] also performed combined PRK and PTK in 16 eyes of 16 patients with myopia and recurrent erosions. At 26 to 42 months, no patient had had an episode of recurrent painful symptoms, and uncorrected vision was better than or equal to 20/40 in all eyes. Overall, PTK is a very successful treatment for recalcitrant recurrent erosions with minimal side effects.

PTK for Other Anterior Corneal Dystrophies

There have been several reports of excimer laser PTK to treat stromal dystrophies where the bulk of the pathology lies in the anterior cornea (Table II). Small case series described successful treatment of Reis-Bücklers' dystrophy,[57] Avellino dystrophy,[58] macular dystrophy,[59,60] Schnyder's crystalline dystrophy,[61] granular and lattice dystrophies,[62] and recurrent granular dystrophy after corneal transplantation.[63] Two somewhat larger series describing good results in Reis-Bücklers' dystrophy, one with 9 eyes of 7 patients[64] and the other with 11 eyes of 8 patients,[65] were reported by the same authors. Best corrected vision improved at least 2 lines in all eyes, with all patients reaching 20/40 or better. A hyperopic shift was seen in all eyes, ranging from minimal to +8.0 D at 1 month and +7.0 D at 6 months. One of the largest series of PTK for patients with corneal dystrophies included 33

TABLE II: REFERENCES FOR CASE REPORTS AND SERIES OF PTK FOR CORNEAL DYSTROPHIES

CORNEAL DYSTROPHY	1-4 CASES	5-10 CASES	> 10 CASES
Anterior basement membrane dystrophy	9, 15, 17, 38, 39, 40, 43	9, 11, 19	42, 44, 51, 54, 55, 80
Meesmann's dystrophy	19, 44		
Granular dystrophy	15, 16, 17, 19, 34, 38, 39, 43, 62, 63	36, 40, 44	80
Lattice dystrophy	7, 9, 17, 34, 62	37, 80	16, 19, 44
Avellino dystrophy	43, 58	67	
Reis-Bücklers dystrophy	7, 16, 19, 37, 38, 57	39, 40, 44, 64	65, 80
Schnyder's crystalline dystrophy	11, 34, 38, 39, 40, 44, 61, 80	19	
Macular dystrophy	16, 34, 37, 59, 60		
Fuchs' dystrophy	19, 73		
Corneal dystrophy, unspecified			18, 42

eyes, 11 with lattice dystrophy, 8 with anterior basement membrane dystrophy, 5 with Schnyder's crystalline dystrophy, and 4 with granular dystrophy.[19] With a mean follow-up time of 9 months, they found vision improved 2 or more lines in 23 of 27 eyes (85%) treated for decreased vision, and no eye developed worse vision. A consistent finding in most of these reports was hyperopic shift, the degree of which appeared to be associated with depth of ablation.

Corneal Surface Changes After PTK

A study evaluated ocular surface changes before and 3 months after PTK in 45 eyes of 33 patients and compared them to controls (40 eyes of 20 patients). Thirty-three percent of eyes had Avellino dystrophy, 31% had granular dystrophy, 18% had band keratopathy, and 13% had corneal scars.[66] The investigators found significant improvements in corneal sensitivity, tear film break-up time, lipid layer interference results, and conjunctival squamous metaplasia grades. Schirmer test and goblet cell density did not show significant changes after PTK. The investigators concluded that improved corneal regularity led to a healthier, more stable tear film and healthier epithelium. Many of the same investigators also reported ocular surface changes in 5 eyes of 5 patients with recurrent granular/Avellino dystrophy after PTK.[67] They found improvements in the health of the ocular surface, as measured by corneal sensitivity, tear film break-up time, lipid layer interference, and conjunctival squamous metaplasia grades, in all eyes after PTK. They also noted that these improvements deteriorated with recurrence of the disease process. The recurrences occurred between 7 and 15 months after PTK.

PTK COMPLICATIONS AND SIDE EFFECTS

As with any corneal surgery, PTK has complications and side effects. Since an epithelial defect is created, there tends to be a significant amount of discomfort or pain after surgery. These symptoms can be managed by pressure patching, frequent application of ointment, a bandage soft contact lens, and topical nonsteroidal anti-inflammatory medications. Great care needs to be taken to promote reepithelialization. Prolonged epithelial defects are not uncommon after PTK, as PTK is often performed in eyes predisposed to healing difficulties, such as eyes with corneal grafts or previous herpetic keratitis. Chronic epithelial defects can cause corneal scarring. Additionally, there is always a chance of infection. Bacterial keratitis has been reported after PTK.[45,68,69] Reactivation of latent herpes simplex virus by the excimer laser has been demonstrated in mice.[70] Three cases of recurrent herpes simplex keratitis after PTK were reported.[71] A Wessely-type immune ring has also been reported after PTK.[72] Severe scarring developed in an eye with Fuchs' dystrophy treated with PTK, requiring a corneal transplant to improve vision.[73] Many eyes develop an anterior stromal reticular haze similar to what is seen after PRK. In some eyes it can be substantial and may reduce vision. Severe haze, while rare, has been treated with topical mitomycin C with good results.[74] Fortunately, the corneal endothelial cells do not seem to be adversely affected by PTK.[75]

REFRACTIVE CHANGES AFTER PTK

Refractive changes are typical after PTK. The most common is induced hyperopia secondary to central tissue ablation causing central corneal thinning and flattening. If the peripheral cornea is ablated preferentially, myopia can also be induced. Irregular, and less typically regular, astigmatism can also result from PTK. Irregular astigmatism will often occur when a noncentral ablation is performed. If an ablation will remove a significant amount of stromal tissue, it is best to perform it centrally, even if the pathology is paracentral, to avoid creating a significant amount of induced astigmatism.

The exact amount of hyperopia that is induced during a PTK procedure varies greatly with the specific corneal pathology, PTK technique, use of masking agents, and especially ablation diameter and ablation depth. The Munnerlyn formula[73,76,77] was developed for myopic excimer laser treatments. It relates the diopters of flat-

tening directly to the depth of ablation in microns divided by the ablation diameter squared:

$$\text{Diopter effect} = 3(\text{ablation depth in microns}) / (\text{ablation zone diameter in mm})^2$$

Some surgeons have used this formula as an approximation for the hyperopic shift after PTK; however, the correlation is much weaker than for PRK.[73] With typical stromal ablations in the 25- to 100-µm range, several diopters of hyperopic shift can be expected after PTK, which is not commonly a desirable change.

There are several techniques used to avoid significant corneal flattening and induced hyperopia. In general, a large ablation zone, such as 6-mm diameter, is used. As per the Munnerlyn formula, the larger the ablation zone diameter, the smaller the degree of induced hyperopia for the same ablation depth. An extremely important parameter is to minimize the depth of ablation. A critical point in the successful performance of PTK is to realize that the cornea does not need to be crystal-clear to function well. A patient with a corneal opacity with 20/200 vision may improve to 20/30 vision with a 75-µm total ablation that removes 90% of the opacity and does not induce significant hyperopia. To clear the last 10% of the opacity and potentially improve the vision to 20/20 might require another 75 µm of ablation. However, that extra 75 µm of ablation may induce an added 3 to 6 D of hyperopia, and possibly increase the risk of post-PTK haze.

Additional techniques to reduce induced hyperopia include blending the edges of the ablation by gently rocking the head during stromal ablation.[45] Another option is to perform an ablation at the edge of the central stromal ablation. This peripheral ablation is similar to the treatments for hyperopia, which just treat the paracentral cornea to steepen the central cornea.[9,15,16,42,45,77] The best antihyperopia ablation size and exact amount of peripheral ablation to neutralize the central flattening are unknown.

Two studies specifically evaluated refractive changes after PTK.[78,79] In 45 patients primarily with recurrent corneal erosions, central corneal scars, and corneal dystrophies, Amm and Duncker[78] found a hyperopic shift in 41% of eyes treated with a stromal ablation (mean, +1.7 D; range, 0.5-4.0 D). Twenty-two percent developed an increase in regular astigmatism (maximum increase, 2.75 D). Nine percent developed a myopic shift (maximum, –1.5 D). Not unexpectedly, the investigators found no refractive change in the patients with recurrent erosion who were treated with minimal-depth ablations. They noted a correlation between depth of ablation and hyperopic shift and concluded that stromal ablations of 100 µm or less were desirable to achieve the best clinical results. Dogru and coworkers[79] evaluated 112 eyes of 80 patients with a variety of corneal disorders, including stromal dystrophies, band keratopathy, and corneal scars. They found a +4.25 D shift at 1 month, which declined to +3.42 D at 1 year, at which point it was stable. As expected, eyes with greater than 100 µm stromal ablation had a statistically significantly greater degree of induced hyperopia (+4.42 D) than eyes treated with less than 100 µm stromal ablation (+2.85 D). Additionally, eyes treated with a 1.0-mm transition zone beyond the ablation also had less hyperopic shift than those treated without the transition zone. Interestingly, the investigators did not find a difference in induced hyperopia between 5.0- and 6.0-mm ablation zone diameters, although the number of eyes was small and the treatment depths were less than 100 µm in the 5.0-mm ablation zone group. They concluded that limiting the depth of corneal stromal ablation, when possible, was important to avoid a significant hyperopic shift.

RECURRENCE OF DISEASE AFTER PTK

Unfortunately, PTK is not a "cure" for corneal dystrophies. Just as corneal dystrophies can recur after corneal transplantation, they can recur after PTK. Dinh and colleagues[80] reviewed 50 PTK procedures in 43 eyes of 33 patients with corneal dystrophies before and after corneal transplantation, evaluating them for recurrence of the dystrophy. These included 13 eyes with Reis-Bücklers' dystrophy, 11 eyes with granular dystrophy, 11 eyes with anterior basement membrane dystrophy, 7 eyes with lattice dystrophy, and 1 eye with Schnyder's crystalline dystrophy. Recurrence occurred in 47% of the Reis-Bücklers' dystrophy eyes a mean of 22 months after PTK, in 23% of the granular dystrophy eyes a mean of 40 months after PTK, and in 14% (1 eye) of lattice dystrophy eyes 6 months after PTK. Dystrophies recurred at similar rates in eyes with and without previous corneal transplantation. As mentioned earlier, recurrence of granular/Avellino dystrophy was noted in 5 eyes of 5 patients between 7 and 15 months after PTK.[67] Postviral subepithelial infiltrate scars removed with PTK were reported to recur in one case 4 months after surgery.[81]

ULTRASOUND BIOMICROSCOPY OF THE CORNEA AND ANTERIOR SEGMENT

Accurate preoperative determination of the depth of corneal pathology would be extremely beneficial in selecting the best candidates for PTK by avoiding patients with deep central pathology. Additionally, it would guide the surgeon in determining the exact depth of PTK treatment in each patient. Ultrasound biomicroscopy (UBM) is a relatively new method for obtaining high-resolution images of the cornea and anterior portion of the globe. This technique involves using high-frequency ultrasound

(50 MHz) to produce cross-sectional views of the anterior segment to a depth of approximately 5 mm. UBM has been used to evaluate numerous conditions in the front portion of the eye, including anterior segment masses,[82] cystinosis,[83] intracorneal epithelial cyst,[84] and Maroteaux-Lamy syndrome.[85] It is also extremely useful in the detection and localization of both known and occult anterior segment foreign bodies.[86-91] UBM has been helpful in determining the status of intraocular structures in eyes with corneal opacities undergoing corneal transplantation.[92] This information can guide the surgeon in both surgical planning and predicting the success of the surgery. UBM has also been shown to be useful in the surgical planning of limbal dermoid removal.[93] In this condition, the exact depth of the limbal dermoid often cannot be determined by slit-lamp evaluation because of the density of the lesion. UBM evaluation could differentiate the dermoid tissue from the normal surrounding and underlying tissue.

One of the difficulties of excimer laser PTK is predicting the depth of pathology preoperatively to help determine whether the patient is a good candidate for this procedure. Additionally, the depth of pathology predicted preoperatively aids the surgeon in determining how much tissue to remove during the actual PTK procedure. Slit-lamp examination combined with ultrasound corneal pachymetry measurement is useful, but often not conclusive. The ultrasound pachymeter measures the full thickness of the cornea, while the slit-lamp evaluation gives an estimate of the percentage of corneal involvement, eg, 20% involvement in a 500-µm cornea gives a value of 100 µm of pathology. If the involvement was really only 15%, then the pathology would be only 75 µm. If 100 µm of tissue were removed based on preoperative slit-lamp estimation, then an extra 25 µm of tissue would have been removed.

A key goal in PTK surgery is to remove as little tissue as necessary in order to reduce the chances of significant refractive shift, especially induced hyperopia. If UBM could accurately predict the depth of corneal pathology before PTK, candidates could be screened better and the likelihood of excess tissue removal could be reduced. A major goal of this study was to evaluate the efficacy of UBM in predicting the depth of pathology that was removed during PTK.

MATERIALS AND METHODS

PATIENT POPULATION

This prospective study included 20 consecutive eyes (12 left, 8 right) of 14 patients (5 women, 9 men) with corneal stromal dystrophies who underwent excimer laser PTK at our institution. Patients' ages ranged from 22 to 81 years (mean, 51 ± 16 years) (Table III). All patients older than 21 years with a stromal corneal dystrophy and anterior corneal pathology that affected visual function were eligible for inclusion. Eyes with significant corneal thinning (<400 µm centrally), deep corneal pathology, or corneal edema were excluded. Eyes with uncontrolled uveitis, uncontrolled glaucoma, or significant ocular surface disease were also not eligible.

Nine eyes of 6 patients had granular dystrophy. Both eyes of one patient with granular dystrophy had undergone excimer laser PRK 6 to 7 years previously. One eye had lattice dystrophy, and 4 eyes of 3 patients had recurrent lattice dystrophy in grafts performed 7 to 25 years previously. Six eyes of 4 patients had recurrent Reis-Bücklers' dystrophy. Four of the 6 Reis-Bücklers' eyes had undergone corneal transplantation 6 to 25 years previously. Two of these eyes had also undergone previous PTK, and one eye had undergone lamellar keratectomy in the most recent corneal graft. Two eyes of one patient with Reis-Bücklers' dystrophy had had prior lamellar keratectomy and later PTK prior to entrance into this study. The study was approved by the institutional review board of Wills Eye Hospital, and all patients gave informed consent.

EXAMINATIONS

All patients underwent routine ophthalmic examinations, including uncorrected Snellen visual acuity, best manifest spectacle-corrected Snellen visual acuity, slit-lamp biomicroscopy, keratometry readings (Haag-Streit Co, Bern, Switzerland), computerized corneal topography (EyeSys/Premier, Irvine, CA), central ultrasound pachymetry (Accutome Inc, Malvern, PA), anterior segment photography, and ultrasound biomicroscopy (Humphrey Instruments Inc, San Leandro, CA, upgraded by Paradigm Inc, Salt Lake City, UT). The corneal topography analysis determines a simulated keratometry reading and a central corneal power determination. All measurements were repeated approximately 6 to 8 weeks postoperatively. In certain eyes, it was impossible to obtain keratometry readings and/or computerized corneal topography readings because of corneal irregularity. In other eyes, the corneal topography analysis revealed a central power reading but no simulated keratometry reading.

ULTRASOUND MICROSCOPY

UBM was performed by a highly experienced technician using a 50-MHz transducer. Examinations were performed using an eyecup and carboxymethylcellulose 1% (Celluvisc, Allergan Inc, Irvine, CA) as the coupling agent. Scans were performed with the settings of 60- to 72-dB/mm gain, 5-dB/mm time-gain compensation, and a 2.24-mm delay. An attempt was made to keep the corneal image at the focal point of the ultrasound probe for best resolution. The cornea was imaged horizontally and verti-

TABLE III: PATIENT DEMOGRAPHIC INFORMATION

PT NO.	AGE	SEX	EYE	CORNEAL DYSTROPHY	PREVIOUS CORNEAL SURGERY
1	78	F	L	Recurrent lattice	PK '76
2	22	F	L	Granular	-
3R	62	M	R	Recurrent lattice	PK '89
3L	64		L	Recurrent lattice	PK '84, '94
4R	57	M	R	Granular	-
4L	58		L	Granular	-
5R	39	M	R	Granular	-
5L	39		L	Granular	-
6	81	M	L	Granular	-
7R	43	M	R	Recurrent granular	PRK '92
7L	43		L	Recurrent granular	PRK '93
8	58	M	L	Granular	-
9R	57	F	R	Recurrent Reis-Bücklers	PK '85, PTK '93, '97
9L	55		L	Recurrent Reis-Bücklers	PK '79, LK '88, PK '91
10R	35	M	R	Recurrent Reis-Bücklers	LK '88, PTK '93, '98
10L	33		L	Recurrent Reis-Bücklers	LK '87, PTK '95
11	26	F	L	Recurrent Reis-Bücklers	PTK '92, PK '94, PTK '97
12	65	F	R	Recurrent lattice	PK '82
13	63	M	L	Recurrent Reis-Bücklers	PK '54, '64, '75, LK '85
14	46	M	R	Lattice	-

LK, lamellar keratectomy; PK, penetrating keratoplasty; PRK, photorefractive keratectomy; PTK, phototherapeutic keratectomy.

cally. Images were obtained centrally and then 1, 2, and 3 mm off center nasally, temporally, superiorly, and inferiorly. The images were stored on the hard drive of the system for subsequent interpretation. The surgeon did not see the UBM images prior to the PTK procedure.

At a later date, the technician retrieved the UBM images and, using the cursor on the screen, measured the total corneal thickness and determined the depth of pathology for each image. Often the depth of pathology varied throughout the image. In these cases, the middle of the pathology was measured in the center of the image.

THE PTK PROCEDURE

Phototherapeutic keratectomy was performed with the VISX S2 excimer laser (VISX Inc, Santa Clara, CA). The laser operates at a radiant exposure of 160 mJ/cm^2. Eyes were treated preoperatively with topical ofloxacin (Allergan) and proparacaine 0.5%. A lid speculum was applied to the operative eye, and the fellow eye was covered. A transepithelial approach utilizing a 6.0-mm ablation zone with no transition zone was used for all eyes. The ablation was centered on the entrance pupil. A pulse rate of 6 Hz was used. An initial 60- to 75-µm treatment was applied based on the clinical appearance of the depth of pathology from the preoperative slit-lamp evaluation. The patient was then examined at the slit lamp, and additional treatment was applied as needed. Occasionally, a small amount of balanced salt solution was then applied as a masking agent to smooth out the ablation. The treatment goal was a smoother, clearer central cornea. Typically, the central cornea was not crystal-clear at the end of the PTK treatment. The amount of laser treatment was recorded. For purposes of calculation of ablation depth when a masking agent was used, the surgeon estimated how much laser treatment was masked and subtracted that amount from the depth delivered according to the laser system computer. To prevent bias in amount of ablation performed, the surgeon had not seen the UBM images prior to PTK treatment.

In certain eyes, especially those with deep ablations

and preoperative hyperopia, the surgeon performed an antihyperopia ablation. In these cases, the joystick of the laser was used to apply a 2-mm-diameter circular ablation to the periphery of the 6-mm central ablation, straddling the initial ablation. The total depth of antihyperopia treatment varied between 80 and 200 µm, depending on the degree of expected corneal flattening. Using the joystick, the 2-mm ablation was slowly moved around the periphery of the central ablation for two full circles, ablating 50% of the total depth with each circle.

Postoperatively, patients were treated with 1 drop of ofloxacin, scopolamine 0.25%, ketorolac (Acular, Allergan) and 0.5-inch of erythromycin 0.5% ophthalmic ointment and a pressure patch. Patients were prescribed acetaminophen with codeine as needed. The pressure patch was removed on postoperative day 1 and healing was evaluated. Eyes were treated with erythromycin ophthalmic ointment every 2 hours while patients were awake and when they returned 2 days later. Patients were examined every few days until the epithelial defect had completely healed. Topical corticosteroids (ie, fluorometholone, loteprednol, or prednisolone acetate) were used in some patients once the epithelial defect had resolved if corneal haze or graft inflammation was noted.

STATISTICAL ANALYSIS

Visual acuity results were converted to decimal numbers for analysis and then reconverted to Snellen acuity. Mean ± standard deviation is reported. Spearman correlations and least squares regression were used to determine the association between the different variables. The power of this study could detect a correlation of 0.6 given the number of eyes evaluated. A P value of $<.05$ was considered significant.

RESULTS

All 20 procedures were performed by the author between February 1999 and April 2001. Follow-up examinations were performed in all patients at a mean of 7.1 weeks (range, 6-14 weeks) postoperatively.

TREATMENT

In all patients, the ablation proceeded through the entire thickness of the epithelium, through Bowman's membrane and into the stroma. Patients were then examined at a slit lamp and had additional ablation performed as determined by the surgeon to substantially clear the central cornea. Total excimer laser ablation depths, including epithelium and stroma, ranged from 85 to 130 µm (mean, 103.5 ± 14.2 µm) (Table IV). A small amount of balanced salt solution masking agent was used in 7 of 20 eyes (35%). It was not used during the initial transepithelial/stromal ablation, but only when smoothing was required after the first deep ablation and the cornea had been evaluated at the slit lamp. One patient (9L) had a thin corneal membrane removed mechanically when a distinct edge was noted after the initial ablation. It was estimated to be 10 µm in thickness, which was added to the laser ablation of 75 µm, for a total treatment of 85 µm.

CLINICAL FEATURES

Superficial corneal opacities were successfully removed in all but one eye (patient 14). This patient had moderately deep corneal amyloid deposits of lattice dystrophy, which were not sufficiently removed even with the deepest PTK treatment in this study (130 µm) (Figure 1). In all the other eyes, the central cornea was much clearer (Figures 2 through 4). In several eyes, especially those with granular dystrophy, many deep, scattered opacities remained after PTK treatment (Figure 5).

VISUAL ACUITY OUTCOME

Visual acuity results are summarized in Table V. Uncorrected visual acuity ranged from 20/40 to 20/400 preoperatively and from 20/30 to 20/400 postoperatively. There was a mean improvement of 1.25 ± 3.27 Snellen lines (range, 7 lines better to 4 lines worse). Mean uncorrected Snellen acuity improved from 20/102 to 20/69. Six eyes were essentially unchanged (±1 line), four eyes gained 2 or 3 lines, two eyes gained 4 or 5 lines, and three eyes gained 6 or 7 lines. Four eyes lost 2 or 3 lines, and one eye lost 4 lines (Figure 6).

Preoperative best spectacle-corrected visual acuity ranged from 20/30 to 20/200 and postoperatively from 20/25 to 20/200. There was a mean improvement of 2.35 ± 2.48 Snellen lines (range, 7 lines better to 4 lines worse). Mean best spectacle-corrected Snellen visual acuity improved from 20/62 to 20/38. Six eyes were essentially unchanged (±1 line), 10 eyes gained 2 or 3 lines, none gained 4 or 5 lines, and three eyes gained 6 or 7 lines. No eyes lost 2 or 3 lines, and one eye lost 4 lines (Figure 7).

Preoperative uncorrected vision correlated with preoperative best corrected vision (Spearman correlation 0.56, P =.01), and postoperative uncorrected vision correlated with postoperative best corrected vision (Spearman correlation 0.59, P = .007). Preoperative and postoperative uncorrected vision were not correlated (Spearman correlation 0.15, P =.54) nor were preoperative and postoperative best corrected vision (Spearman correlation 0.17, P = .47).

REFRACTIVE CHANGES

Manifest Refraction Spherical Equivalent

Refractive results are summarized in Table VI.

TABLE IV: PTK TREATMENT AND POSTOPERATIVE COURSE

PT NO.	NAME	DEPTH OF PTK TX (MICRONS)	ANTIHYPEROPIA TX (MICRONS)	MASKING AGENT USED	DAYS TO REEPITHELIALIZE	POSTOPERATIVE CORTICOSTEROIDS
1		111	-	-	3	-
2		100	-	-	3	Fluorometholone 0.1%
3R		85	160	-	41	Prednisolone 1%
3L		84	120	+	9	Loteprednol 0.5%
4R		100	120	-	3	Fluorometholone 0.1%
4L		100	120	-	3	Fluorometholone 0.1%
5R		90	-	-	3	-
5L		122	120	+	5	-
6		99	120	+	8	Fluorometholone 0.1%
7R		100	200	-	4	-
7L		115	120	-	3	-
8		111	80	+	3	Fluorometholone 0.1%
9R		100	80	-	3	Fluorometholone 0.1%
9L		85	-	-	3	-
10R		123	120	+	3	Loteprednol 0.5%
10L		100	120	-	3	Prednisolone 1%
11		105	120	-	4	Fluorometholone 0.1% Loteprednol 0.5%
12		85	120	-	3	-
13		125	120	+	3	-
14		130	160	+	10	-
Mean:		103.5	125.0		6.0	
SD:		14.2	28.8		8.5	

PTK, phototherapeutic keratectomy; Tx, treatment.

Preoperatively, the mean spherical equivalent was –0.17 ± 2.84 D. Postoperatively, the mean spherical equivalent was –1.09 ± 4.17 D. Comparing preoperative and postoperative refractions for individual patients, there was a mean change in refraction of –0.92 ± 4.32 D (range, –13 to +3.88 D). There was no statistically significant correlation between the change in manifest refraction spherical equivalent and the actual PTK laser ablation depth (Spearman correlation –0.01, $P = .96$) (Figure 8).

Haag-Streit Keratometry Readings

Mean preoperative Haag-Streit keratometry reading in the 17 eyes where readings were obtainable was 43.45 ± 2.17 D. Mean postoperative keratometry reading in the 19 eyes in which it was obtainable measured 43.81 ± 3.27 D. In the 16 eyes with both preoperative and postoperative keratometry readings, the mean change was –0.25 ± 2.54 D (range, 5.24 D steeper to 2.75 D flatter). There was no statistically significant correlation between change in keratometry reading and the laser ablation depth (Spearman correlation –0.22, $P = .40$). There was also no statistically significant correlation between change in keratometry reading and change in manifest refraction spherical equivalent (Spearman correlation –0.47, $P = .0651$).

Corneal Topography Simulated Keratometry Readings

Preoperative EyeSys corneal topography analysis generated simulated keratometry measurements in 17 eyes. Mean simulated keratometry reading was 44.23 ± 2.2 D. Postoperative measurements were obtainable in 19 eyes. Mean postoperative measurement was 43.24 ± 3.37 D. In the 16 eyes with both preoperative and postoperative measurements, the mean change in simulated keratometry readings was –1.57 ± 2.34 D (range, 3.39 D steeper to

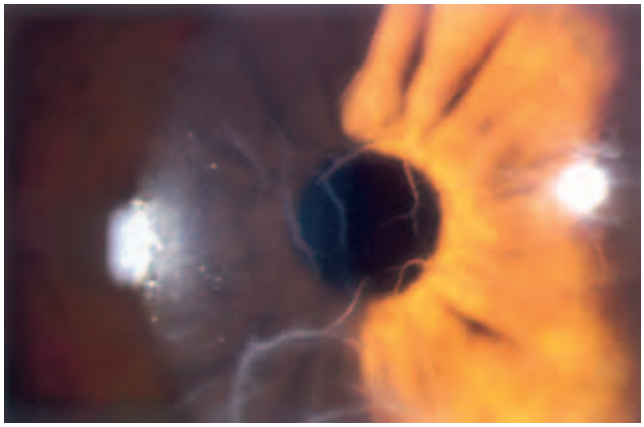

FIGURE 1A
Preoperative lattice dystrophy with moderately deep lattice lines in patient 14.

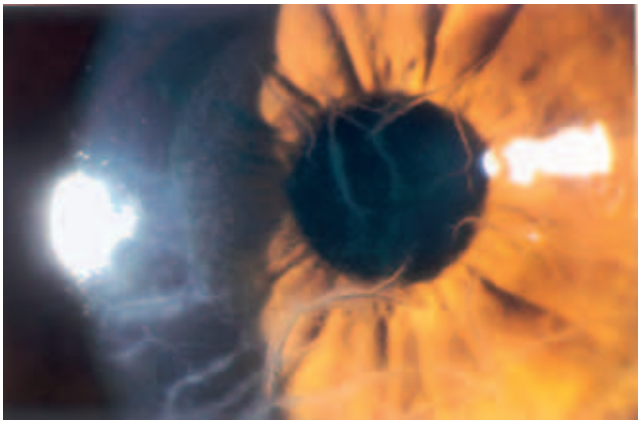

FIGURE 1B
Six weeks postoperatively, lattice lines in patient 14 were essentially unchanged. Mild anterior stromal reticular haze at the edge of the ablation can be seen.

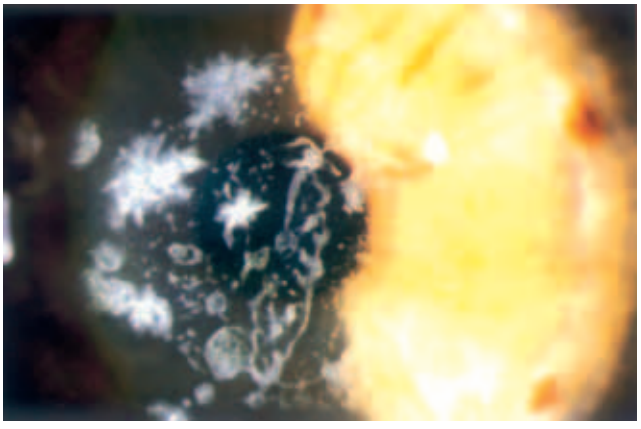

FIGURE 2A
Preoperatively, patient 7L had severe central corneal opacities secondary to granular dystrophy. Most of the opacities were relatively superficial.

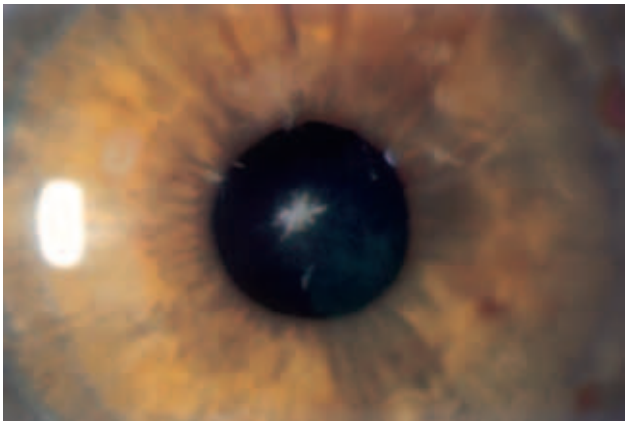

FIGURE 2B
Six weeks after PTK, superficial central opacities in patient 7L were eliminated. A deep stellate granule was still present centrally; however, the patient reported much improved quality of vision.

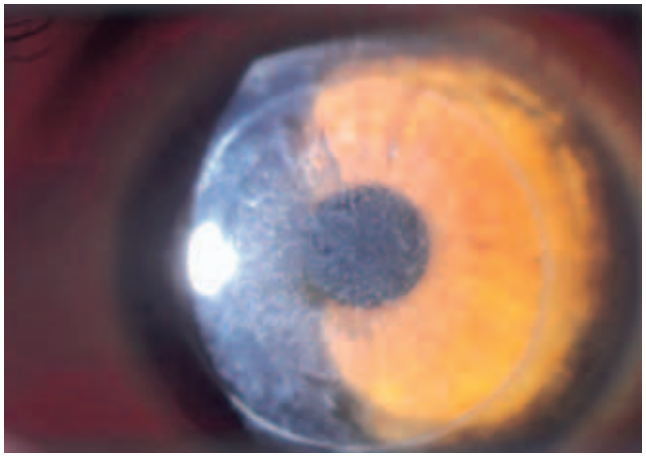

FIGURE 3A
Preoperatively, patient 11 had recurrent Reis-Bücklers' dystrophy 6 years after a corneal transplant and 3 years after PTK.

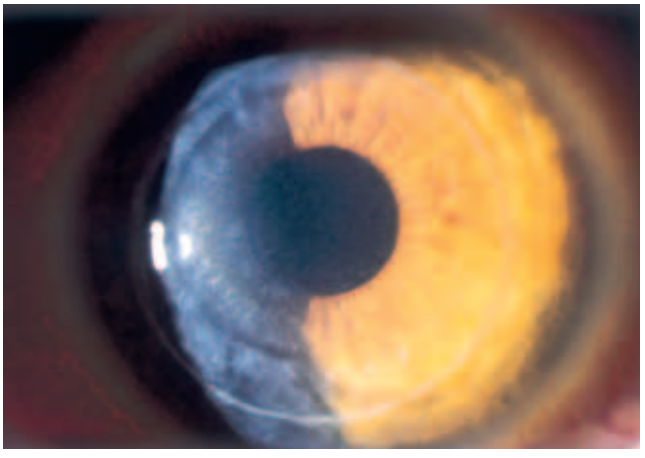

FIGURE 3B
Ten weeks postoperatively, there was considerable clearing of the central opacity in patient 11, although some haziness persisted.

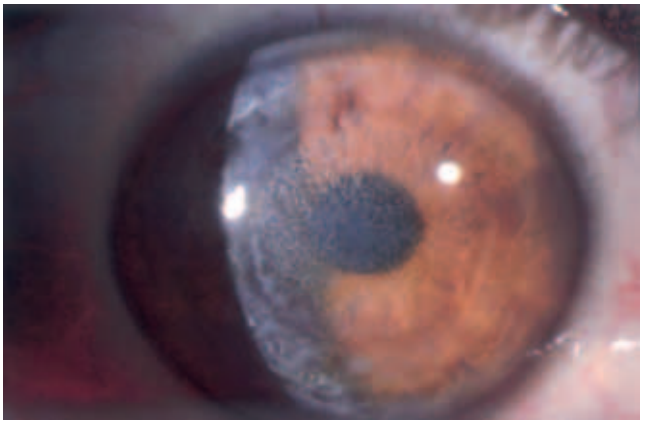

FIGURE 4A
Preoperatively, patient 10R had recurrent Reis-Bücklers' dystrophy 13 years after a 9-mm-diameter superficial keratectomy and 8 and 3 years after two previous 6-mm-diameter PTKs.

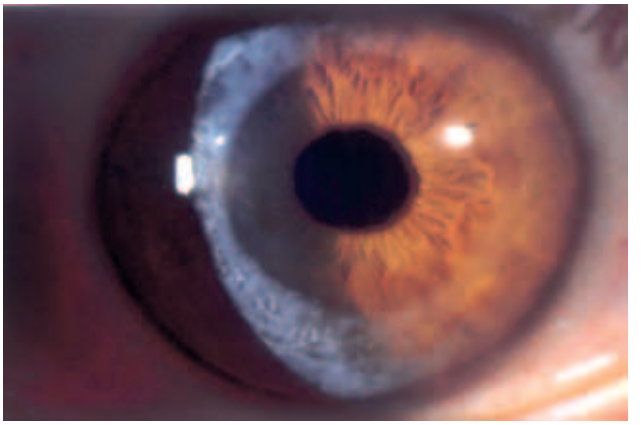

FIGURE 4B
Eight weeks postoperatively, the central cornea in patient 10R is considerably clearer.

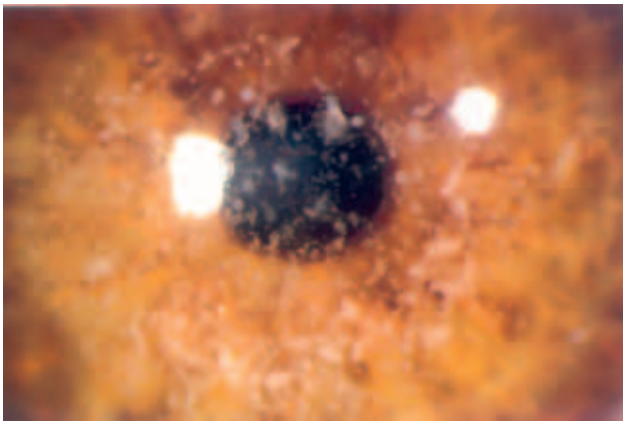

FIGURE 5A
Preoperatively, patient 5R had almost confluent central corneal opacities from granular dystrophy and complained of poor vision.

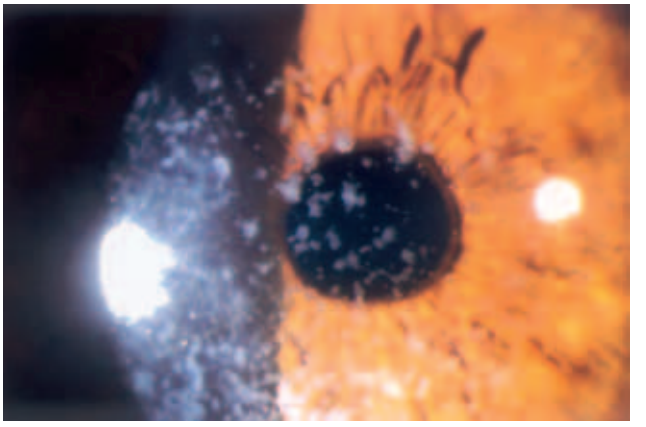

FIGURE 5B
Postoperatively, there are notably more clear zones between the deeper residual granular deposits in patient 5R. Patient noted much improved quality of vision even though significant deposits persisted.

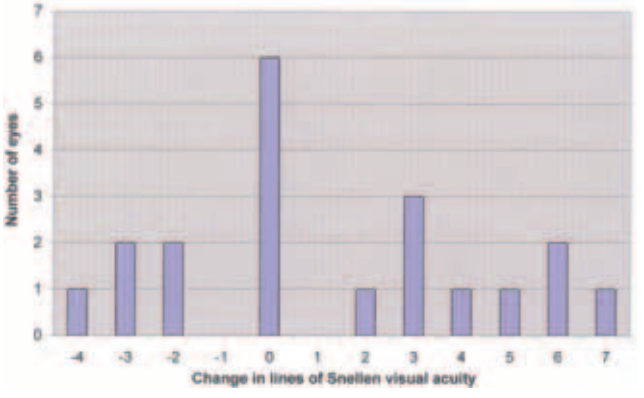

FIGURE 6
Change in lines of uncorrected Snellen visual acuity after excimer laser PTK.

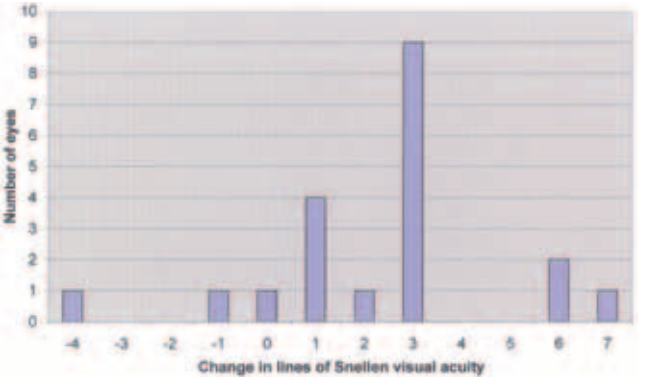

FIGURE 7
Change in lines of best spectacle corrected Snellen visual acuity after excimer laser PTK.

TABLE V: VISUAL ACUITY RESULTS

PT NO.	WEEKS F/U	VASC PREOP	VASC POSTOP	CHANGE IN SNELLEN LINES	VACC PREOP	VACC POSTOP	CHANGE IN SNELLEN LINES
1	6	20/400	20/400	0	20/60	20/30	3
2	6	20/50	20/30	2	20/50	20/30	2
3R	7	20/400	20/80	3	20/60	20/30	3
3L	7	20/200	20/200	0	20/50	20/40	1
4R	6	20/200	20/40	6	20/60	20/30	3
4L	14	20/80	20/40	4	20/70	20/40	3
5R	6	20/70	20/100	-2	20/70	20/40	3
5L	7	20/200	20/200	0	20/70	20/40	3
6	8	20/70	20/200	-3	20/60	20/200	-4
7R	6	20/200	20/70	3	20/200	20/30	7
7L	6	20/40	20/40	0	20/30	20/30	0
8	8	20/50	20/80	-2	20/50	20/40	1
9R	7	20/400	20/80	3	20/70	20/40	3
9L	6	20/400	20/60	5	20/100	20/60	3
10R	8	20/100	20/30	6	20/50	20/25	3
10L	6	20/60	20/60	0	20/50	20/40	1
11	10	20/400	20/40	7	20/100	20/30	6
12	6	20/200	20/200	0	20/200	20/40	6
13	6	20/70	20/400	-4	20/70	20/60	1
14	6	20/80	20/400	-3	20/50	20/60	-1
Mean:	7.1	20/102	20/69	1.25	20/62	20/38	2.35

Postop, Postoperative; Preop, preoperative; Vacc, best spectacle-corrected visual acuity; Vasc, uncorrected visual acuity.

6.24 D flatter). There was no statistically significant correlation between change in corneal topography simulated keratometry reading and the laser ablation depth (Spearman correlation –0.48, P = .0616). There was no statistically significant correlation between the change in Haag-Streit keratometry and the change in corneal topography simulated keratometry readings (Spearman correlation 0.47, P = .0906) or change in manifest refraction spherical equivalent and change in corneal topography simulated keratometry readings (Spearman correlation –0.42, P = .0979) (Figures 9 through 14).

Corneal Topography Central Corneal Power Measurements

Central corneal power measurements from the EyeSys corneal topographic analyses were generated in 19 eyes preoperatively and all 20 eyes postoperatively. Mean central power was 44.71 ± 2.23 D preoperatively and

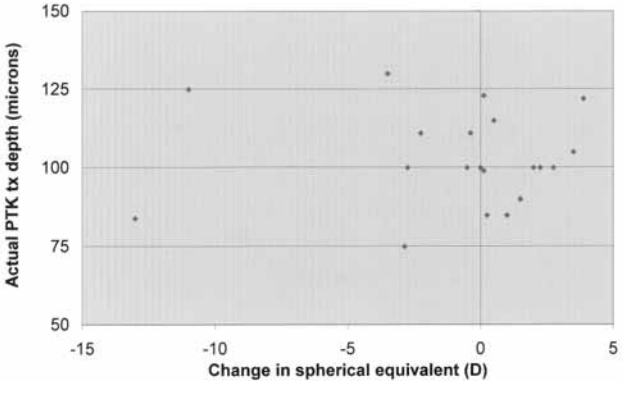

FIGURE 8

Change in manifest refraction spherical equivalent compared to actual PTK treatment depth. There was no statistically significant correlation.

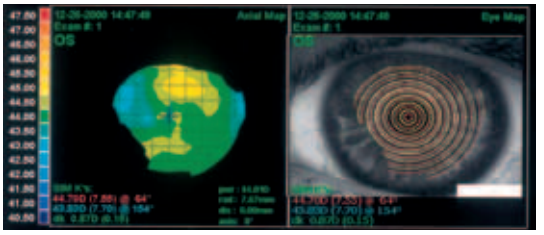

FIGURE 9A

Preoperative computerized corneal topography for patient 2. The simulated keratometry readings are found in the lower left cornea of the color map located on the left. The central corneal power measurement is found in the lower right cornea of the same color map.

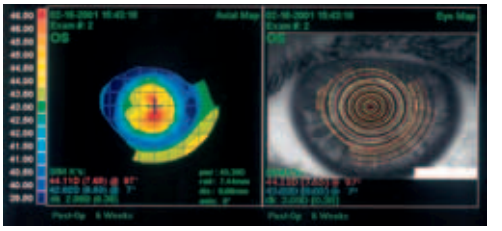

FIGURE 9B

Postoperative computerized corneal topography for patient 2. Patient underwent 100-µm PTK ablation without use of masking agent and with no antihyperopia treatment. While there appears to be significant central steepening compared to preoperative corneal topography in Figure 9A, color scales found on left are different.

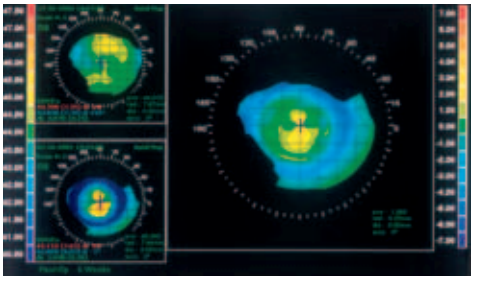

FIGURE 9C

Preoperative (upper left), postoperative (lower left), and difference (right) computerized corneal topography maps for patient 2. Note the central area of the difference map demonstrates only a mild steepening from preoperatively to 6 weeks postoperatively.

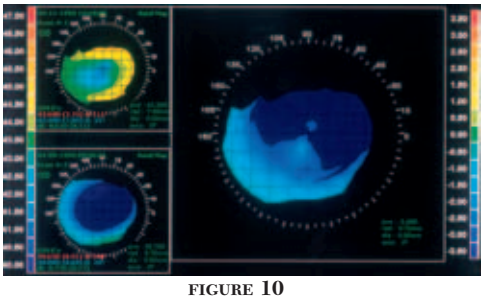

FIGURE 10

Preoperative (upper left), postoperative (lower left), and difference (right) computerized corneal topography maps for patient 5. After 90-µm PTK ablation and no antihyperopia treatment, there was approximately 3.5 D of central corneal flattening. There was corresponding 1.5-D hyperopic shift in manifest refraction.

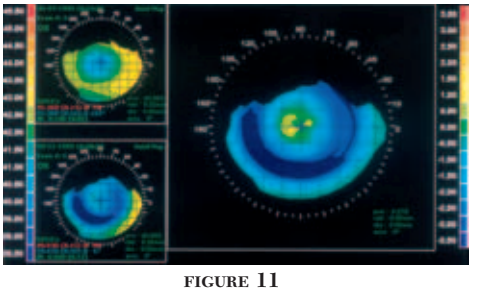

FIGURE 11

Preoperative (upper left), postoperative (lower left), and difference (right) computerized corneal topography maps for patient 7R. The difference map revealed essentially no change in central corneal curvature after a 100-µm PTK ablation and 200-µm total antihyperopia treatment. There was a 2.5-D myopic shift in manifest refraction.

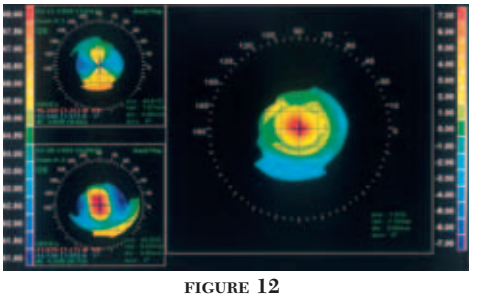

FIGURE 12

Preoperative (upper left), postoperative (lower left), and difference (right) computerized corneal topography maps for patient 10R. Patient underwent 123-µm PTK treatment and 120-µm total antihyperopia treatment. While difference map demonstrates approximately 7 D of central steepening, manifest refraction only changed from +2.50 (20/50) preoperatively to +2.00 (20/40) postoperatively.

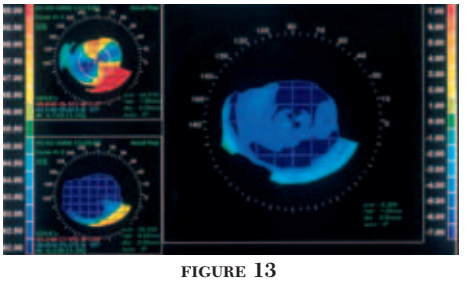

FIGURE 13

Preoperative (upper left), postoperative (lower left) and difference (right) computerized corneal topography maps for patient 11. After a 105-µm PTK ablation and a 120-µm total antihyperopia treatment, there was significant corneal flattening demonstrated on difference map (6 D) associated with a 3.5-D hyperopic shift in manifest refraction.

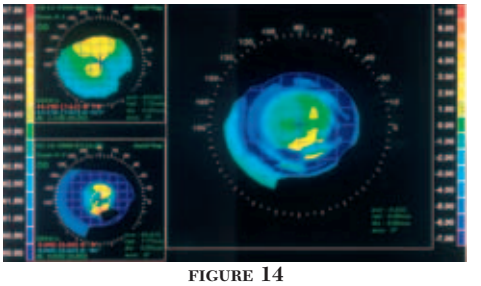

FIGURE 14

Preoperative (upper left), postoperative (lower left), and difference (right) computerized corneal topography maps for patient 14. The patient underwent a 130-µm PTK ablation with a 160-µm total antihyperopia treatment. While the difference map demonstrates almost no change in central corneal curvature, there was a 3.5-D myopic shift in manifest refraction.

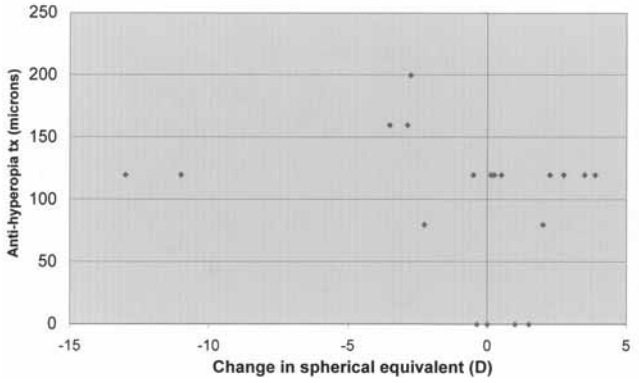

FIGURE 15
Change in manifest refraction spherical equivalent compared to the amount of antihyperopia treatment. There was no statistically significant correlation.

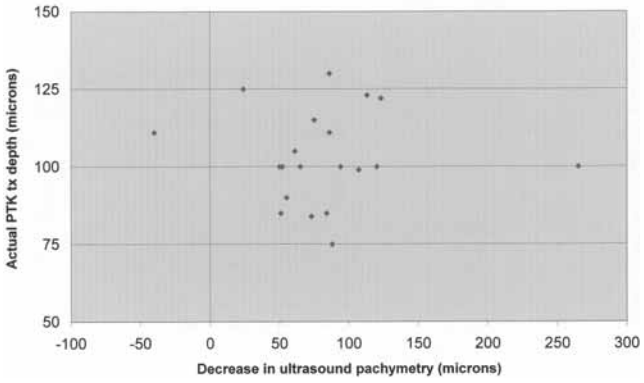

FIGURE 16
Change in ultrasound pachymetry measurement of corneal thickness compared to actual PTK treatment depth. There was no statistically significant correlation. Note that the ultrasound pachymetry measurement increased in one eye after PTK.

44.33 ± 3.73 postoperatively. There was a mean change of –0.44 ± 4.12 D (range, 7.91 D steeper to 9.06 D flatter) in the 19 eyes with both preoperative and postoperative data. There was no statistically significant correlation between the change in corneal topography central power measurements and change in manifest refraction spherical equivalent (Spearman correlation –0.42, $P = .0760$) or change in Haag-Streit keratometry readings (Spearman correlation 0.19, $P = .4914$). There was a statistically significant correlation between the change in corneal topography central power measurements and the change in corneal topography simulated keratometry readings (Spearman correlation 0.72, $P = .0017$) (Figures 9 through 14).

Astigmatism

Since a primary goal of PTK is creating a more regular cornea, the absolute amount of astigmatism, regardless of axis, was evaluated. There was minimal change in manifest refraction cylinder (±1 D) in 14 eyes (70%) and an increase of >1 to 2 D in two eyes (10%). There was a decrease in manifest refraction cylinder of 2 to 3 D in one eye (5%) and 4 to 6 D in three eyes (15%).

Haag-Streit keratometry readings were available preoperatively and postoperatively in 16 eyes. The keratometric cylinder was essentially unchanged (±1 D) in 8 eyes (50%). There was an increase in keratometric cylinder of >1 to 2 D in one eye (6%), >2 to 3 diopters in two eyes (13%), and 4 to 5 diopters in one eye (6%). There was a decrease of >1 to 2 diopters of keratometric cylinder in three eyes (19%) and 2.5 diopters in one eye (6%).

Simulated keratometry readings from the EyeSys corneal topography machine were available preoperatively and postoperatively for 16 eyes. In six eyes (38%) there was minimal change in cylinder (±1 diopter). In six eyes (38%) there was an increase of >1 to 2 D, in one eye (6%) an increase of 2.5 D, and in one eye (6%) an increase of 3.5 D. There was a decrease of >1 to 2 diopters of topographic simulated keratometric cylinder in two eyes (13%). There were no statistically significant correlations between the three measurements of astigmatism.

Effect of Antihyperopia Treatment

Antihyperopia treatments were performed on 16 of the 20 eyes. Depth of ablation for the entire antihyperopia treatment ranged from 80 to 200 µm (mean, 125 ± 29 µm). There was no statistically significant correlation between amount of central ablation and amount of antihyperopia treatment (Spearman correlation 0.13, $P = .57$). There was no statistically significant correlation between the amount of antihyperopia treatment and change in manifest refraction spherical equivalent (Spearman correlation –0.30, $P = .20$) (Figure 15), change in Haag-Streit keratometry (Spearman correlation 0.34, $P = .20$), change in EyeSys topographic simulated keratometry (Spearman correlation 0.17, $P = .52$) or change in EyeSys topographic central power (Spearman correlation -0.02, $P = .93$). There was a statistically significant correlation between the amount of antihyperopia treatment and number of days required for reepithelialization (Spearman correlation 0.64, $P = .0026$).

ULTRASOUND MEASUREMENTS

Ultrasound Pachymetry

Preoperatively, central ultrasound pachymetry ranged from 400 to 780 µm (mean, 650 ± 87 µm). Postoperatively, central ultrasound pachymetry ranged from 380 to 645 µm (mean, 479 ± 58 µm). Taking each eye individually, there was a mean decrease in central pachymetry of 82 ± 57 µm (range, increase of 40 µm to a decrease of 265 µm) (Table VII). There was no statistically significant correlation between difference in ultrasound pachymetry from preoperatively to postoperatively and the PTK ablation depth calculated at the time of

TABLE VI: REFRACTIVE RESULTS

PT NO.	MR PREOP	MR POSTOP	HAAG-STREIT K'S PREOP	HAAG-STREIT K'S POSTOP	EYESYS SIM K'S PREOP	EYESYS SIM K'S POSTOP	EYESYS POWER PREOP	EYESYS POWER POSTOP
1	-7.25+6.50x22	-7.50+6.25x20	unable	42x105/50x20	unable	43.43/49.05x5	45.49	47.71
2	plano	plano	44.25/46.50x95	43.5/45.0x100	43.83/44.70x64	42.02/44.11x97	44.01	45.39
3R	+3.75+5.25x180	+2.25+2.50x15	unable	43/44.5x15	unable	42.72/45.91x171	unable	45.44
3L	+1.00+6.00x30	-9.00 sphere	43/48.50x145	47.47/54.50x45	45.0/49.48x30	47.60/53.65x27	47.35	50.58
4R	-2.25 sphere	-0.50+1.00x140	45.0 sph	42.5/45.0x100	44.46/45.30x62	42.88/45.54x100	53.49	44.43
4L	-2.50 sphere	plano+0.50x30	44/45.50x60	43 sphere	44.23/45.91x78	41.82/42.39x31	43.04	41.94
5R	+0.50+0.75x180	+2.00+0.75x80	42.50/43.50x90	40.50/41.50x90	42.99/43.60x111	38.88/39.65x100	42.2	38.79
5L	-1.50+1.50x30	+2.50+1.25x175	42/43.50x90	38.0/42.0x90	42.93/43.83x69	38.61/41.20x74	43.5	40.81
6	+1.00+0.50x9	+0.50+1.75x180	40.50/42x180	40 sphere	40.46/41.71x20	39.33/44.06x32	40.97	46.06
7R	-1.00 sphere	-4.00+0.50x90	41.25/41.50x45	41.5/42.5x65	41.66/42.08x180	40.85/41.76x52	41.79	42.13
7L	+0.25 sphere	+0.75 sphere	39.50 sphere	unable	41.36/41.46x72	39.47/40.03x96	40.58	40.85
8	-0.50+0.25x55	-3.00+0.75x70	43/44.5x10	40.5/42.120	43.38/45.18x13	39.47/41.66x35	45.67	43
9R	plano+5.00x80	+4.00+1.00x90	39/48x70	40/47.75x75	40.03/45.79x73	40.27/47.20x79	42.84	43.52
9L	-3.50 sphere	-3.00+1.00x165	unable	44/51x150	45.48/53.57x149	45.06/51.92x143	49.16	48.88
10R	-0.25+4.50x75	-0.50+5.25x75	40/45.50x75	36.75/43.25x75	39.75/45.0x69	36.09/42.93x80	42.25	42.52
10L	+2.50 sphere	+2.0 sphere	42/49x90	41/45.5x100	42.34/46.16x93	42.72/47.07x95	44.61	52.52
11	-5.0+5.0x40	+1.0 sphere	37/43.50x125	36/43x120	42.45/48.28x112	36.01/42.24x122	44.9	38.23
12	-6.75+2.50x140	-6.50+2.50x125	45/48x150	47/50x115	unable	47.33/48.35x162	44.4	47.37
13	plano	-11.50+1.0x140	46/46.50x125	47/47.50x125	45.98/47.87x28	42.66/47.0x47	49.38	43.05
14	-0.75 sph	-5.0+1.50x50	40.75/42x75	43.50/49.50x95	43.10/44.58x71	unable	43.84	43.41

K's, keratometry readings; Postop, postoperative; Preop, preoperative; Sim K's, simulated keratometry readings.

surgery (Spearman correlation 0.02, $P = .93$) (Figure 16).

UBM Analysis

Because of a hard-drive malfunction, UBM data was available for 35 of the 39 examinations performed. One patient declined to undergo the postoperative UBM examination because of discomfort during the preoperative examination. The central vertical and horizontal images were used to evaluate total corneal thickness and depth of pathology. The average of the vertical and horizontal measurements was used for statistical analysis (Figures 17 through 19). The 1-, 2-, and 3-mm off-center UBM images were not used for analysis in this study.

Central Corneal Thickness. Preoperative UBM central corneal thickness measurements ranged from 510 to 730 µm (mean, 616 ± 58 µm). Postoperatively, UBM central corneal thickness measurements ranged from 430 to 701 µm (mean, 547 ± 64 µm). There was a highly statistically significant correlation between preoperative ultrasound pachymetry and preoperative UBM pachymetry (Spearman correlation 0.82, $P<.001$) (Figure 20) and postoperative ultrasound pachymetry and postoperative UBM pachymetry (Spearman correlation 0.92, $P<.001$) (Figure 21). For the 16 eyes with both preoperative and postoperative data, UBM central pachymetry decreased 29 to 113 µm (mean, 70 ± 26 µm) (Table VII). There was no statistically significant correlation between the difference in UBM corneal thickness measurements from preoperatively to postoperatively and the PTK ablation depth calculated at the time of surgery (Spearman correlation –0.20, $P = .47$) (Figure 22). There was also no statistically significant correlation between difference in ultrasound pachymetry measurements and difference in UBM corneal thickness measurements from preoperatively to postoperatively (Spearman correlation 0.04, $P = .89$).

Corneal Pathology Thickness. UBM estimates of

TABLE VII: A-SCAN AND UBM PACHYMETRY RESULTS

PT NO.	ULTRASOUND PREOP	ULTRASOUND POSTOP	ULTRASOUND DIFFERENCE	UBM PACHYMETRY PREOP	UBM PATHOLOGY PREOP	UBM PACHYMETRY POSTOP	UBM DIFFERENCE PACHYMETRY
1	534	448	-86	N/A	N/A	N/A	N/A
2	540	475	-65	N/A	N/A	N/A	N/A
3R	600	512	-88	654	191	541.5	-112.5
3L	535	462	-73	631.5	150.5	532.5	-99
4R	659	565	-94	682.5	133	619.5	-63
4L	650	530	-120	677	156.5	593	-84
5R	495	440	-55	590	145.5	526.5	-63.5
5L	503	380	-123	527.5	111.5	469	-58.5
6	560	453	-107	607.5	139	527	-80.5
7R	528	476	-52	581.5	167	544	-37.5
7L	520	445	-75	547	116	510	-37
8	400	440	40	614	174	504.5	-109.5
9R	780	515	-265	671.5	162.5	625.5	-46
9L	696	645	-51	729.5	156.5	701	-28.5
10R	550	437	-113	N/A	N/A	527	N/A
10L	542	492	-50	613	162	533	-80
11	522	461	-61	579	151	N/A	N/A
12	601	517	-84	654	150	596	-58
13	430	406	-24	509.5	127	429.5	-80
14	558	472	-86	607.5	105	521	-86.5
Mean:	560.2	478.6	-81.6	616.3	146.9	547.1	-70.3
SD:	87.1	58.5	56.7	58.4	22.9	63.8	25.6

All values in microns.
N/A, not available; Postop, postoperative; Preop, preoperative; UBM, ultrasound biomicroscopy.

corneal pathology preoperatively ranged from 105 to 191 µm (mean, 147 ± 23 µm) (Table VII). When this measurement was compared with the actual PTK treatment depth for each patient, there was no statistically significant correlation (Spearman correlation –0.45, $P = .07$) (Figure 23). There was actually a trend toward the UBM measurement of corneal pathology being inversely correlated with the amount of treatment necessary to clear the majority of the corneal opacity. That is, the deeper the UBM measurement of pathology, the less PTK treatment tended to be required. UBM measurement of corneal pathology also generally overestimated the depth of treatment.

DAYS TO REEPITHELIALIZATION AND COMPLICATIONS

Thirteen eyes (65%) were totally reepithelialized by postoperative day 3 (Figure 24). Three additional eyes reepithelialized by postoperative day 4 or 5. Three eyes required 8 to 10 days and one eye required 41 days to reepithelialize (Table IV). The eye that required 41 days to reepithelialize had undergone a penetrating keratoplasty 10 years prior to PTK for lattice dystrophy. This delay in reepithelialization resulted in a small paracentral corneal scar (Figure 25). The fellow eye underwent PTK in this study for recurrent lattice dystrophy in a penetrating graft performed 7 years earlier and required 9 days to reepithelialize. There was a statistically significant correlation between the amount of antihyperopia treatment and number of days for the surface to reepithelialize (Spearman correlation 0.64, $P = .0026$). There was no correlation between actual PTK treatment depth and days to reepithelialization (Spearman correlation –0.11, $P = .6341$).

Trace to mild reticular haze was seen at the periphery of the ablations in most eyes. In none of the eyes was this reticular haze considered significant. Eleven eyes (55%) developed mild central haze and were treated with a topical corticosteroid drop (fluorometholone 0.1% in 7 eyes, loteprednol 0.5% in 3 eyes, and prednisolone acetate 1% in 2 eyes; one received both fluorometholone and loteprednol). It was generally used four times a day for the first month and then tapered over 2 to 4 months. No eye developed significant central haze. There was no difference found in corneal clarity, visual acuity, or refractive or reepithelialization results between the 11 eyes that were treated and the nine eyes that were not treated with topical corticosteroids postoperatively.

There were no corneal infections or graft rejections. Two patients (11 and 14) underwent subsequent penetrating keratoplasty, 12 and 3 months, respectively, after the PTK because of poor vision after PTK (Figure 26). These procedures were not any different than in eyes that had not previously undergone PTK.

RESULTS AFTER PREVIOUS CORNEAL SURGERY

There was no difference found in corneal clarity, visual acuity, refractive, or reepithelialization results between the 12 eyes with and the 8 eyes without previous corneal surgery.

Selected statistical correlations are found in the Appendix.

HISTOPATHOLOGY

Histopathologic analysis was performed on the two corneas that underwent penetrating keratoplasty. Patient 11 had undergone previous corneal transplantation and PTK for Reis-Bücklers' dystrophy. Centrally in the area of photoablation, Bowman's layer and the anterior part of the stroma were absent and the epithelium was irregular in caliber with a saw-toothed configuration. A thin layer of intensely eosinophilic finely crystalloid material consistent with the subepithelial deposits of Reis-Bücklers' dystrophy was present beneath the epithelium. The periphery of the specimen contained larger deposits of the eosinophilic material.

Patient 14 had undergone PTK for lattice corneal dystrophy type I. The corneal button showed marked variation in the caliber of the corneal epithelium (Figure 27A). Peripherally, the epithelium was normal in thickness. Centrally, where PTK had photoablated Bowman's layer and nearly half of the stroma, the epithelium had undergone massive compensatory hyperplasia. Here, a large placoid facet of epithelium approximately 100 µm in thickness filled the defect in the anterior stroma and served to maintain a smoothly curved anterior corneal surface. The underlying stroma was approximately 300 µm in thickness. The Congo red stain and polarization microscopy disclosed ovoid deposits of amyloid material consistent with lattice corneal dystrophy deep to the area of ablation and throughout the thickness of the corneal stroma (Figure 27B).

DISCUSSION

Twenty eyes of 14 patients were prospectively enrolled in this study to evaluate the use of UBM analysis of anterior corneal pathology as a predictor of depth for excimer laser PTK treatment. The visual and refractive results were also analyzed, especially in relation to an antihyperopia peripheral ablation. A relatively uniform patient population with superficial stromal corneal dystrophies was studied to obtain the most consistent results. It has been shown that visual recovery after PTK for corneal dystrophies occurs relatively quickly, usually in the first several months.[44,79,80] The postoperative follow-up period of 6 to 8 weeks was selected for this study to maximize visual recovery while minimizing corneal remodeling and long-term recurrence of dystrophies to obtain the best analysis of the actual effects of the laser ablation on corneal pathology and curvature. By 6 to 8 weeks, epithelialization has generally been completed for several weeks and the corneal surface is typically quite smooth. However, there has not been enough time for significant epithelial or stromal remodeling or recurrence of the dystrophy to occur, minimizing the effect of these potential confounding variables. It is possible that UBM measurements would have different correlations with the amount of PTK required to treat pathology with longer follow-up periods.

VISUAL ACUITY

Uncorrected visual acuity improved 2 to 7 Snellen lines in 9 eyes (45%) and decreased 2 to 4 lines in 5 eyes (25%). Best corrected visual acuity improved 2 to 7 lines in 13 eyes (65%) and decreased 4 lines in one eye (5%). This improvement in visual acuity is consistent with previously published reports.[9,15,16,19,34,36,37,40-44] Preoperative and postoperative uncorrected vision were not correlated ($P = .54$) nor were preoperative and postoperative best corrected vision ($P = .47$), as many eyes with poor preoperative vision improved greatly and those with better preoperative vision could not improve as much. Consequently, preoperative vision was not found to be a determinant of postoperative vision.

UBM MEASUREMENT OF DEPTH OF CORNEAL PATHOLOGY

One of the most important factors determining the success of excimer laser PTK is the depth of the pathology. The depth of pathology determines the extent of treatment required to remove the majority of the opacity. Deep abla-

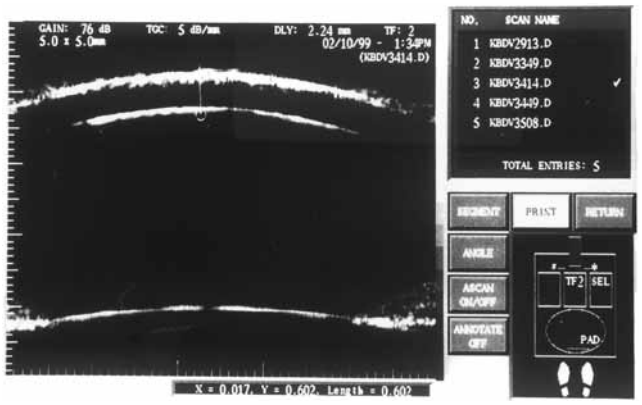

FIGURE 17A

Preoperatively, a UBM image was obtained to measure the corneal thickness and thickness of pathology in patient 7 with granular dystrophy. Cursor is placed at the most anterior and posterior extent of the central cornea at a 90° angle, and length is measured at the bottom of the screen (0.602 mm).

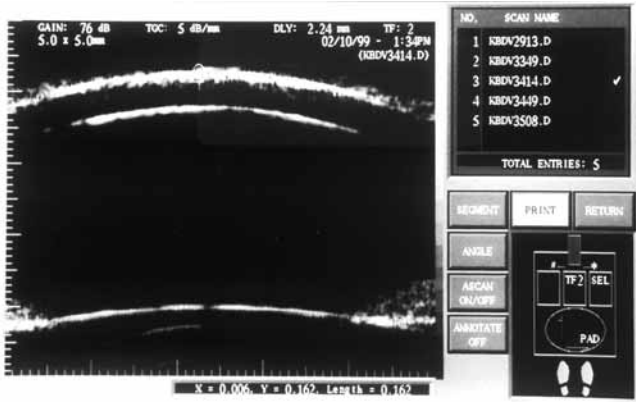

FIGURE 17B

The same image as in Figure 17A was used to measure the thickness of the corneal opacity in an identical manner. It measured 0.162 mm.

FIGURE 17C

Six weeks postoperatively, the UBM image is used to remeasure the corneal thickness (0.567 mm) in patient 7.

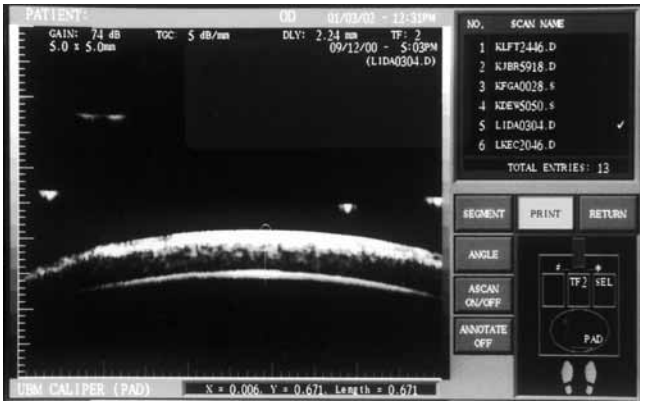

FIGURE 18A

Preoperatively in patient 9R with recurrent Reis-Bücklers' dystrophy in a graft, the central corneal thickness measured 0.671 mm.

FIGURE 18B

Preoperatively, the pathology in patient 9R measured 0.162 mm.

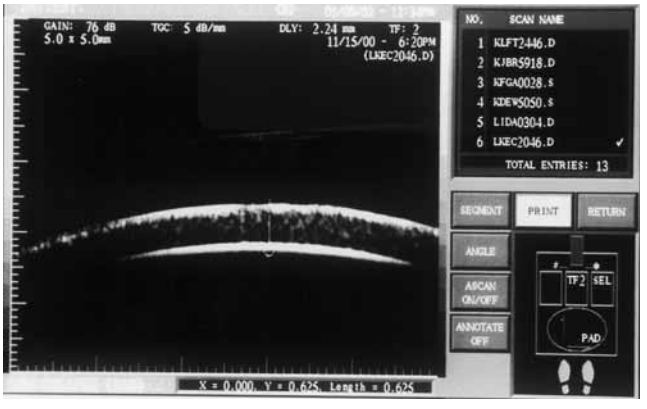

FIGURE 18C

Postoperatively in patient 9R, the corneal thickness measured 0.625 mm.

FIGURE 19A

UBM image of central cornea of patient 14 with lattice dystrophy before PTK. Note deep hyperreflective area on right of the image, which corresponded to deep amyloid deposits. Central corneal thickness measured 0.613 mm.

FIGURE 19B

Same image as in Figure 19A is used to measure central anterior corneal pathology (0.104 mm).

FIGURE 19C

Six weeks postoperatively, the UBM measured the central corneal thickness in patient 14 to be 0.521 mm.

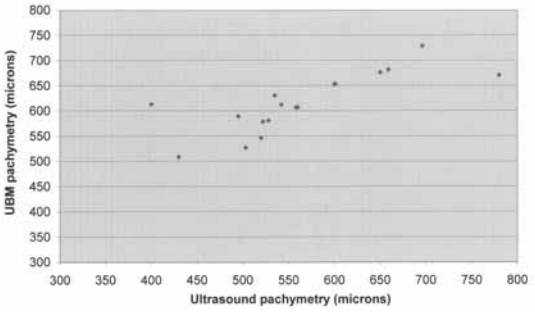

FIGURE 20

Comparison preoperative ultrasound pachymetry measurement of corneal thickness to UBM measurement of corneal thickness. Measurements were highly correlated ($P<.001$).

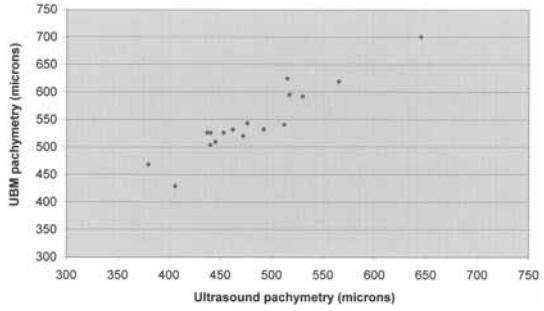

FIGURE 21

Comparison postoperative ultrasound pachymetry measurement of corneal thickness to UBM measurement of corneal thickness. Measurements were highly correlated ($P<.001$).

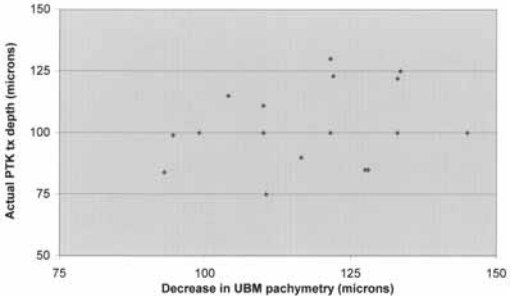

FIGURE 22

Change in UBM pachymetry compared to actual PTK treatment depth. There was no statistically significant correlation.

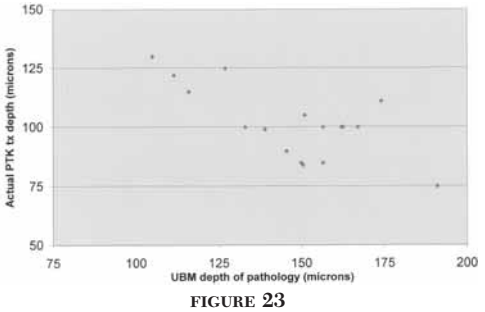

FIGURE 23

Comparison of UBM measurement of corneal pathology and actual PTK treatment depth. There was no statistically significant correlation. There was a trend (P = .07) of an inverse correlation between UBM measurement of corneal pathology and actual PTK treatment depth.

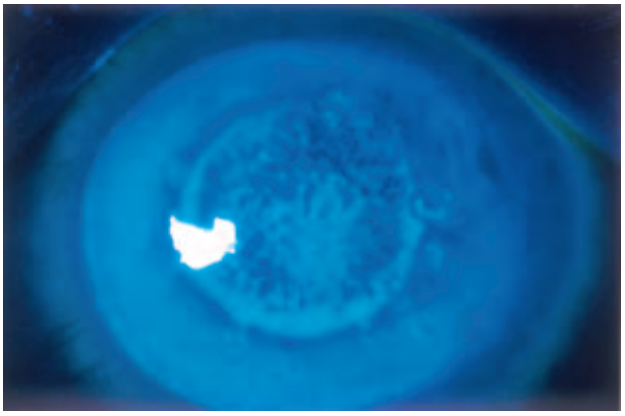

FIGURE 24
Three days after PTK in patient 7L, surface has reepithelialized. Corneal thinning in the central 6-mm area of PTK treatment is apparent and there is fluorescein pooling at edge of the ablation zone.

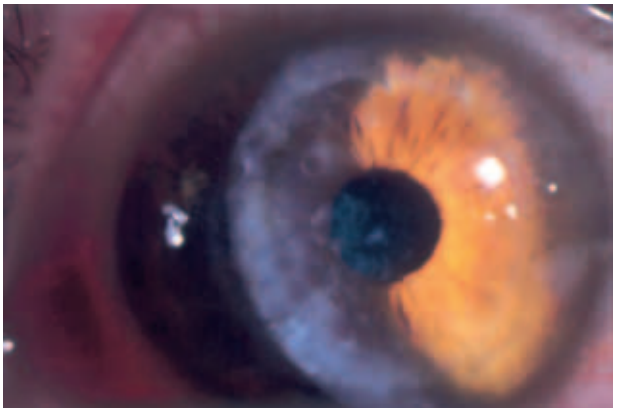

FIGURE 25A
Preoperatively, patient 3R had significant recurrent lattice dystrophy 10 years after penetrating keratoplasty.

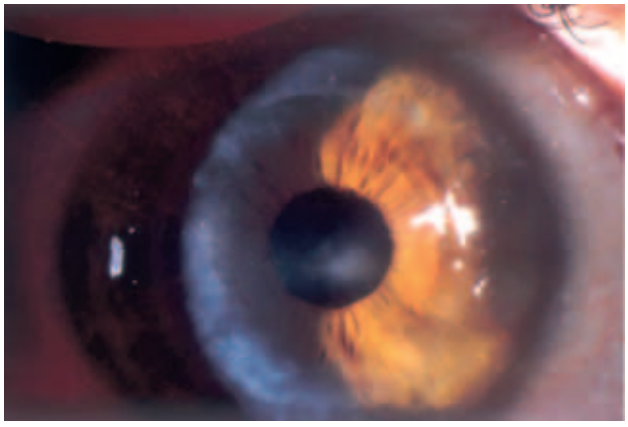

FIGURE 25B
This eye (3R) required 41 days to completely reepithelialize. The chronic paracentral epithelial defect left a corneal scar when it finally resolved. Seven weeks after PTK, the scar is visible at the inferonasal pupillary margin. The surrounding central cornea is much clearer than preoperatively and both uncorrected and best corrected visual acuity improved 3 Snellen lines.

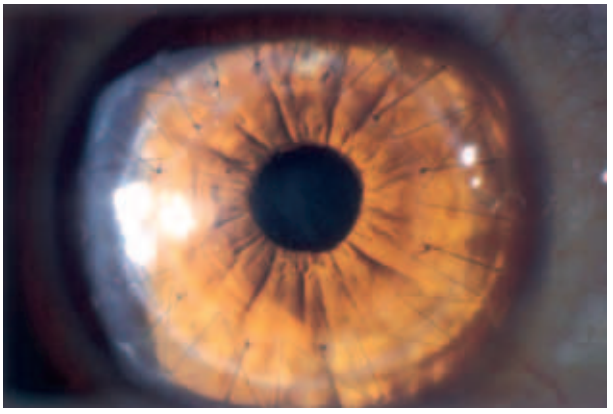

FIGURE 26
Patient 14 underwent a penetrating keratoplasty 4 months after PTK on account of worsened vision. One year after transplant, corneal graft is clear and the vision without correction is 20/50.

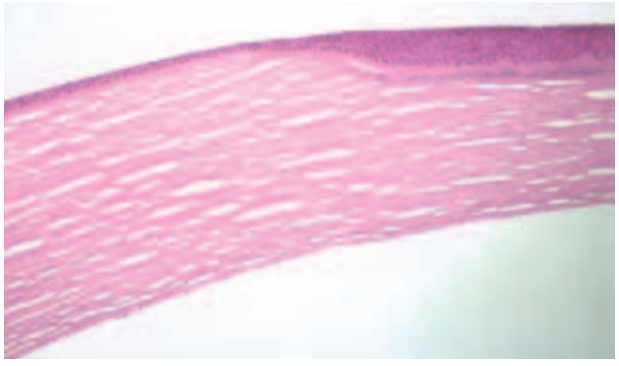

FIGURE 27A
Penetrating keratoplasty specimen for patient 14. A large placoid facet of epithelium that has undergone compensatory hyperplasia fills the defect in anterior part of central cornea caused by photoablation. Approximately 100 μm in thickness, the thickened epithelium maintains the smooth contour of anterior corneal surface (hematoxylin-eosin, original magnification ×50).

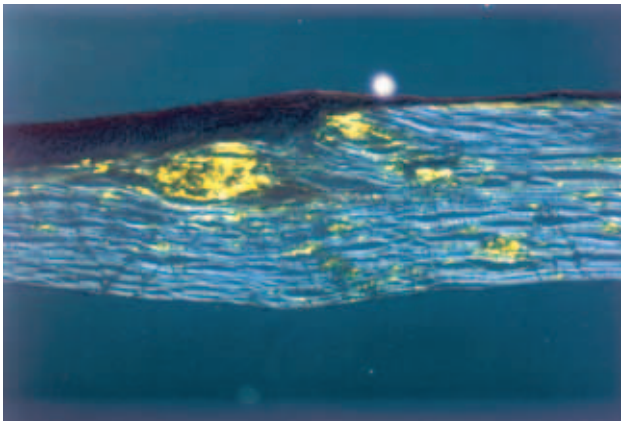

FIGURE 27B
Polarization microscopy discloses birefringent apple-green deposits of amyloid consistent with lattice corneal dystrophy throughout the corneal stroma. A large deposit is seen deep to the hyperplastic epithelium in the area of photoablation. (Congo red stain with crossed polarizers, original magnification ×50).

tions have been associated with significant corneal flattening and hyperopic shift.[15-19] A goal of this study was to determine whether UBM was effective in predicting the depth of treatment required to clear the bulk of corneal pathology prior to PTK treatment. The results of this research demonstrated that preoperative estimation of depth of pathology using UBM was not correlated with actual treatment depth required during the procedure (Spearman correlation –0.45, $P = .07$). There was actually a trend toward an inverse correlation between UBM measurement of corneal pathology and PTK treatment. That is, the greater the UBM pathology measurement, the less PTK treatment tended to be necessary. In addition, UBM measurement of corneal pathology tended to overestimate the amount of PTK treatment required to remove the majority of the pathology. If the UBM measurement of corneal pathology were used to screen candidates for PTK, many acceptable candidates might be turned away, as the depth of their pathology tended to be overestimated. Additionally, if the UBM measurement were used to treat a patient, more tissue than necessary would tend to be removed. While the number of eyes in this study was relatively small, given the results, it is doubtful that a larger number of eyes would have shown UBM to accurately predict PTK treatment depth.

The reason that UBM could not predict actual treatment depth is most likely multifactorial. One of the most important issues is that, while UBM resolution is relatively good, it is certainly not capable of the submicron accuracy of the excimer laser. Attempting to measure the extent of the pathology on the UBM computer screen, even by a very experienced technician, was quite difficult in many eyes. Explanations for this difficulty include suboptimal resolution and the fact that the pathology was not uniform throughout the UBM sections. This nonuniformity is quite evident clinically at the slit lamp in certain eyes. A patient with granular dystrophy may have localized areas of deep, relatively confluent granules and other areas of relatively clear cornea. In addition, the cursor on the UBM computer screen has a minimal change of 6 µm horizontally and 12 µm vertically, preventing higher degrees of precision. Another reason is that the depths of pathology and the depths of treatment of eyes in this study did not vary greatly, since all procedures were performed in eyes that were thought to be good candidates for PTK based on slit-lamp evaluation. That is, all patients had enough pathology to cause visual symptoms, but the opacities were not extremely deep. This relative uniformity in extent of pathology and treatment depth makes small differences difficult to confirm statistically.

CHANGES IN CORNEAL CURVATURE

Multiple measurements of corneal curvature were evaluated in this study, because manifest refractions are not always accurate in eyes with poor vision. Keratometry and corneal topography measurements are more objective, but are not always obtainable, or very precise, in corneas with irregular surfaces. Haag-Streit keratometry readings, EyeSys simulated keratometry readings. and EyeSys corneal power measurements all correlated with each other both preoperatively and postoperatively, demonstrating consistency in corneal curvature measurements. The refractive effects of PTK, measured by changes in manifest refraction spherical equivalent, Haag-Streit keratometry readings, EyeSys corneal topography simulated keratometry readings, and central corneal power measurement, could not be correlated to depth of ablation or antihyperopia treatment, most likely because the depth of ablation and antihyperopia treatment tended to cancel each other out.

While depth of ablation has been shown to correlate with corneal flattening and induced hyperopia, most of these studies used a wide variety of ablation depths, including many eyes with very deep ablations (>100 µm stromal ablation).[11,15,16,18,43] Additionally, previous studies generally did not use antihyperopia treatments in attempt to reduce corneal flattening and hyperopic shift. In this study, deep ablations were avoided. Furthermore, all ablation depths were in a relatively narrow band, between 75 and 130 µm, which included epithelium (typically 40 to 50 µm thick) and stroma. On account of the relatively small number of patients who did not receive an antihyperopia treatment, it was not possible to separately evaluate the refractive effects of depth of ablation and the antihyperopia treatment. The results of this study found an approximately 1 D mean myopic shift 6 to 8 weeks after PTK; however, the range of change in spherical equivalent refraction was large, –13 to +3.88 D. The unpredictability was much more of an issue than a hyperopic shift in this study. The unpredictability is at least partly due to the difficulty in obtaining accurate refractions in patients with poor vision and precise measurements of corneal curvature in eyes with irregular surfaces. There was no statistically significant correlation between central PTK treatment depth and change in spherical equivalent, change in Haag-Streit keratometry readings, change in EyeSys simulated keratometry readings, or change in EyeSys corneal power measurements. This lack of correlation between central PTK treatment depth and measures of corneal curvature is most likely related to several factors, especially relatively shallow treatment depths and the antihyperopia treatments.

GOALS OF PTK

The ultimate goal of PTK treatment is good clinical results and patient satisfaction. This objective makes isolating one variable, such as treatment depth, difficult to achieve. Without the antihyperopia treatment, many of the abla-

APPENDIX: SELECTED STATISTICAL CORRELATIONS

VARIABLE 1	VARIABLE 2	SPEARMAN COEFFICIENT	*P* VALUE	*P*<.05
Preop uncorrected vision	Preop best-corrected vision	0.56	0.010	*
Postop uncorrected vision	Postop best-corrected vision	0.59	0.007	*
Preop uncorrected vision	Postop uncorrected vision	0.15	0.538	
Preop best-corrected vision	Postop best-corrected vision	0.17	0.470	
Mean preop Haag-Streit keratometry	Mean preop EyeSys simulated keratometry	0.66	0.005	*
Mean postop Haag-Streit keratometry	Mean postop EyeSys simulated keratometry	0.91	<0.001	*
Mean preop Haag-Streit keratometry	Mean EyeSys preop corneal power	0.66	0.004	*
Mean postop Haag-Streit keratometry	Mean EyeSys postop corneal power	0.66	0.002	*
Mean preop EyeSys simulated keratometry	Mean EyeSys preop corneal power	0.89	<0.001	*
Mean postop EyeSys simulated keratometry	Mean EyeSys postop corneal power	0.89	<0.001	*
Decrease in mean Haag-Streit keratometry	Decrease in mean EyeSys simulated keratometry	0.47	0.091	
Decrease in mean Haag-Streit keratometry	Decrease in EyeSys central corneal power	0.19	0.491	
Decrease in mean EyeSys simulated keratometry	Decrease in EyeSys central corneal power	0.72	0.002	*
Increase in spherical equivalent	Decrease in mean Haag-Streit keratometry	0.47	0.065	
Increase in spherical equivalent	Decrease in mean EyeSys simulated keratometry	0.43	0.098	
Increase in spherical equivalent	Decrease in EyeSys central corneal power	0.41	0.076	
Change in manifest refraction cylinder	Change in Haag-Streit keratometry cylinder	0.05	0.841	
Change in manifest refraction cylinder	Change in EyeSys simulated keratometry cylinder	0.18	0.500	
Change in Haag-Streit keratometry cylinder	Change in EyeSys simulated keratometry cylinder	0.41	0.150	
Ultrasound pachymetry pre-op	UBM pachymetry preop	0.82	<0.001	*
Ultrasound pachymetry post-op	UBM pachymetry postop	0.92	<0.001	*
Decrease in ultrasound pachymetry	Decrease in UBM pachymetry	0.04	0.892	
UBM measurement of pre-op pathology	Central PTK treatment	-0.45	0.071	
Decrease in ultrasound pachymetry	Central PTK treatment	-0.06	0.817	
Decrease in UBM pachymetry	Central PTK treatment	-0.03	0.912	
Increase in spherical equivalent	Central PTK treatment	-0.01	0.964	
Decrease in mean Haag-Streit keratometry	Central PTK treatment	0.40	0.090	
Decrease in mean EyeSys simulated keratometry	Central PTK treatment	0.22	0.403	
Decrease in EyeSys central corneal power	Central PTK treatment	0.48	0.062	
Antihyperopia treatment	Increase in spherical equivalent	-0.30	0.203	
Antihyperopia treatment	Decrease in mean Haag-Streit keratometry	-0.34	0.200	
Antihyperopia treatment	Decrease in mean EyeSys simulated keratometry	-0.17	0.517	
Antihyperopia treatment	Decrease in EyeSys central corneal power	0.02	0.933	
Antihyperopia treatment	Days to reepithialization	0.64	0.003	*
Central PTK treatment	Days to reepithialization	-0.11	0.634	
UBM measurement of preop pathology	Central PTK treatment	-0.45	0.071	

tions would be expected to produce significant hyperopia, which would have been unacceptable clinically. Overall, a small mean refractive shift, such as was achieved in this study, is desirable.

Contrary to previously published research,[11,15,16,18,43] the entire PTK process used in this study did not result in a consistent and predictable refractive shift. This "process" includes numerous steps, each of which is important to avoid poor corneal clarity and refractive results. The process begins with patient selection based on refraction and slit-lamp examination. Eyes with deep pathology, that is, greater than 20% to 25% corneal thickness on slip-lamp evaluation, are deemed not to be good candidates for PTK. Determining depth of pathology at the slit lamp can be difficult as anterior pathology blocks the view of more posterior pathology.

Based on results of this study, UBM evaluation does not appear to be helpful, since preoperative UBM measurement of corneal pathology was not correlated with actual PTK ablation depth. The surgical procedures were quite similar for all patients. A transepithelial approach was used with minimal to no masking agent to obtain the smoothest surface possible. The "ablate and check" method was used in each patient to remove the least amount of corneal tissue while eliminating the bulk of the opacity. Depending on depth of ablation, preoperative refraction, and refraction of the fellow eye, the surgeon elected to perform an antihyperopia treatment in selected eyes. The total depth of antihyperopia treatment, ranging from 80 to 200 µm, was also determined by similar factors. The amount of antihyperopia treatment could not be correlated with changes in manifest refraction, keratometry readings or corneal topographic analyses; therefore, the best amount of antihyperopia treatment for a given ablation depth is still unknown. A statistically significant correlation was found between amount of antihyperopia treatment and

days to reepithelialization. This association could be due to more damage to the epithelium peripheral to the central 6-mm-diameter ablation from deeper antihyperopia treatments, causing delayed reepithelialization.

A weakness of this study is its relatively small size and the fact that four UBM analyses were unretrievable. A well-defined, relatively uniform patient population was selected for this study in order to minimize potentially confounding variables to strengthen the study's ability to determine the effects of the antihyperopia treatment and the accuracy of UBM in determining the depth of PTK ablation. Patients with elevated pathology, such as Salzmann's nodular degeneration, generally do not undergo ablation deep into the stroma, so preoperative evaluation of depth of pathology is not as critical. Additionally, since deep ablations are not being performed, significant corneal flattening and a hyperopic shift are not expected, so antihyperopia treatments are generally not performed. The other common indication for PTK is recurrent erosion syndrome, where only 4 to 6 µm of tissue is being removed, so preoperative UBM analysis and antihyperopia treatments are unnecessary. Eyes with anterior stromal dystrophies are where these two modalities are utilized. Participation in this study was discussed with all eligible patients undergoing PTK at our institution for the entire 27-month duration of the study. All eligible patients elected to participate and were enrolled in this study. Unfortunately, this is a limited patient population.

While Reis-Bücklers', granular, and lattice dystrophies are not rare, most patients have good enough vision to delay or avoid surgery altogether. Other patients with these conditions have extensive, deep corneal involvement and are not good candidates for PTK. Anterior corneal dystrophies can recur superficially in grafts over many years, but these patients are few and far between. Patients with anterior stromal pathology such as superficial stromal corneal dystrophies are some of the best candidates for PTK. They suffer from decreased vision and often from painful corneal erosions for which medical therapies have poor success. Prior to the advent of excimer laser PTK, these patients required lamellar keratectomy, lamellar keratoplasty, or penetrating keratoplasty. PTK has allowed many patients to prevent or postpone more aggressive corneal surgery for many years. Even with a greater number of subjects in this study, it is not likely that UBM would be demonstrated to be an effective tool in the preoperative evaluation of corneas potentially undergoing PTK, since there was actually a trend toward UBM measurement of pathology being inversely correlated with actual PTK treatment depth.

Another limitation of this study is the relatively short follow-up of 6 to 8 weeks. This time period was selected to maximize visual recovery while minimizing corneal remodeling and recurrence of the dystrophy in order to obtain the best analysis of the effect of the PTK treatment on corneal pathology and curvature. It is likely that visual acuity and refractive and corneal clarity results would be different with longer follow-up. It is possible that the UBM measurements of depth of pathology would have different correlations with the amount of treatment required to remove the bulk of the pathology at longer follow-up intervals. However, longer follow-up times would increase the variables potentially confounding the results.

CONCLUSION

The PTK procedure results in improved vision, both uncorrected and best corrected for many or most patients. Epithelial healing is typically rapid; however, certain eyes may have delayed reepithelialization, especially those undergoing more extensive antihyperopia treatments. Close follow-up is required for all eyes until reepithelialization has occurred. If PTK does not result in significantly improved vision, a corneal transplant can be performed without additional risk from the PTK procedure. Using ablations just deep enough to remove the majority of the pathology and antihyperopia treatments in selected eyes, no predictable refractive error was induced while best-corrected vision was improved in most patients. Change in refraction was variable and occasionally quite large, potentially requiring a contact lens for binocular vision. PTK is a very good option for a relatively small number of patients with visual symptoms due to anterior corneal pathology. UBM did not accurately predict the depth of PTK treatment due to limitations of this technology. Further study with better imaging techniques than UBM, perhaps using more refined optical coherence tomography,[94-99] may help identify which patients respond best to this procedure. In the meantime, careful evaluation at the slit lamp and a judicious surgical technique typically lead to very good clinical results and gratified patients.

ACKNOWLEDGMENT

The author would like to thank Elizabeth L. Affel, MS, for help with the ultrasound biomicroscopic evaluation and interpretation, Marcia Polansky, ScD, for biostatistical support, and Ralph C. Eagle, Jr, MD, for assistance in histopathological analysis.

REFERENCES

1. American Academy of Ophthalmology. Ophthalmic procedure preliminary assessment:excimer laser photorefractive keratectomy (PRK) for myopia and astigmatism. *Ophthalmology* 1999;106:422-437.

2. Sugar A, Rapuano CJ, Culbertson WW, et al. Laser in situ keratomileusis for myopia and astigmatism:safety and efficacy. A report by the American Academy of Ophthalmology. *Ophthalmology* 2002;109:175-187.
3. Trokel S. Evolution of excimer laser corneal surgery. *J Cataract Refract Surg* 1989;15:373-383.
4. Seiler T, McDonnell PJ. Excimer laser photorefractive keratectomy. *Surv Ophthalmol* 1995;40:89-118.
5. Rapuano CJ. Excimer laser phototherapeutic keratectomy. *Int Ophthalmol Clin* 1996;36:127-136.
6. Thompson V, Durrie DS, Cavanaugh TB. Philosophy and technique for excimer laser phototherapeutic keratectomy. *Refract Corneal Surg* 1993;9(suppl):S81-S85.
7. Hersh PS, Spinak A, Garrana R, et al. Phototherapeutic keratectomy: strategies and results in 12 eyes. *Refract Corneal Surg* 1993;9(suppl):S90-S95.
8. Thompson VM. Excimer laser phototherapeutic keratectomy:clinical and surgical aspects. *Ophthalmic Surg Lasers* 1995;26:461-472.
9. Hersh PS, Burnstein Y, Carr J, et al. Excimer laser phototherapeutic keratectomy surgical strategies and clinical outcomes. *Ophthalmology* 1996;103:1210-1222.
10. Gallo JP, Raizman MB. Phototherapeutic keratectomy for superficial corneal disorders. *Int Ophthalmol Clin* 1997;37:155-170.
11. Foster W, Atzler U, Ratkay I, et al. Therapeutic use of the 193-nm excimer laser in corneal pathologies. *Graefes Arch Clin Exp Ophthalmol* 1997;235:296-305.
12. Kornmehl EW, Steinert RF, Puliafito CA. A comparative study of masking fluids for excimer laser phototherapeutic keratectomy. *Arch Ophthalmol* 1991;109:860-863.
13. Stevens SX, Bowyer BL. Corneal modulators and their use in excimer laser phototherapeutic keratectomy. *Int Ophthalmol Clin* 1996;36:119-125.
14. Stevens SX, Bowyer BL, Sanchez-Thorin JC, et al. The BioMask for treatment of corneal surface irregularities with excimer laser phototherapeutic keratectomy. *Cornea* 1999;18:155-163.
15. Sher NA, Bowers RA, Zabel RW, et al. Clinical use of the 193-nm excimer laser in the treatment of corneal scars. *Arch Ophthalmol* 1991;109:491-498.
16. Stark WJ, Chamon W, Kamp MT, et al. Clinical follow-up of 193-nm ArF excimer laser photokeratectomy. *Ophthalmology* 1992;99:805-812.
17. Campos M, Nielsen S, Szerenyi K, et al. Clinical follow-up of phototherapeutic keratectomy for treatment of corneal opacities. *Am J Ophthalmol* 1993;115:433-440.
18. Fagerholm P, Fitzsimmons TD, Orndahl M, et al. Phototherapeutic keratectomy:long-term results in 166 eyes. *Refract Corneal Surg* 1993; 9(suppl):S76-S81.
19. Orndahl M, Fagerholm P, Fitzsimmons T, et al. Treatment of corneal dystrophies with excimer laser. *Acta Ophthalmol* 1994;72:235-240.
20. Steinert RF, Puliafito CA. Excimer laser phototherapeutic keratectomy for a corneal nodule. *Refract Corneal Surg* 1990;6:352.
21. Ward MA, Artunduaga G, Thompson KP, et al. Phototherapeutic keratectomy for the treatment of nodular subepithelial corneal scars in patients with keratoconus who are contact lens intolerant. *CLAO J* 1995;21:130-132.
22. John ME, Martines E, Cvintal T, et al. Excimer laser photoablation of primary familial amyloidosis of the cornea. *Refract Corneal Surg* 1993; 9(suppl):S138-S141.
23. O'Brart DPS, Gartry DS, Lohmann CP, et al. Treatment of band keratopathy by excimer laser phototherapeutic keratectomy:surgical techniques and long term follow up. *Br J Ophthalmol* 1993;77:702-708.
24. Goldstein M, Loewenstein A, Rosner M, et al. Phototherapeutic keratectomy in the treatment of corneal scarring from trachoma. *J Refract Corneal Surg* (suppl) 1994;10:S290-S292.
25. Cameron JA, Antonios SR, Badr IA. Excimer laser phototherapeutic keratectomy for shield ulcers and corneal plaques in vernal keratoconjunctivitis. *J Refract Surg* 1995;11:31-35.
26. Kremer I, Blumenthal M. Excimer phototherapeutic keratectomy for cornea subepithelial cryoglobulin deposits. *J Cataract Refract Surg* 1997;23:1119-1121.
27. Talu H, Tasindi E, Ciftci F, et al. Excimer laser phototherapeutic keratectomy for recurrent pterygium. *J Cataract Refract Surg* 1998;24:1326-1332.
28. Fong Y-C, Chuck RS, Stark WJ, et al. Phototherapeutic keratectomy for superficial corneal fibrosis after radial keratotomy. *J Cataract Refract Surg* 2000;26:616-619.
29. Faschinger CW. Phototherapeutic keratectomy of a corneal scar due to presumed infection after photorefractive keratectomy. *J Cataract Refract Surg* 2000;26:296-300.
30. Lazzaro DR, Starr MB, Donnenfeld ED, et al. Phototherapeutic keratectomy for anterior scarring in an epikeratophakia lenticule. *CLAO J* 2000;26:52-53.
31. Stahl J, Fulcher S, Berkeley R. Corneal subepithelial nodular scarring treated with phototherapeutic keratectomy in a child with Rothmund-Thomson syndrome. *Cornea* 2000;19:110-115.
32. Thomann U, Meier-Gibbons F, Schipper I. Phototherapeutic keratectomy for bullous keratopathy. *Br J Ophthalmol* 1995;79:335-338.
33. Thomann U, Niesen U, Schipper I. Successful phototherapeutic keratectomy for recurrent erosions in bullous keratopathy. *J Refract Surg* 1996;12(suppl):S290-S292.
34. Tuunanen TH, Tervo TM. Excimer laser phototherapeutic keratectomy for corneal diseases:a follow-up study. *CLAO J* 1995;21:67-72.
35. Rao SK, Fogla R, Seethalakshmi G, et al. Excimer laser phototherapeutic keratectomy:Indications, results and its role in the Indian scenario. *Indian J Ophthalmol* 1999;47:167-172.
36. Amano S, Oshika T, Tazawa Y, et al. Long-term follow-up of excimer laser phototherapeutic keratectomy. *Jpn J Ophthalmol* 1999;43:513-516.
37. Kasetsuwan N, Puangsricharern V, Piriyakanok L. Excimer laser phototherapeutic keratectomy for corneal diseases. *J Med Assoc Thai* 2000;83:474-482.
38. Rapuano CJ, Laibson PR. Excimer laser phototherapeutic keratectomy. *CLAO J* 1993;19:235-240.

39. Rapuano CJ, Laibson PR. Excimer laser phototherapeutic keratectomy for anterior corneal pathology. *CLAO J* 1994;20:253-257.
40. Rapuano CJ. Excimer laser phototherapeutic keratectomy; long-term results and practical considerations. *Cornea* 1997;16:151-157.
41. Migden M, Elkins BS, Clinch TE. Phototherapeutic keratectomy for corneal scars. *Ophthalmic Surg Lasers* 1996;27:S503-S507.
42. Zuckerman SJ, Aquavella JV, Park SB. Analysis of the efficacy and safety of excimer laser PTK in the treatment of corneal disease. *Cornea* 1996;15:9-14.
43. Starr M, Donnenfeld E, Newton M, et al. Excimer laser phototherapeutic keratectomy. *Cornea* 1996;15:557-565.
44. Maloney RK, Thompson V, Ghiselli G, et al. A prospective multicenter trial of excimer laser phototherapeutic keratectomy for corneal vision loss. *Am J Ophthalmol* 1996;122:149-160.
45. Badr IA, Al-Rajhi AA, Wagoner MD, et al, for the KKESH Excimer Laser Study Group. Phototherapeutic keratectomy for climatic droplet keratopathy. *J Refract Surg* 1996;12:114-122.
46. Sridhar MS, Rapuano CJ, Cosar CB, et al. Phototherapeutic keratectomy versus diamond burr polishing of Bowman's membrane in the treatment of recurrent corneal erosions associated with anterior basement membrane dystrophy. *Ophthalmology*. In press.
47. Dausch D, Landesz M, Klein R, et al. Phototherapeutic keratectomy in recurrent corneal epithelial erosion. Refract Corneal Surg 1993;9:419-424.
48. John ME, Van Der Karr MA, Noblitt RL, et al. Excimer laser phototherapeutic keratectomy for the treatment of recurrent corneal erosion. *J Cataract Refract Surg* 1994;20:179-181.
49. Lohmann CP, Sachs H, Marshall J, et al. Excimer laser phototherapeutic keratectomy for recurrent erosions: a clinical study. *Ophthalmic Surg Lasers* 1996;27:768-772.
50. Bernauer W, De Cock R, Dart JKG. Phototherapeutic keratectomy in recurrent corneal erosions refractory to other forms of treatment. *Eye* 1996;10:561-564.
51. Orndahl MJP, Fagerholm PP. Phototherapeutic keratectomy for map-dot-fingerprint corneal dystrophy. *Cornea* 1998;17:595-599.
52. Morad Y, Haviv D, Zadok D, et al. Excimer laser phototherapeutic keratectomy for recurrent corneal erosion. *J Cataract Refract Surg* 1998;24:451-455.
53. Ho CL, Tan DTH, Chan WK. Excimer laser phototherapeutic keratectomy for recurrent corneal erosions. *Ann Acad Med Singapore* 1999;28:787-790.
54. Cavanaugh TB, Lind DM, Cutarelli PE, et al. Phototherapeutic keratectomy for recurrent erosion syndrome in anterior basement membrane dystrophy. *Ophthalmology* 1999;106:971-976.
55. Jain S, Austin DJ. Phototherapeutic keratectomy for treatment of recurrent corneal erosion. *J Cataract Refract Surg* 1999;25:1610-1614.
56. Kremer I, Blumenthal M. Combined PRK and PTK in myopic patients with recurrent corneal erosion. *Br J Ophthalmol* 1997;81:551-554.
57. McDonnell PJ, Seiler T. Phototherapeutic keratectomy with excimer laser for Reis-Bücklers' corneal dystrophy. *Refract Corneal Surg* 1992;8:306-310.
58. Cennamo G, Rosa N, Rosenwasser GOD, et al. Phototherapeutic keratectomy in the treatment of Avellino dystrophy. *Ophthalmologica* 1994;208:198-200.
59. Droutsas DD, Tsioulias GE, Kotsiras JE, Koufala CJ, Lambropoulos JE. Phototherapeutic keratectomy in macular corneal dystrophy with recurrent erosions. *J Refract Surg* 1996;12(suppl):S293-S294.
60. Wagoner MD, Badr IA. Phototherapeutic keratectomy for macular corneal dystrophy. *J Refract Surg* 1999;15:481-484.
61. Paparo LG, Rapuano CJ, Raber IM, et al. Phototherapeutic keratectomy for Schnyder's crystalline corneal dystrophy. *Cornea* 2000;19:343-347.
62. Nassaralla BA, Garbus J, McDonnell PJ. Phototherapeutic keratectomy for granular and lattice corneal dystrophies at 1.5 to 4 years. *J Refract Surg* 1996;12:795-800.
63. Maclean H, Robinson LP, Wechsler AW, et al. Excimer phototherapeutic keratectomy for recurrent granular dystrophy. *Aust N Z J Ophthalmol* 1996;24:127-130.
64. Lawless MA, Cohen P, Rogers C. Phototherapeutic keratectomy for Reis-Bücklers' dystrophy. *Refract Corneal Surg* 1993;9(suppl):S96-S98.
65. Rogers C, Cohen P, Lawless M. Phototherapeutic keratectomy for Reis-Bücklers' corneal dystrophy. *Aust N Z J Ophthalmol* 1993;21:247-250.
66. Dogru M, Katakami C, Miyashita M, et al. Ocular surface changes after excimer laser phototherapeutic keratectomy. *Ophthalmology* 2000;107:1144-1152.
67. Dogru M, Katakami C, Nishida T, et al. Alteration of the ocular surface with recurrence of granular/Avellino corneal dystrophy after phototherapeutic keratectomy: report of five cases and literature review. *Ophthalmology* 2001;108:810-817.
68. Al-Rajhi AA, Wagoner MD, Badr IA, et al. Bacterial keratitis following phototherapeutic keratectomy. *J Refract Surg* 1996;12:123-127.
69. Fulton JC, Cohen EJ, Rapuano CJ. Bacterial ulcer 3 days after excimer laser phototherapeutic keratectomy. *Arch Ophthalmol* 1996;114:626-627.
70. Pepose JS, Laycock KA, Miller JK, et al. Reactivation of latent herpes simplex virus by excimer laser photokeratectomy. *Am J Ophthalmol* 1992;114:45-50.
71. Vrabec MP, Anderson JA, Rock ME, et al. Electron microscopic findings in a cornea with recurrence of herpes simplex keratitis after excimer laser phototherapeutic keratectomy. *CLAO J* 1994;20:41-44.
72. Teichmann KD, Cameron J, Huaman A, et al. Wessely-type immune ring following phototherapeutic keratectomy. *J Cataract Refract Surg* 1996;22:142-146.
73. Alaa M, Waring GO III, Malaty A, et al. Increased corneal scarring after phototherapeutic keratectomy in Fuchs' corneal dystrophy. *J Refract Surg* 1997;13:308-310.

74. Majmudar PA, Forstot L, Dennis RF, et al. Topical mitomycin-C for subepithelial fibrosis after refractive corneal surgery. *Ophthalmology* 2000;107:89-94.
75. Frueh BE, Bohnke M. Endothelial cell morphology after phototherapeutic keratectomy. *German J Ophthalmol* 1995;4:86-90.
76. Munnerlyn CR, Koons SJ, Marshall J. Photorefractive keratectomy:a technique for laser refractive surgery. *J Cataract Refract Surg* 1988;14:46-52.
77. Rowsey JJ. Methods for calculating the requisite phototherapeutic ablation for corneal scars and surface irregularities. *Int Ophthalmol Clin* 1996;36:137-140.
78. Amm M, Duncker GIW. Refractive changes after phototherapeutic keratectomy. *J Cataract Refract Surg* 1997;23:839-844.
79. Dogru M, Katakami C, Yamanaka A. Refractive changes after excimer laser phototherapeutic keratectomy. *J Cataract Refract Surg* 2001;27:686-692.
80. Dinh R, Rapuano CJ, Cohen EJ, et al. Recurrence of corneal dystrophy after excimer laser phototherapeutic keratectomy. *Ophthalmology* 1999;106:1490-1497.
81. Starr MB. Recurrent subepithelial corneal opacities after excimer laser phototherapeutic keratectomy. *Cornea* 1999;18:117-120.
82. Augsburger JJ, Affel LL, BenArosh DA. Ultrasound biomicroscopy of cystic lesions of the iris and ciliary body. *Trans Am Ophthalmol Soc* 1996;94:259-271.
83. Mungan N, Nischal KK, Heon E, et al. Ultrasound biomicroscopy of the eye in cystinosis. *Arch Ophthalmol* 2000;118:1329-1333.
84. Rao SK, Padmanabhan P, Fogla R, et al. Ultrasound biomicroscopy of an intracorneal cyst (letter) *Cornea* 2000;19:249-250.
85. Casanova FHC, Adan CBD. Allemann N, et al. Findings in the anterior segment on ultrasound biomicroscopy in Maroteaux-Lamy syndrome. *Cornea* 2001;20:333-338.
86. Deramo VA, Shah GK, Baumal CR, et al. The role of ultrasound biomicroscopy in ocular trauma. *Trans Am Ophthalmol Soc* 1998;96;355-367.
87. Deramo VA, Shah GK, Baumal CR, et al. Ultrasound biomicroscopy as a tool for detecting and localizing occult foreign bodies after ocular trauma. *Ophthalmology* 1999; 106:301-305.
88. Barash D, Goldenberg-Cohen N, Tzadok D, et al. Ultrasound biomicroscopic detection of anterior ocular segment foreign body after trauma. *Am J Ophthalmol* 1998; 126:197-202.
89. Chakrabarti HS, Atta HR. Use of ultrasound biomicroscopy in the localization and management of an anteriorly situated intraocular foreign body (letter). *Br J Ophthalmol* 1998; 82:459-460.
90. Looi ALG, Gazzard G, Tan DTH. Surgical exploration minimized by ultrasound biomicroscopy localization of intraocular foreign body (letter). *Eye* 2001; 15:234-235.
91. Fineman MS, Sharma S, Shah GK, et al. Ultrasound biomicroscopic diagnosis of an occult intrascleral foreign body: an unusual case of ocular siderosis. *Retina* 2001; 21:265-267.
92. Madhavan C, Basti S, Naduvilath TJ, et al. Use of ultrasound biomicroscopic evaluation in preoperative planning of penetrating keratoplasty. *Cornea* 2000; 19:17-21.
93. Lanzl IM, Augsburger JJ, Hertle RW, et al. The role of ultrasound biomicroscopy in surgical planning for limbal dermoids. *Cornea* 1998; 17:604-606.
94. Hirano K, Ito Y, Suzuki T, et al. Optical coherence tomography for the noninvasive evaluation of the cornea. *Cornea* 2001; 20:281-289.
95. Bechmann M, Thiel MJ, Neubauer AS, et al. Central corneal thickness measurement with a retinal optical coherence tomography device versus standard ultrasonic pachymetry. *Cornea* 2001; 20:50-54.
96. Feng Y, Varikooty J, Simpson TL. Diurnal variation of corneal and corneal epithelial thickness measured using optical coherence tomography. *Cornea* 2001; 20:480-483.
97. Wirbelauer C, Scholz C, Hoerauf H, et al. Corneal optical coherence tomography before and immediately after excimer laser photorefractive keratectomy. *Am J Ophthalmol* 2000; 130:693-699.
98. Ustundag C, Bahcecioglu H, Ozdamar A, et al. Optical coherence tomography for evaluation of anatomical changes in the cornea after laser in situ keratomileusis. *J Cataract Refract Surg* 2000; 26:1458-1462.
99. Maldonado MJ, Ruiz-Oblitas L, Munuera JM, et al. Optical coherence tomography evaluation of the corneal cap and stromal bed features after laser in situ keratomileusis for high myopia and astigmatism. *Ophthalmology* 2000; 107:81-87.