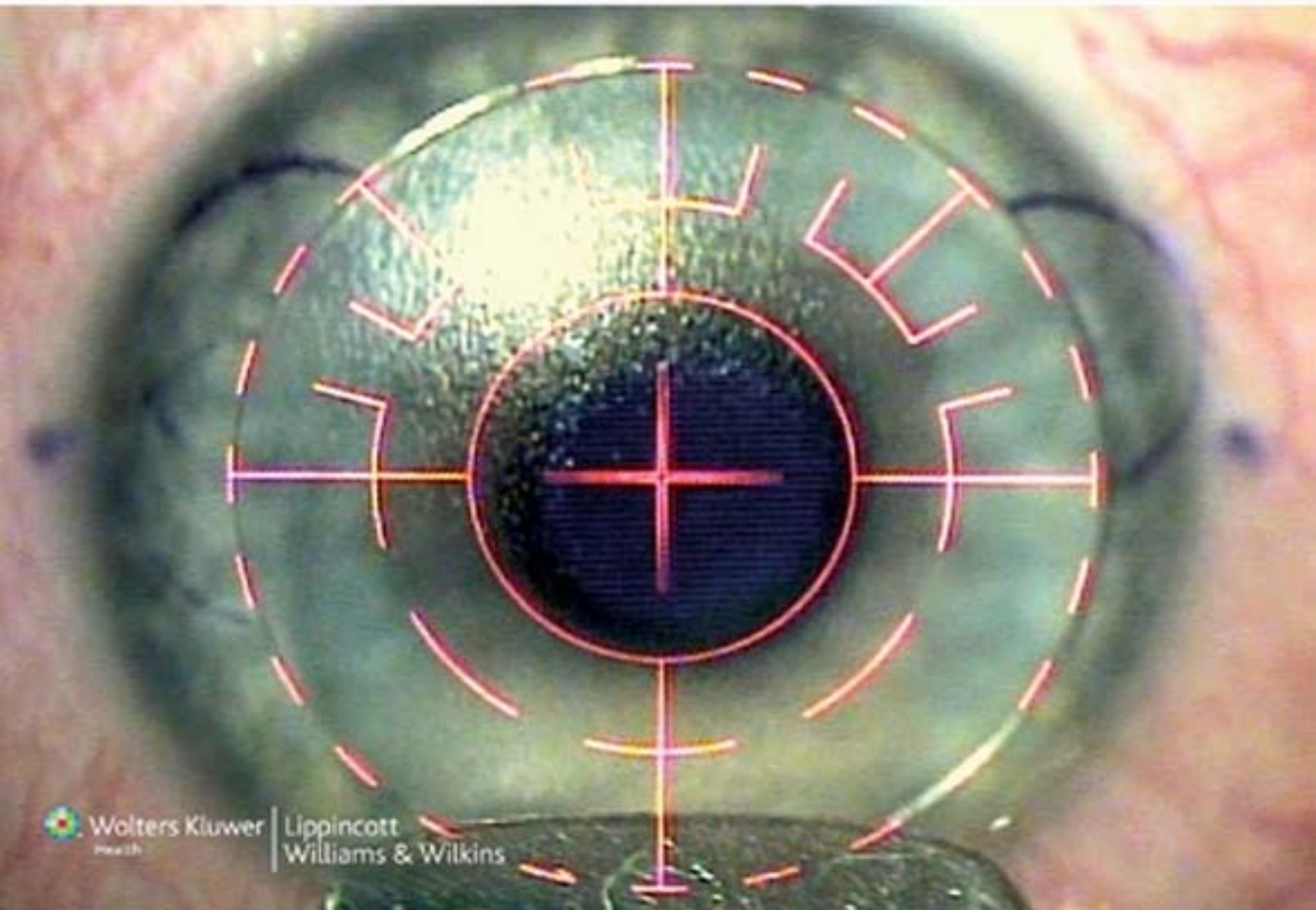
Includes access to online videos and self-assessment test

THE LASIK HANDBOOK

A CASE-BASED APPROACH SECOND EDITION

ROBERT S. FEDER



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The LASIK Handbook

A CASE-BASED APPROACH

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SECOND EDITION

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DEDICATION

This book is dedicated to my parents, Howard and Geraldine Feder, two extraordinary individuals. Many of the lessons I learned from their example enabled me to complete this project. My father taught me to think out-of-the-box. He is a colorful storyteller, and his stories often have a lesson or "take home message." He has always been about the art of the possible and showed me the power of collaboration in completing a project. My mother's message has always been that time passes no matter what you do, so you should make it count. She has also demonstrated the discipline needed to stick to a timeline. They both took great interest in this project, and I have appreciated their support. To my wife, Randi, and sons, Alex and Seth, I can now disconnect myself from my laptop. I thank you for your understanding and encouragement.

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PREFACE

The second edition of the LASIK Handbook: a Case-based Approach reflects the ever-changing field of refractive surgery. This is no coffee-table book that once purchased is rarely read. This is your pocket companion, ready to assist you if you're an experienced LASIK surgeon and ready to help train you if you're just learning. The essence of this book has not changed at all. It is still a user-friendly manual of evaluation and technique with a wealth of wisdom in the indexed cases chosen by experts for their teaching value with "Take-Home Points" following each presentation. But much has changed in the second edition.

When the first edition was being prepared we felt it necessary to include a short section on a new technology, the femtosecond laser. This laser is now used in approximately 50% of the LASIK surgeries performed in the United States. The second edition has an entire chapter devoted exclusively to the femtosecond laser. New in the second edition is a collection of videos, which illustrate techniques and complications that serve as a companion to the text. The library of cases has been expanded to over 100, covering the full spectrum of preoperative, intraoperative, and postoperative challenges. There are new chapters on collagen cross-linking, optical coherence tomography (OCT), and commonly used excimer laser systems. If you have struggled to choose the proper IOL power for a post-LASIK patient having cataract surgery, there is a new chapter on this topic that should help. The case study index has been redesigned to make the cases much more accessible. Even the self-assessment test has been expanded.

The second edition will appeal to an international audience, with contributors from China, South Korea, Singapore, Brazil, Germany, Turkey, Israel, and India. An enlightening new chapter treats the reader to a virtual world tour of refractive surgery, introducing the reader to LASIK technique and practice through the eyes of our international colleagues.

Our domestic and international contributors are top-notch surgeons and teachers. I hope you will agree that this collaboration has resulted in a unique resource that meets your needs if you are an experienced LASIK surgeon or a resident just learning the basics. Whether you rigorously study the cases, review techniques on video, or look up important information on the laser system or microkeratome you use, this book is at the ready to assist you as you strive to bring expert refractive surgery to your patients.

Robert S. Feder

ACKNOWLEDGMENTS

I wish to acknowledge the many clinicians who have contributed their time, energy, commitment, and expertise for the purpose of creating this state-of-the-art teaching tool. I particularly would like to single out two contributors: Dr. Robert W. Weisenthal, for his extraordinary contribution of 2 chapters, 8 cases, excellent illustrations and videos. Dr. Christopher Rapuano was helpful in recruiting several of our international contributors, he wrote a wonderful revision to his complications chapter and wrote a new chapter on cataract surgery in the post-refractive patient. All the contributors have endured my steady barrage of e-mails and edits with courtesy and patience. I am grateful for their talent and friendship.

My refractive surgery partners at Northwestern LASIK Physicians, Paul J. Bryar, Surendra Basti, and Michael Rosenberg, appreciated the value of this project and participated with enthusiasm, each bringing their personal experience and creativity to the effort. Jesse Arseneau, our video producer, and Sheila Macomber, our medical illustrator, helped us to transform ideas and images into teaching instruments. Our talented contributors and support personnel have created an up-to-date training manual, an extraordinary library of video vignettes, and an unparalleled collection of clinical cases, each based on real world experience. I thank them all for their dedication to this project.

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SECTION I

LASIK Fundamentals

chapter 1

Basic LASIK

ROBERT S. FEDER

Patient Evaluation

Careful patient evaluation is essential in order to determine whether a patient is a candidate for LASIK surgery. The criteria used to determine candidacy are divided into two parts, psychosocial and anatomical. Each will be considered individually.

PSYCHOSOCIAL FACTORS

A good candidate for LASIK surgery should be capable of understanding the risks of the procedure and that risk-free surgery does not exist. The patient must be willing and able to follow instructions before, during, and after surgery. A patient who resists listening to a discussion of the risks may be a poor candidate for surgery. If the patient is unable to understand the surgeon due to a language barrier or disability, adequate preoperative counseling and intraoperative instructions will be more difficult to achieve. The patient must be available for postoperative follow-up. Beware of the patient with a challenging schedule who may not understand the care that is required after surgery.

Managing patient expectations is one of the greatest challenges a LASIK surgeon faces. This begins during the preoperative consultation. The patients should be told what level of visual acuity is reasonable to expect, with a subsequent enhancement procedure if needed. This can be expressed as an expected range of visual acuity a particular patient would be likely to achieve. It is helpful to mention the surgeon's rate of enhancement for patients of a similar age with similar refractive error. A patient who expects perfection after surgery is destined to be unhappy postoperatively. Do not confuse visual acuity with visual function. A patient with 20/20 Snellen acuity may be unhappy due to loss of near vision, ghosting, decreased contrast sensitivity, glare, or other problems that affect the quality of vision. Personal characteristics of the best LASIK patients include an easygoing nature, a positive outlook, a well-adjusted personality, a patient comfortable using less than a full refractive error correction, and a willingness to wear glasses for reading or night driving. Intense individuals, patients with a grim outlook, highly emotional or vitriolic patients, or highly critical patients may not be well suited for LASIK surgery.

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The patient's psychosocial candidacy for the procedure should be assessed while the history is taken as well as during the examination. Input from well-trained technicians or office personnel is valuable information that should not be dismissed. However, it should not be considered a substitute for the surgeon's personal evaluation.

ANATOMICAL FACTORS

In general, the most reproducible results are obtained when LASIK is performed on a healthy patient with healthy eyes. There is less risk when the orbital and lid anatomy allow adequate exposure for the microkeratome or a femtosecond laser ring. The refractive error should preferably be well within the approved limits for the specific excimer laser being used (see Table 1.1). Patients with severe dry eye, absent corneal sensation, or inadequate eyelid closure are poor candidates for surgery. If a mechanical microkeratome is to be used and the corneal contour is abnormally steep or flat, the surgeon and the patient should be aware of the increased respective risks of buttonhole and free cap. The risk of buttonhole or free cap related to abnormal contour is of less concern when the flap is created with a femtosecond laser. LASIK may be a poor choice if the corneal diameter is unusually small. Finally, the corneal thickness is a major factor in determining the amount of refractive error that can safely be treated.

EVALUATION

A standardized laser refractive surgery form, designed for recording the history and examination, can assist the surgeon in documenting pertinent information in an orderly manner. Using such a form can reduce the chance of inadvertent oversight in the evaluation. A sample preoperative form is shown in Figure 1.1. Postoperative forms are also helpful (Fig. 1.2). There is an advantage to using a form in which the results of multiple postoperative visits can be easily tracked. The sample forms shown in Figures 1.1 and 1.2 can be modified to suit the particular needs of a surgeon or practice. As practices transition to electronic medical records, templates should be modified to incorporate elements required for LASIK evaluation. While risks can be quickly recorded in a dot phrase, it is worthwhile to addend the statement to document the discussion of particular risks that are relevant to the specific patient.

History

The history should begin with a question about the patient's goals for surgery. While LASIK surgery is approved for patients at least 18 to 21 years of age, many patients will not have attained refractive stability by this age. The refractive history should contain questions about refractive stability. Ideally the refraction should be stable for at least 1 year before LASIK surgery is considered. If a glasses change of >0.50 diopter (D) has occurred within 1 year, the patient should be reevaluated at 6-month intervals until the measurement is stable. Patients approaching age 40 years should be questioned about their willingness to wear reading glasses. A contact lens history should be obtained and should include the type of lens (e.g., hard, rigid gas permeable, or soft), the duration of lens wear in years, and the typical duration of daily lens wear or use of extended wear. The use of contact lenses to obtain monovision should be noted. The contact lens prescription should be obtained. This will help the surgeon plan the proper amount of undercorrection in the nondominant eye of a myopic patient. If the presbyopic myope has not previously used a monovision correction and is interested, a contact lens trial, undercorrecting the nondominant eye, will need to be tried at home, at work, and during leisure activities. If the patient has an astigmatic component in the refraction, a spherical contact lens correction may not adequately simulate a myopic astigmatic laser treatment. If the contact lens trial is successful, surgical monovision may be an option.

The past ocular history should be obtained. A history of recurrent corneal erosion, corneal ulceration or other ocular infection, glaucoma or glaucoma surgery, or cataract may all have an impact on the

TABLE 1.1 FDA-Approved Indications for Excimer Laser Refractive Surgery

Company (Model)	PRK for Myopia and Astigmatism	LASIK for Myopia and Astigmatism	PRK for Hyperopia and Astigmatism	LASIK for Hyperopia and Astigmatism	Mixed Astigmatism
Abbott Medical Optics (VISX Model B & C [Star & Star S2])	Myopia from 0 to –6.00 D (P930016; 03/27/96) Myopia from 0 to –6.00 D with or without astigmatism from –0.75 to –4.00 D (P930016/S3; 04/24/97) Myopia from 0 to –12.00 D with or without astigmatism from 0 to –4.00 D (P930016/S5; 01/29/98)				
Abbott Medical Optics (VISX Star S2)		Myopia < –14.00 D with or without astigmatism between –0.50 and –5.00 D (P990010; 11/19/99)	Hyperopia from +1.00 to +6.00 D (P930016/S7; 11/2/98)		
Abbott Medical Optics (VISX Star S2/S3)			Hyperopia from +0.50 to +5.00 D with or without astigmatism +0.50 to +4.00 D (P930016/S10; 10/18/00)	Hyperopia between +0.50 and +5.00 D with or without astigmatism up to +3.00 D (P930016/S12; 04/27/01)	Mixed astigmatism up to 6.00 D; cylinder > sphere and of opposite sign (P930016/S14; 11/16/01)
Abbott Medical Optics (VISX Star S3, EyeTracker)		Myopia < –14.00 D with or without astigmatism between –0.50 and –5.00 D with eye tracker (P990010/S1; 04/20/00)			
Abbott Medical Optics (VISX Star S4 & Wave-Scan WaveFront System) wavefront-guided		Myopia up to –6.00 D with or without astigmatism up to –3.00 D (P930016/S16; 05/23/03) Monovision treatment for myopia up to –6.00 D with or without astigmatism up to –3.00 D allowing for retention of myopia from –1.25 to –2.00 D (P930016/S25; 07/11/07)		Hyperopia up to +3.00 D with or without astigmatism up to +2.00 D (P930016/S17; 12/14/04)	Mixed astigmatism from 1.00 to 5.00 D (P930016/S20; 03/17/05)

continued

TABLE 1.1 FDA-Approved Indications for Excimer Laser Refractive Surgery (Continued)

Company (Model)	PRK for Myopia and Astigmatism	LASIK for Myopia and Astigmatism	PRK for Hyperopia and Astigmatism	LASIK for Hyperopia and Astigmatism	Mixed Astigmatism
Abbott Medical Optics (VISX Star S4 & Wave-Scan WaveFront System) wavefront-guided		Myopia from –6.00 to –11.00 D with or without astigmatism up to –3.00 D (P930016/S21; 08/30/05)			
Alcon (Apex & Apex Plus)	Myopia from –1.50 to –7.00 D (P930034; 10/25/95)				
Alcon (Apex Plus)	Myopia from –1.00 to –6.00 D with or without astigmatism from –1.00 to –4.00 D (P930034/S9; 03/11/98)	Myopia < –14.00 D with or without astigmatism from 0.50 to 5.00 D (P930034/S13; 10/21/99)	Hyperopia from +1.50 to +4.00 D with or without astigmatism < –1.00 D (P930034/S12; 10/21/99)		
Alcon (LADAR Vision)	Myopia from –1.00 to –10.00 D with or without astigmatism < –4.00 D (P970043; 11/02/98)	Myopia < –9.00 D with or without astigmatism from –0.50 to –3.00 D (P970043/S5; 05/09/00)		Hyperopia <6.00 D with or without astigmatism < –6.00 D (P970043/S7; 09/22/00)	Mixed astigmatism < +6.00 D sphere with < –6.00 D cylinder (P970043/S7; 09/22/00)
Alcon (LADAR Vision) wavefront-guided		Myopia up to –7.00 D with or without astigmatism < 0.50 D (P970043/S10; 10/18/02) Myopic astigmatism up to –8.00 D sphere with –0.50 D to –4.00 D cylinder and up to –8.00 D SE at the spectacle plane (P970043/S15; 06/29/04)		Hyperopia < +5.00 D with or without astigmatism < –3.00 D	Mixed astigmatism from 1.00 to 5.00 D; cylinder > sphere and of opposite sign
Alcon (WaveLight ALLEGRETTO WAVE)		Myopia up to –12.00 D with or without astigmatism up to –6.00 D (P020050; 10/07/03)		Hyperopia up to +6.00 D with or without astigmatism up to +5.00 D (P030008; 10/10/03)	Mixed astigmatism up to 6.00 D at the spectacle plane (P030008/S4; 04/19/06)

Company (Model)	PRK for Myopia and Astigmatism	LASIK for Myopia and Astigmatism	PRK for Hyperopia and Astigmatism	LASIK for Hyperopia and Astigmatism	Mixed Astigmatism
Alcon (WaveLight ALLEGRETTO WAVE) wavefront-guided		Myopia up to –7.00 D with up to –7.00 D of spherical component and up to 3.00 D astigmatic component (P020050/S4; 07/26/06)			
Bausch & Lomb Surgical (KERACOR 116)	Myopia from –1.50 to –7.00 D with or without astigmatism < –4.50 D (P970056; 09/28/99)				
Carl Zeiss Meditec (MEL 80)		Myopia ≤ –7.00 D with or without astigmatism ≤ –3.00 D (P060004; 08/11/06)			
Nidek EC-5000	Myopia from –0.75 to –13.00 D with astigmatism ≤ –0.75 D and myopia –1.00 to –8.00 D with astigmatism –0.50 to –4.00 D (P970053/S9; 10/11/06)	Myopia from –1.00 to –14.00 D with or without astigmatism ≤ –4.00 D (P970053/S9; 10/11/06)		Hyperopia between +0.50 and +5.00 D with or without astigmatism from +0.50 D to +2.00 D (P970053/S9; 10/11/06)	
Technolas Perfect Vision GmbH* (Technolas 217a)		Myopia from < –11.00 D with or without astigmatism < –3.00 D (P99027; 02/23/00)		Hyperopia between 1.00 and 4.00 D with or without astigmatism up to 2.00 D (P99027/S4; 02/25/03)	
Technolas Perfect Vision GmbH (Technolas 217z) wavefront-guided		Myopia up to –7.00 D with or without astigmatism up to –3.00 D (P99027/S6; 10/10/03)			

*Technolas Perfect Vision GmbH is a joint venture of Bausch & Lomb and 20/10 Perfect Vision AG

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1

NORTHWESTERN VISION CORRECTION ASSOCIATES
REFRACTIVE SURGERY
CONSULTATION

Name: _____ **NMFF#:** _____

Age: _____ **Date:** _____

Motivation: _____ Medications: _____

POHx: _____ Allergies: _____

PMHx: _____ Soc Hx: _____

FamHx: _____ ROS: _____

Vsc: **V**cc: _____ **OD:** **OS:**

W: **K:** Pachymetry: Pupil Size: Diameter:

M: Dominance: Tension:

I have discussed the LASIK procedure with_____.

This discussion has included the visual prognosis (approximate 98% 20/40 or better, approximately_____ % 20/20-20/25. We have discussed the possible need for glasses for reading and under other special conditions. I have discussed the probability of retreatment (____). We have discussed the possible night vision problems of glare and haloes. We have discussed complications including infection and inflammation leading to corneal transplant, retinal detachment, flap complications of displacement, wrinkles, debris under the flap, and poor flap construction. We have discussed temporary dry eye syndrome and the need for teardrops, medication, and/or plugs. We have discussed CustomVue™ LASIK and I have elected to (have / not have) CustomVue™ LASIK. We have discussed IntraLase® and I have elected to (have / not have) IntraLase® to create the flap. We have discussed Photorefractive Keratectomy (PRK) including the issues of postoperative discomfort, potential haze, and extended use of cortisone eye drops. The doctor has explained the risk of surgery to me and I understand it. All my questions have been answered to my satisfaction.

Patient Signature:_____ Date:_____ Physician Signature: _____

MEASUREMENTS

Date: _____ **WaveScan Done** _____ **Custom:** _____

M: **Topography Done** _____ **Plate:** _____

C: **Dilated with 1% Myd.** _____ **Ring:** _____

K: **Motility:** _____ **Zone:** _____

SLE: **Lids & Lashes:** _____ **Fundus** **Laser flap**

Conj: _____ **Disc:** _____ **Diameter:** _____

Cornea: _____ **Vessels:** _____ **Thickness:** _____

AC: _____ **Macula:** _____

Iris: _____ **Periphery:** _____ **Special Instructions:**

Lens: _____

FIGURE 1.1

Sample preoperative refractive surgery consultation form.

POSTOPERATIVE REFRACTIVE SURGERY FORM

Name: _____ Age: _____ Occupation: _____

Original Procedure: OD:_____OS:_____
Original Procedure Date: OD _____ Cyc Ref: _____ BCV: _____ K: _____ P: _____
OS _____ Cyc Ref: _____ BCV:_____ K: _____ P: _____

1st Retreat Procedure: OD: _____ OS:_____
Date of 1st Retreat: OD _____ Cyc Ref: _____ BCV:_____ K: _____ P: _____
OS _____ Cyc Ref: _____ BCV:_____ K: _____ P: _____

2nd Retreat Procedure: OD:_____OS:_____
Date of 2nd Retreat: OD _____ Cyc Ref: _____ BCV:_____ K: _____ P: _____
OS _____ Cyc Ref: _____ BCV:_____ K: _____ P: _____

Date: C/O: Meds:

Date: C/O: Meds:

Date: C/O: Meds:

Date: C/O: Meds:

Date: C/O: Meds:

FIGURE 1.2

Sample postoperative refractive surgery form.

1

patient's candidacy for LASIK surgery. Past medical history including diabetes, rheumatoid arthritis, systemic immunosuppression, pregnancy, or nursing an infant is important. Diabetics, in addition to retinal ischemia and edema, may have poor epithelial adhesion, increasing the risk of erosion. They may also be more likely to have cataract. Approval may not have been obtained for laser refractive surgery in patients with certain systemic diseases such as rheumatoid arthritis. If off-label use of the laser is entertained, the patient should be made aware that this is the case. Pregnant or nursing patients may have unstable refractions, and it is best to delay surgery until 6 to 12 weeks after nursing has ended. Patients who become pregnant after LASIK should understand that a refractive error change may result from the pregnancy and may not be caused by regression of the effect of refractive surgery. The change may resolve after delivery without retreatment.

Examination

Visual acuity at distance and near should be measured with and without correction. The best-corrected visual acuity should be at least 20/20 preoperatively. If the acuity is <20/20, the surgeon must seek an explanation. If the acuity is reduced because of refractive amblyopia, the patient may still be a candidate for surgery, provided the patient has realistic expectations for postoperative vision. Reduced preoperative visual acuity related to irregular corneal astigmatism is a contraindication to LASIK surgery.

Contact lens wear will need to be discontinued until the refraction becomes stable. In general, refractive stability will take longer for rigid gas permeable lens users than for soft lens users. The duration of lens wear and the intensity of lens wear are also important factors affecting the time to achieve refractive stability. A rule of thumb for patients wearing soft lenses or hard lenses for 10 years would be to discontinue lens wear for 2 and 4 weeks, respectively. Longer duration of lens wear will likely require longer periods of abstinence. Serial examinations are recommended to ensure refractive stability. Once stability is achieved and final measurements are acquired, the patient can return to lens wear until a few days prior to surgery.

For myopia, the manifest refraction should not differ from the cycloplegic refraction by >0.50 D, and the axis of cylinder should not differ by more than 15 degrees. For hyperopia, the manifest and cycloplegic refractions should not differ by >0.75 D.

Keratometry values should be used to calculate the predicted postsurgical corneal contour. If the estimate of the postsurgical corneal contour is <35.00 D, keratorefractive surgery outcome may be less than ideal because the cornea may be too flat to support good visual function. To estimate the postsurgical corneal contour, the spherical equivalent of the proposed treatment is multiplied by a conversion factor of 0.7 or a more conservative 0.8. The product is subtracted from the average of the keratometric values. If the result is only slightly >35.00 D, a significant retreatment may leave the cornea too flat to support good visual function. This possibility would be important to discuss with a patient who has such a preoperative estimate. Hyperopic treatments induce corneal steepening. The conversion factor for estimating postoperative steepening is 1.0 and the postoperative cornea should remain below 50 D.

Ocular dominance should be recorded. It can be determined by asking the patient to wink. Generally, patients have difficulty winking the dominant eye. Hand the patient a disposable camera and ask the patient to pretend to take a picture. The camera will be held in front of the dominant eye. Finally the patient can be asked to create an "o" with the fingers and thumb on each hand and then create a tube by stacking the hands. The patient will use the dominant eye when asked to look through the tube. Ocular dominance is important in performing a monovision treatment. The dominant eye is usually corrected for distance.

A careful external examination is required to identify diseases such as acne rosacea, which can be associated with ocular inflammation, and may require treatment prior to surgery. In addition, an assessment of the degree of ocular exposure is essential. The surgeon should determine whether the degree of lid laxity, the orbital aperture, the prominence of the brow, the position of the globe,

and palpebral fissure height are adequate to accommodate a flap making apparatus. If the aperture is small or tight or if the eye is deep set, photorefractive keratectomy (PRK) may be a more preferable option.

Significant lagophthalmos and associated exposure may be problematic postoperatively, given the temporary neurotrophic status of the flap. If the eyes are dry, the patient can be reassessed 1 month after initiating treatment with tear supplements, topical cyclosporine, and/or punctal plugs. Encouraging good oral hydration is also important in patients who exercise heavily. If significant tear deficiency remains despite these measures, LASIK should be avoided. Low ambient humidity in the patient's work or home environment will be unfavorable for the borderline dry eye patient. Patients who do extensive reading or computer work may be at greater risk of an evaporative dry eye postoperatively.

The patient should be examined for the presence of a relative afferent pupillary defect. The pupil diameter can be measured in the dark with one of the commercially available devices designed for this purpose, for example, a Colvard pupillometer (OASIS Medical, Inc., Glendora, CA). The significance of large pupil size and its relationship to the quality of night vision is not at all certain. There is convincing evidence that pupil size is not a significant factor in predicting postoperative glare and haloes (refer to Suggested Readings). Many surgeons believe that reducing higher order aberrations with custom treatment is much more important. The degree of myopic correction is a much more significant factor. Some surgeons routinely use the largest treatment zone possible given corneal thickness constraints regardless of pupil size. Others continue to prefer a treatment zone that extends beyond the edge of the dark-adapted pupil in the hope of minimizing night vision symptoms, despite the lack of strong supportive evidence.

Motility function should be assessed to rule out a latent condition that might become symptomatic in the event of significant postoperative anisometropia. This is especially true in the case of a patient considering monovision treatment or for the patient with a past history of strabismus surgery. A patient able to control a significant phoria may develop diplopia, if fusion is disrupted. A patient with a moderate- to large-angle alternating tropia may tolerate monovision, because this individual currently fails to use the eyes together and is capable of using either eye independently. Monovision may not be suitable for a patient with a constant tropia and a strong fixation preference for one of the eyes. Monovision would force this patient to use the deviated, nondominant eye for near vision, which might seem unnatural.

The slit-lamp examination should begin with an assessment of the lids and lashes. Inflammation in this area should be controlled prior to surgery. It is critically important to rule out the presence of corneal pathology. Contact lens–wearing patients may have peripheral corneal neovascularization, punctate keratopathy, sterile keratitis, stromal thinning, scarring, or subepithelial fibrosis. Keratitis and punctate keratopathy are usually reversible and may clear after a period of time without lens wear. Active keratitis is a contraindication to LASIK surgery. If it does not clear spontaneously, a treatment regimen should be initiated and the patient reevaluated. Subepithelial fibrosis and neovascularization are permanent changes that may impact the surgical plan or the decision to do surgery.

Corneal diameter should be noted. If the cornea is small it may be challenging to reliably create a microkeratome flap of adequate size to accommodate the proposed ablation. A surface ablation procedure may be the better option, however, the femtosecond laser may allow the surgeon greater control over flap diameter making safe LASIK possible.

Special attention to the corneal thickness is important. If the cornea is thin, the residual stromal bed following the intended treatment might be inadequate to support a stable corneal contour long term, increasing the risk of post LASIK ectasia. In such a case LASIK surgery may be contraindicated. The preoperative corneal contour should be regular. An irregular contour suspected on slit-lamp examination should be investigated with corneal topography. LASIK surgery is most reliable when the contour is regular.

Corneal scarring within the proposed ablation zone is a relative contraindication to the surgery. LASIK may be possible if scarring is in the periphery and thinning is mild, provided

the cause is not prior herpes simplex keratitis. Herpes viral infections can be reactivated by the ultraviolet radiation of the excimer laser. The presence of epithelial basement membrane dystrophy may indicate a possible defect in epithelial adhesion. Patients with this dystrophy are more likely to experience epithelial sloughing, possibly with diffuse lamellar keratitis or epithelial ingrowth. The risk of epithelial sloughing has been substantially reduced with the femtosecond laser. Patients with confluent guttae may be at risk for poor flap adhesion postoperatively, if the endothelial pump functions poorly. An abnormally thick cornea, especially in the early morning, may be a sign of abnormal endothelial pump function.

All abnormalities of the anterior segment should be noted. The presence of cataract may be a contraindication to LASIK surgery. It is best to avoid LASIK surgery on the patient with a visually significant or progressive cataract. Lens-induced myopia from a nuclear cataract can be misinterpreted as LASIK regression. Glare from a posterior subcapsular cataract might be thought to be due to the refractive surgery.

If a peripheral cataract is found on the presurgical examination, it is wise to follow the patient until it can be determined whether or not the cataract is progressive. The patient who decides to proceed with refractive surgery should be informed that, although the cataract may appear to be stable and not visually significant, it could unexpectedly progress and undermine the LASIK result. If cataract surgery is needed, determination of the lens implant power will be more challenging than it otherwise would be. If standard keratometry is used in biometry for a cataract patient after LASIK surgery has been done, the selected lens implant may be underpowered. This topic is more completely discussed in Chapter 14.

Intraocular pressure (IOP) should be measured preoperatively. If the cycloplegic refraction is to be done on the same day, the pressure should be measured following the refraction in order to avoid disturbing the corneal surface. If IOP is elevated, the significance should be interpreted. The pressure would, for example, be less significant if the cornea is thicker than normal and the optic nerve is normal. Significant optic nerve cupping should be evaluated with visual field evaluation and possibly an ocular coherent tomography (OCT) to assess nerve fiber layer thickness. In the presence of glaucomatous field changes, the potential for nerve damage occurring when the suction ring increases the eye pressure should be considered. In this situation, an alternative refractive surgery option such as a surface ablation procedure can be discussed with the patient. If the patient has a filtering bleb, a suction ring should not be used. Finally, one must recognize that IOP measurement in a thin postoperative patient may be less accurate.

The dilated fundus examination is an essential part of the preoperative evaluation. While it need not be done during an initial screening examination, it must be done prior to surgery. If significant abnormalities are found, the patient should be informed. The cycloplegic refraction on which the LASIK treatment is based should be performed before the retina is exposed to intense illumination.

The fundus examination is particularly important for the myopic patient who is at greater risk for retinal detachment. In the presence of peripheral retinal pathology, a consultation from a retinal specialist is advisable. The result of this consultation should be included in the record. Preoperative prophylactic treatment can be delivered if required. The retina surgeon should determine the timing of LASIK surgery, following any treatment. If a retinal problem were to develop postoperatively, the patient will already have a relationship with a specialist.

Diabetic retinopathy if present may impact the decision to do LASIK. Patients with evidence of significant retinal ischemia may be at risk for an ischemic event related to intraoperative IOP elevation. Macular edema, epiretinal membranes, and degenerative changes in the macula may all limit the postsurgical visual outcome. These issues should be discussed with the patient. It is not uncommon for previously undiagnosed retinal disease to be uncovered during the LASIK evaluation.

If the optic nerve does not appear normal, an evaluation of optic nerve function should be conducted. This evaluation would include measurement of central acuity, pupil reactivity,

color vision, brightness comparison, and visual field. Obviously, some of this evaluation will already have been done before the retinal examination. Highly myopic patients often have tilted discs with peripapillary atrophy. The surgeon should rely on his or her own experience to determine if the appearance of the disc is inconsistent with the patient's refractive error.

Corneal pachymetry should be measured after the refraction has taken place to prevent surface disruption. This is a critical measurement and should be performed with an ultrasonic device. The surgeon is cautioned against relying on slit-beam–generated pachymetric maps; for example, Orbscan (Bausch & Lomb, Rochester, NY), to determine whether the cornea is thick enough for LASIK surgery. These maps provide a relative comparison of thickness at different points on the cornea but may not accurately measure the corneal thickness at any one point. Sheimpflug-based pachymetric maps as generated by Pentacam (Oculus, Inc., Lynnwood, WA) provide accurate measurements of corneal thickness. It reliably determines the thinnest part of the cornea and can be used in lieu of ultrasonic pachymetry. When ultrasonic pachymetry is relied upon, care must be taken to be certain that the thinnest part of the cornea is being measured. Remember the thinnest part of the cornea may not be in the center, for example, pellucid marginal degeneration (PMD) or forme fruste keratoconus (FFKC).

Because contact lens wear can increase corneal thickness, it is more accurate to measure the thickness after the patient has discontinued lens wear. However, if the patient is measured just after contact lenses have been removed and the cornea is too thin for LASIK surgery, a second measurement following a period without contact lens wear will usually not improve the patient's candidacy for surgery. If the cornea is significantly thicker than 620 µm, one must determine whether abnormal endothelial function is the explanation. A correlation with the slit-lamp evaluation and possibly specular microscopy is indicated in this situation. While the cornea may be thicker than normal with normal endothelial function, the consequence of not detecting poor endothelial function is a postoperative flap adhesion problem.

Corneal topography must be done on every patient prior to LASIK surgery in order to avoid operating on a patient with an abnormal corneal contour. When the contour is abnormal preoperatively, the postoperative outcome is unpredictable, even when the cornea is of adequate thickness.

The topographical analysis may also indicate significant contact lens–induced irregularity. Serial topography performed during a period of contact lens abstinence can be used to track the corneal contour during the resolution of the irregularity and ultimately confirm that the corneal surface has become regular and stable.

The refractive surgeon must be capable of identifying preclinical or forme fruste keratoconus. A young patient with subtle signs of ectasia may go on to manifest the clinical signs of keratoconus over time. Refractive surgery would hasten the development of symptomatic disease. Pellucid marginal degeneration is a noninflammatory thinning disorder in which there is typically a band of inferior thinning with protrusion of the cornea superior to the thin area. Laser refractive surgery should also be avoided in patients with PMD. This condition has a characteristic power map sometimes described as a "crab claw" appearance. Corneal topography including the signs of early keratoconus is discussed in greater detail in Chapter 2.

No one method is foolproof for reducing the risk of postoperative ectasia. It is recommended that multiple factors and analyses be used to determine whether a particular patient is suitable for keratorefractive surgery. Randleman et al.[1] have developed a conservative ectasia risk scale that combines corneal topography pattern, residual stromal bed thickness, patient age, preoperative corneal thickness, and manifest refraction spherical equivalent. Risk assessment for ectasia after corneal refractive surgery is discussed later on in this chapter in greater detail.

Wave scan can be done at the same time as topography if custom LASIK is being considered; however, wave scan is not a substitute for topography. The scan used for the actual surgery should be obtained after the patient has been out of contact lenses long enough for

the refraction to stabilize. The wave scan will determine the degree and type of higher order aberrations. It also determines the refractive error in an objective way that can aid the surgeon when performing refraction. wave scan technology can be used postoperatively to assess the degree of higher order aberrations that may be induced by refractive surgery. The nuances of wave scan interpretation and custom LASIK as performed with several commonly used systems will be discussed later in the text.

DISCUSSING THE RISKS OF SURGERY

Presentation Overview

One of the greatest challenges for the beginning LASIK surgeon is to explain the actual operation and the risks of the procedure with confidence and in a manner that informs without terrifying the patient. The choice of words will make a significant difference in the patient's perception of the procedure and the surgeon. Speaking in lay language, in a manner easily understood by the patient, is key to communicating the information needed to make an informed decision. A discussion presented with enthusiasm will help as well.

The explanation of the procedure and the risks should follow the examination. If the surgeon uncovers a contraindication to LASIK surgery, this can be explained and the consultation concluded without having gone through a detailed discussion.

Explain to the patient that the discussion will cover most of the commonly asked questions. Encourage the patient to interrupt if a particular point is not clear or if there is a question, and inform the patient that there will be time at the end to ask any additional questions. Remember the goals of the dialogue are both to inform completely and reduce anxiety. Anticipate your patient's questions and answer them before the patient needs to ask them. For example, if you wear glasses, anticipate that your patient will want to know why you haven't had the procedure. Have an answer prepared so you can present this information without being asked. This helps to instill confidence. Withholding information is improper and may increase anxiety and contribute to dissatisfaction with the surgery. Proper preoperative preparation will make the entire surgical process easier for the patient, surgeon, and staff. While many surgeons have others in the office explain the procedure and risks, there is an advantage for the surgeon to have the discussion personally. There is an opportunity to get to know this patient and determine his or her candidacy for the procedure from a psychosocial perspective. If the patient is unusually nervous, acts in an inappropriate way, seems inattentive or suspicious, or appears to have unreasonable expectations, he or she may be a poor candidate.

It is helpful to listen to one or more experienced surgeons present this material. A recording of the presentation or a typewritten script can help the beginning surgeon to prepare the first few discussions with prospective patients. Over time the surgeon will develop a talk that incorporates both the answers to questions that arise during discussion as well as portions of other doctors' presentations that seem to fit appropriately. When the presentation feels natural, the physician will appear self-assured and the patient will sense this.

Because one of the goals of the initial encounter is to instill the patient with feelings of confidence and comfort with the surgeon and staff, try to minimize the wait time in the office prior to the consultation and at every postoperative visit. During introductions, ask the patient how he or she prefers to be called and ask permission to address the patient in that manner.

Sample Preoperative LASIK Patient Discussion

Here is a sample LASIK presentation. It should be tailored as needed for each individual patient. Dialogue directed to the patient is in italic type. *What are you hoping LASIK surgery will do for you*? The most common response is "to get rid of my glasses and contact lenses." The ideal response is "to become less dependent on glasses and contact lenses." Responses such as "I want to be more attractive," "I want to improve my vision beyond what I see in glasses or contact lenses," or "I don't know, I just want the surgery" are not particularly

appropriate and should raise a red flag about the candidacy of the particular patient. At this point it is helpful to remind the patient that LASIK reduces the dependence on glasses and contact lenses, but that glasses may be needed for reading when one reaches the mid-40s. "*Correcting the dominant eye for distance and the nondominant eye for near, can reduce the need for reading glasses. This is called monovision.*" This discussion is appropriate for patients of presbyopic age. "*Glasses may also be needed for some distance activities, such as driving at night or in the rain, but it is rare for patients to require distance glasses full time*."

Vision Expectations. The first question every patient wants an answer to is, "How well will I see after surgery?" If the patient is a myope with ≤ –10.00 D of spherical error and ≤ +3.00 D of cylindrical, it is reasonable to expect an uncorrected visual acuity of 20/25 or better. "*Retreatment may be required to achieve this level of visual acuity. A typical retreatment rate is approximately 10%, meaning 90% of patients achieve their vision goals with one laser surgery. Retreatment rates are generally higher for patients who need stronger glasses*." It is important to explain to the hyperopic patient that in order to successfully correct distance vision in the long run, an initial overcorrection is necessary. This will result in good near vision, but blurring in the distance, and may require the need for distance glasses. Over a 3- to 6-month period the distance vision will improve and the near vision may weaken.

Night Vision. "*Nearsighted patients often feel they don't see as well at night. They may be aware of glare from car headlights or haloes around streetlights*." If the patient does not appear to understand what glare is, dim the overhead lights and shine a light toward the patient from 2 to 3 feet away. Ask the patient if rays of light are seen coming from the light source. "*It is important for patients to become familiar with their night vision preoperatively so they have a basis for comparison postoperatively. Following LASIK surgery some patients will be aware of increased glare or haloes around lights, especially in the first 3 months after surgery. This tends to occur in patients with night vision problems prior to surgery, and in patients with large corrections (> –7.00 D)*." Pupil size as a risk factor for impaired night vision is controversial. (Refer to Schallhorn et al.[2]) *It is rare for a patient to feel completely disabled at night. Night vision problems can also be related to residual nearsightedness or astigmatism. In this case glasses used for night driving may help. Retreatment may also be a consideration*."

"*Some patients will achieve significant improvement in night vision following surgery if they were not well corrected before surgery*." A discussion of custom LASIK as a means to reduce the risk of night vision symptoms could be included here if this is an available option. "*If you are concerned about night vision following surgery, you may want to consider custom LASIK. This approach depends on wavefront technology, in which light is shined into the eye and the reflected light that comes out of the eye is analyzed by the computer. The computer determines your need for glasses and your higher order aberrations. These are imperfections in the visual system, which are unique to each of us and contribute to night vision problems. Custom LASIK is designed to correct both the need for glasses and the higher order aberrations. A study reviewed by the FDA (for CustomVue LASIK with the VISX laser) showed fewer problems with night vision for the majority of patients treated. Having custom LASIK does not guarantee that you won't experience night vision issues. This more advanced procedure may remove more of the cornea and it may cost more than conventional LASIK* (some surgeons charge the same for custom and conventional LASIK), *but if you are concerned about night vision or want more advanced technology, this is it*."

Dry Eye. "*Dryness affects many LASIK patients in the first 3 months following surgery. Women and patients older than 50 years are the most likely to have these problems. In addition, people who consistently spend many hours in a dry environment either working on the computer or reading may experience dry eye related to evaporation of tears from the eye after surgery. Certain medications or medical conditions can contribute to dryness after LASIK surgery. Artificial teardrops help. If tear supplements are not adequate, plugs can be placed in the tear drainage ducts of the lower lids to increase the amount of*

tear fluid on the eyes. A desk top humidifier may also be helpful to reduce postoperative dryness." If the patient is borderline tear deficient preoperatively, the following can be added: "*Sometimes tear therapy, plug insertion, and/or topical medication* (topical cyclosporine)*are considered prior to the surgery in order to improve the condition of the eye. Patients with moderate to severe dry eye preoperatively that cannot be sufficiently improved with therapy are not good candidates for LASIK surgery.*"

Infection. "*Infection is a complication that we take very seriously. The risk around the country is approximately 1 in 2,000*." If there have been no infections in your center or if your infection rate is <1/2,000, it may be helpful to tell that to the patient. "*We have potent antibiotics that are effective against the kind of bacteria that cause infection after LASIK. We take steps to reduce the risk of infection prior to surgery and use antibiotic drops after surgery. However, if an infection occurs within the line of sight, it could have a profound impact on visual function. In the rare event that infection does occur, the damaged cornea could be replaced with clear corneal tissue. This is called a cornea transplant and is exceedingly rare following LASIK surgery*."

Retinal Detachment. "*Nearsighted people are at risk for a retinal detachment whether they have LASIK surgery or not. The chance increases with the degree of nearsightedness. A retinal detachment means the 'movie screen' in the back of the eye becomes loose. Surgery is needed to reattach the retina. LASIK surgery may increase the chance of retinal detachment, but the overall risk is small at about 1 in 1,500. A careful examination of the retina is done prior to the surgery to be certain there is no preexisting pathology that might predispose a patient to a retinal problem*."

Contour Instability. "*The goal of surgery is not only to reduce dependence on glasses and contact lenses, but to perform surgery in a manner that provides long-term stability. Laser treatment for nearsighted correction works by thinning the cornea. A certain amount of cornea must be left untouched for the shape to remain stable. If the cornea is too thin prior to surgery or if the treatment will thin the cornea too much, laser surgery may not be possible. Adherence to safety guidelines reduces the risk of returning to glasses, contact lenses, or the need for further surgical intervention.*" It may be appropriate to consider a discussion of PRK, phakic intraocular lens (IOL), or clear lens exchange rather than LASIK. "*Some patients have a preoperative contour that is irregular and may not be candidates for LASIK even when the cornea is thick enough. Contour mapping and thickness measurements help to determine which surgical options are most safe*."

At this point it is appropriate to summarize what has been said. "*So far we have reviewed six important topics: vision expectations, night vision, dry eye, infection, retinal detachment, and contour instability. Do you have any questions about this information?*" If there are no questions, it is appropriate to move on to the next part of the discussion. Additional risks of the procedure can be explained in the context of a step-by-step explanation of the procedure.

Setup for the Procedure. "*Many patients take a sedative pill prior to the surgery to control anxiety. Some feel it is unnecessary. Usually both eyes are operated on at the same time, but if you prefer, it can be done one eye at a time.*" If the patient is of presbyopic age and the refractive error of the nondominant eye is appropriate for near vision, sequential surgery can be planned to give the patient an attempt at monovision. If unsuccessful, the second eye can be treated in a subsequent surgery. "*Anesthetic drops are used to keep the eyes comfortable and reduce the urge to blink. A cleaning solution is used around the eyes. One of the eyes is covered to reduce distraction. The chair is rotated to position you under the microscope. This is not a claustrophobic experience. There is nothing covering your nose or mouth, you are not restrained in any way, and you are given something to occupy your hands. Your head is supported by a form-fit cushion, which allows you to feel secure and comfortable. You will be shown exactly where to look*" Patients are usually anxious about where to look, so it is helpful to demonstrate the fixation light at the beginning of the procedure and to inform the patient when the fixation light may become blurred or absent."*Small sticky drapes are placed on the eyelids to cover the eyelashes, additional anesthetic*

is applied, and an eyelid holder is inserted."The prep and drape will vary between surgeons. Prep and drape will occur before a microkeratome procedure, while some surgeons prefer to drape after the femtosecond laser procedure. It is important to assess exposure and the degree of eyelid laxity during the preoperative examination by spreading the lids apart. This test serves the dual purpose of also simulating the sensation of the speculum. "*An eyelid holder will prevent blinking. So there is no need to worry about an inadvertent blink*." A lid speculum may be unnecessary prior to a femtosecond laser procedure, because the ring is sufficient for eyelid support.

Creation of the Flap. "*At this point a ring-shaped device is placed on the surface of the eye overlying that portion where the color part of the eye meets the white part. This device will be used to raise the pressure of the eye. The sensation is not unlike the pressure sensation that occurs when blood pressure is measured or when you push on the eye. The pressure may get high enough to cause the lights to dim and go out. This is normal and necessary in order to make a perfect flap. Once the eye has reached a sufficiently high pressure, the flap can be made.*" It is appropriate to explain the sounds and sensations associated with the particular mechanical microkeratome or laser being used for flap creation. "*The entire flap-making process takes <30 seconds, so you will not feel the pressure sensation for very long. After the flap has been made, the pressure is released, the lights come back, and the entire apparatus is removed. The procedure can then be repeated on the fellow eye. It is extremely rare for the flap to be too small, too thin, off center, or incomplete, meaning it cannot be adequately lifted to expose an appropriate area for the laser treatment. In this case the flap is replaced and the vision generally returns to the preoperative level. We would then wait for 6 months and try again to make a flap.*"This is true for the mechanical microkeratome, but not for the femtosecond laser. Abnormal flaps are extremely rare since the advent of the femtosecond laser. "*The flap-making equipment is highly reliable and generally makes great flaps. I will tell you about the quality of your flap, so you don't have to wonder or worry about it*."

"*An alternative way to make a flap is to use a laser. This is a technology that has several potential advantages over the mechanical microkeratome. The laser more precisely creates a flap of the desired thickness, preserving as much cornea as possible. The potential for an abnormally thin, small, or free flap to occur is far less than with a blade microkeratome. Finally, in the event of a loss of suction, an incomplete flap can be corrected at the time of surgery* (IntraLase, Abbott Medical Optics, Santa Ana, CA). *If it were to become necessary, the laser-created flap may be more difficult to relift a year after surgery. However, this also means that the flap is more resistant to movement in the event of an injury*." As the femtosecond laser gradually replaces the mechanical microkeratome, it becomes increasingly unnecessary to describe both methods of creating a flap.

The Laser Procedure. "*At this point we are ready to do the reshaping portion of the procedure. The laser is not a gun, as depicted in science fiction movies. It is simply ultraviolet light. It is cool and painless. Every patient worries that they will look in the wrong place and the wrong time. Our laser has a tracking device that will find the center of your pupil, and if your eye moves within the tracking zone, the laser will follow. This is similar to the technology in fighter jets. If your eye moves outside the tracking zone, which occurs only rarely, the laser will not fire. The reaction time is extremely short, 30 milliseconds*." (True for the VISX S3 and S4 lasers) "*Therefore, either the laser is treating in exactly the correct place or not at all. This is a wonderful safety feature and should help to reduce fears about the laser firing in the wrong place*." Not every laser has a tracking device. It is important to be familiar with the features of the laser you will use.

"*When the flap is lifted, there is no sensation, but the vision may become blurred temporarily. The laser locks on the pupil center and the treatment begins. The laser makes a clicking sound. Each click is a pulse of laser energy acting to reshape the cornea. The treatment usually lasts less than a minute*."

After the Laser Reshaping Procedure. "*After the laser treatment, the flap is replaced. Fluid is used to irrigate beneath the flap to remove debris;*

1

and the flap is gently stroked into proper position. The alignment is checked. If all is well, the process is repeated on the fellow eye."

"*Patients often ask what holds this flap in place because no stitches, glue, or staples are used in the procedure. There is a natural force that holds the flap in position, in a manner similar to the force that holds a thin slice of apple in place on the apple. If you rub or bump the eye, the flap may become dislodged, requiring repositioning. For this reason eye protection in the form of safety glasses or goggles are used for a time after surgery. Over 2 to 3 days, surface cells will cover the edge of the flap, but it takes a year or longer for a strong bond to form between the underside of the flap and the remaining cornea. This weak bond is used to our advantage after LASIK. For example, microscopic wrinkles in the flap called microstriae, similar to wrinkles in a bedsheet, can cause ghosting or a reduction in the best possible vision. The flap can be lifted and the wrinkles smoothed out. If there is inflammation that does not respond to drops or pills, the flap can be lifted and inflammatory material removed. If cells from the surface are caught beneath the flap and grow into a little bump, the material can be removed after lifting the flap*."

"*Most nearsighted eyes respond to the laser in a predictable manner. However, if your eye responds more than expected, farsightedness might result. Too little response and the result would be residual nearsightedness. Once the correction stabilizes, usually at 2 to 3 months after surgery, the flap could be lifted and additional laser treatment performed. Of course this depends on there being adequate remaining cornea. Occasionally, between months 1 and 3, the result drifts back toward nearsightedness. When this regression occurs, it is usually on the order of 10% of your original correction. Retreatment for regression is also possible provided the postoperative cornea is thick enough*."

"*Postoperatively the patient is examined with the slit-lamp microscope. Any abnormalities in or under the flap can be adjusted at that time. Eyedrops will be provided and should be administered four times daily. The vision will be hazy for a day or two and will gradually clear. It is normal for the eyes to feel scratchy or irritated for a couple of days. Over-the-counter pain relievers may be helpful. Patients are examined the next day, the next week, at 1 month, 3 months, 6 months, and at 1 year. The LASIK fee is all-inclusive and will cover the cost of postoperative visits, retreatment or revision, and eyedrops. It will not cover the cost of cornea transplant or retina surgery in the unlikely event that either was needed*." For many surgeons a global fee covers 1 year of service.

Finally, it is important to discuss the surgeon's background and experience. Patients will wonder how many procedures the surgeon has performed and performs routinely. It is worth preparing a statement that is added at the end of the discussion, so that the patient will not be required to question the surgeon's qualifications to perform the surgery.

Acknowledge that this was a lot of material and express willingness to answer any questions. Tables 1.2 to 1.4 summarize the key points of the discussion.

Surgical Planning

Once the evaluation has been completed, the risks have been explained, and the patient has decided to proceed with LASIK, the surgeon can begin the next step, which is to develop a surgical plan. This is a crucial step in obtaining safe and predictable results. It will require an intimate knowledge of the patient's needs and expectations as well as familiarity with the equipment that will be used to perform surgery. Here lies both the challenge and satisfaction for the LASIK surgeon. The goal of this manual is to give the LASIK surgeon insight into this most important step in the surgery. The factors presented herein should be used when working the cases later on in the handbook.

The surgical plan should be developed well in advance of the scheduled surgery. Decisions made just prior to surgery may not be adequately thought out, particularly if the surgeon is relatively new to LASIK surgery. Even when the plan is developed in advance of the surgery, the data entries and calculations should be rechecked as part of a surgical "time-out" just prior to the actual surgery. Developing this habit will help avoid costly errors.

A basic set of principles will be presented here. These principles are applicable across the landscape of equipment options available. Because the planning will vary depending on the various microkeratomes and lasers used,

TABLE 1.2 Discussion of LASIK Risks

- Vision expectations
  - Postoperative uncorrected vision expected given patient's refraction
  - Possible need for reading glasses and/or driving glasses
  - Possible need for retreatment to achieve visual goals
- Night vision
  - Glare and haloes
  - Custom LASIK
- Dry eye
  - Possible need for tears, medication, or plugs
- Retinal detachment
- Infection
- Inappropriate flap
  - Too small or thin
  - Incomplete or off center
- Flap striae
  - Ghosting
  - Possible need to lift flap to remove striae
- Flap adherence
- Flap displacement
  - Need for eye protection
- Inflammation
  - Need for drops or pills to control inflammation
  - Possible need to lift flap to remove inflammatory material
- Ingrowth
  - Possible need to lift flap for removal
- Corneal ectasia
  - Need for contact lens wear
  - Need for cornea transplant
- Postoperative ametropia
  - Over/undercorrection
  - Regression
  - Need and timing for retreatment

TABLE 1.3 Discussion of the LASIK Procedure

- Optional need for sedation
- Topical anesthetic reduces the urge to blink
- Simultaneous vs. sequential surgery
- Prep and drape
- Lid speculum prevents blinking
- Fixation light
- Creation of flap
  - Pressure sensation
  - Lights become dim and go out
  - Sounds
- Mechanical vs. laser flap creation
- Flap assessment
- Lifting the flap
- Laser
  - Describe the type of laser
  - Tracker
  - Sound
- Reposition the flap
- Remove drape
- Switch to fellow eye

the reader should refer to the sections that discuss the specific equipment available. As an example, Table 1.5 illustrates factors important in developing a treatment plan using the Hansatome and the VISX laser. Many of the concepts apply to other microkeratomes and lasers. Table 1.1 presents the FDA-approved indications for excimer laser refractive surgery.

In general, the goal of the plan is to determine how best to address the following questions: What correction should be entered into the laser's computer? What is the appropriate treatment zone? What is the maximum ablation depth? What is the appropriate flap diameter? What is the ideal hinge position or hinge width? Once the answers to these questions have been determined, the surgeon must put this into language that the scrub technician and laser engineer can use with the available equipment at hand.

TABLE 1.4 Postoperative Information

- Postoperative sensations
  - Vision hazy, but improved; nap speeds vision improvement
- Scratchy irritation; acetaminophen or aspirin helps
- Eye protection
  - Do not rub or touch the eyes for at least 1 wk after surgery
  - Use of protective eyewear
  - Avoid injury during eyedrop instillation
  - No swimming for at least 2 wk after surgery
- Eyedrop instructions
- Follow-up appointment
- Physician's emergency number

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TABLE 1.5 Decision Making for Treatment Plan[a]

Degree of correction	FDA-approved indications for the VISX laser:
	Myopia: ≤ −12.00 D sphere and/or ≤ +5.00 D of cylinder
	Hyperopia: ≤ +5.00 D sphere and/or +4.00 D of cylinder (≤6.00 spherical equivalent)
	Mixed astigmatism: astigmatism > myopic sphere with ≤6.00 D cylinder
	Custom myopia: ≤6.00 D sphere with ≤3.00 D cylinder
	Custom hyperopia: ≤ +3.00 D sphere with ≤ +2.00 D cylinder
	Custom mixed astigmatism: ≤5.00 D cylinder
Steep cornea; average *K* > 48.50 D increased risk of buttonhole	If average *K* > 45.00 D, use 8.5-mm Hansatome ring
	Consider femtosecond laser flap
	Caution: flaps cut on steep corneas with blade microkeratomes tend to be large
	If buttonhole: replace flap, no laser, consider PTK-PRK with or without mitomycin-C 0.2 mg/cc application
Flat cornea; average *K* < 40.00 D increased risk of free cap	If average *K* < 45.00 D, use 9.5-mm Hansatome ring
	Consider femtosecond laser flap
	Caution: blade-cut flaps on flap corneas tend to be small. If free flap or small flap, replace flap, no laser, BCL, return in 6 mo to cut new flap using thicker plate
Small corneal diameter	Select smaller ring diameter to avoid bleeding unless flat or large flap needed
	Consider femtosecond laser flap or PRK
	Caution: risk of bleeding, conjunctival or scleral extension
Large corneal diameter	Use larger 9.5-mm ring to create larger flap unless steep
Corneal vascularization	Use smaller ring to avoid bleeding; less of a problem with femtosecond laser
Corneal thickness	Leave >250–300 µm of corneal bed untouched
	Hansatome plates (130, 160, 180, and 200 µm): flap thickness usually less than expected and even thinner on second eye. If initial flap very thin, increase plate thickness on second eye
	Caution: If cornea too thin, consider PRK, although risk of haze increases > −5.00 D or ≥75 µm ablation depth. Consider using mitomycin-C or phakic IOL
	If preoperative pachymetry <520 µm, recommend intraoperative pachymetry of stromal bed; 160- or 180-µm Hansatome plates most commonly used. Thin flap creation may be more reliable with femtosecond laser
Ablation depth	Ablation rule of thumb example
	VISX 6.0-mm zone: 12 µm/D treated
	VISX 6.5-mm zone: 15 µm/D treated
	Blend zone 8.0 mm: add 8 µm for <10.00 D treatment; 11 µm for ≥10 D
Humidity	Adequate humidity: 30%–50%
	Caution:
	Low humidity: cornea dehydration, ↑ ablation/pulse may cause overcorrection
	High humidity: ↓ ablation/pulse may cause undercorrection
Pupil size	Consider measuring pupil size in dark with pupillometer
	<6.0 mm: use 6.0-mm zone
	6.0–6.5 mm: use 6.0 or 6.5-mm zone with blend if thickness adequate
	≥6.5 mm: use 6.0 or 6.5-mm zone with blend zone if thickness adequate
	Note: More contemporary thinking is that pupil size has little if any impact on night vision and it is best to simply choose the largest zone that can safely be used regardless of pupil size
	Caution: Custom treatment preferred when night vision quality is a significant concern
Surgical exposure	*Caution:* Small fissure, tight lids, deep orbit → poor flap
	Consider one-piece microkeratome/nasal hinge
	Consider micro ring (outer diameter 1 mm smaller)
	Consider stronger speculum or no speculum

[a]This decision-making algorithm is for the VISX laser and the Hansatome.

With regard to hinge width, some surgeons prefer a nasal rather than a superior hinge in a patient with a history of tear deficiency. With some equipment, the hinge width can be adjusted. A narrower hinge allows greater flap retraction, making more of the stromal bed available for treatment of a large zone. Refer to Figure 5.2 in Chapter 5 on the femtosecond laser.

WHAT CORRECTION SHOULD BE ENTERED INTO THE LASER COMPUTER?

Excimer laser energy delivered within the stroma as occurs in LASIK will correct more myopia than when the same amount of energy is delivered during surface ablation. The VISX laser was designed and approved for PRK and a reduction factor is often needed for LASIK surgery to achieve the desired effect. More reduction may be needed as either the correction or patient age increases. Overcorrection may result if an appropriate adjustment to the correction is not made. It is important to note that some surgeons using certain lasers routinely will perform conventional (not custom) treatment without using a correction factor. This methodology may be surgeon or laser-specific. Some surgeons will correct based on the manifest refraction, while others prefer to use the cycloplegic refraction. This may be a function of how close the patient is to presbyopic age. Some surgeons prefer to base the astigmatic correction on the manifest refraction and the spherical correction on the cycloplegic refraction. Caution is advised if there is a significant difference between the two measurements.

Several nomograms have been developed to appropriately adjust the correction. One example is the Bansal-Kay nomogram, which is designed for use with the VISX Star laser and only in patients with myopia or myopic astigmatism. The reader should refer to the appropriate laser type within this book for a recommended nomogram or reduction rule to follow. Nomograms are specific to the type of correction; that is, a nomogram for myopia correction should not be used for treatment of hyperopia.

For hyperopia a different nomogram is required. There is a tendency for regression of the laser effect with a hyperopic ablation; therefore, an overcorrection may need to be added to the intended treatment to compensate for this. It is important to be familiar with the laser system being used in order to properly develop a suitable treatment plan.

WHAT IS THE APPROPRIATE TREATMENT ZONE?

Multiple factors contribute to the planning of the treatment zone. Refractive error, corneal thickness, corneal diameter, corneal contour, and peripheral corneal pathology are all important. Surgeons have mixed opinions about the importance of the pupil in determining the treatment zone, although the evidence does not support a correlation between pupil size and night vision disturbance. One rule of thumb is to use the smallest zone that will accomplish the refractive treatment as safely as possible, minimizing the ablation depth when possible. In contrast, to this previously long held strategy, many surgeons now routinely use the largest zone that can safely be used without consideration of pupil size.

Many surgeons continue to prefer overall treatment that is larger than the maximum pupil size in the dark. They believe this will reduce nighttime aberrations related to the treatment zone edge. For example, in a patient with a pupil of 6.0 mm, a zone of 6.5 mm or larger is desirable. One could also combine a 6.0-mm zone with a blend zone when the pupil is larger than 6.0 mm. The VISX laser can treat up to 8.0 mm by adding a blend zone, which corrects 1 D of myopia with an 8.0 mm zone. CustomVue treatment with the VISX laser can treat up to 9.0 mm. The surgeon must be mindful that the larger the treatment zone, the deeper the ablation will be. Custom treatment based on wave scan technology will also remove more stromal tissue.

The greater the degree of myopic correction, the deeper the laser ablation needed to correct it. As a rule, when possible use a smaller zone when corrections are large. For example, if a patient with a large myopic correction had a pupil diameter of <6.0 mm, many surgeons would consider a 6.0-mm zone with or without a blend to be most appropriate. This will preserve as much cornea as possible.

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In a patient with a small or flat cornea, it may be challenging to make a flap with a microkeratome that is large enough to add a blend zone. These might be important factors if the same patient also had a large pupil and you believed it was a risk for night vision problems. Treatments of hyperopia and mixed astigmatism require large treatment zones and therefore require flaps large enough to accommodate the treatment. The femtosecond laser provides more flexibility and precision than a mechanical microkeratome in creating larger flaps in small, flat, or steep corneas.

If the cornea is somewhat thin or the myopic refractive error is large, a large treatment zone or custom treatment may not be possible. Surface ablation (PRK), which preserves more corneal tissue, may be more appropriate than LASIK, although stromal haze becomes an issue for deeper ablations. Some surgeons have moved from LASIK to laser-assisted subepithelial keratomileusis (LASEK) in which the epithelium is brushed aside prior to the laser treatment and replaced after surgery. Haze is still a concern after large ablations. Epi-LASIK is a procedure in which a special microkeratome with a blunted blade is used to create an epithelial flap, which can be replaced after laser surgery. While some surgeons prefer Epi-LASIK over PRK, visual rehabilitation is slower after these procedures and there is more postoperative discomfort compared to LASIK. A patient with a large myopic correction, large pupil, and thin cornea may present a particular surgeon with hurdles too great for keratorefractive surgery. The best advice in this setting may be to advise against laser surgery and perhaps suggest an alternative refractive procedure. Refer to Chapter 15 for a discussion on alternatives to excimer laser surgery.

In the presence of peripheral corneal neovascularization, pterygium, or nonherpetic scar, a smaller zone may be advantageous. This is because a smaller flap would avoid the peripheral corneal pathology. In cases of peripheral neovascularization the risk of significant bleeding is far less when the femtosecond laser rather than a blade microkeratome is used to create the flap.

Once an appropriate zone has been determined, the maximum ablation depth can be predicted. Once the ablation depth has been calculated, the surgeon may need to adjust the ablation zone or change to a form of surface ablation. For example, for patients with a large correction and a thinner cornea, LASIK with a 6.5-mm zone with a blend or custom treatment may not be possible. A 6.0-mm zone with a blend or PRK may be a safer alternative.

WHAT WILL BE THE MAXIMUM ABLATION DEPTH?

The amount of cornea ablated for each diopter of treatment is specific to each laser system. To make proper calculations, surgeons must become familiar with the conversion factor (ablation depth per diopter) unique to the laser to be used. The treatment zone, as explained earlier, also affects the amount of corneal ablation per diopter of treatment. The larger the treatment zone, the more corneal tissue will be ablated. Blend zones add additional ablation depth to a treatment. Flying spot lasers remove more tissue than variable spot or broad-beam lasers. Custom LASIK also removes more corneal tissue than conventional LASIK. The surgeon must know the laser, the type of treatment, the proposed treatment zones, and the refractive correction before calculating ablation depth. While the laser computer will calculate the maximal ablation depth prior to the actual ablation, this may be based on a nomogram-adjusted refraction and, therefore, should not be used. To determine the ablation depth, the non–nomogram-adjusted refraction should always be used. This cannot be overemphasized. Surgeons who do not adjust the treatment would use the refraction to determine ablation depth.

It is helpful to have a rule of thumb to follow for converting the spherical equivalent of the cycloplegic refraction into a corresponding ablation depth. The training course for the laser being used will usually provide the appropriate conversion factor for various treatment zones.

The ablation depth is a crucial calculation, because if the ablation is too deep relative to the patient's corneal thickness, the result will be an unstable corneal contour after surgery or post-LASIK ectasia. Originally many refractive surgeons used 250 μm for the residual stromal

bed (RSB) thickness or the minimum amount of cornea that should be left untouched after the ablation has been completed. However, with increasing concern about postoperative ectasia, minimum RSB thickness has been increasing. Some surgeons now use 275 µm and others use 300 µm. There is no proof that a particular RSB thickness will prevent ectasia. Surgeons have experienced patients with unstable refractions or even ectasia despite their best efforts to obey this rule. It is possible that the flap was actually thicker than expected and the residual stromal bed was <250 µm. The ablation may be deeper than expected if the ambient humidity in the laser suite is low or if the nomogram-adjusted refraction is used to calculate a "safe" ablation depth. New technologies such as the femtosecond laser allow surgeons to create flaps that are closer to the intended thickness.

It is possible that for some patients an RSB thickness of 275 µm or even 300 µm is simply not enough to maintain a stable postoperative contour. This may occur if the preoperative corneal topography is irregular, despite being thick enough for surgery. Some surgeons believe that the residual corneal thickness should not be <50% of the original thickness, since the structural support for the cornea has been shown to reside in the anterior cornea. Each surgeon must develop his or her own safety limit for the RSB, but this should not be <250 µm.

The thickness of the central stromal bed can and should be measured with ultrasonic pachymetry. By subtracting the stromal bed thickness from the preoperative central thickness measured just prior to surgery, the surgeon can monitor the accuracy of the intended flap thickness. The surgeon, having previously added the intended ablation depth to the preferred RSB safety limit before surgery, can then use the pachymetric RSB measurement to ensure an adequate stromal bed prior to excimer ablation. Since the stromal bed will be ablated after contact with the disinfected and dried probe tip, the risk of infection from intraoperative pachymetry is extremely low.

Randleman et al.[1] reviewed 171 post-refractive ectasia cases in order to determine risk factors for ectasia. They determined that the risk factors in order of importance were abnormal preoperative corneal topography, residual stromal bed thickness, patient age, preoperative corneal thickness, and spherical equivalent and created an ectasia risk profile. Various risks are assigned points in a weighted model and the total number of points can serve as a guide regarding ectasia risk. The model in their study had a specificity of 91% and a sensitivity of 96%. This is illustrated in Tables 1.6 and 1.7. Some have criticized this risk scale as being too conservative, arguing that some patients who would have been deemed unsafe for LASIK by this scale have undergone the procedure without developing ectasia. It is clear that we don't yet have a perfect system for predicting ectasia, but most surgeons agree that ectasia risk is multifactorial and the development of post-LASIK ectasia may occur over many years. While a conservative approach may result in advising more patients against the surgery, the patient's long-term safety should always feature prominently in the refractive surgeon's decision making and counseling.

TABLE 1.6 Ectasia Risk Score Determination

Parameter	4	3	2	1	0
Topography pattern	FFKC	IS/SRA		ABT	Normal/SBT
RSB thickness (µm)	<240	240–259	260–279	261–300	>300
Age (years)		18–21	22–25	26–29	>30
Corneal thickness (µm)	<450	451–480	481–510		>510
MRSE (D)	>–14	>–12 to –14	>–10 to –12	>–8 to –10	≤–8

ABT, asymmetric bowtie; CT, preoperative corneal thickness; D, diopters; FFKC, forme fruste keratoconus; IS, Inferior steepening; MRSE, preoperative spherical equivalent manifest refraction; RSB, residual stromal bed; SBT, symmetric bowtie; SRA, skewed radial axis.

Source: Adapted with permission from Randleman JB, Woodward M, Lynn MJ, et al. Risk assessment for ectasia after corneal refractive surgery. *Ophthalmology.* 2008;115(1):37–50.

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TABLE 1.7 Ectasia Risk Rating and Recommendation

Cumulative Risk Scale Score	Risk Rating	Recommendation
0–2	Low risk	Proceed with LASIK or surface ablation
3	Moderate risk	Proceed with caution
		Consider special consent
		Safety of surface ablation has not been established
≥4	High risk	Do not perform LASIK
		Safety of surface ablation has not been established

Note: Additional considerations: stability of refraction, degree of astigmatism, topographic asymmetry between the eyes, pachymetric asymmetry between the eyes, and family history of ectatic disorders.
Source: Adapted with permission from Randleman JB, Woodward M, Lynn MJ, et al. Risk assessment for ectasia after corneal refractive surgery. *Ophthalmology*. 2008;115(1):37–50.

WHAT IS THE APPROPRIATE FLAP THICKNESS?

As a rule of thumb with mechanical microkeratomes, thin flaps occur in patients with thin corneas, defined as a central thickness of ≤520 µm. In normal or thicker than normal corneas, the actual flap will be closer to the plate thickness. When the same blade is used on the second eye, the flap will generally be thinner. The femtosecond laser flaps are generally less variable than those made with a blade microkeratome. Regardless of how the flap is created, measuring flap thickness with ultrasonic pachymetry can help the surgeon become familiar with the variance associated with corneas of different thickness and different equipment. Armed with this knowledge, the surgeon can incorporate a truer estimation of the expected thickness into the treatment plan. In addition, retreatment planning is considerably easier if the actual flap thickness has been measured. Caution is advised in patients with large corrections or thin corneas, because surprises can occur with flaps that are thicker than expected, leaving a thinner stromal bed available for ablation.

Some microkeratomes routinely create flaps that are slightly thicker than intended. Manual microkeratomes (see the discussion of the Moria microkeratome in Chapter 4) will create thinner flaps if the surgeon makes a faster pass. A slower pass would result in a thicker flap. The surgeon has no control over the speed of the pass if an automated microkeratome is used. The sharpness of the blade is important as well. Many surgeons use a single blade for bilateral simultaneous surgery. The sharper the blade, the deeper the cut and the thicker the resulting flap. As previously stated, if the same blade is used the flap in the second eye is usually thinner by about 20 µm. With the femtosecond laser the variance issue appears to be less of a problem as the actual flap thickness is usually within 10 µm of the intended thickness.

What is the ideal flap thickness? Many surgeons prefer a thickness between 100 and 120 µm. Thick flaps are said to be associated with an increased incidence of microstriae due to flap edema during the procedure. Very thin flaps can be difficult to handle and may be more prone to buttonhole. They can also be more problematic during retreatment. With the advent of the femtosecond laser, thin flap LASIK has become more popular. Flaps of 100 µm have become the standard in some practices. This approach leaves more stromal bed available for excimer ablation. Extra care must be taken during flap dissection when flaps <100 µm are created in order to avoid unintended flap trauma. The incidence of flap irregularity is greater when the targeted flap thickness is <100 µm.

If the surgeon is using the femtosecond laser, the scrub tech will require a flap diameter and thickness to enter into the device. The scrub tech will require a particular plate and ring size for use with the mechanical microkeratome. For example, unless the cornea is relatively flat, a 160-µm Hansatome plate with an 8.5-mm ring will generally provide a good

diameter and thickness flap for LASIK. (A more detailed discussion on the microkeratomes and femtosecond lasers appears in Chapters 4 and 5, respectively.) If the cornea is quite thin, however, the resulting flap with a 160-µm flap may be thinner than desirable. If the second eye has a thin cornea, and the flap in the first eye was thinner than desired, the surgeon should consider increasing the plate thickness to 180 µm or using a new blade. The latter approach is obviously more costly.

Patients older than 50 years of age are at greater risk of corneal epithelial slip or abrasion associated with the microkeratome pass. Microkeratome manufacturers have incorporated modifications designed to reduce epithelial trauma. An example is the Zero Compression Head developed for the Hansatome. Adequate preoperative and intraoperative lubrication is helpful. Some surgeons release suction on the reverse pass to limit epithelial trauma. In general, problems with intraoperative epithelial disruption are less likely to occur when using a femtosecond laser to create the flap. Diffuse lamellar keratitis is more likely to occur if an epithelial defect resulted from the microkeratome pass or flap dissection after femtosecond laser application. A defect is usually treated with a bandage contact lens (BCL). A contact lens is usually not needed if a small epithelial slip occurs.

If an epithelial defect occurs on the first eye, modifications may be made to protect the epithelium on the second eye. The same modifications mentioned earlier can be made if the epithelium is simply loosened and shifts.

WHAT IS THE APPROPRIATE FLAP DIAMETER?

In general, flap size is much easier to predict with a laser-created flap. Flap size with a mechanical microkeratome varies depending on the inner diameter of the ring and the steepness of the cornea. A larger inner ring diameter will allow more tissue to protrude through the ring, exposing it to the microkeratome blade. The same is true if the cornea is steep. In both cases a larger flap will result. Therefore, when a larger flap is required, a larger inner ring diameter may be needed. However, if the corneal curvature is ≥45.00 D, the increased steepness of the cornea will provide the necessary boost to flap diameter even if a smaller ring is used. If average keratometry readings are ≥48.00 D, not only will a large flap occur, but a buttonhole is also more likely. Femtosecond laser use has dramatically reduced the risk of buttonhole and free cap related to preoperative curvature.

Larger flaps are essential when the treatment zone is large; for example, in hyperopic LASIK, custom LASIK, or mixed astigmatism treatment. A larger flap is also helpful if retreatment for overcorrection becomes necessary; however, larger flaps with edges closer to the limbus increase the risk of intraoperative bleeding and may be more difficult to lift long after surgery.

When a larger flap is required in a patient with a flat cornea with keratometry readings of <41.00 D, a larger ring is essential to ensure that an adequate amount of the cornea will be exposed to the microkeratome blade. A patient with a small corneal diameter, <11 mm, may present a special challenge, particularly if a large treatment zone is required, because the edge of a large flap will be close to the limbus. The femtosecond laser is advantageous in this situation because the flap diameter can be more accurately determined. PRK should also be a consideration in this situation.

A certification course on microkeratome use or femtosecond laser operation may be required prior to using some equipment. Practice on animal eyes is helpful to gain comfort and experience with the operation of the equipment. Observing experienced surgeons during cases is also invaluable. Finally, having an experienced surgeon/mentor present during your first few cases is very worthwhile.

The Procedure

PREOPERATIVE MEDICATION

Not all patients require sedation for LASIK surgery. For some the idea of taking a sedative may be anxiety provoking. Unless the surgeon has a strong feeling about the need for sedation, the patient can be given the choice. Patients are usually happy about the choice they make,

and it gives them a feeling of control. If an oral agent is given, it should be administered at least 30 minutes before the procedure so that the effect is present during the surgery. Benzodiazepam 5 mg is usually sufficient for most patients. Remember the purpose is to allow the patient to feel "normal," not sleepy, silly, or overly anxious. Beware of the patient who has taken a minor tranquilizer at home and is requesting additional sedation. Excessive sedation can be counterproductive, resulting in a very relaxed patient who is unable to maintain fixation. While it is helpful for all patients to be escorted from the laser center, a patient receiving a sedative must have an escort home.

If a patient is prone to vasovagal episodes, consideration should be given to pretreatment with atropine. An intramuscular injection of 0.4 mg of atropine 30 minutes prior to surgery can prevent the symptoms of a vasovagal reaction. Patients with this history usually welcome a treatment that can prevent these unwelcome symptoms even if it does require an injection. The patient can also be reassured that while in the supine position the symptoms are less likely to occur. If a vasovagal reaction occurs, the immediate postoperative examination at the slit lamp could be challenging.

If the patient is to have PRK, consideration should be given to pretreating the patient with an oral nonsteroid anti-inflammatory agent an hour prior to surgery and for the first 2 days following surgery. Some surgeons have found pretreatment and postoperative treatment with oral gabapentin useful. This will in most cases significantly reduce postoperative discomfort. Narcotic analgesia is rarely required.

MARKING THE PATIENT

If the patient will have astigmatic or custom LASIK treatment, marking both sides of the 90- or 180-degree meridian at the limbus and aligning the marks with the operating microscope reticle may improve the accuracy of the ablation. This is known as *registration*. Significant cyclotorsion can occur when the patient is placed in the supine position. Without a visible mark, the treatment could potentially be delivered in an incorrect meridian. Before creating a flap, the registration process is performed, at which time the head position is adjusted to align the operating microscope reticle with the limbal marks. If adjustment is needed, it is better to rotate the form-fit pillow rather than the patient's head. The patient's head is less likely to slip back into the incorrect position if only the pillow is adjusted.

The 180-degree meridian is generally easier to mark. After instillation of topical anesthetic in each eye, the slit beam is oriented in the 3 to 9 o'clock meridian, and the beam is adjusted to maximum length and narrowed to a slit. The patient is asked to focus on a distant target to avoid cyclotorsion related to convergence. A sterile skin marker is then used to identify each side of the limbus in each eye. Several applications of ink during the marking process are usually necessary to achieve a mark that lasts throughout the procedure.

For some surgeons computer-controlled iris registration as part of a custom laser treatment eliminates the need for marking the limbus. Other surgeons continue to mark the limbus in case iris registration cannot be achieved. For more information on iris registration, refer to the discussion on various excimer laser systems in Chapters 6 to 9.

Alignment marks can be made before or after the flap is created. These marks will help to ensure excellent realignment after the flap is replaced. If the laser is used, the marks can be applied following flap creation. If a microkeratome is used, the alignment marks should be made prior to the cut, especially in the case of a flat cornea when there is increased risk of a free cap. The marks should be asymmetrical so a free cap cannot be placed upside down. If the intended flap will be large, the marks should be placed closer to the limbus to ensure that the flap will bisect the marks. The marks can be placed farther from the limbus if the flap will be smaller.

SETTING THE OCULARS

Setting the oculars is important to help ensure reliable focus on the cornea during the laser procedure. The surgeon should never assume the oculars are set properly unless they have been personally checked. It is convenient to set the oculars while the patient is being prepped. One

method of checking the oculars is to use the laser ablation test card as the target. The magnification should be set to the same level used for the ablation; for example, 1.6× with the VISX laser rather than the lower magnification used for flap creation. The oculars are set to the plus side by rotating them counterclockwise. While the opposite eye is closed, each ocular is rotated clockwise until the target is just in focus.

Once the oculars have been set, it is convenient to check the calibration card. The laser engineer will periodically cut plastic with the laser to ensure an accurate ablation. Unlike the YAG or argon laser, in which the laser settings are adjusted intraoperatively based on effect, excimer laser settings are adjusted preoperatively. It is also useful to check the appearance of the ablation on the calibration card for signs of irregularity. If, for example, water droplets splash up against the underside of the microscope, an uneven ablation may result. This could be detected by an examination of the ablated card.

ENVIRONMENTAL CONDITIONS IN THE LASER SUITE

The laser suite conditions should be stable and consistent. They should be recorded so that you can track results and, if necessary, make appropriate adjustments. VISX recommends that the temperature be between 60°F and 80°F and the relative humidity range from 35% to 65%. Stability of conditions within these ranges is the most important aspect of monitoring room conditions, because constant changes in temperature and humidity can alter outcomes and may confound your efforts to optimize the nomogram adjustment. Environmental conditions can vary widely depending on the region or the country in which you practice as well as the season of the year. These variables need to be monitored on a daily basis and the room conditions adjusted accordingly with humidifiers and dehumidifiers as needed.

PREOPERATIVE CHECKLIST

To avoid errors during the procedure, the surgeon, the scrub technician, and the laser engineer should develop a checklist that is routinely followed on every case. Ideally, the checklist should be reviewed just prior to surgery. The procedure should not begin until each item on the checklist has been confirmed. Good communication with a staff trained to recognize a problem and empowered to bring a potential problem to the attention of the surgeon is critically important to accomplish safe and reliable surgery. Use of such a "time-out" procedure has been mandated in most institutional operating rooms in the United States.

Microkeratome or Femtosecond Laser

The scrub technician and the surgeon should review the checklist designed for the microkeratome or femtosecond laser prior to the operation of the unit. This should include checking the blade for imperfections and that it is seated properly in the microkeratome head, checking that the device is assembled correctly and for the proper eye, confirming that the desired plate and ring have been selected, and briefly running the microkeratome unit to be certain the blade oscillates freely. In the case of the femtosecond laser, the scrub technician should confirm that the suction ring is intact and operational, that the cone is intact, that the applanation lens is not cracked or dirty, that the settings for flap diameter and thickness are appropriately set, that the hinge width and side cut angle are correct, and that the energy settings for the flap and the side cut are appropriate.

Excimer Laser

The laser engineer should confirm for each eye the diameter of the treatment zones, whether a blend zone is being added, and whether the correction entered into the laser is the desired one. Custom treatments should be reviewed to make certain that the appropriate wave scan has been selected and entered and that desired physician adjustments have been entered.

PREP, DRAPE, AND SPECULUM INSERTION

After anesthetic has been instilled, the corneas are prone to epithelial disruption; therefore, the drops should not be instilled until

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immediately prior to surgery. Some surgeons instill a drop of a chilled ocular decongestant such as naphazoline hydrochloride 0.25 mg/mL or pheniramine maleate 3 mg/mL to reduce the likelihood of subconjunctival hemorrhage related to the suction ring. The patient should be instructed to keep the eyes closed as much as possible. The eyelids are prepped with 5% povidone iodine. Plastic drapes are placed on the lashes. With the eye in downgaze, the upper lid is draped. The lower lid is draped with the eye in upgaze. This helps to ensure that the lashes will be completely covered and also minimizes corneal epithelial disruption.

Many surgeons prefer to use an aspirating speculum to reduce the chance of debris collecting in the stromal interface. Speculum insertion is facilitated by inserting the upper blade with the eye in downgaze and the lower blade with the eye in upgaze. Avoid rapid separation of the speculum blades, which can cause pain and blepharospasm.

PATIENT POSITIONING

Once the chair has been reclined, the patient should be positioned in order to maximize the range of motion of the table. If the patient has a large nose, slight rotation of the head in the direction opposite the eye being treated can facilitate exposure. In other words, if the right eye is being treated, the head is rotated slightly to the left to move the nose out of the field.

If the microkeratome is used to create a flap with a superior hinge, exposure inferiorly is especially important. This enables the microkeratome to clear the lower lid and speculum. Positioning the patient in a slight chin-down position can optimize inferior exposure, facilitating the microkeratome pass. This is less important with microkeratomes that create a nasal hinge. If the femtosecond laser, for example IntraLase, is used, there should be ample exposure superiorly to allow slightly more sclera to show within the ring superiorly.

If a superior hinge has been created, it is helpful to reflect the flap back onto the superior bulbar conjunctiva. In other words, the flap epithelium is laid down on the conjunctival epithelium. This helps to keep the flap moist and keeps the flap from wrinkling. Positioning the patient with the chin up slightly after the flap has been created will expose the superior bulbar conjunctiva, facilitating flap placement in preparation for the laser procedure.

RING PLACEMENT

Proper ring placement will ensure that the hinge will be created in the periphery of the cornea. If the hinge position is too central, the result might be a decentered flap that does not expose enough of the corneal stroma to permit the entire laser ablation to be performed. To avoid this, the ring should extend just beyond the limbus in the area where the hinge will be made. For example, the ring should be placed just beyond the limbus superiorly to ensure a properly placed superior hinge. This is especially important if a large treatment area is required. If the ring is placed too far beyond the limbus, the hinge will be too peripheral. The potential consequences are bleeding from the limbal blood vessels and a decentered flap that does not expose adequate stroma opposite the hinge to allow the complete laser treatment to be performed. If the ring is decentered too much, a femtosecond laser ablation may result in intracameral air bubble formation. These bubbles may impact excimer laser tracking, but will be absorbed with time.

It is important after correct ring positioning to apply firm posterior pressure to the ring before the suction is applied. This is true regardless of the type of flap-making equipment used. Firm pressure will prevent the globe from rolling as suction is being applied. It will also help avoid pseudosuction, in which the pressure is applied to the conjunctiva but not the sclera. If the eye pressure is inadequate, a small or shredded flap or a free cap may occur. Once good suction is achieved, the external digital pressure on the ring can be released and the ring supported lightly. This will allow the globe to "float" anteriorly and will facilitate engaging the ring with the microkeratome. Occasionally, firm posterior pressure can cause the ring to abruptly slip under the speculum. If this occurs and suction is good, the ring should

be gently lifted anteriorly so that the speculum will not block the microkeratome pass. Spreading the speculum wider can be helpful in this situation. Any time the surgeon lifts the ring with suction applied, care should be taken to be certain that suction has not been lost. Signs of lost suction include a pupil that becomes reactive, a patient that again sees the light, the cornea dropping posteriorly, and the presence of a sucking noise.

If the eye rolls in the nasal or temporal direction beneath the ring during the application of suction and there is a question of whether the laser treatment will fit completely under the flap, suction should be released. If the eye rolls in the temporal direction, a nasal flap will result. The opposite will occur if the eye rolls in the nasal direction. Two maneuvers can help compensate for a rolling eye. First, as previously stated, simply increasing the external pressure of the ring onto the globe can reduce the movement of the eye beneath the ring while suction is being obtained. If this fails to solve the problem, placing the ring with temporal decentration for an eye that rolls in the temporal direction, or nasal decentration for an eye that rolls in the nasal direction, will often solve the problem. The eye should roll into proper position. Remember that reapplying suction several times may result in conjunctival chemosis that can lead to pseudosuction. If significant chemosis does occur it is best to wait several hours at a minimum before reapplying suction.

If a decentered flap does occur and the ablation zone is not too large, it may still be possible to proceed. Nasal decentration may still be acceptable because the treatment is centered on fixation, and most patients have a positive angle kappa. Remember, however, that a laser with automatic centration and a tracking device will center the ablation on the pupil center. The microscope reticle is a helpful guide in determining whether a laser treatment can be delivered completely under the flap. Extreme decentration can result in a microkeratome flap edge at the limbus. This can be associated with hemorrhage from limbal blood vessels and blood in the interface. All blood must be cleared with a sponge to avoid an uneven ablation. Blood in the interface also increases the risk of diffuse lamellar keratitis (DLK).

In the presence of peripheral pannus or corneal neovascularization, bleeding may be avoided by creating a smaller flap. However, flap size must be adequate to accommodate the entire laser ablation. If bleeding from peripheral vessels occurs, direct pressure with a microsurgical sponge will tamponade the site of hemorrhage and usually help control it. It is preferable to control the bleeding before lifting the flap. This may reduce the chance of bleeding into the interface. Significant bleeding from the peripheral cornea is far less common with the femtosecond laser.

If the palpebral fissure is narrow or small or if the lids are tight, a microkeratome system, which uses a ring with a smaller outer ring diameter, can be advantageous. The use of a one-piece microkeratome has the advantage of clearing the lids more effectively; however, most of these microkeratomes when used in routine fashion create a nasal hinge. If the femtosecond laser ring can be inserted and suction applied, the flap can usually be cut without difficulty. A trial ring insertion can be attempted in the office prior to surgery. Topical anesthetic should be used.

If a two-piece microkeratome is being used, the surgeon should become very familiar with its assembly prior to surgery to minimize the suction time. If using a two-piece microkeratome in a patient with deep-set eyes, it may be difficult to lock the microkeratome on the ring. The speculum may be blocking the microkeratome from engaging the ring. Spreading the blades more fully may be helpful. Pushing the speculum posteriorly may also help provide adequate exposure. The inferior blade of the speculum may abruptly drop posterior to the orbital rim, which will enhance exposure but may be uncomfortable for the patient. Conjunctiva, lashes, and plastic drape should be cleared away from the ring with a forceps before engaging the microkeratome.

Before activating the microkeratome it is important to confirm that the IOP is sufficiently elevated. The patient's confirmation of the loss of light perception and the physician's observation of pupil dilation are important indications of an elevation above

perfusion pressure. The Barraquer tonometer (Ocular Instruments, Bellevue, WA) is a useful tool for measuring and confirming that the IOP exceeds 65 mmHg. The femtosecond laser procedure does not require such a high IOP. While light perception may be lost, this may not occur. The pupil may not dilate. It is important that the globe be firmly gripped by the ring and not be free to roll.

If the femtosecond laser is used to make the flap, most surgeons will create both flaps before performing the excimer laser ablation. At this point surgeons vary with regard to immediately proceeding to the excimer laser ablation. If significant waste gases accumulate, creating an opacified bubble layer (OBL), some surgeons will wait for this to dissipate before proceeding with the excimer laser ablation.

FLAP POSITIONING

Various techniques are used for lifting the flap after it has been made. Some surgeons prefer to slide an instrument completely across the underside of the flap at a position 2 or 3 mm inferior to the hinge. Care must be taken while using this technique not to scrape the epithelium peripheral to the flap edge, dragging it under the flap. The flap is then reflected toward the hinge and laid epithelial side posteriorly onto the bulbar conjunctiva. This keeps the flap moist and wrinkle free. The flap should be lifted slowly and carefully, because in some cases it may be adherent to the underlying stromal bed. If the flap is lifted too quickly in such cases, there is an increased risk of a torn hinge.

An alternative method of lifting the flap is to use a tying forceps at the edge of the flap opposite the hinge to grab the flap and lift it up, bending it back and rolling it in the direction of the hinge until the flap epithelium is completely laid over the bulbar conjunctiva. It is important not to lift the flap too high, or the sides will fold under like a taco. This can lead to wrinkling or uneven flap positioning. Whatever technique is used, it is important to keep the flap moist and to be gentle to avoid trauma to the flap. It is helpful to warn the patient that the vision will blur somewhat when the flap is lifted.

When dissecting a femtosecond laser flap, the greater the bed energy the easier the dissection and the greater the likelihood of DLK. One must strike a balance between the risk of DLK and the ease of dissection. When dissecting the flap it is helpful to score the epithelium on either side of the hinge and enter the interface on one side, carefully dissecting toward the other side, exiting the interface through the scored area on the other side. The dissection can then be completed in three or four strokes within the interface extending from the hinge to the periphery. Once completed, the flap can be reflected back, as described above. Some femtosecond lasers create a flap that requires little, if any, dissection.

FLAP THICKNESS

The technique for determining flap thickness is simple. Central pachymetry is measured before the flap is made. Immediately after lifting the flap, central pachymetry is again measured. The actual thickness of the flap is calculated by subtracting the measurement taken at the stromal bed from the full thickness measurement. The laser engineer should be prepared to make the necessary calculation and communicate the value to the surgeon. The surgeon, having previously written the maximum allowable stromal bed thickness or flap thickness on the worksheet, will immediately know that surgery can proceed safely.

Remember that the central corneal thickness is a variable measurement. It is thinner in the absence of contact lens wear, with increased exposure, and with decreased ambient humidity. Therefore, central pachymetry measured at the start of a case may be significantly different from the reading taken at the screening examination. Only intraoperative readings should be used for flap thickness calculation. The residual stromal tissue also thins as it becomes desiccated, so measurement and ablation should proceed without inordinate delay.

Use a probe tip dedicated to the LASIK suite. This will reduce the risk of contamination of the flap bed with fluorescein or other undesirable material that could adversely affect the stroma and the laser treatment. Laser ablation greatly reduces the risk of

bacterial contamination of the flap bed from the probe tip. The standard 20-Hz probe frequency pachymeter may not work reliably on a flap bed created with a femtosecond laser. An upgrade to a 50-Hz probe frequency unit may be required if flaps will routinely be created with the laser.

If the flap made with a mechanical microkeratome on the first eye is thinner than desired, an appropriate adjustment should be made for the second eye. This is because if the same blade is used, the second flap will likely be even thinner. The options are to use a thicker plate, a new blade, or a slower pass in the case of a manual microkeratome.

THE LASER ABLATION

Before beginning the excimer laser ablation, registration of the laser reticle with the limbal marks is an important first step. This is particularly essential if the ablation involves astigmatism treatment or a custom treatment. If registration is not done, the treatment may be delivered in the wrong axis due to cyclotorsion. If the marks do not line up with the reticle, rotate the patient's headrest until good alignment is achieved. If the particular excimer system includes iris registration, follow the steps as required by that system.

During the LASIK procedure it is important to talk to the patient, constantly reassuring and coaching. This will help to keep the patient calm and to maintain attention on the task at hand. This is especially true during the excimer laser portion of the procedure. If there is no tracking device, the patient's attention on the fixation light is critically important. Occasionally, if the patient is breathing heavily, the tracker will be unable to lock. Asking the patient to take a breath and hold it will stabilize the eye enough for the laser tracking system to lock on to the pupil. Some tracking systems require pupil dilation; some do not. It is important to follow the guidelines set by the manufacturer and the medical monitors for the laser being used.

While laser-tracking systems have provided a significant improvement in the safety of laser refractive surgery, they are not foolproof. If, for example, a patient is slowly drifting away from fixation and the surgeon is following the eye with the joystick, the laser will continue tracking as if the patient were looking at the fixation light, resulting in an inaccurate ablation. It is also possible to have a patient looking at something other than the fixation light, prior to locking the tracking device on the pupil and despite instruction. The tracker may follow the eye even though it is not in the proper position. To avoid these problems, a quick check of the globe position before engaging the tracking device is a good habit. The scrub technician can also watch the globe position during the laser ablation.

Dimming the surrounding illumination can help the patient see the fixation light. The pupil center may vary depending on the lighting. Therefore, for custom LASIK the lighting should match the lighting during wave scan acquisition. This will ensure that the treatment will be centered in the proper location. It is important to focus the microscope on the surface of the stromal bed just prior to the laser procedure. This can be accomplished by defocusing upward until the apex of the cornea is just out of focus. The focus is then brought downward until the view of the corneal apex is clear. Center on the pupil, but do not focus on the pupil. During the laser part of the procedure, it is useful to have the laser engineer or scrub technician perform a countdown at 5- to 10-second intervals. This enables the surgeon and patient to be aware of the amount of time remaining. If the patient is not holding still enough to safely continue the surgery, it is important and necessary to interrupt the laser procedure. The patient can be instructed about proper fixation. Speaking calmly and continuously to the patient can be reassuring and help the patient focus attention on the fixation light. While a tracking device is helpful, it only operates within a predetermined range. If the patient moves outside this range, the laser ablation will be interrupted. The laser system may keep track of where the treatment was interrupted, and after repositioning, the treatment can be completed. One must become familiar with the nuances of the particular laser's tracking device.

If the treatment zone is large or the hinge is more central than desired, it is important to protect it from inadvertent ablation. Accidentally ablating the hinge and the bed would result in duplication of ablation or roughly twice the treatment in the area of the hinge. It is important to cover the hinge with a Merocel (Medtronic, Minneapolis, MN) spear or an instrument designed for hinge protection.

FLAP REPOSITIONING

Following the laser ablation the flap is replaced. The goal is to have a clean interface with no folds or striae in the flap and no areas in which the flap edge is turned under. The flap can be replaced using a single or double irrigating cannula. The double irrigating cannula has the advantage of combining repositioning with irrigation beneath the flap to remove debris. An example is the Viduarri irrigating cannula (BD Visitec no. 585216). Some surgeons irrigate beneath the flap more than once to be certain the interface is clean. Excessive irrigation is ill-advised because an overly hydrated flap may be more prone to striae and poor flap adherence. A saturated non-fragmenting Merocel sponge is used to gently stroke or paint the flap from the hinge across the cornea. The alignment of the previously made corneal marks is checked. A semi-wet sponge can then be used to inspect the trough at the edge of the flap, making certain the trough width is minimized and that it is symmetrical all the way around. Surgeons vary in opinion with regard to the amount of flap stroking or manipulation that is needed to reduce the risk of striae. Surgeons also vary with regard to the time allowed for the flap to dry before removing the speculum. Most wait for 1 to 3 minutes. A viscous artificial teardrop is applied to the cornea at the conclusion of the procedure.

Remove the eyelid drapes first, then the speculum. Gently lift the lower speculum blade anteriorly as the speculum is narrowed and the scrub technician pulls the lower lid inferiorly. Instruct the patient to continue fixating on the target light as the speculum is removed. This will avoid an inadvertent flap displacement. Cover the treated eye and set up for the fellow eye if bilateral surgery is being performed.

IMMEDIATE POSTOPERATIVE EVALUATION

After surgery is completed, the patient is checked at the slit lamp. Explain to the patient that the vision should be hazy and not to worry. Assess the flap for alignment and striae as well as interface debris. The indications for flap relifting, also referred to as *refloating* the flap, immediately after surgery are significant interface debris, poor flap alignment, significant striae that cannot be successfully addressed at the slit lamp, or macrofolds. A low threshold for relifting a flap for any of these abnormalities is advised. It is always easier and usually more effective for the surgeon to refloat a flap immediately after surgery than after days or weeks have passed. Remember that the applied viscous tear may mask subtle striae. The scrub technician should not remove the surgical instruments until the surgeon has confirmed that the flap will not need to be refloated. Striae in the mid-peripheral flap can be stroked out at the slit lamp by gently applying a slightly moistened sponge from the central edge of the striae toward the flap edge. Additionally, debris in the interface near the flap edge can be removed at the slit lamp.

Postoperative instructions include the use of protective eyewear. The duration of eyewear use varies from 1 to 7 days. Some surgeons believe eye protection is needed only at night. The patient should be warned about eye rubbing. Prednisolone 1% and a topical fluoroquinolone should be administered and the patient instructed to use one drop of each four times daily for 1 week. A safe technique for drop instillation should be demonstrated to the patient. Irritation and tearing are not uncommon in the first 2 days after surgery. The patient should be warned about these symptoms and advised to use oral acetaminophen or an oral nonsteroidal anti-inflammatory agent. Instructions should

be given for reaching the doctor in the event of a question or problem. The doctor or an appropriate designee should be available to receive a call. Arrangements should be made for an appointment the following day. The patient is examined at 1 day, 1 week, 1 month, 3 months, 6 months, and 1 year.

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SECTION II

Diagnostic Equipment

chapter 2

Corneal Topography

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An in-depth discussion of corneal topography is beyond the scope of this handbook. However, a working knowledge of topography is necessary to perform LASIK safely. Topography is used as a screening tool during the preoperative evaluation to be certain the contour of the cornea is regular (see Index for topography-related cases). The surgeon must not only rule out the presence of ectatic diseases such as keratoconus and pellucid marginal degeneration (PMD) in an overt form, but must also be able to detect these conditions in a subclinical or subtle form. Occasionally, an adult may present with mild keratoconus in an arrested form, known as forme fruste keratoconus, which does not progress. The patient may be completely asymptomatic and might never develop the clinical disease unless the cornea is thinned and weakened during LASIK surgery. The age of the patient is an important consideration. When the subclinical form is present in a young adult or teenager, one cannot be certain that the condition will not progress into a manifest ectatic disease over time. It is therefore advisable to avoid LASIK surgery in this situation.

Serial corneal topography can also be used to track the corneal contour in a contact lens–wearing patient who is avoiding lens wear in preparation for final LASIK measurements. Topography, keratometry, and refraction are all used during repeated examinations as indicators that the corneal contour has become stable.

Corneal topography is also an essential part of the postoperative management of the LASIK patient. Retreatment should not be performed until the corneal contour has become stable, and topography can help with this determination. Topography can help evaluate a patient with postoperative vision that is less than expected. This can be related to the presence of central or paracentral islands, that is, small, steep, and/or elevated areas detected by topography. Postoperative corneal ectasia following keratorefractive surgery can occur even when no apparent preoperative pathology was detected. The alterations in corneal contour related to flap complications such as epithelial ingrowth, a flap buttonhole, or striae can be evaluated and monitored using this technology. A decentered excimer ablation can also be identified with corneal topography. Comparative maps can help assess the effect of corrective surgical treatment. For all of these reasons, the topography unit is indispensable to the refractive surgeon.

The results from the more common topography units can be confounded in several

important ways. For example, if the patient's fixation is off, the map will not be meaningful. If the surface of the cornea is irregular as a result of a dry eye or exposure keratopathy, the data collection will be limited. Excessive tearing is associated with an enlarged tear meniscus that can distort the map inferiorly. Finally, some topography units will extrapolate data to fill areas for which data could not be obtained. This extrapolation can be misleading. It may be more reliable to use a unit that shows areas of data dropout as blank areas. The computer analysis used to derive color maps is based on certain physical and mathematical assumptions. The data generated are only as accurate as the information captured and the accuracy of the assumptions made. Therefore, careful interpretation of the output from this equipment in the context of the particular patient is always advised.

Modern topography units may generate maps with the potential to demonstrate corneal power, elevation, and thickness. Before interpreting a map, it is important to look at the scale on which the map is based. Maps generated on different days or on different machines should have the same scale in order to be meaningfully compared. The scale for an axial or power map is given in diopters. Steeper areas are red or orange, and flatter areas are blue or purple. The scale for an elevation maps is given in micrometers. This refers to the micrometer above or below a calculated best-fit sphere. Cornea below the sphere is blue and above the sphere is red or orange. In some cases, the elevation maps are mathematically derived rather than the result of a direct measurement. Pachymetry maps are expressed in micrometers.

The difference between power and elevation can be a source of confusion in interpreting maps. How can a cornea be flat and elevated at the same time? The appearance of a mesa or a flattened mountaintop is a geological structure that is flat and elevated. A similar contour abnormality on the cornea would appear blue (indicating flattening) on a power map and orange or red on an elevation map. Likewise, a spire at the bottom of a valley would appear steep on a power map, but depressed on an elevation map. Understanding the differences between power and elevation gives the surgeon a deeper understanding of the corneal contour when interpreting these maps.

Available Systems

Several types of topography units are on the market and the prices vary considerably. The most common type of unit and the most affordable one is based on a corneal reflection from a Placido disk. It is generally most accurate for measuring the power of the paracentral rather than the peripheral cornea. Concentric rings are projected onto the cornea, and various points on these rings are sampled, digitized, and computer analyzed. Points on adjacent rings will be spaced closer together in areas of steepening contour. The normal cornea is steepest centrally and flattens peripherally to meet the flatter scleral curve. Inferior steepening of the cornea is abnormal and may be a sign of keratoconus. The color maps that are generated correspond to the corneal power in diopters at various locations on the cornea. As stated previously, warmer colors indicate areas of steepening, and cooler colors are areas of flattening. In addition to the videokeratoscopic view and the axial or power map, tangential maps, refractive maps, elevation maps, and difference maps can be generated.

Placido disk-only systems are limited in that they only measure the anterior surface of the cornea. These systems do not directly measure elevation. One of the pitfalls in analysis of images based on a Placido disk is the assumption that the line of sight, the corneal apex, and the center of the keratoscopic image are all in the same place. Inaccuracies in computer software analysis may result in faulty interpretation, particularly in a patient with a decentered corneal apex. The EyeSys (EyeSys Vision, Houston, TX), Humphrey Atlas (Zeiss-Humphrey, Dublin, CA), Keratron Scout topographer (Optikon 2000 SpA, Rome, Italy), and TMS (Tomey Technology, Waltham, MA) units are examples of topography machines based on Placido disk systems.

The Orbscan (Bausch & Lomb, Rochester, NY) uses a combination of a Placido disk and

a slit-scanning system. The slit beam scans the cornea from limbus to limbus, taking photographs at various intervals from a pass around the cornea. In addition to the axial or power map derived from the corneal reflection of the Placido disk, it uses the slit images to generate anterior and posterior elevation maps. The maps compare the elevation of the anterior and posterior cornea to a reference best-fit sphere. Warm colors illustrate areas where the cornea is anterior or elevated compared to the reference sphere, and cool colors indicate cornea depressed compared to the reference. The scale is measured in micrometers. When evaluating the elevation maps, the surgeon should be mindful of the inherent inaccuracy related to comparing the aspheric cornea to a sphere.

Finally, the Orbscan generates a pachymetric map. The thickness map does not provide as accurate a measurement of corneal thickness as does ultrasonic pachymetry, but it can give a relative impression of corneal thickness over a large area of the cornea. It allows the surgeon to compare the thickness of the central cornea, where the cornea should be the thinnest, with the peripheral cornea. A potential disadvantage of the Orbscan is the length of time it takes to perform a study. Eye movement, if inadequately tracked, could result in a faulty interpretation due to inaccurate data acquisition. Pachymetric data following LASIK surgery may not be as accurate as in unoperated eyes.

Another type of topography unit uses a rotating slit-scanning device that captures images using Scheimpflug photography. The Pentacam (Oculus, Inc., Lynnwood, WA) is an example of such a unit. Using this photographic technique, images of the entire anterior segment are recorded, enabling the unit to measure anterior and posterior corneal elevation and thickness. Pachymetry measurements are accurate enough to use in preoperative planning. Curvature maps are also generated. The Pentacam can also be used to evaluate other anterior segment structures, such as the angle, iris, and lens. It, therefore, can be used in sizing a phakic intraocular lens implant. It can take up to 2 seconds to perform a study and thus must rely on a tracking device to identify and compensate for eye movements. Although this device has the potential to provide much more information than other available units, it is also substantially more expensive. The Galilei (Ziemer Ophthalmic Systems AG, Port, Switzerland) is a relatively new entrant in the field of Scheimpflug-based topography systems.

Keratoconus Detection

Topography is a key element of the LASIK evaluation because it can be used to screen for preexisting ectatic disease. Characteristic findings of keratoconus in the post-LASIK patient may be suggestive of iatrogenic ectasia. Some topography units, particularly those based on Placido disk technology, come equipped with keratoconus detection software. No one index is foolproof for identifying keratoconus or preventing postoperative ectasia. It is recommended that several indices and analyses be used to determine whether a particular patient is suitable for keratorefractive surgery. A detailed preoperative discussion with the patient, including chart documentation, is warranted when the risk of ectasia is greater than average. Keratorefractive surgery is ill-advised when the likelihood of surgically induced ectasia is high.

The pattern of inferior elevation coincident with thinning in the area of maximal protrusion, inferior steepening with superior flattening, asymmetric dumbbell, and deviation of the axis of the superior part of the dumbbell are all patterns that could be consistent with keratoconus (Fig. 2.1). Rabinowitz[1] referred to this deviation of the superior part of the dumbbell as skewed radial axes (SRAX) and has suggested that a deviation >21 degrees is an important index in screening patients for the diagnosis of keratoconus. He has suggested three additional quantitative videokeratographic indices: a central corneal power value >47.2 diopters (D), an inferior-superior dioptric asymmetry (I-S value) >1.2 D, and Sim-K astigmatism >1.5 D. In addition to the Rabinowitz's KISA% index[3], and the Klyce/Maeda and Smolek/Klyce methods provide additional ways of screening patients for keratoconus on Placido disk-based systems.

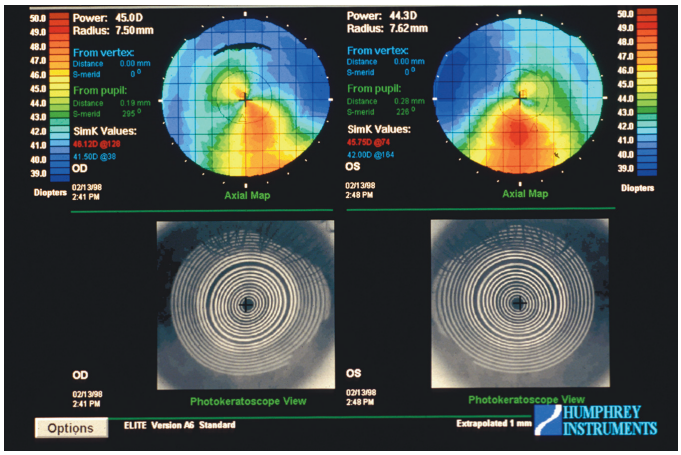

FIGURE 2.1

Power maps demonstrating forme fruste keratoconus OU. Note inferior steepening with superior flattening, asymmetric dumbbell, and deviation of the axis of the superior part of the dumbbell (skewed radial axes), which are all topographic findings suggestive of keratoconus. (Courtesy of Robert S. Feder, M.D.)

Another useful index found on the Bausch & Lomb Orbscan unit is the posterior elevation difference with best-fit sphere (Fig. 2.2). Rao et al.[2] have described its use as a screening tool. The value for the posterior elevation difference is found when the cursor is placed on the highest part of the posterior elevation map. The value in the gray box to the left should ideally be <0.04 mm. A reading between 0.04 and 0.05 mm should alert the surgeon to the need to look for other corroborating evidence of preexisting ectasia and the heightened risk of postoperative ectasia. When the reading is >0.05 mm, there is often evidence in other

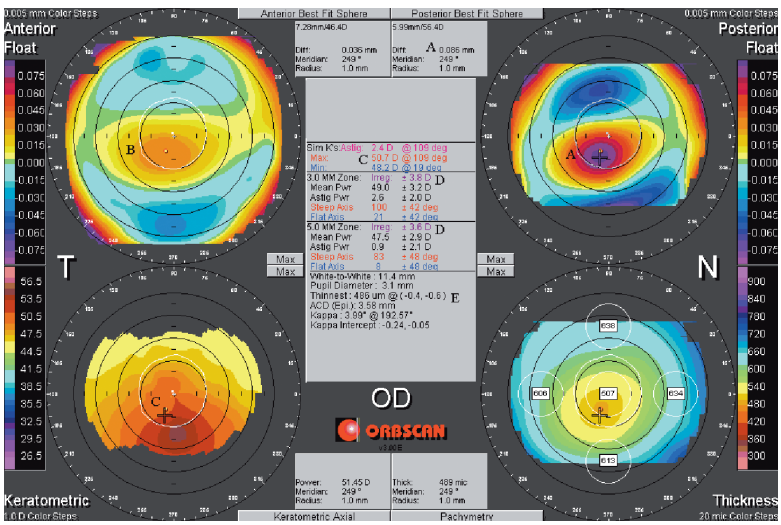

FIGURE 2.2

Orbscan II of a 39-year-old with 20/30 uncorrected acuity in this eye. **A:** Upper right map shows a prominent posterior float. With the cursor "+" at the apex, the posterior curve is 86 µm above the best-fit sphere. **B:** Prominent anterior float with apex in the same position as the apex in the upper right map. **C:** Steep Sim-K correlates with steep power map. Also note prominent inferior steepening. **D:** Irregularity in this topographical analysis is ±3.8 and ±3.6 D at 3 and 5 mm, respectively. This is well above the accepted limits of irregularity. **E:** Thinnest part of the cornea is 486 µm. Ultrasonic pachymetry would likely measure even thinner. All of the above strongly suggest the diagnosis of keratoconus. (Courtesy of Robert S. Feder, M.D.)

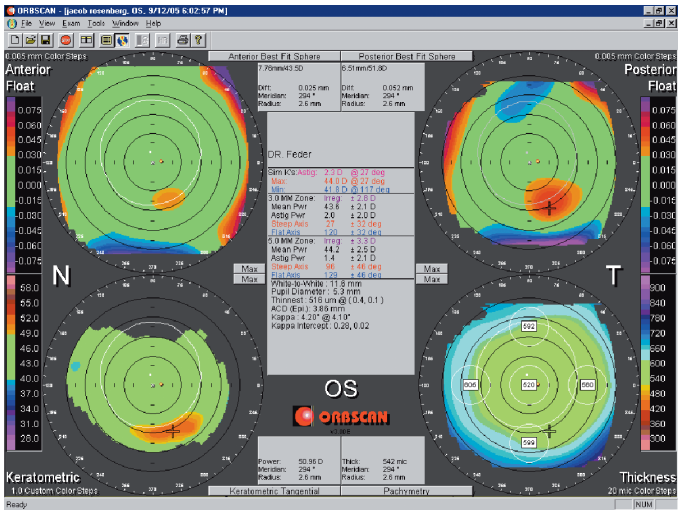

FIGURE 2.3

Orbscan provides a normal band scale, which is found by going to *View* in the toolbar, selecting *Quad Maps* in the drop-down menu, and choosing *Normal Band*. This normal band view shows orange in three of the four maps, which is one indicator suggesting against keratorefractive surgery. (Courtesy of Robert S. Feder, M.D.)

maps of preexisting ectasia. Most surgeons advise against LASIK surgery in this situation.

Caution is also recommended when the irregularity at the 3.0-mm zone is ±1.5 D or the irregularity at the 5.0-mm zone is ± 2.0 D (Fig. 2.2). Less conservative surgeons use ±2.0 and ±2.5 D, respectively. Finally, if the thinnest part of the cornea is >30 µm thinner than the central thickness, if the thinnest part of the cornea is >2.5 mm from the center, or if the peripheral cornea is not at least 20 µm thicker than the center of cornea, the postoperative ectasia risk may be increased.

Another type of analysis described by Vukich and Karpecki (P. Karpecki, O.D., *personal communication,* April 25, 2005) can be performed with the Orbscan using the normal band scale. This is found by going to *View* in the toolbar and selecting *Quad Map* in the drop-down menu. Then select *Normal Band,* which colors all values within a "normal range" as green. Abnormally elevated, steep, or thin areas will be depicted as orange on the otherwise green map. LASIK should probably not be done if orange areas are seen in two or more maps. If orange is present in two maps, surface ablation would be a better option, provided the risk of ectasia has been explained to the patient. When orange is seen in three maps, the patient should probably not have corneal refractive surgery (Fig. 2.3).

An evaluation known as Belin-Ambrosio analysis is available with the Pentacam and accentuates areas of abnormal elevation. The area around the thinnest portion of the cornea is eliminated from the calculation of the best-fit sphere both anteriorly and posteriorly. Caution should be exercised when Belin-Ambrosio difference maps appear yellow and in cases where these maps have central red areas, LASIK surgery is ill-advised (Fig. 2.4). Another helpful analysis available with the Pentacam makes use of the pachymetry measurements. Curves of the pachymetry plotted from the thinnest part of the cornea to the periphery are compared with normals. In an ectatic cornea, the thickness will increase toward the periphery more rapidly than the normal cornea, and the curve will be seen to drop below the normative curve (Fig. 2.5).

Pellucid marginal degeneration (PMD) is a noninflammatory thinning disorder that presents as a band of stromal thinning 1 to 2 mm wide, occurring 1 to 2 mm central to the inferior limbus usually between the 4 and 8 o'clock meridian. Corneal protrusion occurs superior to the band of thinning in contrast to keratoconus, in which protrusion occurs

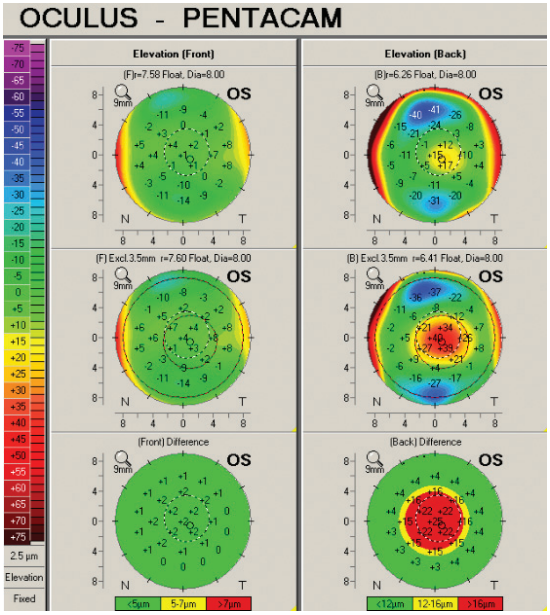

FIGURE 2.4

Belin-Ambrosio enhanced ectasia analysis provided with the Pentacam topography unit. The area surrounding minimal corneal thickness is eliminated from the calculation of best-fit sphere (seen in the second set of maps), enhancing the area of elevation. When the difference map seen in the bottom set is yellow, caution is advised in considering LASIK surgery. When it shows red, LASIK is ill-advised. (Courtesy of Michael Belin, M.D.)

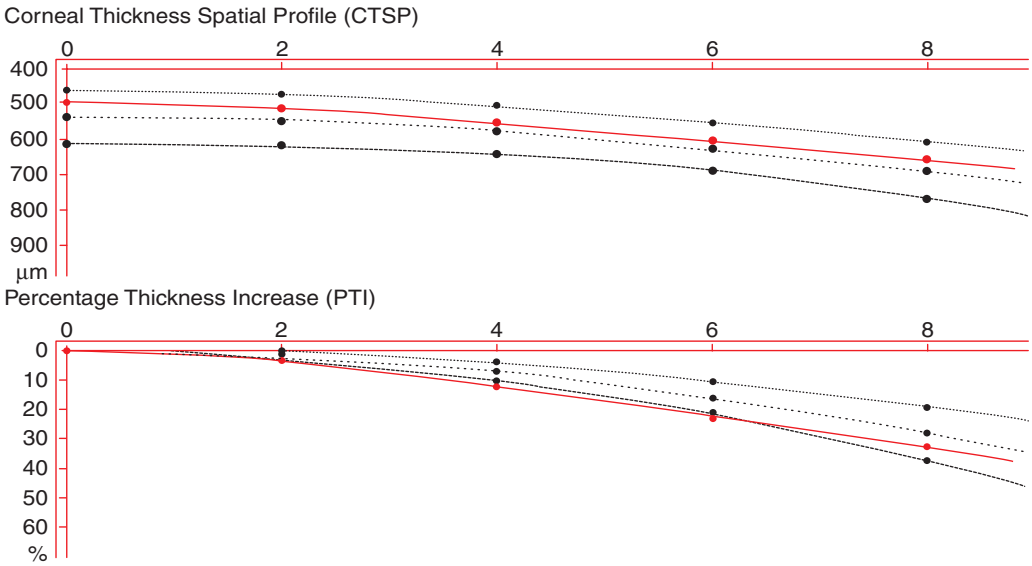

FIGURE 2.5

In the Belin-Ambrosio analysis of pachymetry, thickness is plotted from the thinnest part of the cornea to the periphery and compared with normals. In an ectatic thin cornea, a more rapid increase in thickness will occur as measurements are made toward the periphery. Corneal thickness is plotted directly *(above)* and as a percentage thickness increase *(below)*. The red curves, representing the patient in this case, are noted to dip down particularly in the PTI graph below. This is suggestive of corneal ectasia. (Courtesy of Michael Belin, M.D.)

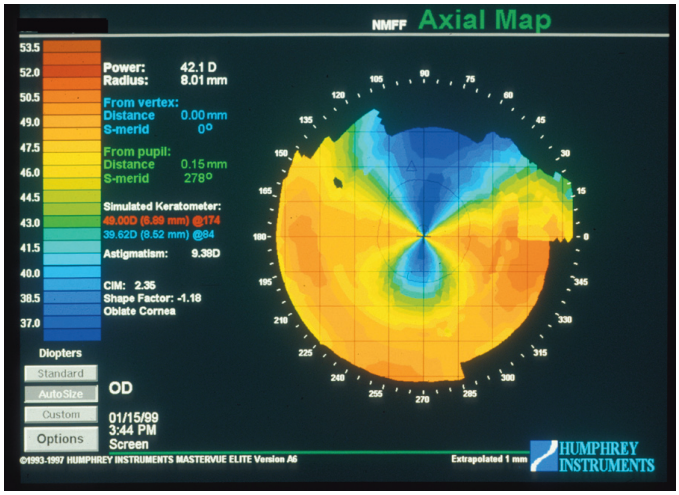

FIGURE 2.6

Power map of pellucid marginal degeneration. (Courtesy of Robert Grohe, O.D.)

at the area of maximal thinning. The axial or power map in PMD typically shows against-the-rule astigmatism superiorly and with-the-rule astigmatism inferiorly resulting in a crab claw pattern. This pattern is characteristic of PMD (Fig. 2.6).

The following scenario illustrates the use of topography as a LASIK screening tool. A 30-year-old man presented for LASIK measurements after a brief screening consultation. He had reasonable expectations, understood the risks of surgery, and appeared to be an excellent candidate for surgery. The patient corrected to 20/20 with a manifest refraction of −3.00 + 1.75 × 30 degrees OS. The corneal topography is shown in Figure 2.7. Notice the prominent posterior elevation with a difference from the best-fit sphere of 0.056 mm. There is also a prominent anterior elevation with the peak in the same place as the posterior

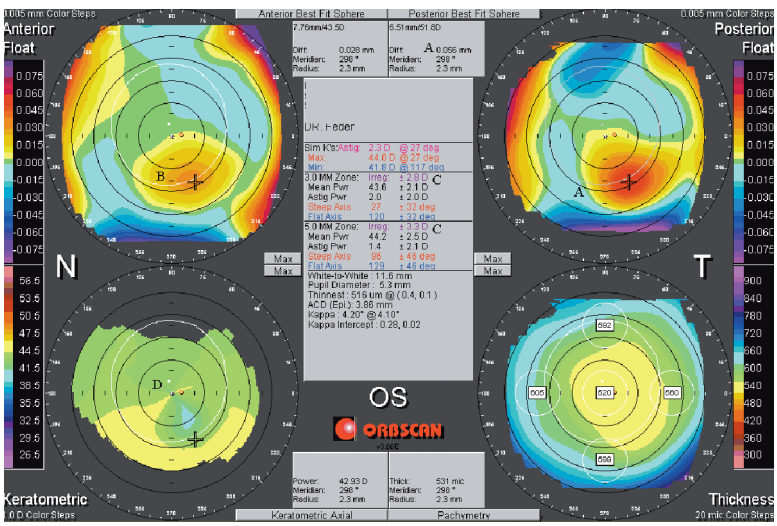

FIGURE 2.7

Preoperative patient topography. A: Prominent posterior float 56 µm above best-fit sphere. **B:** Prominent anterior float coincident with posterior float. **C:** Irregularity at 3 and 5 mm is greater than the ±2.0 and ±2.5 D upper limit. **D:** Power map suggestive of PMD. Normal band view of this preoperative patient is seen in Figure 2.3. (Courtesy of Robert S. Feder, M.D.)

float. The irregularity at 3.0 and 5.0 mm exceeds the recommended maximum limit. The power map is quite abnormal and resembles the map in Figure 2.6, suggesting PMD. The normal band view (Fig. 2.3) shows orange in three maps. Taken together, these data should raise a large red flag that this patient should not have corneal refractive surgery.

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chapter 3

Optical Coherence Tomography

ROBERT W. WEISENTHAL

Optical coherence tomography (OCT) is a noninvasive technology that produces two-dimensional, high-resolution, and high-definition cross-sectional images based upon low coherence interferometry. It has multiple uses in refractive surgery. As a screening tool, it can map the cornea and help identify the patient with abnormal corneal thinning or measure the depth of a corneal scar. Postoperatively, it can be used to accurately measure flap thickness as well as the residual stromal bed in consideration of retreatment. Diagnostically, it can help differentiate diffuse lamellar keratitis from pressure-induced keratitis. Epithelial ingrowth can be more carefully characterized with OCT.

There are two types of OCT systems used in ophthalmology, Time-domain OCT (TD-OCT) and Fourier-domain (FD-OCT), also named spectral or spectral-domain (SD-OCT). In TD-OCT, the light in the reference arm is directed into an oscillating mirror, which must be moved mechanically, limiting the scan speed in the range of several thousand per second. The recombined light is processed by conversion into electrical waveform by a detector, which then generates the axial scan. In contrast, in SD-OCT the reference mirror is stationary, so the frequency of the scan is limited only by the frame rate of the camera, increasing the speed of the image capture from tens of thousands to hundreds of thousands of scans per second. In addition, in SD-OCT, the recombined light from the reference and sample arms is passed through a spectrally separated detector (grate), which splits the light into a spectral interferogram. A computer then transforms the spectral interferogram into an axial scan. Overall, the use of SD-OCT improves the imaging speed dramatically, increases the signal-to-noise ratio, and improves the resolution of the images.

OCT Instruments

The first commercially available OCT system to image the anterior segment was the Visante (Carl Zeiss Meditec, Dublin, CA) with TD-OCT using a 1,300 nm wavelength beam (Table 3.1). The longer wavelength light had stronger water absorption, which produced less scatter. As a result, there was better visualization of turbid tissue such as cloudy cornea, sclera, iris, anterior chamber angle, and to a lesser extent, the ciliary body.

The Visante has a standard and a high-resolution mode. The standard resolution is 16 mm in width and 6 mm in depth, while the high-resolution mode provides a more detailed image over a smaller area, 10 mm in width and 3 mm in depth. The Visante in the standard mode performs 256 scans in 0.125 seconds and in the high-resolution mode performs 512 scans in 0.25 seconds. The Visante OCT 3.0 software package includes a comprehensive anterior segment imaging and biometry mode that images the anterior chamber depth and width, anterior chamber angles, and crystalline lens rise (CLR). There is corneal imaging and a pachymetry mode with a 16 mm width and 6 mm depth scan. A refractive tools software module is capable of evaluating residual stromal bed thickness and the position of phakic intraocular lenses (IOLs). An iridocorneal tools module images the anterior chamber angle.

The advantages of the Visante include limbus to limbus visualization of the anterior segment (16 mm in width), ease of use, and

TABLE 3.1 Comparison of Anterior Segment Oct Instruments

Name of Unit	Visante OCT	Visante Omni	Optovue RTVue	Heidelberg Spectralis
Type of OCT	TD-OCT	TD-OCT with Atlas corneal topography	SD-OCT	SD-OCT
Imaging	Anterior segment only	Anterior segment only	Anterior and posterior segment	Anterior and posterior segment
Scan speed (scans/s)	2,000	2,000	26,000	40,000
Resolution (μm)	17	17	5	7
Wavelength (nm)	1.3	1,300	830	830
Anterior segment imaging	No special lens required	No special lens required	CAM with two lenses providing different magnifications	Single lens with zoom function
Scan width (mm)	16	16	6	16

better depth of tissue penetration. The disadvantages of the Visante are that the image resolution is less than the SD-OCT, it has a slower capture time, making it more dependent upon patient fixation, it may be more difficult to localize isolated lesions, and it only provides images of the anterior segment.

The Visante has also been integrated with the Atlas corneal topography unit in a product called the Visante Omni (Carl Zeiss Meditec, Dublin, CA) combining Placido disc corneal topography with corneal pachymetry. This provides the ability to measure the posterior float by using the thickness data from the OCT and subtracting it from the height data generated by the topography, which is useful in detecting early keratoconus.

The first commercially available SD-OCT instrument for the anterior segment was developed by Optovue (Optovue, Inc., Fremont, CA). The first device released was the RTVue SD-OCT in 2006. A portable version called the iVue compact SD-OCT became available in 2010. These units use a shorter wavelength light than the Visante (830 nm vs. 1,300 nm) and for this reason can better penetrate transparent tissue, making it possible to visualize both the anterior and posterior segments. In order to image the anterior segment, the Corneal Anterior Module (CAM) requires special lenses. The wide-angle lens provides a scan width of 6 mm and a transverse resolution (focused spot size) of 15 μm useful for screening. The high magnification CAM lens provides a scan width of 4 mm and a transverse resolution of 10 μm, which can image smaller elements such as acanthamoeba.

Since the Optovue units are based upon SD-OCT, they can generate 26,000 axial scans per second, which allows registration to the tissue rather than relying on patient fixation. SD-OCT also improves the image resolution to 5 μm as compared to the Visante at 17 μm. However, the imaging depth of the RTVue is limited to 2.3 mm as compared to 6 mm with the Visante reducing the visualization through translucent or opaque tissue. Another disadvantage of the Optovue units is that scanning is limited to only the central 6 mm of the cornea.

The 6.0 software available on the RTVue and iVue allows high-speed corneal scanning, which can generate a pachymetry map. It is also possible to generate three-dimensional volumetric maps. There is a corneal angle view, which can provide higher magnification of the images. These programs can map the epithelium, LASIK flap, and the residual stromal bed thickness. There is also special software that provides keratoconus screening and a program to measure the anterior and posterior corneal curvature in the central 3 mm of the cornea. This can be used to derive the true corneal power, which is useful for IOL

calculation after refractive surgery. These applications are illustrated below.

The Spectralis made by Heidelberg Engineering GmbH (Carlsbad, CA) is also based on SD-OCT. An anterior segment module has been commercially available since November 2011. It requires an add-on anterior segment lens similar to the Optovue units. The advantages of the Spectralis anterior segment module is the faster scan speed of SD-OCT technology combined with a wider scan diameter of up to 16 mm, similar to the Visante. The Spectralis unit has enhanced depth imaging with Heidelberg noise reduction as well as active eye tracking with the TruTrack active eye tracking. The axial resolution is 7 µm compared to 5 µm in the RTVue unit. The software includes preset scans of 8 to 11 mm designed to capture specific anatomical features, combined with an interactive zoom function for greater magnification and measurement tools. All three OCT instruments perform many of the clinical applications for refractive surgery; however, the examples in this chapter are illustrated with the Optovue unit.

Clinical Applications

OCT is a versatile tool for the evaluation of the refractive patient. The high-resolution and high-definition images of the cornea clearly delineate the epithelium, Bowman layer, stroma, Descemet membrane, and endothelium. The corneal mapping pattern allows for accurate measurement of the thickness of the cornea overall and of the individual layers. Figure 3.1 illustrates the layers of the cornea.

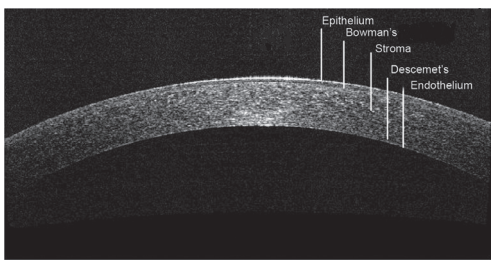


FIGURE 3.1

High magnification image of the cornea demonstrating the layers of the cornea with OCT. (Courtesy of Robert W. Weisenthal, M.D.)

PREOPERATIVE EVALUATION

The most common method to rule out forme fruste keratoconus is to use a Placido-based topography unit, a slit-scanning system, or a combination of the two systems. (See Chapter 2 for a more detailed discussion.) However, in some patients, the results of the Placido disc technology may be confounded by contact lens–induced corneal warpage, misalignment of the corneal apex and visual axis secondary to a large angle kappa, nonpathologic asymmetric astigmatism, irregular tear film, and subepithelial fibrosis or corneal scarring, which typically do not affect OCT measurements. Additionally, in some instances, the early findings in forme fruste keratoconus may not be focal steepening but focal corneal thinning. OCT provides an excellent profile of the corneal pachymetry to identify any areas of focal corneal thinning which might be missed by Placido disc technology. Typically, the thinnest point of the cornea is within 0.7 mm of the central cornea, so if the thinnest point is not central, and particularly, if it is decentered inferiorly or inferotemporally, it may be an early sign of keratoconus.

Proprietary software for the RTVue OCT divides the cornea into eight regions (octants) and then looks for significant asymmetry in corneal thickness. If, for example, the average corneal thickness of the superonasal octant minus the inferotemporal octant is >45 µm, the cornea is considered abnormally asymmetrical. In addition, if the minimum corneal thickness is <470 µm, or if the maximum minus the minimum corneal thickness is >100 µm, the cornea is considered abnormal. If one of these parameters is abnormal, the cornea is considered likely to have keratoconus; if two or more parameters are abnormal, the patient is considered very likely to have keratoconus (Fig. 3.2). Currently Optovue, Inc. is developing new software to improve the accuracy of the diagnostic criteria. This will be based upon pupil centration rather than vertex centration.

One novel technique to identify corneal ectasia is to measure the epithelial thickness profile. Reinstein et al.[1] initially observed that in patients with keratoconus, there was area of epithelial thinning at the steepest portion

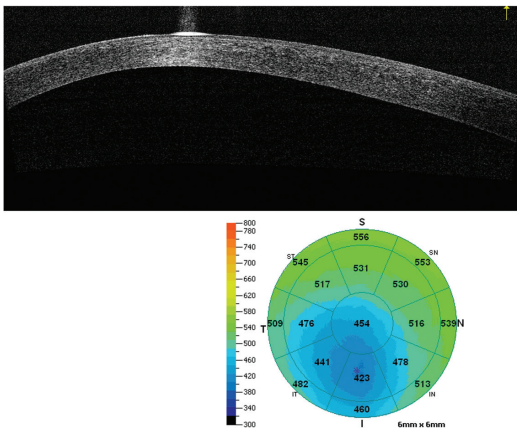


FIGURE 3.2

Keratoconus demonstrated with RTVue software program. (Courtesy of Robert W. Weisenthal, M.D.)

of the cornea surrounded by a zone of epithelial thickening. Since the cone is found inferiorly or inferotemporally in the majority of keratoconus patients, the thinnest area of corneal epithelium is also typically found inferiorly rather than superiorly. This pattern is in contrast to the epithelial thickness profile in the normal cornea, which is typically 6 µm thicker inferiorly than superiorly. Li et al.[2] recently confirmed these findings. The epithelial thickness profile may be a helpful screening tool to rule out forme fruste keratoconus prior to LASIK surgery.

To assure the most accurate prediction of residual stromal bed thickness, it is necessary to measure the thinnest point of the cornea. The assumption that the central corneal reading is the thinnest point of the cornea can lead to a dangerous miscalculation. In fact, the thinnest area of the cornea may be up to 100 µm thinner than a central corneal reading.

OCT can also be used to measure the thickness and profile of corneal scarring and determine if the depth of the scar is amenable to phototherapeutic keratectomy (PTK) therapy. If the corneal scar is too deep, then laser ablation may not be sufficient to remove enough of the scar to obtain adequate visual restoration or may induce an unacceptable hyperopic shift. On the other hand, some investigators are using OCT-guided transepithelial PTK for the treatment of anterior corneal opacities. The depth of the anterior stromal scar is plugged into an algorithm to simulate the amount of the scar that would be removed and calculate the refractive impact of PTK.

POSTOPERATIVE EVALUATION

OCT imaging may also be helpful in differentiating and managing diffuse lamellar keratitis (DLK) and pressure-induced stromal keratitis (PISK). Both conditions are characterized by symptoms of light sensitivity, decreased vision, and an associated stromal haze or infiltrate. DLK is typically seen early in the postoperative course and may involve either a focal area or the entire flap interface. PISK presents at a later stage and usually involves the entire flap (Fig. 3.3). When the presentation is not clear-cut, OCT may provide important information. The OCT image in DLK shows a hyper-reflective flap interface with some increase in stromal reflectivity (Fig. 3.4). In contrast, PISK shows a thickened hypo-reflective area in the interface with overlying flap edema (Fig. 3.5). Differentiating these two conditions is essential because the management of each is so different. DLK is secondary to inflammation and requires intensive topical steroid treatment and if needed, interface irrigation. In contrast, PISK, associated with high intraocular pressure (IOP), may be secondary to steroid use. Treatment in this case requires stopping topical steroids and treating the elevated IOP.

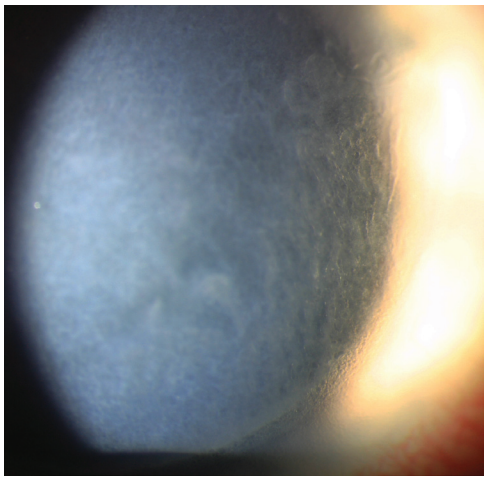
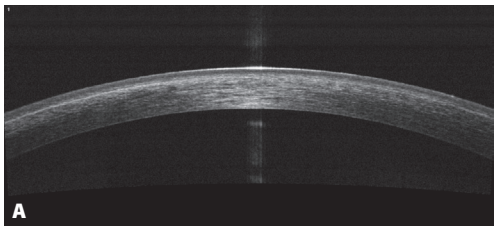


FIGURE 3.3

Slit-lamp photo of pressure-induced stromal keratitis. (Courtesy of Robert W. Weisenthal, M.D.)



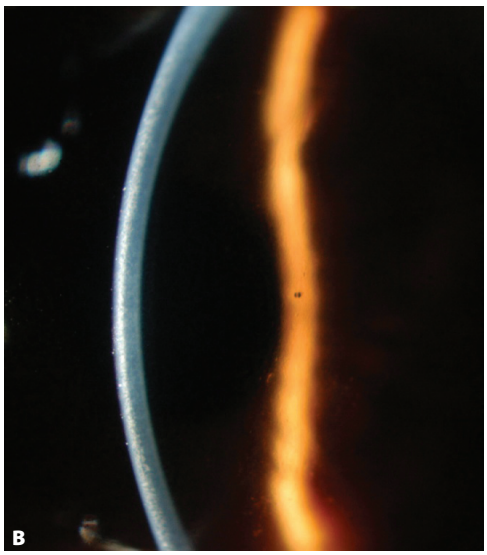


FIGURE 3.4

A, B: (A) Diffuse lamellar keratitis as seen with OCT (*above*) and (B) as seen at the slit lamp (*below*). (Courtesy of Huang D. Vol. II Cornea and Anterior Segment RTVue Fourier-Domain Optical Coherence Tomography Primer Series.)

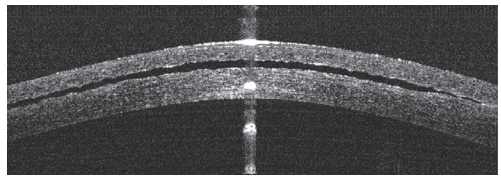


FIGURE 3.5

Pressure-induced stromal keratitis OCT view. (Courtesy of Huang D. Vol. II Cornea and Anterior Segment RTVue Fourier-Domain Optical Coherence Tomography Primer Series.)

The OCT can also provide some critical information in the evaluation and management of epithelial ingrowth. Although epithelial ingrowth has become less common with the increased utilization of the femtosecond laser, it is more common after enhancement surgery. OCT can help establish if an area of epithelial ingrowth is progressing or stable and document its extent. It can also determine and quantify the degree to which ingrowth is elevating or eroding the overlying flap. This provides a basis to monitor the area of involvement and determine the potential need for surgical intervention (Figs. 3.6A and B).

ENHANCEMENT SURGERY

OCT imaging can facilitate the decision-making process in enhancement surgery by providing objective measurement of the flap thickness and residual stromal bed. Figure 3.7 shows a somewhat thick flap of 150 µm with a stromal bed of 316 µm, whereas, in contrast, Figure 3.8 shows an extremely thick flap measuring 272 µm with a thinner residual bed of 273 µm. In the first patient it may be possible to lift the flap and perform further laser treatment for a mild myopic correction. The second patient with a thin residual bed may be at risk for developing corneal ectasia if further laser treatment to correct a moderate myopic undercorrection is performed on the stromal bed. Photorefractive keratectomy (PRK) on the flap would be a better option in this case. Of course, prior to any enhancement, it is necessary to look for any signs of corneal ectasia. At this point, there are no studies evaluating the efficacy of the OCT keratoconus screening software in post-LASIK or PRK patients,

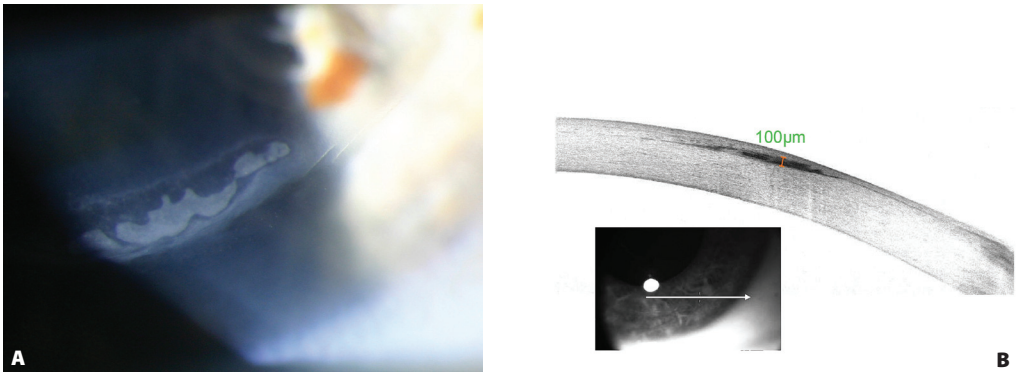


FIGURE 3.6

Slit-lamp photograph of epithelial ingrowth (A) and OCT image of epithelial ingrowth (B). (Courtesy of Robert W. Weisenthal, M.D.)

so corneal topography is essential prior to further surgical intervention.

An interesting application of OCT is to measure the epithelial thickness following PRK surgery to determine whether there is a relationship between an abnormally thick epithelium and myopic regression. There have been several studies, which have shown that epithelial hypertrophy following PRK surgery may produce myopic regression. Gauthier et al.[3] examined 70 patients who had PRK with the Summit laser with small optical zones and found that the epithelium was 21% thicker in the treated eye, which correlated with a postoperative myopic shift. They postulated that for every 18 µm of thickening there was 1 diopter (D) of myopic regression. Erie[4] showed that central epithelial thickness was 44 µm prior to surgery, and increased 7 µm by 3 months and increased another 5 µm between 3 and 12 months. He postulated that epithelial thickening was correlated with myopic regression; a 12 µm increase in epithelial thickening created a myopic regression of –0.41 D. Lindstrom has advocated performing an epithelial PRK for patients with mild (<1 D) symptomatic myopic regression, if the patient has persistent epithelial hyperplasia. This would potentially be ideal for a patient with epithelial thickness >60 µm (Fig. 3.9). There are no long-term studies on the effectiveness of this procedure. As with any PRK enhancement technique, it should only be performed in patients with stable myopia who are at least 6 months following initial PRK. Patients who undergo LASIK may also have epithelial hyperplasia, but it does not appear to play a role in myopic regression.

OTHER APPLICATIONS

Anterior segment OCT is helpful in the preoperative evaluation and postoperative follow-up of phakic IOL patients. Preoperatively, one can measure the corneal vault and anterior chamber width to determine the size of the implant to place. For this study, the Visante or Spectralis will offer better information as the scan width at 16 mm visualizes both angles. Postoperatively, OCT is also valuable to study

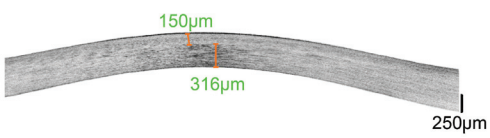


FIGURE 3.7

OCT image of a normal thickness flap with a good residual stromal bed following LASIK surgery. (Courtesy of Robert W. Weisenthal, M.D.)

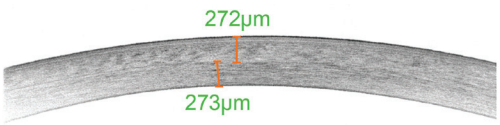


FIGURE 3.8

OCT image of an extremely thick flap with thinner than expected residual bed following LASIK surgery. (Courtesy of Robert W. Weisenthal, M.D.)

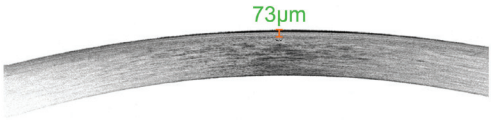


FIGURE 3.9

OCT image of thick epithelial layer following PRK surgery. (Courtesy of Robert W. Weisenthal, M.D.)

the phakic intraocular implant vault over the natural lens, particularly with the Visian implantable collagen lenses. Ideally, the vault should be 350 to 400 µm. OCT has also been used to evaluate the depth of the placement of the intracorneal implants such as the intracorneal ring segments (Intacs, Ferrara) or the ACI 7000 corneal implant for presbyopia.

A promising innovation with the OCT is the ability to measure the true corneal power following refractive surgery for the calculation of IOL power. The RTVue-CAM software measures the central 3 mm diameter curvature of the anterior and posterior corneal surfaces, which are then averaged and used to calculate the total corneal power. This can be used in IOL calculations after refractive surgery with a nomogram available online developed by Dr. David Huang.

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SECTION III

Flap-Making Equipment

chapter 4

Mechanical Microkeratomes

DAVID R. HARDTEN, ROBERT S. FEDER, and STEVEN I. ROSENFELD

The instrumentation used to create a flap has continued to evolve, becoming more reliable, easier to assemble, and safer to use. There are now one- or two-piece microkeratomes, manual or automated models, linear and rotational models, and even disposable microkeratomes. Finally, use of the latest innovation, the femtosecond laser, has steadily grown, largely replacing mechanical microkeratomes. In the last survey of the International Society of Refractive Surgery ophthalmologists, over 50% have now converted to use of the femtosecond laser. At the time of that survey, 8% of surgeons were using either the Bausch & Lomb Zyoptix XP or Hansatome, 12% were using the Moria M2 or LSK, 8% were using the Amadeus, 51% were using the IntraLase, and 6% were using the Ziemer femtosecond keratome. Other keratome use was below 5% among the surgeons surveyed. In this section, those microkeratomes used by over 5% of surgeons will be discussed. The IntraLase and Ziemer femtosecond lasers will be covered in the following chapter. Other lasers for flap creation are becoming available, but have not yet reached significant surgeon usage, and therefore will not be specifically addressed. The material presented is designed as an adjunct to—not as a substitute for—a certification course or a user's manual. For a broader perspective, readers can review the entire section or simply target the material relevant to their available equipment.

Microkeratomes

BAUSCH & LOMB HANSATOME & ZYOPTIX XP

This section will introduce the reader to the Hansatome & Zyoptix XP, which are similar in function. Basic information and pearls for the operation of this instrument are provided; however, a specific certification course must be completed prior to its use.

The Hansatome is a two-piece mechanical device designed to create a superior hinged flap as the microkeratome pivots on the slotted post of a suction ring. The motor is mounted vertically over the microkeratome head and the single-gear mechanism allows it to engage and rotate along the curved elevated gear track on the suction ring opposite the slotted pivot post. The blade oscillates within the microkeratome head at 7,500 rpm. The standard suction rings have an outer diameter of 20 mm.

Micro-rings have the same inner diameters as the standard rings, but have an outer diameter of 19 mm. The micro-rings are useful for patients with narrow palpebral fissures or tight lids. The available inner diameters in both the standard rings and the micro-rings are 8.5 and 9.5 mm. The 8.5-mm ring is appropriate for patients with steeper corneas; that is, keratometry readings of >45.00 diopters (D), or when a smaller flap is adequate (Table 4.1). When a larger flap is required, such as in custom treatments, large pupil treatments, hyperopia, or mixed astigmatism, or when the cornea is relatively flat, the 9.5-mm ring is preferred. Patients with keratometry readings >48.00 D are at increased risk of buttonholed flaps, and patients with readings <40.00 D are at heightened risk of a free cap.

Some surgeons feel that the superior hinge is less desirable in the patient with a relative tear deficiency, because nerve bundles entering the cornea from the 3 and 9 o'clock meridians will both be severed. A nasal hinge would preserve the nerves entering the cornea from the nasal side. Other surgeons do not feel this is a significant problem provided the surface can be stabilized preoperatively with punctal plugs, tear supplements, or topical cyclosporine. Any dry eye patient undergoing LASIK surgery should be cautioned about the added risk. All efforts should be made to enhance tear stability prior to surgery. Dry eye patients whose problem cannot be significantly improved with therapy have more problems with recovery after LASIK surgery, regardless of which microkeratome is used.

The most commonly used plates are the 160- and 180-µm plates; however, 130- and 200-µm plates are also available. The actual central flap thickness is typically less than the chosen plate thickness; however, the surgeon is advised to measure the actual flap thickness using intraoperative pachymetry. This is because of the variance that is possible

TABLE 4.1 Hansatome Rules of Thumb

Steep cornea	If *K* > 45.00 D, use 8.5-mm ring; *K* > 48.00 D risks buttonhole
	Caution: flaps cut on steep corneas tend to be large. If buttonhole: replace flap, no laser, consider PTK-PRK with mitomycin-C (MMC)
Flat cornea	If *K* < 45.00 D, use 9.5-mm ring; *K* < 40.00 D risks free cap
	Caution: flaps cut on flat corneas tend to be small. If small free flap or small flap: replace flap, no laser, bandage soft contact lens (BSCL), consider PTK/PRK with MMC 0.2 mg/cc
Small corneal diameter	Select smaller ring diameter to avoid bleeding unless flat keratotomy readings or large flap needed
	Caution: risk of bleeding, conjunctival or scleral extension
Large corneal diameter	Use larger 9.5-mm ring to create larger flap unless steep keratotomy readings
Corneal vascularization	Use smaller ring to avoid bleeding
Corneal thickness	Leave at least 250 µm of corneal bed untouched
	Hansatome plates (130, 160, 180, and 200 µm): 160- or 180-µm plates most commonly used flap thickness usually less than expected and even thinner on second eye. If initial flap very thin, increase plate thickness on second eye or use new blade
	Caution: If preoperative pachymetry such that residual stromal bed would be below 300 µm, recommend intraoperative pachymetry of stromal bed.
Surgical exposure	*Caution:* small fissure, tight lids, deep orbit, poor flap
	Consider one-piece microkeratome/nasal hinge
	Consider micro-ring (outer diameter 1 mm smaller)
	Consider stronger speculum or no speculum
	Consider flap creation with femtosecond laser

Abbreviations: BSCL, bandage soft contact lens; PTK, phototherapeutic keratectomy; PRK, photorefractive keratectomy.

between intended and actual flap thickness. The Hansatome will usually make an even thinner flap if the patient has a thin cornea. The mean central flap thickness created with the 160-mm plate is 129 µm ± 21µm, and for the 180-µm plate is 136 µm ± 25µm.

An early problem with the Hansatome was the relatively high incidence of epithelial loosening and defects within the newly created flap. This was particularly true in patients more than 50 years old, or with subclinical anterior basement membrane dystrophy. Since the advent of the Zero Compression Head, incidences of epithelial loosening and defects in the flap have fallen dramatically. The left/right eye adapter fits between the motor and the microkeratome head. It is labeled such that only the appropriate label "R" or "L" will be visible once the unit is properly assembled.

Prior to the operation, the scrub technician and surgeon should review the microkeratome checklist. The placement of the suction ring is similar to that for other microkeratomes.

Firm posterior pressure will help avoid pseudosuction, in which suction is applied to the conjunctiva but not the sclera. After suction has been achieved, the ring is allowed to float anteriorly, and the tissue that could potentially interfere with the microkeratome pass is swept aside.

Once suction has been achieved, the intraocular pressure (IOP) should be checked and a pressure >65 mmHg confirmed. The cornea is moistened with topical anesthetic. The Hansatome is placed on the slotted pivot post of the ring. If the microkeratome is not aligned properly, it will not seat. Twisting the head or forcing the microkeratome down on the post will not be effective. The microkeratome should be removed, realigned properly, and then replaced. A pearl for easily aligning the microkeratome with the post is to look for landmarks on the ring and the head. On the ring of the Hansatome there is a ledge central to and just below the gear track that serves as an important landmark. There is a dovetail on either side of the microkeratome head. The leading edge of the appropriate dovetail should be lined up with the inferior border of the ring ledge. This will allow the microkeratome to easily drop down on the pivot post,

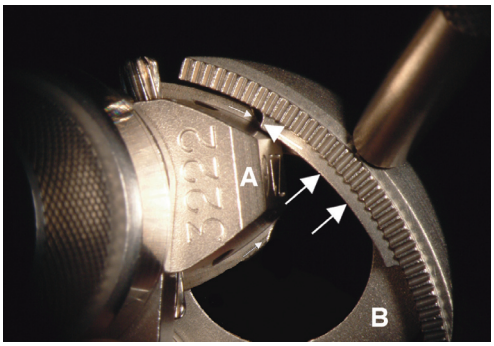

FIGURE 4.1

Hansatome assembly. The Hansatome **(A)** head and **(B)** ring. *Fat arrowheads* delineate the ring ledge just below the gear track. *Thin arrows* are on the dovetails of the microkeratome head. Where a thin arrow points to a fat arrow, the leading edge of the dovetail is aligned with the ring ledge. With this proper alignment, the head will easily drop down on the pivot post and the dovetail will be able to pass beneath the ring ledge. (Courtesy of Robert S. Feder, M.D.)

and the leading edge of the microkeratome will drop beneath the ring ledge. With a slight manual advancement, the microkeratome is fully engaged and ready for automated advancement. Proper alignment of these landmarks is illustrated in Figure 4.1 (See Video 2).

Once the gear is engaged in the track, the forward pedal is depressed and the surgeon can let go of the microkeratome, allowing it to complete its pass. Holding the ring handle stabilizes the device. As the Hansatome is reversed, suction can be released to avoid traumatizing the corneal epithelium. The patient should be cautioned about moving the eye when suction is released and the flap is still within the device. The Hansatome and ring are then lifted off the eye as a unit.

If the microkeratome fails to advance at the first tooth of the gear track, before the cornea has been engaged, it is safe to reverse the device, reengage, and proceed. However, if the flap is partially cut and the microkeratome becomes jammed, do not reverse and then advance. This will result in an irregular flap. If drape, lid, or speculum is blocking the Hansatome pass, clearing the track or widening the speculum may allow the pass to continue. In this case, it is safe to attempt to advance the microkeratome. If the Hansatome becomes jammed and will not reverse at the

end of the pass, suction can be released and the unit lifted anteriorly and inferiorly. The unit should not be disassembled until the flap has been inspected, in case a free cap has occurred and the tissue is still in or on the Hansatome.

Bausch & Lomb has also manufactured the Zyoptix XP microkeratome. The Zyoptix XP was developed in order to reduce the variance seen between the predicted and the actual flap thickness. In contrast to the Hansatome, the Zyoptix XP has an elevated gearless drive assembly designed to minimize contact with eyelashes or drapes. The translation drive has a "two-link" mechanism, and the suction ring supports this link mechanism. The ring has also been designed to reduce the risk of pseudosuction and suction breaks. The microkeratome has the additional advantage of 360-degree variable hinge positioning. The device can be adjusted for the particular eye by flipping a lever to the right or left. Data provided by Bausch & Lomb (2005) for the 120-µm plate show a mean flap thickness of 116.0 µm ± 16.1 µm with a range of 60 to 145 µm ($n = 50$).

Summary

In summary, the Hansatome and Zyoptix XP keratomes are convenient and reliable two-piece automated mechanical microkeratomes. There is a relatively short learning curve for their operation, which can be reduced further by practicing in a wet lab and by observing experienced surgeons. Certification is required prior to use. Many variables can affect the thickness of the flaps obtained with this device. However, once one becomes familiar with the flaps that are created in various situations, it can be used even more reliably. The surgeon is encouraged to routinely perform intraoperative pachymetry in order to be aware of the surprisingly thick or thin flap.

MORIA KERATOMES

CB Manual Microkeratome

Moria has developed microkeratomes with both manual and automated translation systems. The manual Moria Corriazo-Barraquer (Moria CB) microkeratome was one of the first pivoting microkeratomes allowing for superior-hinged LASIK flaps. It allows one to control the flap size according to a nomogram for suction ring selection, and flap thickness according to selection of the appropriate pre-calibrated microkeratome head. Moria currently markets two automated microkeratomes for use in LASIK surgery; the linear One Use-Plus SBK system, and the rotating M2 Single-Use system. The manual CB unit will be discussed to illustrate the contrast between manual and automated systems, and because some readers may not have access to more contemporary units.

The Moria CB microkeratome head fits in a protected dovetail groove, rather than having exposed gears. Thus, once the head is engaged in its groove, nothing can jam the gears or prevent the full excursion of the head in creating the flap. The preassembled blades can only be inserted one way—the correct way—in the microkeratome head, thus preventing improper insertion. The blade oscillates at 15,000 rpm, creating a smooth stromal bed.

There is little risk for confusion with the foot pedals, because there is one pedal for vacuum and one for blade oscillation. The vacuum unit contains two pumps. One pump acts as the backup and will take over instantaneously if the first pump fails.

The Moria CB microkeratome provides flexibility in designing the flap. The location of the flap hinge can be varied for the full 360 degrees simply by placement of the suction ring. The hinge will be located in the quadrant where the suction ring post is located.

One can select a flap diameter by choosing the appropriate suction ring size (−1, 0, +1, +2, or H). A higher ring number indicates a thicker ring. A thicker ring allows less corneal tissue to protrude and be cut by the microkeratome, once adequate suction has been obtained. The steeper the cornea, the more tissue would naturally protrude through the ring; therefore, a higher suction ring size would be selected to compensate for this. Refer to the nomogram in Table 4.2. The H-ring is designed for hyperopia and creates a flap diameter >10 mm, which can be useful for

TABLE 4.2 Moria CB Microkeratome Nomogram

Desired Flap Diameter (mm)	$K \leq 39$ D	39 D < $K \leq 41$ D	41 D < $K \leq 43$ D	43 D < $K \leq 46$ D	46 D < K
8.0	0	+1	+2		
8.5	–1	0	+1	+2	
9.0		–1	0	+1	+2
9.5	H		–1	0	+1
10.0		H		–1	0
10.5			H		–1
11.0				H	

Notes: For corneas <11.0 mm in diameter, optical zone size will increase by 0.25 mm; for corneas >11.5 in diameter, optical zone size will decrease by 0.25 mm.
Verify optical zone with applanator lens; be aware of the large flap diameters created with the H ring. These are suggested combinations only. Appropriate ring selections may vary with individual patients.

hyperopic LASIK where a larger ablation zone is required. An available applanation lens with diameter markings can be temporarily placed on the cornea prior to the microkeratome pass in order to predict the flap diameter.

The flap thickness can be varied by selection of the appropriate-sized microkeratome head. The higher the head number, the thicker the associated plate, and the thicker the flap will be. In addition, the flap thickness can be affected by the translation speed of the microkeratome pass. The faster the pass, the thinner the flap will be. In contrast to an automated microkeratome with a fixed translational velocity, the speed of the pass can be modulated with this manual device. Studies have shown that similar to automated keratomes, the flap of the second eye treated is usually thinner than the flap in the first eye. The blade is duller on the second eye and, therefore, cuts a thinner flap. Finally, flap thickness will vary depending on preoperative corneal thickness with thinner flaps occurring in thinner corneas.

The Moria CB microkeratome also has several disadvantages. The microkeratome heads are labeled as 110, 130, or 150 µm, but in actuality the flaps cut are commonly thicker. The 110-µm head cuts about a 140-µm flap, the 130-µm head cuts about a 160-µm flap, and the 150-µm head cuts about a 180-µm flap. This is in contrast to the Hansatome heads, which usually create flaps thinner than the label on the head (e.g., the 160-µm head cuts around a 130-µm flap). Several studies have demonstrated that the 130-µm head cuts with a great deal of variability with flap thicknesses ranging from 109 to 201 µm. When one is trying to calculate the residual stromal bed during the preoperative evaluation, one must assume some consistent flap thickness in the calculations. If the flap thickness truly varies to such a great extent, it is difficult to be certain that there will be adequate residual stromal bed. Several other studies have shown that most CB microkeratome heads create relatively consistent flap thicknesses, even though there is such variability between similarly labeled heads. It is therefore important to create a unique nomogram with mean flap thickness for each individual microkeratome head.

The ability to vary the translation speed with the manual CB microkeratome is an advantage when trying to modify the flap thickness from the expected thickness. However, it can be difficult to control for the variability in translation speed from case to case because manual operation cannot be as consistent as an automated machine.

Another disadvantage of the Moria CB microkeratome is its high profile—its suction tubing and wires extend vertically from the top of the microkeratome and come very close to the microscope optics on the VISX S4 excimer laser.

Moria M2 Automated Microkeratome

The Moria M2 automated microkeratome has a compact, ergonomic design and offers

options for altering the flap thickness, flap diameter, and hinge chord length. It offers many of the same advantages as the manually operated CB microkeratome, with the added benefit of automated translation for a more consistent microkeratome pass.

The advantages of the Moria M2 automated microkeratome include the low profile, which easily fits underneath the microscope on the laser. The small-diameter suction rings can fit in patients with small lid fissures and deep orbits. There are no gears. The M2 loads easily on its mounting post and is secured in place using a locking ring, rather than a dovetail design.

One particularly attractive feature for many surgeons is the ability to work with both hands once suction is applied. One hand can be used to stabilize the suction ring and the other to clear the speculum and lid out of the way.

The Moria M2 microkeratome possesses two motors, one for blade oscillation and one for translation of the cutting head. The blade oscillates at 15,000 rpm creating very smooth stromal beds.

Like the CB microkeratome, the Moria M2 also utilizes two vacuum pumps, so the backup pump will automatically and instantaneously take over if the first pump fails. The M2 utilizes the same vacuum unit as the CB; thus it also offers a low-vacuum setting for axis alignment of the globe, control of the globe during laser ablation, and the ability to decrease limbal bleeding that can occur with larger flaps.

A customized keratectomy is possible through control of flap thickness, flap diameter, hinge width, and hinge location. The flap thickness is controlled by selection of the microkeratome head. The 110 head cuts about 140 µm, while the 130 head cuts about 160 µm (Table 4.3).The automatic translation provides two constant and reproducible translation speeds, the slower 3.1-second pass and the faster 2.1-second pass. The capability of varying translation speed to affect flap thickness is less versatile than with the manual microkeratome.

The flap diameter can be varied by selecting the appropriate suction ring size (−1, 0, +1, +2) (Table 4.4). The higher the ring number, the thicker the ring base, the less the cornea will protrude, and thus the smaller the diameter of the flap created. Three different stop positions enable the surgeon to modify the hinge size and the size of the bed for ablation. The ability to customize hinge size may be particularly helpful in hyperopic patients where a smaller hinge width will allow for greater exposure of the stromal bed to accommodate the wider ablation zone. The Moria M2 allows maximum flexibility for location of the hinge based on placement of the post on the suction ring, similar to the CB microkeratome.

The disadvantages of the Moria M2 automated microkeratome include the inaccurate labeling of the microkeratome heads, common to almost all companies and models. Although the M2 head creates a more reliable and reproducible flap thickness than the CB unit, there is still a 20- to 30-µm variance between uses. This can be problematic when operating on a thin cornea where the residual stromal bed is of greater importance. Finally, a rotational microkeratome may be more likely to create an epithelial defect or an area of loosened epithelium in the region of the rotational post. This is more common with the manual CB microkeratome.

Moria One Use-Plus System

The other automated microkeratome currently marketed by Moria for LASIK surgery is the

TABLE 4.3 Flap Thickness versus Preoperative Pachymetry for Moria M2

M2	Average corneas	Thick corneas	Thin corneas
Microkeratome	Preoperative pachymetry	Preoperative pachymetry	Preoperative pachymetry
160 µm head flap thickness	535–575 µm 161 ± 16	>575 µm 175 ± 21	<535 µm 141 ± 22

Source: From Stein RM. Experience with Moria M2 Microkeratome. *Refractive Eyecare for Ophthalmologists.* 2001;Suppl 5(12):13.

TABLE 4.4 Moria M2 Nomogram

Steepest Keratometry Reading (D)	Ring	Stop	Flap Diameter (mm)	Stroma Available for Ablation	Hinge Chord Length (mm)
39	–1	7.5	8.75	8.13	4.5
40	–1	7.5	9.0	8.25	5.0
41	–1	8.0	9.25	8.625	4.6
	0	7.5	8.75	8.125	4.5
42	–1	8.0	9.5	8.75	5.1
	0	7.5	9.0	8.25	5.0
43	–1	8.5	9.75	9.125	4.8
	0	8.0	9.25	8.625	4.6
	1	7.5	8.75	8.125	4.5
44	0	8.0	9.5	8.75	5.1
	1	7.5	9.0	8.25	5.0
45	0	8.0	9.5	8.75	5.1
	1	7.5	9.0	8.25	5.0
46	2	7.5	8.75	8.125	4.5
47	2	7.5	9.0	8.25	5.0
48	2	8.0	9.25	8.625	4.6
49	2	8.0	9.5	8.75	5.1

Notes: Select the ring based on the steepest *K*.
Moria does not recommend using the M2 for corneas thinner than 470 µm.
For corneas >11.5 mm in diameter, the flap diameter will decrease by 0.25 mm.

One Use-Plus system (See Video 3). In contrast to the units previously discussed, this is a linear rather than rotational keratome that has the capability of creating a nasal hinge. It comes preassembled and there are several single-use suction rings and heads that allow the surgeon to create various sized flaps. The ring is clear, which may improve visibility during the actual surgery. Single-use systems reduce the potential of damage to the head during the sterilization process at the laser centers. There is no risk of diffuse lamellar keratitis related to the sterilization unit, and assembly errors are also minimized.

ZIEMER KERATOMES

Amadeus II

The Amadeus II is also a linear automated mechanical keratome that, in contrast to the rotational microkeratomes and the Moria One Use-Plus, is completely assembled off the eye. Therefore, after suction is obtained on the eye, the flap can be created immediately, without the need for microkeratome assembly. This reduces suction time and the potential for loss of suction during the assembly process. The microkeratome is vertically high and could potentially interfere with some operating microscopes. The Amadeus platform also has heads for surface ablation, for example, an epi-LASIK head.

The Amadeus II has no external gears, and has independent blade oscillation rate of 8,000 to 15,000 revolutions per minute. There is control over vacuum parameters, and the head-advance speed can vary from 1.0 to 4.0 mm/second. Because of the linear design of the keratome, corneal abrasions appear to be less common than with rotational keratomes. The Amadeus II weighs about 70% less than the first generation of the Amadeus because of a smaller handpiece and lighter, more flexible cords. Voice-confirmation feedback and automated assembly guides help improve safety of the various steps.

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chapter 5

Femtosecond Laser Flap Creation

PAUL J. BRYAR, DAVID R. HARDTEN, and MICHAEL VRABEC

The femtosecond laser represents a significant advance in the field of refractive surgery. Mechanical microkeratomes were the only instruments available for flap creation in the early days of LASIK. In 2001, the FDA approved the first femtosecond laser for the LASIK flap. The use of the femtosecond laser has steadily increased since then. By 2010, over 50% of the LASIK procedures in the United States were performed with the femtosecond laser. Significant improvements in femtosecond technology have occurred over the last decade. In addition to flap creation, the lasers can be used to create channels for intrastromal rings, and can be used for keratoplasty and cataract surgery. IntraLase Corporation of Irvine, California, developed the first commercially available femtosecond laser. Lasers that are FDA approved and currently in use at this time include: Abbott Medical Optics IntraLase FS and iFS, Alcon WaveLight FS200, Carl Zeiss Meditec VisuMax, Technolas Perfect Vision 520F, and Ziemer Ophthalmic Systems Femto LDV.

Laser Physics

The femtosecond laser is a focusable infrared laser similar to the Nd-YAG (neodymium–yttrium-aluminum-garnet) laser used for the posterior capsulotomy procedure; however, this laser delivers ultrashort laser pulses, firing in the femtosecond duration range (100×10^{-15} second). The advantage of a femtosecond laser is that the extremely short laser pulse of focused energy causes minimal thermal damage or disruption in adjacent tissues. This adjacent disruption in the corneal stroma has been measured and extends out on the order of 1 µm. The femtosecond laser pulse vaporizes small amounts of tissue by the process of photodisruption. The vaporized tissue forms an intrastromal cavitation bubble of microplasma, which is composed of water and carbon dioxide. Focusing the laser energy at a specified tissue depth and placing successive laser spots in close proximity to one another, multiple bubbles are created in a lamellar corneal dissection plane. Some lasers create the dissection plane using a raster (zigzag) line pattern, while others use a spiral pattern. The laser-controlled software can be programmed by the surgeon to create lamellar, axial (side cut), or pocket cuts in a wide range of depths and diameters. Typically after the lamellar cut has been completed, the side cut is created with a series of vertically placed spots along the flap edge.

Significant advances have been made with femtosecond technology over the last decade. First generation femtosecond lasers had repetition rates of approximately 15 kHz, and flap creation could take 60 to 90 seconds. Some current generation lasers operate in the 150 to 200 kHz range and have flap creation time of <10 seconds. Other lasers such as the Ziemer Femto LDV use very high pulse rate in the MHz range with lower energy per pulse. Despite the differences in laser dynamics and parameters from one laser to another, there

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are basic principles and practices that are applicable to all femtosecond lasers. The rest of the chapter will focus on the important clinical concepts that can be applied to any femtosecond laser platform used for LASIK flap creation.

Advantages & Disadvantages of Femtosecond Lasers

The selection of candidates for LASIK with a femtosecond laser is similar in many respects to that for the blade microkeratome. First and foremost is patient safety, followed by the ability to meet patient expectations. However, femtosecond technology may expand the limits of candidacy for LASIK surgery. The advantages and disadvantages of the femtosecond laser for flap creation are summarized in *Table 5.1*.

Various studies have demonstrated that when compared to mechanical microkeratomes, femtosecond lasers create flaps with more predictable thickness. Femtosecond lasers can also create thinner flaps. The ability to create thinner flaps combined with tighter variance between expected and actual flap thickness may allow more patients with relatively thin corneas or highly myopic patients to undergo the procedure. Intraoperative pachymetry in such cases is still recommended prior to excimer ablation to ensure adequate residual stromal bed thickness.

Femtosecond lasers also create more predictable flap diameters and shapes compared to flaps created with a microkeratome. With a mechanical microkeratome, patients with steeper corneas are at a higher risk for a buttonhole flap or a wider than anticipated flap diameter. Patients with flat corneas are at a higher risk for free flap or a smaller than anticipated flap diameter. With femtosecond lasers, the above mentioned complications are unlikely to occur even in patients with contours at the upper and lower ends of the normal range. Patients with smaller corneas can be treated with less risk of invading the sclera, because of the ability to better adjust flap diameter. Additionally, femtosecond lasers create flaps with a more desirable planar configuration and uniform thickness. Flaps created with a microkeratome have a meniscus shape with the flap periphery being thicker than the center (see Fig. 5.1).Most blade microkeratomes create thinner flaps on the second eye when the same blade is used for both eyes. They also create thinner flaps in thinner corneas and thicker flaps in thicker corneas. This is not the case with the femtosecond laser.

Femtosecond lasers are capable of creating more predictable and desirable side-cut

TABLE 5.1 Summary of the Advantages and Disadvantages of Femtosecond Laser Flap Creation

Advantages	Disadvantages
Greater predictability of flap thickness; ability to create thinner flaps	High cost
Greater predictability of flap diameter	Need to acquire new skills
Flap creation independent of corneal contour or corneal diameter	Increased risk of inflammation (DLK)
Reduced incidence of button hole, partial flap, and intraoperative abrasion	TLSS or Good Acuity Plus Photosensitivity (GAPP); also Peripheral light spectrum phenomenon/Rainbow glare
Ability to retreat in the event of a suction break	OBL may interfere with excimer ablation
Epithelial sloughing of the flap is unlikely	Rarely intracameral bubbles can interfere with laser tracking, delaying surgery
Increased flap adherence long term reduces risk of traumatic flap displacement	Increased flap adherence makes flap lift for retreatment long term more difficult
Less bleeding from corneal neovascularization	Not suited to LASIK after RK or PK due to increased flap manipulation and potential wound disruption
Creation of a more planar flap	

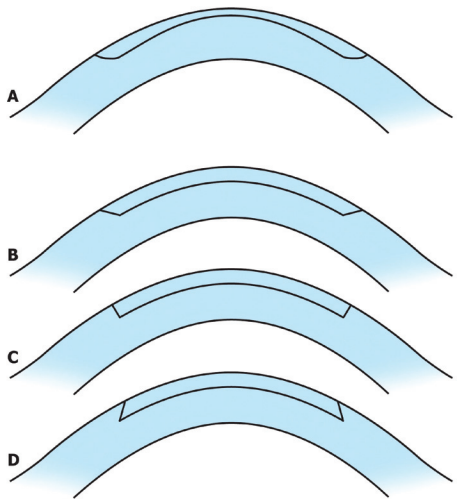

FIGURE 5.1

Mechanical microkeratomes cut a flap with a sloping side-cut angle and some cut a flap with a meniscus contour, i.e. thicker in the periphery and thinner in the center **(A)**. In contrast, femtosecond lasers create a planar flap with an angled side cut **(B)**, a perpendicular side cut **(C)**, or a reversed beveled side cut **(D)**.

profiles. With mechanical microkeratomes, the side-cut angle is more tapered or sloped. Femtosecond lasers allow the surgeon to specify the side-cut angle. The side-cut angle range varies with different laser manufacturers, but vertical, near-vertical, or reverse beveled angles can be created (refer to Fig. 5.1).

Proposed mechanisms of epithelial ingrowth include a defect or gap at the flap margin facilitating epithelial migration under the flap, as well as seeding of the stromal bed during the microkeratome pass. Because side-cut angles created with the femtosecond laser are more vertical, the epithelium is less likely to migrate beneath the flap. This may explain the reduced likelihood of significant epithelial ingrowth following LASIK surgery using the femtosecond laser.

The angle on the side cut theoretically may make the flap more resistant to displacement soon after surgery, and now can be varied over a wide range, with some potential strength advantages to an inverted side cut that has an angle of more than 90 degrees. The flap is definitely more resistant to displacement 1 year after surgery; in fact, it may be difficult to lift the flap for retreatment.

Femtosecond Laser Parameters

The surgeon has control over many of the flap parameters. Each type of laser has a particular range of adjustable parameters that can be manipulated by the surgeon. Despite the differences between lasers, an understanding of the common parameters and their impact on flap creation is necessary for a surgeon to optimize the femtosecond laser settings. The important parameters are flap thickness, bed energy, spot size and separation, flap diameter, hinge location, pocket profile, and side-cut angle/energy. It is wise to heed the recommendations of the representatives of the laser manufacturer and other more experienced surgeons when adjusting settings. As the surgeon gains more intraoperative experience, for example, trouble lifting the flap, and postoperative experience, such as inflammation or associated photophobia, fine-tuning adjustments can be made with various parameters to minimize side effects and facilitate flap creation. A summary of some of the parameters for current generation lasers is in Table 5.2.

FLAP THICKNESS

The surgeon can specify the flap thickness within the parameters of the given laser. The actual thickness of laser-made flaps measured by OCT or subtraction pachymetry comes closer to the intended thickness than does the thickness of flaps made with a microkeratome. It remains helpful intraoperatively to measure the stromal bed after the flap lift in order to calculate the anticipated post-ablation residual stromal bed.

BED ENERGY, SPOT SIZE

In general, the goal is to create a flap that is easy to lift using the lowest amount of energy. Insufficient energy will result in a flap that is harder to lift and possibly increase the chance of flap striae or flap tear. Excessive energy will increase the likelihood of postoperative inflammation, for example, diffuse lamellar keratitis (DLK) or Transient Light Sensitivity Syndrome (TLSS). The power of each spot can be adjusted and must be specifically set for

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TABLE 5.2 Summary of Parameters of Various Currently Available Femtosecond Lasers Expand Transient Light Sensitivity Syndrome (TLSS)

	Alcon WaveLight FS200	AMO IntraLase iFS	Carl Zeiss Meditec VisuMax	Technolas Perfect Vision 520F	Ziemer Femto LDV
Pulse rate	200 kHz	150 kHz	500 kHz	80 kHz	>5MHz
Side-cut angle (degrees)	30–150	30–150	45–135	60–120	28 (fixed)
Cone-cornea interface	Flat	Flat	Curved	Curved	Flat
Duration	300 fs	600–800 fs	220–580 fs	500–700 fs	200–350 fs
Wavelength	1,050 nm	1,053 nm	1,043 nm	1,053 nm	1,045 nm
Pulse energy	0.1–2.4 mJ	800–1,000 nJ	180–220 nJ	650–2,500 nJ	<100 nJ
Laser type	Amplifier	Amplifier	Amplifier	Amplifier	Oscillator
Ablation pattern	Raster	Raster	Spiral	Spiral	Raster

each individual laser. Spot separation is the space between each laser spot that will create a cavitation bubble. Some lasers also permit the surgeon to specify the space between each line of laser spots created during the raster pattern treatment. Smaller spot separation or line separation will result in more laser spots being delivered during the procedure. Therefore, either an increase in bed energy or a decrease in spot or line separation will lead to more energy being delivered during the procedure. Conversely, a decrease in bed energy or increase in spot or line separation will lead to reduced energy being delivered during the procedure. Once power settings and spot or line separation are at desirable levels, they are usually not adjusted for each patient.

FLAP DIAMETER

Flap diameter must be specified by the surgeon. The diameter choice will depend on the corneal diameter, the presence of peripheral corneal pathology, and the preferred excimer ablation zone. Beginning surgeons are advised to select a flap diameter slightly greater than necessary to accommodate suboptimal centration. Recentration after suction is applied may result in a smaller flap diameter. Some femtosecond lasers also allow for different flap shapes, for example, an elliptical shape.

HINGE LOCATION AND POCKET PROFILE

Femtosecond lasers allow the surgeon to specify the location of the hinge; for example, a superior or nasal hinged flap. The angle of the hinge (hinge width) can also be specified. For a given flap diameter, a large hinge angle will result in less stromal bed being exposed for treatment, while a smaller hinge angle will result in more exposed stromal bed (see Fig. 5.2). If the hinge angle/length is too small, flaps may have less stability and be more likely to be displaced.

Various parameters of the pocket can be specified such as width, depth, and size. The pocket is created to allow gas to escape peripherally rather than into the stromal bed. Some lasers allow independent adjustment of the laser energy that creates both the pocket and the bed, while others couple the bed and the pocket.

SIDE-CUT ANGLE AND ENERGY

Side cuts can be created with much more precision using a femtosecond laser. More vertical or beveled angles may result in less epithelial ingrowth and may be more resistant to displacement soon after surgery (see Fig. 5.1).

Techniques and Management Considerations

As with any surgical procedure, there is a learning curve associated with using the femtosecond laser. Adequate certification training, including didactic study, wet lab, and observation with intraoperative mentoring during the first several cases using the available laser is necessary for safe and effective patient

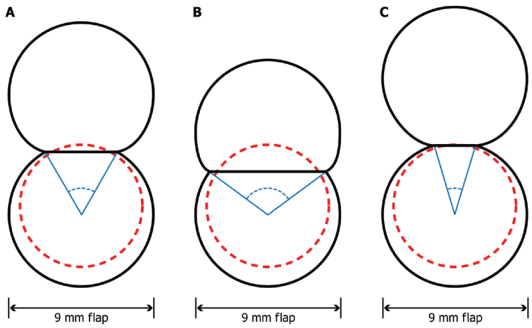

FIGURE 5.2

A: A proper hinge angle provides good flap stability and adequate stromal bed exposure for the excimer ablation. **B:** If the hinge angle is too large, the flap cannot be adequately reflected to expose the necessary stromal bed. **C:** If the hinge angle is too narrow, adequate bed can be exposed, but the flap may be less stable.

treatment. With practice, the techniques described can be mastered without difficulty. As the surgeon gains experience, small adjustments in the various laser settings described above may help optimize the laser procedure.

A small dose of a minor tranquilizer (e.g., oral diazepam 5 mg) may be given preoperatively to reduce anxiety. A drop of chilled naphazoline instilled preoperatively will reduce the risk of associated subconjunctival hemorrhage caused by the suction ring.

The patient is placed in the supine position on a laser chair with three-axis adjustment, if possible. The chair and the laser should be centered to allow for the full range of motion that might be necessary for a successful ablation. Surgeons vary with regard to which eye is routinely treated first: the dominant, the nondominant, or the same eye each time. The fellow eye is covered to avoid patient distraction. Sterile, chilled buffered proparacaine is applied to the cornea. Some surgeons instill a drop of topical fluoroquinolone or a drop of prednisolone 1%. The patient is prepped with povidone-iodine 5% and the lashes are draped to aid in exposure and lessen the chance of contamination, although the risk of contamination is extremely low and some surgeons do not drape the lashes until prior to lifting the flap. The suction ring can be inserted and used without lid specula. It is typically easier to insert the ring beneath the lower lid first and then the upper lid.

The next several steps describe the use of the IntraLase femtosecond laser (Abbott Medical Optics, Irvine, CA).The laser cone (Fig. 5.3) is examined and the applanating lens should be inspected under the laser microscope to identify any debris or faults that could adversely affect the ablation of the cornea. The patient is then brought underneath the laser microscope and the head is adjusted to allow for equal exposure of the superior and inferior bulbar conjunctiva.

The suction ring (Fig. 5.4) is a manually operated, syringe-controlled device. The increase in IOP associated with its use is generally less than the pressure achieved with the pump-controlled suction devices used with microkeratomes. It is inspected to make sure it is in good working order. The ring is placed on the eye and centered on the pupil, which is decentered slightly nasally in most

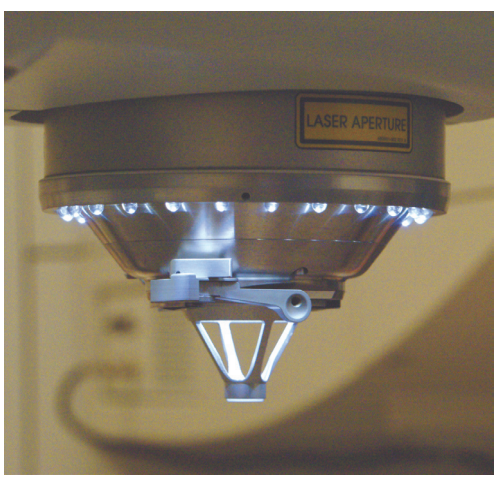

FIGURE 5.3

IntraLase with cone attached. (Courtesy of Robert S. Feder, M.D.)

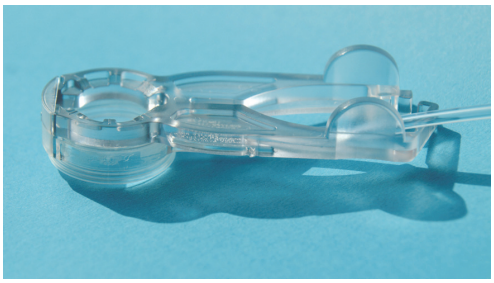

FIGURE 5.4

IntraLase suction ring. (Courtesy of Robert S. Feder, M.D.)

patients. Hash marks on the ring are useful in confirming good pupil centration (Fig. 5.5). It is difficult to compensate for inadequate ring centration during the docking process, so it is important to center the ring properly before engaging suction. Slight superior decentration ensures that the hinge will be located peripherally and this will not affect the docking process adversely. Suction is applied by releasing the depressed syringe. It is important to observe the eye during this process in order to detect globe movement, which can occur during suction application. Posterior pressure on the ring prior to applying suction will help prevent globe movement as suction is being applied. A decentered flap can result from undetected globe rotation. If globe rotation occurs, suction should be released and the ring reapplied so as to compensate for an expected rotation. Once the ring has been successfully applied, it is helpful to rotate the patient's head away from the eye being treated. This will

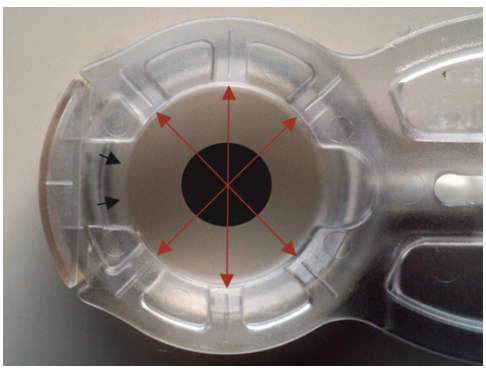

FIGURE 5.5

Hash marks on the IntraLase ring can be used to help match the ring center with the pupil center (*red arrows*). The ledge indicated by the *black arrows* will change appearance when suction has been achieved.

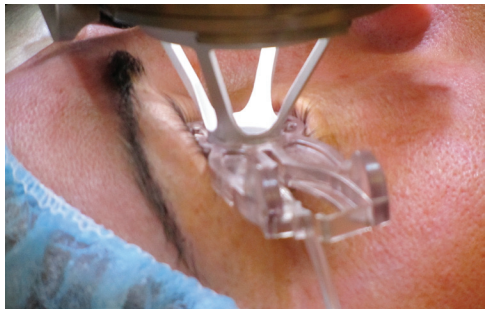

FIGURE 5.6

The cone is docked within the suction ring. A speculum is unnecessary even with deep-set eyes. (Courtesy of Robert S. Feder, M.D.)

ensure that the patient's nose will not interfere with the successful docking of the laser applanating lens. The chin height should also be adjusted so that the iris plane is parallel with the floor, which will increase the likelihood of easy docking. It is important to be certain there is no pool of tears or anesthetic within the ring prior to the docking procedure. Fluid within the ring can create a fluid meniscus that cannot be adequately moved to the periphery during docking. A sponge should be used to remove fluid if detected. (See Video 13)

The next step is to slowly lower the laser cone down along the Z-axis in order to dock the cone in the ring (Fig. 5.6). Observing the video display during the docking process will help confirm that centration is ideal. When the ring handle is locked, the ring is in the dilated position. When the handle is unlocked, the ring is constricted. Some surgeons prefer to leave the ring handle locked until after docking has been successful, while other surgeons prefer to start with the handle unlocked and then squeeze the handle to dilate the ring for docking. As the cornea is applanated, the ring needs to stay parallel to the eye avoiding torque in order to prevent a break in suction. It is helpful to carefully support the ring by the handle as the lens is entering the ring. If applanation or centration is poor, the handle should again be squeezed to increase the aperture of the ring and release the applanation lens, allowing the lens to be elevated for repeat docking. The shape of the patient cone interface varies with the laser manufacturer. Some cones have a flat, planar interface, while others have a curved interface.

With most femtosecond laser systems, complete applanation of the cornea must be achieved or an incomplete flap or side cut may occur. A small meniscus of non-applanated cornea outside the flap is preferable and allows for release of gas bubbles into this space. After successful applanation, the outline of the flap will appear on the viewing monitor of the laser. Any fluid meniscus should move peripherally. Slight decentration can be corrected using the arrow keys on the laser keyboard; however, the diameter of the flap will be decreased as the degree of adjustment increases. It is not uncommon for the pupil to dilate widely, so some surgeons prefer not to use the pupil as a reference. If a very large decentration is noted after docking, the surgeon should consider re-docking the laser cone. Alternatively, one can release suction and reposition the ring, and restart the process.

Once the docking is completed, the laser is engaged. If the applanation pressure is light, dark areas may be seen within the normally white ablation pattern. This does not seem to cause a detectable irregularity of the ablation or difficulty lifting the flap. In addition to the flap, the laser creates the pocket near the hinge for waste gases, namely carbon dioxide and water, to vent. If the applanation pressure is excessive, the energy settings are high, as occurs with high bed energy or decreased spot separation, or if the pocket is too shallow or too close to the limbus, the waste material will accumulate, creating an opacified bubble layer (OBL) (See Video 1). Extensive OBL rarely can interfere with the excimer laser-tracking device. If it does, waiting for 15 minutes will usually allow the waste products within the corneal stroma to dissipate (Fig. 5.7).

The speed of laser ablation varies between various laser platforms and settings, and can be observed through the microscope or on the video display. The 60-kHz laser ablation takes <20 seconds, while faster lasers are now available, up to 150-kHz, which can create a flap, even with a tighter spot/line separation in 10 to 15 seconds. During stromal ablation, the surgeon observes the progression of the raster pattern on the monitor for signs of OBL or a suction break. After successful creation of the side cut, the suction ring is released. The second eye is treated in a similar manner.

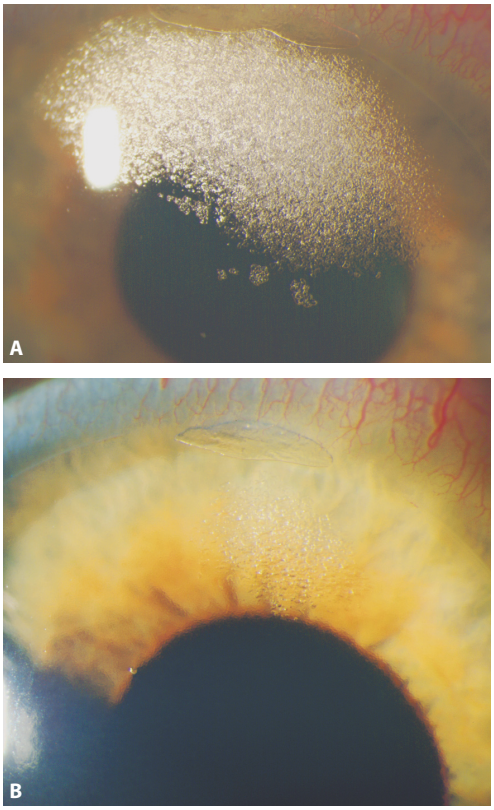

FIGURE 5.7

A: OBL noted immediately after creating a flap with the femtosecond laser. **B:** OBL dissipates after 20 to 30 minutes. (Courtesy of Robert S. Feder, M.D.)

If loss of suction were to occur during flap creation (See Videos 14 & 15), the laser should be stopped immediately by releasing the laser foot pedal. Because the suction ring is a manual device, independent from the laser, a loss of suction will not stop the ablation from proceeding. A loss of applanation and movement of the eye are easily identifiable signs of a suction break seen on the monitor. Loss of suction during flap creation can occur either when the raster pattern is being created or when the side cut is being made. Assuming suction can be regained, the surgeon can retreat immediately, at the same depth. This is a significant advantage of the IntraLase over the blade microkeratome. If this occurs, it is important to use the same applanation lens to ensure that ablation will occur at the same depth. If suction loss occurs while the raster is in the visual axis, one could consider

postponing the treatment for a period of time, for example, 1 month, and subsequently creating a thicker flap.

If suction loss occurs during the side cut, the surgeon can replace the suction ring, reacquire suction with the same laser cone, and perform a side-cut only laser pattern with a smaller diameter than the initial cut. The above suction loss scenarios are general guidelines. Follow the individual laser manufacturer's instructions for each situation.

Risk factors for suction loss during laser flap creation include excessive X-Y joystick movement after docking, conjunctival edema from multiple suction attempts, deep-set eyes, and excessive eyelid squeezing.

Rarely air bubbles can appear in the anterior chamber during the creation of the flap (See Fig. 17.2 and See Video 12). This is usually seen in a patient with a small corneal diameter or in the case of a large or peripheral flap. It is caused by gas diffusing into the anterior chamber, possibly through the canal of Schlemm and the trabecular meshwork. The bubbles are harmless, but may interfere with excimer laser tracking systems and cause a delay in treatment. They will dissipate over several hours.

Prior to lifting the flap, reference marks are placed over the flap edge in order to aid in flap realignment following the excimer ablation. Lifting the flap requires care and patience. The patient is positioned under the excimer laser, the eyelids are draped, and the speculum inserted. A Sinskey hook or Lehmann IntraLase Spatula with a semi-sharp edge (ASICO AE 2827) (Fig. 5.8) is used to start the lift, for about a millimeter under the flap and for about 1 clock hour. There may be some variance in the side cut, especially if it was near an area of non-ablated tissue. This may result in the side cut not being complete. In this case, an alternate area should be chosen to start the lift. The surgeon must watch to ensure that he or she is in fact in the lamellar plane and not simply lifting up an edge of epithelium. If the surgeon finds inconsistent or incomplete side cuts on several consecutive cases, the side-cut energy should be increased by 0.1 or 0.2 mJ. Increased side-cut energy may be associated with increased postoperative inflammation.

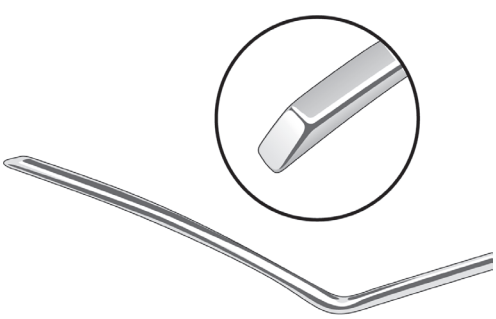

FIGURE 5.8
Lehman IntraLase spatula with a semi-sharp edge.

An alternative way to begin the flap lift is to score the side-cut incision for a few millimeters on either side of the hinge. The spatula is inserted from the scored incision on one side across the flap, sweeping peripherally to ensure the interface is connected with the pocket superiorly, and the flap is dissected all the way to the hinge (Fig. 5.9A). The spatula then exits through the scored area on the other side.

The blunt spatula is then used to separate the flap from the underlying stroma (Figs. 5.9B and C). The 30-, 60-, and 150-kHz lasers are fast enough to allow a larger number of smaller spots, which greatly facilitates flap dissection. With a superior hinge, the spatula should be swept from the superior hinge in the inferior direction with no more than a third to half of the flap being dissected at a time. Following the contour of the cornea, that is, uphill superiorly and downhill inferiorly, is a pearl that helps to facilitate the dissection. Being overly aggressive, for example, trying to lift the flap in one broad sweep, may result in a flap tear, a free cap, or striae. If an area is difficult to lift, multiple small sweeps can dissect the peripheral aspect of the area until ultimately the entire portion of the flap has been separated. If a second laser pass was performed after an incomplete ablation, it may be better to start the dissection inferiorly. This will help establish the interface at the correct depth.

If vertical gas breakthrough has been noted during the creation of the flap, special care should be taken during flap dissection. Vertical gas breakthrough occurs when gas moves anteriorly through the epithelium. It typically presents as a focal collection of gas bubbles between

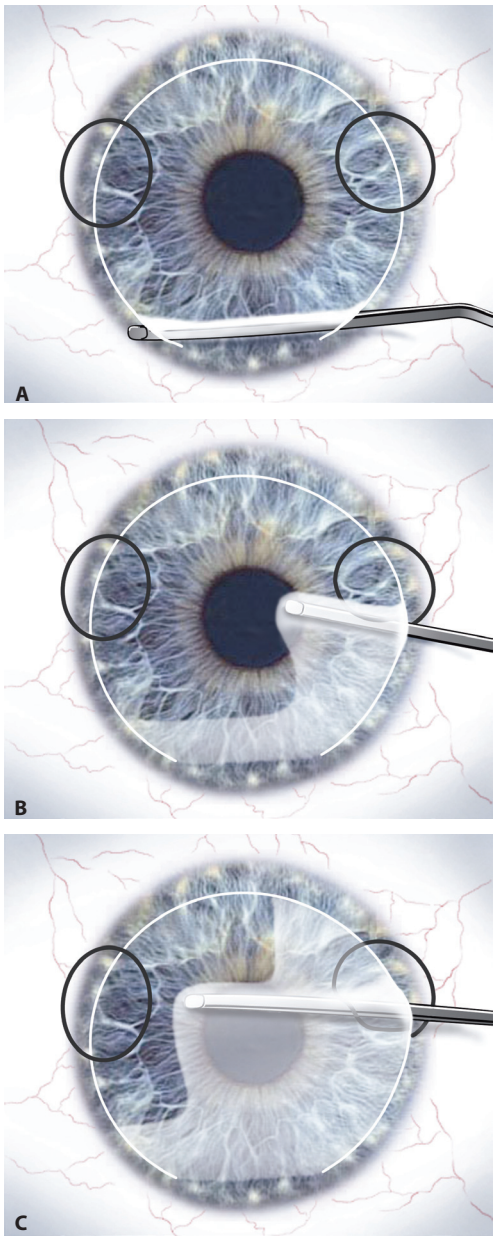

FIGURE 5.9

Flap-lift technique following femtosecond laser application. **A:** After scoring the flap edge near the hinge on either side, a spatula is passed across the flap. **B:** The interface is separated by starting at the superior hinge and sweeping inferiorly. **C:** Dissecting one-third of the flap at a time reduces the risk of tearing the hinge.

the laser cone and the epithelium. Gas can also break into the subepithelial space without breaking the epithelium. Risk factors for this include thin flaps (<90 µm) and corneal scars. Corneal scars may contain areas of thin stroma, breaks in Bowman layer, or significant fibrosis that does not allow penetration of cavitation bubbles in the plane of the flap. During creation of the raster pattern, if one observes what appears to be a micro suction break with small bubbles between the corneal epithelium and the laser cone, care must be taken during flap dissection to prevent a flap tear or a larger buttonhole. A flap tear or buttonhole can be a nidus for epithelial ingrowth; and if large or central, LASIK should be abandoned in favor of subsequent PRK.

After the flap is completely retracted, the remainder of the treatment proceeds in the usual fashion. After excimer ablation, the flap is put back into position and the corneas are checked for flap alignment, striae, and interface debris. If any of these are detected, the problem should be immediately corrected. Inspecting the pre-lift markings and identifying a uniform peripheral flap margin is necessary to assess correct flap alignment.

Postoperative complications such as striae, DLK, epithelial ingrowth, and flap displacement are discussed in detail in Chapter 11. LASIK Complications and Management. The following postoperative conditions are unique to the femtosecond laser.

TLSS can occur in up to 1% of patients. It presents days to weeks after LASIK surgery in patients with a normal examination who complain of photophobia. This usually resolves with aggressive topical steroid treatment. A reduction in the frequency of TLSS can be achieved with lower energy settings. Rainbow glare is associated with the subjective complaint of seeing colored bands around white lights. This is thought to be due to the grating pattern on the back surface of the flap causing diffraction of light. In the majority of patients it is usually not visually significant. The incidence of rainbow glare has decreased with better laser focusing and with the optics in the newer generation femtosecond lasers.

Femtosecond Laser Alternatives

Femtosecond laser technique was demonstrated in the previous section by highlighting the IntraLase, which is the most commonly used femtosecond laser in the United States.

5

To provide balance, a brief discussion of the Ziemer Femto LDV Crystalline is provided. Ziemer Ophthalmic Systems AG markets the second most commonly used femtosecond laser for LASIK flap creation in the United States. This is a compact and mobile femtosecond laser. The laser operates at a pulse frequency in the megahertz range, in contrast to the kilohertz range for most femtosecond lasers. It utilizes high-aperture optics, and does not require an amplifier. It is all solid state, and has very high pulse rates. This allows small, tightly overlapped dissection spots facilitating the flap lift.

The delivery system is handheld. It comes on an articulated arm, and the patient need not be repositioned after the femtosecond laser procedure. The handpiece incorporates a vacuum suction ring, which is mounted over the applanation window that is below the handpiece. There is a real-time color video imaging system that provides a view of the applanated eye of the patient.

The resection is linear, and requires applanation of the cornea. The Ziemer system treats along the lamellar plane. This creates an edge with approximately 45-degree angulation. In contrast to IntraLase, the suction is controlled using a computer-monitored vacuum system. In the event that the vacuum falls below certain levels, the cutting procedure will be stopped. Either screens on the computer or a foot pedal can be used to activate both the suction and the laser.

Vryghem et al.[1] published the results of 111 eyes treated with the Ziemer FEMTO LDV femtosecond laser, and reported that the mean flap thickness was 106.6 ± 12.6 μm. They saw epithelial sloughing in 10.8%, flap decentrations in 4.5%, adhesions of the flap in 5.4%, slightly irregular flap borders in 5.4%, and mild microstriae in 5.4% of eyes. The visual outcomes were good with 94.6% of eyes having uncorrected acuity of 20/20 or better at 6 months.

The use of the femtosecond laser to create a flap has dramatically increased since it was introduced in 2001. The available lasers have dramatically increased in number as well. For comparison, Table 5.2 lists various laser parameters of various available femtosecond lasers used for LASIK surgery.

Use of the femtosecond laser has resulted in a decrease in complications such as incomplete flaps, buttonhole or free caps, anterior chamber penetration, flap displacement, and epithelial ingrowth. An increase in DLK and other entities such as TLSS and rainbow glare have been described, but are less common with reduced energy settings. The femtosecond laser has allowed previously rejected patients with smaller corneas, steep or flap contours, thinner corneas, deep-set eyes, or vascular pannus to be considered for LASIK surgery. This laser technology has brought a new level of precision to the LASIK procedure. As its use in LASIK surgery, intrastromal ring segment insertion, keratoplasty, and cataract surgery increases, we can look forward to continued improvement in the technology.

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SECTION IV

Excimer Lasers

chapter 6

The Technolas 217z Platform

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The Technolas 217z system is capable of conventional laser treatment with PlanoScan software as well as wavefront-guided treatment using the Zyoptix system. The laser treatment is delivered with flying spot technology utilizing a 1 or 2 mm beam at 100 Hz. The FDA-approved treatment ranges are listed in Table 6.1. The Technolas 217z laser has Advanced Control Eyetracking (ACE) and iris registration software. The iris registration software ensures that the correct patient and eye are treated. It checks for rotational misalignment between the diagnostic examination (sitting) and laser treatment (supine) and compensates for pupil center shifts between the dilated and undilated examinations. The ACE technology tracks in four dimensions (*x*, *y*, and *z* axis as well as cyclorotation). The active eye tracker consists of an infrared imaging camera system capturing the geometric center of the undilated pupil at a sampling rate of 240 Hz plus a scanning system to respond and compensate for any detected pupil movement within 2.4 ms. The *x*-*y* active tracking range is defined as a deviation of 1.5 mm from original fixation. Within this active range, the laser adjusts the excimer pulses to the intended location according to the pupil position. If, however, the eye moves outside this range, the laser will interrupt the treatment. To account for very fast eye movements (e.g., sudden loss of fixation), a dynamic tracking module recognizes the speed of eye movements by calculating positional changes of the center of the pupil between pictures captured by the eye tracker's video camera system. If the eye speed exceeds a clinically significant value, the eye tracker software simply interrupts the pulsing until the eye stabilizes again. The surgeon defines the treatment center prior to each ablation according to pupil reference, maintaining full visual control throughout the entire treatment. Using the keypad, the surgeon can manually adjust the treatment center at any time; although this is usually unnecessary once the treatment has begun. The dynamic rotational eye tracking system actively tracks and adjusts for cyclorotation during the laser ablation at a sampling rate of 25 Hz within a 15-degree range. The tracker for the *z*-axis is passive, interrupting the laser treatment if movement during treatment exceeds 0.5 mm from the initial setting.

TABLE 6.1 Nomogram for Technolas PlanoScan

Age (y)	OZ (mm)	Blend Zone in Original PlanoScan (Spherical Correction)	Microns Removed per Diopter Original Algorithm (µm)	Blend Zone in Advanced PlanoScan Algorithm (Spherical Correction)	Microns Removed per Diopter with Advanced PlanoScan Algorithm (µm)	Blend Zone in Advanced Zyoptix Nomogram (Spherical Correction)	Percentage of MR with Flap Creation with IntraLase	Percentage of MR with Flap Creation with Moria Microkeratome or PRK
18–30	7.0	9.9 × 9.9	24	8.9 × 8.9	20	9.2 × 9.2	OD 103% OS 101%	OD 102% OS 100%
31–39	6.5	9.6 × 9.6	21	8.5 × 8.5	17	8.7 × 8.6	OD 102% OS 100%	OD 100% OS 98%
40–49	6.2	9.1 × 9.1	19	8.2 × 8.2	16	8.3 × 8.3	OD 101% OS 99%	OD 99% OS 97%
>50	6.0	8.9 × 8.9	18	7.9 × 7.9	14	8.1 × 8.1	OD 100% OS 98%	OD 98% OS 96%

The above represents Dr. Weisenthal's personal nomogram for use with the Technolas excimer laser.

PlanoScan for Conventional LASIK

The PlanoScan platform is approved for treatment of myopia ≤ −12.0 diopter (D) with ≤3.0 D of cylinder, and hyperopia ≤ +4.0 D and ≤2.0 D of cylinder. It is not FDA-approved for treatment of mixed astigmatism, but it can be treated off-label using a two-card approach. The PlanoScan treatment still offers significant flexibility in programming due to the customizable optical zone (OZ) ranging from 4.0 to 7.0 mm in 0.1 mm increments, although an OZ <5.0 mm is not recommended. The PlanoScan ablation profile also includes a blend zone that extends the diameter of treatment from an additional 2.0 to 3.0 mm. As such, a 6.0-mm optical zone provides a total ablation of 8.9 mm for spherical corrections, and even larger ablations for cylindrical corrections. For cylindrical corrections, the Technolas 217z maintains the minor axis of the ellipse and extends the major axis. This is in contrast to other systems, which decrease the minor axis, in order to create an elliptical ablation. For this reason, the incidence of subjective night vision symptoms with conventional treatment compares favorably with custom treatments using other excimer laser systems.

It is felt that employing a large optical zone optimizes the visual outcome as well as promoting long-term refractive stability. However, a large optical zone also increases the depth of tissue ablation, so caution must be exercised when performing LASIK in patients with large corrections or relatively thin corneas. The rule of thumb ablation depth for the PlanoScan treatment has been approximately 15 µm/D at a 6.0-mm optical zone, but ranges from 10 µm/D at a 4.5-mm optical zone to 25 µm/D at a 7.0-mm optical zone. However, there is now an advanced PlanoScan algorithm designed to conserve tissue while maintaining the sphero-cylindrical profile of the ablation. This is accomplished using a combination of 1- and 2-mm beam sizes during the laser treatment rather than a 2-mm flat top beam exclusively as in the original PlanoScan ablation. The variation in spot size reduces the blend zone and slightly reduces the central ablation depth. The difference in tissue ablation between the two algorithms can be found in Table 6.1.

To optimize results using the PlanoScan, it is important for the surgeon to create a personalized nomogram. For the new surgeon it is suggested that one should treat the full manifest refraction in patients under 40 years and the cycloplegic refraction in patients over 40. The optical zone should be programmed to exceed the diameter of the mesopic pupil. The scientific basis for using the pupil diameter to determine the optical zone has not been well established. After 2- to 3-month follow-up of the first 20 cases, the manufacturer will help analyze the outcomes in order to develop a surgeon-specific nomogram for future treatment plans. One should continually monitor outcomes and modify treatment plans especially after a major maintenance service call or a change in the optics.

An example of one nomogram for PlanoScan treatment is found in Table 6.1. In this nomogram, the treatment plan is based exclusively on the manifest refraction as this is felt to be the "gold standard" for measurement of the refractive error in planning the laser treatment. Prior to the evaluation, the patient must discontinue contact lens wear until there is a stable refraction and examination, which for soft contact lens wear is usually at least 1 week and for rigid lens wear for at least 3 to 4 weeks or longer depending on the duration of wear. During the initial workup, the patient has both a manifest and cycloplegic refraction and then returns on another day for a post-cycloplegic manifest refraction. It is helpful if the same individual does the refraction in the same room to standardize technique. Particular care is taken in patients over 40 years old if the cycloplegic and manifest refractions are significantly different, that is, >0.5 D.

As can be seen from Table 6.1, the refractive error treated is modified depending upon the age of the patient and the method of flap creation. The selection of optical zone diameter is chosen at minimum to exceed the mesopic pupil size by at least 0.3 to 0.5 mm as measured during the preoperative evaluation. In the younger age group (20 to 30 years), a 7.0-mm OZ is utilized if there is sufficient

tissue. In instances where the cornea is thin or the refractive error is high, the option of reducing the optical zone size in order to leave a residual stromal bed >300 µm versus surface ablation with a larger optical zone is discussed with the patient. It is better to have a large optical zone with surface ablation than have LASIK with a reduced OZ diameter in younger patients. For patients in their 30s, a 6.5-mm OZ is utilized unless there is a large mesopic pupil (>6.6 mm). The minimum optical zone used regardless of age (40s and 50s) is 6.0 mm. The reduction in the optical zone size with increasing age is designed to minimize the possibility of overcorrection as a larger optical zone creates a deeper ablation profile and risks the production of a hyperopic postoperative result. The laser treatment is also reduced by percentage of the manifest refraction in the older patient and in the second eye to compensate for dehydration, which can occur during the treatment of the first eye (see Table 6.1). This nomogram assumes there will be a uniform surgical technique with consistent operating room conditions.

Custom LASIK

The Technolas 217z Zyoptix System for personalized laser vision correction consists of three components: (1) the Zywave Diagnostic Workstation, incorporating the Orbscan IIz and Zywave II, (2) the Zylink software, and (3) the Technolas 217z excimer laser. Wavefront-guided, "custom" treatments may be performed for myopic corrections up to >7.00 D and astigmatic corrections up to –3.00 D with a spherical equivalent ≤ –7.50 D at the spectacle plane. The Zyoptix system is not currently approved for treatment of mixed astigmatism, hyperopia, or hyperopic astigmatism. For corrections outside the approved range, conventional treatment with PlanoScan software can be considered. The wavefront-guided treatment has been enhanced with the release of the Zyoptix Advanced Personalized Technologies (APT) system, comprised of Zywave II software, the Zyoptix advanced nomogram, and a Zyoptix customer support network –TruLink.

The Zywave II aberrometer is indicated for measuring, recording, analyzing, and displaying visual aberrations; for example, myopia, hyperopia, astigmatism, coma, and spherical aberration. It assists in prescribing refractive corrections; for example, by exporting wavefront data and other types of patient-specific data to a compatible refractive laser indicated for wavefront-guided treatments. The Zywave II aberrometer measures the complete optical system with the use of an advanced wavefront sensor based on the Hartmann-Shack principle. The surgeon receives highly detailed wavefront information about the way in which light reflected from the patient's eye is unevenly scattered, thereby affecting the quality of vision.

THE HARTMANN-SHACK PRINCIPLE

The Zywave II projects low-intensity HeNe infrared light into the eye (Fig. 6.1A) and captures the diffuse reflection from the retina. The reflected light is focused by a Lenslet array and displayed by a CCD camera (Fig. 6.1B). The captured image is known as the *centroid picture*. An aberrant eye will show the white dots with different intensities and patterns, indicating deviation of the wavefront (Fig. 6.1C). The deviations are calculated based on the image captured by the CCD camera, and the actual wavefront pattern is shown graphically in color-coded maps (Figs. 6.2A and B).

WAVEFRONT-GUIDED TREATMENT

For patients undergoing wavefront-guided treatment, it is suggested that prior to Zywave analysis soft lenses be discontinued for at least 2 weeks and rigid lenses for at least 3 to 4 weeks or until the refraction and topography are normal and stable. In planning custom or wavefront-guided Zyoptix treatments, the size of the pupil at the time of wavefront measurement will determine what the surgeon can program for the optical zone size. Technolas recommends that the optical zone be 0.2 to 0.5 mm larger than the mesopic pupil size, or a minimum of 6.0 mm, whichever is larger. As stated previously, the scientific basis for this is unclear. In some instances, it may be difficult

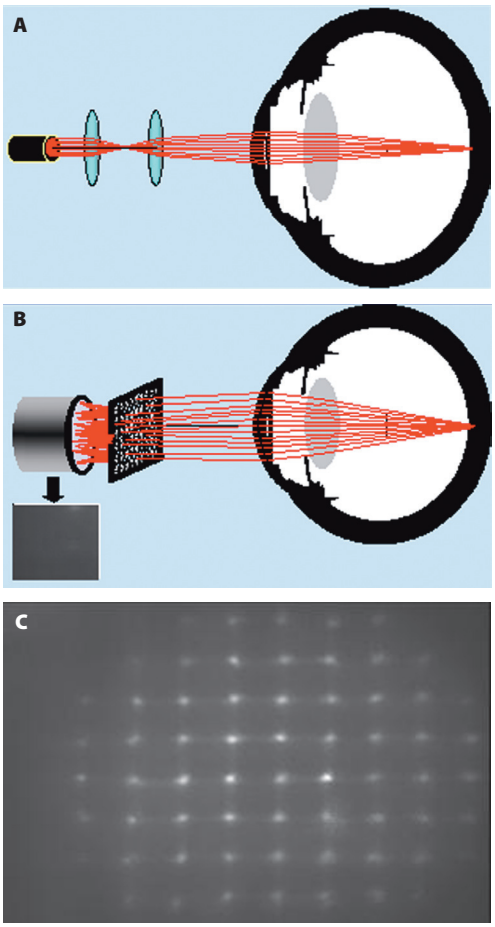

FIGURE 6.1

Hartmann-Shack principle. **A:** Low-intensity HeNe infrared light is projected into the eye and captures the diffuse reflection from the retina. **B:** The reflected light is focused by a Lenslet array and displayed by a CCD camera. **C:** An aberrant eye will show the white dots with different intensities and patterns indicating wavefront aberration. (Courtesy Bausch & Lomb.)

to obtain an adequate optical zone treatment due to a miotic pupil, so techniques such as darkening the room or covering the patient's head and instrument with an opaque cloth are employed. If this is insufficient, it may be necessary to pharmacologically dilate the pupil; however, this can shift the pupillary center and adversely impact the higher order aberration measurement. To increase the size of the optical zone treatment without resorting to dilatation, Technolas developed the Zywave II software. The software extrapolates the peripheral wavefront data outside the undilated pupil by 10% and allows for the treatment of an optical zone size 10% greater than that measured during the examination. If the pupil is only 6.0 mm, the wavefront data are extrapolated to 6.6 mm allowing the selection of a 6.6-mm OZ. In two large series with the Zywave II software, 80% to 95% of patients were treated without the need for pharmacologic dilation. If pupillary dilation is still required to provide an adequate optical zone treatment, the recommended regimen would be to instill phenylephrine 2.5% and capture the wavefront data within 10 to 15 minutes. This will provide adequate dilation in the absence of cycloplegia during the wavefront examination. If the patient is being treated on the same day as the Zywave examination, a minimum waiting time of 4 hours is recommended prior to treatment, provided the pupil <7 mm in diameter. Corneal thickness or maximum allowable optic zone size in the Zyoptix software may constrain this recommendation. Use of pharmacologic dilation for treating patients with inadequate pupil size is not recommended for VISX CustomVue treatment. Tissue ablation by the Zyoptix program is similar to the advanced PlanoScan program (see Table 6.1). If the surgeon wishes to use a fixed optical zone for all Zyoptix patients, a 6.5-mm optical zone may be used. Based on the clinical results reported in the Zyoptix FDA study, however, the pupil size must be at least 5.9 mm during the diagnostic examination to make this optical zone selection.

Once the Zywave wavefront measurements and Orbscan data have been collected, the Zylink software generates a predicted phoropter refraction (PPR). The PPR is estimated from the wavefront pattern, and is not used for treatment. The treatment is based directly on the wavefront. If the difference between the subjective refraction and the PPR ≥0.75 D (sphere), 0.5 D (cylinder), or 15 degrees (axis), the Zywave will give a warning (exclamation point adjacent to the refraction in the Zywave printout). This is for informational purposes only; the software will still allow the user to perform the ablation.

A retrospective analysis[1] of patient outcomes with the original Zyoptix nomogram revealed a trend toward hyperopic overcorrection

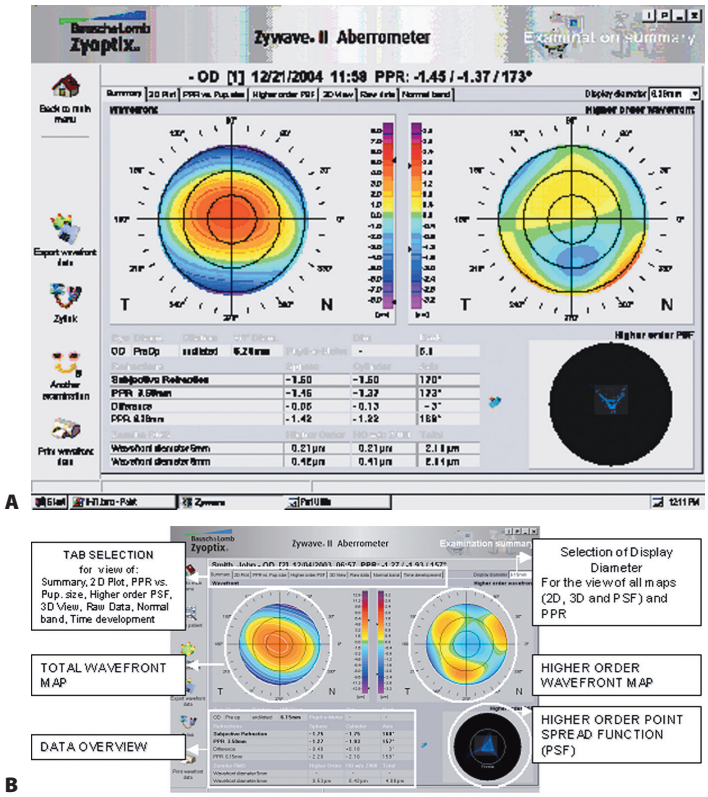

FIGURE 6.2

A, B: Zywave II aberrometer color-coded maps. (Courtesy Bausch & Lomb).

associated with the treatment of the measured higher order aberrations. The Technolas system measures and treats up to fifth-order aberrations, which produced a coupling phenomenon due to "aberration interactions." The amount of preoperative positive spherical aberrations, third-order trefoil and coma led to an overcorrection in the spherical component. The treatment of the preoperative third-order coma led to an overcorrection of the treatment of the cylindrical correction. As a result, the advanced nomogram for Zyoptix was developed to compensate for the "aberration interactions." This incorporated the preoperative manifest refraction, both sphere and cylinder, to improve postoperative predictability. In a large series[2] of patients, the advanced Zyoptix nomogram produced a postoperative spherical equivalent of –0.11 ± 0.34 D with 91.5% of patients within 0.5 D of target while reducing retreatments from 8% to 3%. The advanced Zyoptix nomogram is available with the APT. Regardless of the type of laser programming used, each surgeon should carefully examine personal results, and individualize the nomogram. As with PlanoScan, Technolas will assist in the analysis of the first 20 patients treated with the advanced nomogram after 1 to 3 months of follow-up. In the Zylink software, the surgeon can select an adjustment factor, based on this individual nomogram, to modify the spherical correction of the laser treatment plan. The cylindrical component cannot be adjusted.

An important component to any wavefront-guided ablation is the ability to place the laser pulses precisely in the location desired. This is accomplished by iris recognition software and the active tracking system. A photograph is taken initially while the patient is sitting at the Zywave II aberrometer. The Zyoptix remote support II –TruLink, which comes with the

APT, provides wireless connectivity across the Zyoptix network so that one can transfer the data from the Zyoptix diagnostic workstation to the laser. In addition to this, internet network allows for backup of data and treatment planning remotely, prior to going to the laser center. Data from the laser are also sent to a server at Technolas in St Louis, MO, over the internet in order to monitor the performance of the laser and facilitate proactive service maintenance to minimize any laser downtime.

Once the patient is supine under the laser, a second photograph is taken just prior to treatment to confirm the operative eye and to provide static registration for alignment of the astigmatism. The laser treatment is divided into two to six segments. The laser treatment can take between 20 and 60 seconds depending upon the amount of laser correction and the size of the optical zone. The Zyoptix treatment consists of one-half of the laser spots at 2-mm diameter and the other half at 1-mm diameter in an optimized truncated Gaussian beam profile. There is a new Zyoptix algorithm called the 2.38 available internationally, which reduces the amount of laser pulses by 40% with a 40% reduction of total laser treatment time (around 20 seconds for larger corrections) based upon using 70% of the treatment at a 2-mm spot size and 30% at a 1-mm spot size. In addition, the treatment is divided into only two segments, interrupted only by the movement of the robotic arm within the laser to change the beam profile from 2 to 1 mm. The 2.38 algorithm also optimizes the transition zone or blend zone through a standardized tangential linear extrapolation from the periphery of the OZ.

There is also a new laser platform available outside the United States called the Technolas 217 P. It has redesigned ergonomics in order to share the laser bed between the Technolas Excimer laser and Technolas Femtosecond Workstation 520F. The bed has a greater range of movement in the *z*-axis to accommodate the positioning of the bed under the fixed femtosecond laser. Additional options in the Technolas 217P configuration include a slit lamp, heated mattress, and an integrated optical coherence pachymetry (OCP) unit produced by Heidelberg Engineering (Carlsbad, CA). The OCP is installed within the top arm of the laser and runs down through the visual optics. There is a separate CPU and monitor, which provides the option of preoperative measurement of corneal pachymetry, and, if left in real time, measurement of the pachymetry change during and after the laser ablation.

Although some of the modifications of the laser platform such as the slit lamp may not require FDA review, other options such as the 2.38 algorithm may require a full technical premarket approval (PMA) application to be filed with the FDA. Technolas will likely pursue approval for this platform because it allows for the shared use of the bed for the excimer and femtosecond laser; however, the time frame for the approval process is unknown. One other feature currently being studied outside the United States is Presby-Lasik with Supracor, which modifies the laser ablation to provide both near and distance vision correction.

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chapter 7

VISX Star S4 Platform

COLMAN KRAFF

The AMO VISX Star S4 (Software Version. 5.22) laser platform with ActiveTrak can be used to perform conventional LASIK as well as custom surgery. (See Videos 1 & 2) CustomVue LASIK with this laser requires the use of the WaveScan, a separate device used to acquire and analyze wavefront images, and allows the surgeon to design an appropriate custom treatment profile. These data are then transferred to the laser. Conventional and custom treatment will each be discussed. The main focus of the discussion will be the software and hardware that is available within the United States. The AMO VISX system that is available outside the United States has software and hardware that allow the surgeon greater flexibility and treatment ranges currently restricted in the United States by FDA guidelines.

Conventional LASIK

The purpose of this section is to discuss conventional LASIK with the VISX Star S4 laser. Generic comments pertaining to the use of the excimer laser to perform LASIK surgery are found in Chapter 1.

The VISX laser is one of the most widely used excimer lasers in the United States. A number of hardware and software technologies that have become available since its FDA approval in 1998 have made the system safer and easier to operate. These include ActiveTrak 3-D eye tracking, variable spot scanning, autocentering, CustomVue, and iris registration. The ActiveTrak 3-D eye tracking system available on the Star S4 laser platform tracks eye movements with an undilated pupil within a zone of 2.0 mm in the z-axis and 1.5 mm in the x-y-axis. Eye movement outside this tracking zone will be sensed within 30 ms and the surgeon will be unable to fire the laser. When proper fixation is reestablished, the tracking system will resume tracking with the same reference point, and laser treatment can continue from the point of interruption.

Variable spot scanning (VSS), available on the VISX Star S4 system, represents a change from the older broad-beam laser delivery system to variable laser spot size delivery with the spot diameter varying from 2 to 6 mm. The advantage of this innovation is a smoother treatment, possibly reducing the incidence of haze after surface ablation. It also allows the laser to smoothly integrate a blend zone extending the ablation zone out to 8.0 mm. This can be used to reduce the risk of postoperative glare and haloes. The use of the blend zone feature requires at least 1 diopter (D) of treatment at the corneal plane, a well-centered flap large enough to accommodate the treatment, and a cornea that is thick enough to accommodate the added ablation depth. The added ablation depth is 8 µm for treatments up to 10 D and 11 µm for treatments beyond 10 D. There are additional advantages of VSS. The ablation with VSS is not as deep as a typical flying spot laser, and the treatment time is not as lengthy as the flying spot laser with a single-sized small spot. Finally, the VSS keeps the corneal temperature constant. This is important because the laser will ablate more tissue as the tissue temperature increases. The VSS treatment is currently only available for CustomVue treatments in the United States. Outside the United States, the VSS platform is available for use with conventional treatments.

The VISX Star S4 laser pulse repetition rate can be adjusted from 1.5 to 10 Hz for conventional treatment and from 6 to 20 Hz for custom treatment. The repetition rate for the custom treatment is variable and is set by the laser. Currently, the S4 platform is required for custom treatment.

The autocentering feature on the Star S4 laser automatically finds the geometric center of the undilated pupil, so it is unnecessary for the surgeon to find the pupil center prior to engaging the tracking device. The pupil center can vary under different lighting conditions. It is therefore important to keep the lighting as low as possible at the time of autocentering and engaging the active tracking system so that the center of the pupil during treatment will be the same as the pupil center during refraction or WaveScan.

Iris registration is available on the Star S4 platform. This supplants the need for mechanically marking the patient prior to a custom laser treatment, but is not available for conventional LASIK. This will be discussed in greater detail in the next section on LASIK with the VISX CustomVue.

One of the major advantages of the VISX Star S4 laser is the wide range of refractive errors approved by the FDA. Table 1.1 shows a comparison of the FDA-approved treatments for various lasers. Unlike many available laser systems, the VISX system has been approved for conventional treatment of myopia and hyperopia with and without astigmatism as well as mixed astigmatism. Approved patient treatment for myopia extends to −14.00 D with up to +5.00 D of astigmatism. Hyperopic treatment is up to +5.00 D with up to +3.00 D of astigmatism provided the spherical equivalent (SE) is < +6.00 D. The mixed astigmatism treatment is approved for up to +6.00 D of astigmatism, as long as the myopic sphere is less than the cylinder with the treatment in plus cylinder form. The laser is also approved for custom treatment for all three of these situations. The range of available treatment is somewhat narrower for custom than for conventional treatment. Conventional treatment at the upper limits of the approved range is less reliable than at lower levels of refractive error. Most surgeons will explore alternatives to LASIK at the extremes of refractive error (see Chapter 15 for a discussion on alternatives to LASIK).

TREATMENT ZONES

The treatment zones available for conventional LASIK using the VISX Star S4 laser for the correction of myopia are 6.0 and 6.5 mm. As stated earlier, the blend zone will extend the treatment zone to a diameter of 8.0 mm. Hyperopic treatment requires a treatment zone of 9.0 mm with the deepest part of the ablation occurring at 5.0 mm, that is, 2.5 mm from the center of the ablation. Mixed astigmatism treatment also requires an ablation zone of 9.0 mm. When planning these treatments, the flap must be of adequate size and centration to accommodate the entire treatment zone.

NOMOGRAM ADJUSTMENT

Several nomograms are available for treatment of myopia and myopia with astigmatism. Some surgeons use rules of thumb rather than a nomogram specifying the adjustment for specific corrections and/or decade of age. Because a starting place is necessary, nomograms for myopia and hyperopia are provided. When beginning to plan treatments, the reader is encouraged to seek out the advice of experienced colleagues who use the VISX laser in the specific laser suite that will be used. Advice from faculty at a VISX certification course or from the medical directors at the company is also of value.

MYOPIA

Because ablation within the corneal stroma using the VISX laser to correct myopia results in a greater refractive effect than surface ablation, an adjustment to the intended treatment is needed to prevent an overcorrection. The nomogram-adjusted treatment is what will be entered into the laser. The Bansal-Kay nomogram was designed only for treatment of myopia with the VISX STAR S2 laser system, but continues to be effective for conventional myopia treatment with the S4 laser system. In

TABLE 7.1 Bansal-Kay LASIK Myopia Nomogram for VISX STAR Laser

Diopters	Age 18–20	21–25	26–30	31–35	36–40	41–45	46–55	≥56
0–1	4	4	4	5	6	7	7	8
1–2	4	4	4	5	6	7	7	8
2–3	4	4	5	5	7	8	8	8
3–4	5	5	5	6	7	8	8	8
4–5	5	5	6	6	8	8	8	9
5–6	5	5	6	6	8	9	9	10
6–7	6	6	7	7	9	10	10	11
7–8	7	7	7	8	9	10	11	12
8–9	8	8	8	8	10	11	12	12
9–10	9	9	9	9	11	11	13	13
10–11	10	10	10	10	12	13	14	14
11–12	11	11	12	12	13	13	15	15

Notes: Multiply percentage by spherical equivalent and subtract from the sphere in the cycloplegic refraction.
Nomogram target = plano, adjust to undercorrect.
Individual results will vary with each laser, surgeon, humidity, and altitude.
Some data have been extrapolated.
Recommend starting laser ablation within 15 seconds of lifting flap.
Source: From Dr. Jay Bansal, unpublished data, with permission.

this nomogram, the percentage reduction increases with age and with the amount of correction in the SE. The percentage reduction is applied only to the spherical component of the desired correction. The astigmatism component is left unadjusted. This nomogram is a useful starting point; however, surgeons should always carefully evaluate postoperative data from many cases and adjust their preferred nomogram accordingly.

Use of the Bansal-Kay nomogram (Table 7.1) requires five steps:

Step 1: Calculate the SE from the cycloplegic refraction (CR). For corrections with >7 D of myopia, the vertex distance of the CR should be noted. The VISX Star S4 laser uses 12.5 mm as the default vertex distance and converts this to the refraction at the corneal plane. The correct vertex distance should be entered in patients with high myopia.
Step 2: Find the appropriate reduction percentage on the nomogram by locating the correct diopter range in the left-hand column and the correct patient age range in the top row.
Step 3: Multiply the SE by the selected percentage reduction to obtain the appropriate diopter reduction.
Step 4: Reduce the sphere in the desired refractive correction by the calculated diopter reduction. (Note: Some surgeons use the CR routinely. Some use the cylinder axis from the manifest refraction. Others routinely use the manifest refraction (MR) in younger patients provided it is close to the CR.)
Step 5: This final refraction is given to the laser engineer to enter into the laser computer.
Example. Patient A is 26 years old and has a CR of $-3.50 + 1.00 \times 90$ and, therefore, a SE of −3.00 D. Based on the nomogram (Table 7.1), a 5% correction is necessary to achieve the desired refractive result.

$5\% \times -3.00$ (SE) = 0.15 (the sphere in the CR is reduced by this amount)

$-3.50 + 1.00 \times 90 + 0.15$

$-3.35 + 1.00 \times 90$ (Enter this into the VISX system.)

An alternative rule of thumb used at Wills Eye Hospital involves three steps.

Step 1: Convert the intended correction to minus cylinder form;

Step 2: Reduce the sphere by 10% for patients under age 50 years and 15% for those older than age 50; and

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Step 3: Reduce the cylinder 5–10% for refractive astigmatism <1.5 D and 10–15% for >1.5 D.

HYPEROPIA

For LASIK surgery or photorefractive keratectomy (PRK) with a conventional ablation to correct hyperopia with or without astigmatism using the VISX Star S4 laser, the MR should not differ from the CR by more than 0.75 D. With the VISX laser, regression of the ablation effect is expected to occur over a 3- to 6-month period. Therefore, enhancement should not be considered until the surgeon is certain the correction has stabilized. Because of this anticipated regression, a compensatory nomogram-adjusted boost to the spherical portion of the treatment is required for LASIK surgery. It is usually not required for surface ablation, that is, for PRK the desired correction can be directly entered into the VISX laser. The nomogram adjustment will induce myopia in the short run and patients should be warned about this possibility preoperatively. Hyperopic patients of presbyopic age or older will usually appreciate the improved unaided near vision that occurs in the short run.

Similar to the myopia nomogram, the percentage adjustment increases with increased SE and age. In contrast, however, the nomogram adjustment is added to the sphere portion of the treatment. The astigmatism correction is left unadjusted.

Example. Patient B is 56 years old and has a CR of +2.50 + 1.00 × 90 and, therefore, a SE of +3.00 D. Based on the hyperopic nomogram (Table 7.2), a 30% addition is necessary to achieve the desired corrected value needed for LASIK surgery.

30% × +3.00 D (SE) = 0.90 (the sphere in the CR is increased by this amount)

+2.50 + 1.00 × 90 + 0.90

+3.40 + 1.00 × 90 (Enter this into the VISX system.)

This hyperopic nomogram was originally designed for the VISX Star S2 laser. It still has utility for use with the Star S4 laser; however, individual surgeons need to modify the nomogram based on an analysis of postoperative results from many cases. The laser suite conditions (e.g., temperature and humidity) and the particular VISX laser can affect the surgical outcome.

MIXED ASTIGMATISM

The mixed astigmatism treatment on the VISX Star S4 laser is not a nomogram-adjusted treatment. In other words, the desired treatment can be entered directly into the laser computer. Surgeons differ with regard to whether they enter the CR or modify the MR retaining the astigmatism power and axis, but reducing the sphere to be consistent with the CR. The FDA-approved mixed astigmatism profile for conventional and custom ablation is a distinct advantage of the VISX laser, because other laser systems may not have such approval, requiring off-label multi-card treatments to achieve the desired result.

ABLATION DEPTH CALCULATION

Myopia

To calculate the ablation depth, the *non–nomogram-adjusted* refraction is used. This cannot be overemphasized. Ablation depth rules of thumb for the VISX laser are 12 µm/D of SE for myopia correction with a 6.0-mm treatment zone and 15-µm/D for a 6.5-mm treatment zone. The addition of an astigmatic component to a myopic treatment will make the SE less than the sphere. Therefore, the resultant ablation depth will be less when astigmatism is being treated in addition to myopia.

Since the last edition of this book, LASIK surgeons have become evermore conscious of reducing ectasia risk by reducing stromal ablation when possible. Using the blend zone can allow the surgeon to choose a 6.0-mm optical zone rather than a 6.5-mm optical zone without a noticeable increase in nighttime glare or haloes. This saves 3 µm/D of stromal ablation. The addition of an 8.0-mm blend zone adds 8 µm to the maximum ablation depth for treatments of <10 D and 11 µm for treatments >10 D. This is not a per-diopter addition, but an addition to the overall ablation depth.

TABLE 7.2 VISX Laser Nomogram for Primary and Secondary Hyperopia

Preoperative Manifest SE				Secondary Hyperopia	
Age (y)	**0–2 D (%)**	**2–4 D (%)**	**4–6 D (%)**	**Post-RK (%)**	**Post-LASIK (%)**
20–29	0	+10	+20	−4	−14
30–39	+10	+18	+25	−2	−10
40–49	+17	+23	+28	−1	−4
50–59	+30	+30	+30	0	+4
60–69	+35	+32	+31	+2	+8

Notes: Table indicates the percentage of the preoperative manifest spherical equivalent that is added to or subtracted from the spherical component of the correction. The full cylinder is entered into the laser. For example, a +2.00 + 2.50 × 90 degrees refraction in a 33-year-old with primary hyperopia would be adjusted as follows: +3.25 D (SE) × 0.18 = 0.59, which results in a treatment of +2.59 + 2.50 × 90 degrees.
The nomogram was derived from a regression analysis for trends by Drs. Lindstrom, Hardten, and associates, using a Hansatome and the VISX S2 Smoothscan at 10 Hz. Actual results were included for age groups when there were enough patients to influence the results of the regression analysis.
Source: Adapted from Lindstrom RL, Linebarger EJ, Hardten DR, et al. Early results of hyperopic and astigmatic laser in situ kertomilleusis in eyes with secondary hyperopia. *Ophthalmology*. 2000;107:1862, with permission.

The following example will illustrate how to calculate the ablation depth for a refraction of −3.50 + 1.25 × 120 degrees using the rules of thumb. The first step would be to decide on the appropriate treatment zone. If the zone were 6.5 mm with an 8.0-mm blend zone, the ablation depth per diopter conversion factor would be 15 µm/D. Multiply the SE by the conversion factor. The blend zone treatment would add an additional 8 µm of treatment. In this case, the SE would be 3.50 − 1.25/2 = 2.88 D. Simply multiply 2.88 D × 15 µm/D = 43.2 µm. Add an additional 8 µm for the blend zone for a total of 51.2 µm or roughly 51 µm for the ablation. Remember, this is for myopia treatment on the VISX laser only; other lasers may ablate more or less per diopter of treatment.

An alternative method for determining the ablation depth with the VISX laser is to use the appropriate ablation depth tables for the 6.0-mm zones (Table 7.3) and 6.5-mm zones (Table 7.4). These tables were generated by entering the various non–nomogram-adjusted corrections for the given zone into the laser. These tables continue to have utility despite being generated on an earlier version of the laser; however, changes in laser delivery can influence the ablation depth. Similar tables can easily be created as newer generations of lasers are developed. Most important is to *avoid* using the nomogram-adjusted treatment to calculate ablation depth, which would underestimate the true ablation depth.

The tables are used in the following manner. After deciding which zone to use, look for the appropriate spherical power in the left column and the amount of cylinder on the top row. If the astigmatic power in the CR is in between two values, simply extrapolate between the values.

For example, if you were calculating the ablation depth for a refraction of −3.50 + 1.25 × 120 degrees for a 6.5-mm treatment zone with a blend zone to 8.0 mm, look at the 6.5-mm table for −3.50 D. The ablation depth for −3.50 D is 54 µm. Added astigmatism correction will lessen the ablation depth. The ablation depth for a hypothetical refraction of −3.50 + 1.00 × 120 degrees is reduced to 39 µm. At a refraction of −3.50 + 2.00 × 120 degrees, the ablation depth shown on the table is decreased to 31 µm. Because 1.25 is one-quarter of the way from 1.00 to 2.00 D, reduce the ablation by one-quarter the difference of the depth for 1.00 and 2.00 D of astigmatism. The appropriate reduction in this case would be 8 × 0.25 or 2. The ablation depth would be 39 µm − 2 µm = 37 µm. An additional 8 µm must be added because of the blend zone for a total ablation depth of 45 µm. This is similar to the 51-µm depth estimated by the conversion factor method. It is always safer to choose the greater of the

TABLE 7.3 Ablation Depth Myopia Treatment with VISX STAR S4 6.0-mm Zone

Depth of Ablation (μm)							
		Plus Cylinder (D)					
		0.00	1.00	2.00	3.00	4.00	5.00
Sphere (D)	−1.00	13	7	9	18	28	38
	−1.25	17	7	11	16	26	36
	−1.50	20	10	13	14	23	33
	−1.75	23	13	15	15	21	31
	−2.00	26	15	14	18	18	28
	−2.25	29	16	14	20	20	26
	−2.50	33	20	14	22	22	23
	−2.75	36	23	18	24	24	24
	−3.00	39	26	21	21	26	26
	−3.25	42	29	23	21	28	28
	−3.50	45	33	25	20	30	30
	−3.75	48	36	27	23	32	32
	−4.00	51	39	30	26	27	34
	−4.25	54	42	32	28	27	36
	−4.50	57	45	34	30	27	38
	−4.75	60	48	35	33	27	40
	−5.00	63	51	39	35	31	34
	−5.25	66	54	42	37	33	33
	−5.50	69	57	45	39	35	33
	−5.75	71	60	48	41	38	33
	−6.00	74	63	51	43	40	36
	−6.25	77	66	54	46	42	38
	−6.50	80	69	57	48	44	40
	−6.75	80	71	60	50	46	42
	−7.00	85	74	63	51	48	45
	−7.25	87	77	66	54	50	47
	−7.50	89	80	69	57	53	49
	−7.75	92	80	71	60	55	51
	−8.00	94	85	74	63	57	53
	−8.25	96	87	77	66	59	55
	−8.50	98	89	80	69	61	57
	−8.75	101	92	80	71	63	59
	−9.00	103	94	85	74	65	61
	−9.25	105	96	87	77	65	63
	−9.50	107	98	89	80	69	65
	−9.75	110	101	92	80	71	67
	−10.00	112	103	94	85	74	69
	−10.25	114	105	96	87	77	71
	−10.50	116	107	98	89	80	73
	−10.75	118	110	101	92	80	75
	−11.00	120	112	103	94	85	77

Notes: Platform: VISX S4, Plus Cylinder, Date: September 15, 2005.

TABLE 7.4 Ablation Depth for Myopia Treatment with VISX STAR S4 6.5-mm Zone

Depth of Ablation (µm)							
		Plus Cylinder (D)					
		0.00	1.00	2.00	3.00	4.00	5.00
Sphere (D)	−1.00	16	9	NA	NA	NA	NA
	−1.25	20	9	NA	NA	NA	NA
	−1.50	24	13	NA	NA	NA	NA
	−1.75	28	16	NA	NA	NA	NA
	−2.00	31	19	18	NA	NA	NA
	−2.25	35	22	17	NA	NA	NA
	−2.50	39	23	17	NA	NA	NA
	−2.75	43	28	23	NA	NA	NA
	−3.00	46	31	26	26	NA	NA
	−3.25	50	35	28	26	NA	NA
	−3.50	54	39	31	26	NA	NA
	−3.75	57	43	34	29	NA	NA
	−4.00	61	46	37	32	34	NA
	−4.25	65	50	39	35	34	NA
	−4.50	68	54	42	38	34	NA
	−4.75	72	57	45	40	34	NA
	−5.00	75	61	46	43	39	42
	−5.25	79	65	50	46	41	42
	−5.50	82	68	54	49	44	42
	−5.75	86	72	57	51	47	41
	−6.00	89	75	61	54	49	45
	−6.25	92	79	65	57	52	47
	−6.50	96	82	68	59	55	50
	−6.75	96	86	72	62	57	53
	−7.00	100	89	75	64	60	56
	−7.25	103	92	79	67	63	58
	−7.50	105	96	82	68	65	61
	−7.75	107	96	86	72	68	63
	−8.00	110	100	89	75	70	66
	−8.25	112	103	92	79	73	69
	−8.50	114	105	96	82	75	71
	−8.75	116	107	96	86	78	74
	−9.00	119	110	100	89	80	76
	−9.25	121	112	103	92	83	79
	−9.50	123	114	105	96	85	81
	−9.75	125	116	107	96	87	84
	−10.00	127	119	110	100	89	86
	−10.25	130	121	112	103	92	88
	−10.50	132	123	114	105	96	91
	−10.75	134	125	116	107	96	93
	−11.00	136	127	119	110	100	95

Notes: Platform: VISX S4, Date: September 15, 2005.

two estimates to determine if the RSB will be adequate.

The standard hyperopic treatment with the VISX laser is a 9.0-mm zone with a maximum ablation depth of 8 µm/D of SE occurring at a 5-mm ring around the treatment center. The maximum ablation depth is therefore in an area of the cornea that is usually thicker than the center. Hyperopic treatments are usually less of a challenge than the myopic treatments regarding ablation depth. In hyperopia, the nomogram-adjusted treatment is greater than the preadjusted refraction; therefore, the greater value should be used for ablation depth calculations.

In mixed astigmatism on the VISX laser there is no nomogram adjustment. Therefore, the expected ablation depth can be taken from the laser computer prior to surgery and used to determine if the cornea is of adequate thickness.

SUMMARY

The VISX S4 laser provides effective treatment for a wide array of FDA-approved refractive errors. The system is easy to operate for the surgeon and the laser engineer. The variable-sized spot available for custom treatments provides a smooth tissue sparing ablation. The blend zone enables patients to be treated with a smaller 6.0-mm optical zone, preserving tissue while reducing the risk of night vision issues. The autocentering and ActiveTrak 3-D eye tracking features of the VISX Star S4 increase LASIK safety and accuracy, particularly for the patient with poor fixation or for patients requiring lengthy treatments. Iris registration is available for custom treatments, but not for conventional treatments, requiring surgeons to continue to mark patients prior to astigmatism treatment.

CustomVue/WaveScan

With the advent of wavefront technology and custom laser ablation, LASIK surgeons have had to acquire new skills and rethink their approach to patient education, patient selection, and treatment planning. Prior to the development of these capabilities, refractive surgeons treated only sphero-cylindrical corrections with varying optical zones. With the availability of CustomVue with the VISX STAR S4 VSS platform, the refractive surgeon can offer the patient a potentially more precise customized treatment. Whether the patient is at greater risk for nighttime vision problems or has a complex mixed astigmatic refractive error with significant higher order aberrations, the surgeon can plan and offer an appropriate treatment. This section will discuss the use of CustomVue and WaveScan, the VISX device used to acquire wavefront data. Hopefully, after reviewing this section, the reader will have a more complete understanding of the critical issues needed to perform CustomVue treatments.

Prior to starting custom treatments, completion of the online VISX CustomVue training course is required. This course reviews the basic hardware and software, as well as the patient data needed to perform treatments.

APPROVED RANGE OF CUSTOMVUE LASIK TREATMENTS

The VISX Star S4 laser with CustomVue is FDA-approved for one of the widest ranges of custom correction of the available laser systems (Table 1.1). Wavefront-guided LASIK with the VISX Star S4 is approved for patients with myopia up to −11 D (maximum wavefront refraction [WR] sphere −11.75 D) with or without astigmatism up to 3.00 D (maximum WR cylinder 3.75 D), as long as the SE does not exceed −11.75 D (MR or WR). Mixed astigmatism, from 1.00 to 5.00 D of cylinder, can now be treated with CustomVue.

Wavefront-guided LASIK is approved for patients with hyperopia and uses a 6.0-mm optical zone and a 9.0-mm treatment zone for the reduction or elimination of hyperopia and hyperopic astigmatism up to +3.00 D sphere (maximum WR SE +3.75 D) with cylinder ≤2.00 D (maximum WR cylinder +2.75 D), up to a maximum MR SE of +3.00 (maximum WR SE +3.75 D).

Although not FDA-approved, the treatment cards for hyperopia allow treatment beyond this range. Caution is advised in this territory until sufficient experience with

CustomVue treatment of hyperopia has been acquired. In higher treatments of this sort, the surgeon must remain mindful of the final estimated keratometric value. High hyperopic corrections in patients with a preoperative keratometry reading >45.00 D can result in corneas above 50.00 D postoperatively, and this could have an adverse impact on BSCVA. Care should also be taken when treating high hyperopic corrections with SEs >4.5 D even with lower preoperative keratometry measurements. There is a greater chance of loss of BSCVA when performing these higher corrections. Patients should be given the appropriate informed consent in these situations. Off-label treatments should be explained to patients as such.

ADVANTAGES AND DISADVANTAGES

In addition to its wide potential treatment range, several other important benefits are observed when using the VISX CustomVue system. It offers improved visual function at night compared with conventional treatment. This is especially important for patients bothered by these complaints prior to surgery, for patients with higher degrees of myopia who are within the approved range of treatment, and when postoperative night vision disturbance is a particular concern. Patients should understand that custom treatment does not guarantee the absence of glare and haloes after surgery. CustomVue LASIK reduces higher order aberrations and may induce fewer new aberrations. Because of the customized nature of the treatment, it is possible that visual function even during the day may be improved beyond the previous best-corrected acuity. It is, however, difficult to predict which patients will achieve this higher function. Iris registration associated with CustomVue LASIK ensures that astigmatic treatment is performed at the proper axis.

Incorporating the refraction acquired from the WaveScan unit into the preoperative patient examination, the so-called wavefront-adjusted manifest refraction (WAMR) can at times result in better visual acuity than that achieved through retinoscopy and more conventional refraction techniques. Greater flexibility exists for modifying treatment zones if accommodation for patients with large pupils is desired or if a larger treatment zone is preferred. An illustration would be the patient with a low myopic correction and large pupil. With conventional treatment on the VISX Star S4, at least −1.00 D at the corneal plane is needed to add a blend zone. This is not the case with the custom treatment. On the WaveScan unit, the ablation zone can be increased to 9.5 mm, although the FDA has only approved increasing the zone out to 9.0 mm. Increasing the treatment zone has no effect on the depth of the ablation. Finally, in the event a retreatment for a patient with excessive higher order aberrations (HOAs) is necessary, a PreVue lens can be cut based on the WaveScan. This allows the patient to determine the potential value of the retreatment both during the day and at night prior to a proposed second surgery.

Surgeons differ in opinion with regard to which patients should be offered CustomVue LASIK. There is a trend to offer the treatment to all patients who are candidates for the procedure. Others prefer to restrict the procedure only to selected patients; for example, patients anxious about postoperative glare and haloes and patients with large pupils or large degrees of HOAs.

The disadvantages of the CustomVue treatment must include the increased cost to the patient although many surgeons do not charge extra for custom treatment. Additional skills are needed to acquire and use the data generated by the WaveScan unit to plan surgery. This will involve more technician time and surgeon time. The approved range of custom surgery is less than for conventional LASIK on the VISX STAR S4. This is especially true for custom retreatment. Not all patients are candidates for the procedure. If there is poor agreement between the wavefront refraction and the MR, the treatment cannot be done. While there is flexibility to adjust the sphere, neither the axis nor power of the cylindrical correction can be modified. The flexibility in sphere adjustment is not great enough to accommodate a monovision treatment, so true monovision cannot be performed using CustomVue. The ablation depth is greater for a custom procedure than the equivalent

conventional treatment (roughly 15 µm/D + 8 µm), prohibiting custom LASIK for some patients with thin corneas. Patients with pupils that are smaller than 5.0 mm often cannot be captured with accurate WaveScan measurements and therefore cannot be treated with CustomVue. This technology will raise patient expectations, and in the event that results do not match expectations, there is the potential for an unhappy patient. The advantages and disadvantages of CustomVue with the WaveScan analysis are listed in Table 7.5.

THE WAVESCAN

The WaveScan (Software Version. 3.68) unit is the VISX wavefront device used to capture the high-quality images that are necessary to create a custom treatment. The older WaveScan software (Version 3.5, June 7, 2004) changed the method of ablation calculation from Zernike polynomial to Fourier analysis. The Fourier analysis utilizes data over the entire pupil, up to 6.0 mm, in incremental 0.1-mm steps. This method reproduces the complex shapes generated by CustomVue software with greater fidelity than when Zernike shapes were used. In addition to changing the way the ablation profile is calculated, it also includes a 4.5% boost over the prior treatment software.

The WaveScan unit can be used as an adjunct for refracting a potential conventional LASIK patient, particularly if a patient cannot be refracted to 20/20. It can also be used to evaluate postoperative LASIK patients, who have complaints despite seemingly excellent visual acuity. The WaveScan data can also be printed to facilitate the comparison of pre- and postoperative HOAs. However, it is primarily used to plan custom LASIK.

The WaveScan is not a screening tool to rule out keratoconus nor is it a substitute for corneal topography. Corneal topography must be used as an independent evaluation to identify patients with ectatic disease, forme fruste disease, or patients at risk for postoperative ectasia. (Refer to Chapter 2 for a more detailed discussion of corneal topography.) The presence or type of HOAs does not indicate whether or not a patient is a candidate for a CustomVue treatment. Even patients with high root mean square (rms) values and a high percentage of HOAs can have CustomVue surgery, provided other previously discussed criteria for LASIK have been met. The rms value is a mathematical representation of the total HOAs in the eye. No clinical correlation has been established between preoperative HOAs and postoperative results. Conversely, patients with a low degree of HOAs may still benefit from custom surgery, since CustomVue is less likely to induce new HOAs.

Some possible ablation profiles generated by the WaveScan software cannot actually be treated with the laser, because the treatment

TABLE 7.5 Advantages and Disadvantages of VISX CustomVue with WaveScan Analysis

Advantages	Disadvantages
Greatest approved treatment range	Increased cost for WaveScan and VISX STAR S4 upgrade
Greater likelihood of improved night vision	Possible increased cost for the patient
Potential for improved BSCVA using wavefront-adjusted manifest refraction	Increased technician time
Ability to adjust power of the sphere and add a nomogram adjustment if results dictate	Increased surgeon time
Flexibility to adjust treatment zones even for low corrections out to a maximum of 9.0 mm	Need to acquire new skills
No need to dilate intraoperatively	Inability to adjust cylinder power or axis
Ability to cut a PreVue lens	Unable to treat monovision
	Deeper ablation than conventional
	Increased patient expectations

may exceed the approved range. This must be evaluated carefully prior to surgery. The newer version of the WaveScan software will indicate whether or not the treatment is within range and is supported by available treatment cards.

There are a number of screens in the software with which one must become familiar. It is important for the surgeon to take an active role in picking the treatments and adjusting the design screen for each patient as surgery is planned. Once the treatment has been selected and designed, the plan is calculated and downloaded for data transfer to the STAR S4 VSS laser. A printout of the treatment plan is produced for the chart and the data are uploaded to the VISX S4 VSS laser.

WAVESCAN ACQUISITION

Acquiring comprehensive and reliable clinical patient data preoperatively is essential to achieving excellent surgical outcomes. Most of the preoperative assessment for custom LASIK is similar to what is required for conventional LASIK. Wavefront data acquisition is a clear departure from the conventional patient evaluation. The following describes the essentials of WaveScan acquisition.

The WaveScan unit should be calibrated daily when it is booted. This is a fast and simple process. The joystick operates much like a slit lamp. Just align the white dots with the horizontal line of the cross and the blue circle with the pupil margin. Use the autofocus button and joystick to focus the white dots and optimize focus.

Be sure the patient is positioned correctly at the instrument and verify the head position between each image. If the pupil does not dilate naturally to at least 5.0 mm, then accurate WaveScan measurements may not be obtained and a CustomVue treatment is not recommended. VISX recommends not dilating patients with inadequate sized pupils in order to acquire a treatment profile. The VISX treatment algorithms are based on the natural pupil and intentional pharmacologic alteration, either topical or systemic, may alter the quality of the results. In order to achieve maximal physiological dilation, the patient may need to sit for a while in a darkened room. It is important that the patient does not accommodate while being imaged. To aid younger patients and ease accommodation, instruct them to look "through" the target and not to stare "at" the target. Getting several good-quality WaveScan images with a large enough pupil can be difficult at times, especially with older patients.

Always take at least three good-quality images per eye, trying to get all four check marks green. If the system does not recognize the image as acceptable (e.g., pupil <5 mm), it will not automatically save it, but it can be saved manually. However, it is not recommended to use such profiles for treatment, because the data can be unreliable. The system will create a treatment profile (designated by a "T"), and this profile should be transferred to the laser using a USB memory stick and a copy printed for the patient record. Always upload the treatment data to the laser in advance of surgery to confirm that the treatment profile is available. Because of the larger image file, IR treatments must be downloaded and transferred to the laser using the USB memory stick.

Some additional basic guidelines include the following:

- Set the vertex distance on the WaveScan to 12.5 mm.
- Set the convention to minus or plus notation, depending on the convention that is more familiar.
- For myopic patients, verify that the sphere does not exceed −11.75 D, the cylinder does not exceed 3.75 D, and the SE is ≤ −11.75 D. These are the FDA limits, beyond which no treatment option is currently available.
- For hyperopic patients, verify that the SE does not exceed +3.00 D, and verify that the cylinder does not exceed +2.00 D. Treatment is possible beyond these ranges, but is considered off-label.
- Obtain at least three undilated WaveScan captures with at least a 5-mm and preferably a 6-mm pupil.
- Check the quality of the images. There should be at least three out of four green checks in the quality box.

Patients within the range of approved refractive error that have been successfully captured on the WaveScan (pupil diameter ≥5.0 mm) must also have sufficient corneal thickness, regular topography, and good correlation with the refraction in order to be treated with the CustomVue system.

TREATMENT PLANNING

The second step in preparing to perform a CustomVue treatment is the design of the ablation shape for each individual eye. The VISX instruction and training protocols recommend use of the Automated Exam Selection Mode, which requires a minimum of three quality WaveScan measurements. Even when using the automated selection mode, it is important for the surgeon to verify the quality and accuracy of the selected scan. The surgeon always has the ability to override the automated selection and pick a more appropriate scan. This is a good way to start incorporating CustomVue into a refractive practice. This mode will signal a warning if one or more of the selected examinations exceed the following criteria:

- One or more examinations have a <5.0-mm pupil size.
- Two or more examinations have SE values differing by >1.0 D.
- The selected examination has a higher order rms that differs from the average by more than 0.07 µm.

The surgeon always has the option of ignoring the warning and proceeding with the treatment.

An alternative method can be considered as one becomes more comfortable with the instrumentation and more confident with the clinical outcomes. Set the "treat" setting to a single exam and select the WaveScan refraction (WR) that most closely correlates with the MR and CR. This also allows one to check image quality and evaluate the pupil image. Individually checking and selecting the WaveScan ensures that only high-quality measurements are used for treatment. As IR becomes the standard for CustomVue treatments, the ability to check image quality and pupil image will become more important. Occasionally, the manifest and wavefront refractions are consistent and accurate, but the image of the eye will illustrate that the eyelid is covering a portion of the pupil. In this circumstance, this particular WaveScan should be disregarded and another selected. Sometimes, more images will need to be captured to ensure good quality. During evaluation of the images, do not let preoperative higher order rms values determine eligibility for treatment, because these are subtle features that vary greatly among individuals. The FDA clinical trials did not base any inclusion or exclusion criteria on HOAs or rms values. Instead, look for correlation between the WR, MR, and CR using the criteria in Table 7.6. In general, the WR cylindrical power and axis are very accurate. If the differences between MR/CR and WR sphere exceed the guidelines, then:

- Repeat both. WR may be more minus if the patient is accommodating.
- Check the BSCVA using the WR (WAMR).
- Check the CR.

If the MR and WR deviate greater than allowed by these guidelines, then the patient may not be suited for a wavefront-guided treatment.

When beginning CustomVue treatments, use the full WaveScan refraction with no nomogram adjustment. The newer Fourier analysis is very accurate and minimal nomogram adjustment is needed. It is still important for surgeons to monitor individual results because of the variations in outcome that result from technique, environmental conditions due to the season and geography, and WaveScan and laser variability. It is helpful for surgeons to keep records of cases and results 1-month postoperatively to revisit the adjustment question. It will take several dozen cases to get enough data on which to base a nomogram adjustment for treatment.

The design screen offers the surgeon two options for treatment adjustments. The surgeon has the ability to adjust the amount of spherical correction ±0.75 D. Additionally, a second option for adjustment on the design screen is the percent nomogram adjustment. This can be adjusted ±10%. The nomogram adjustment makes the change to the entire treatment, sphere, cylinder, and HOAs. Once the surgeon starts to analyze

TABLE 7.6 Allowable Difference Between WR, MR, and CR

	Myopia	Hyperopia
MR and CR	<0.75 D	<0.75 D
MR and WR (WR – MR)	–0.50 to +0.75 D	<0.75 D
CR and WR	–0.50 to +0.75 D	<0.75 D
For cylinder >0.50 D	<15°	<15°

the outcomes, these two methods allow sufficient flexibility to fine-tune the treatments to improve postoperative results. When it is time to incorporate an adjustment, use the design screen and be sure to check that the proper vertex distance is entered. Use only new, non-recycled diskettes to download treatment or the VISX USB stick, because the laser may not recognize the ablation profile. Before surgery, always check the diskettes or USB stick on the laser to be sure the laser will read the profile.

The default ablation diameter for CustomVue treatments is 8.0 mm with an optical zone of 6.0 mm. For hyperopia, the optical zone is 5.0 mm with an ablation diameter of 9.0 mm. Many surgeons prefer to keep the ablation zone diameter slightly larger than the measured mesopic pupil size, while others simply use the largest zone that can safely be used. The ablation zone can be enlarged beyond the default zone setting, if needed. This does not increase the amount of tissue removed during the ablation, but rather increases the diameter of the smoothed edge. The maximum ablation diameter approved by the FDA is 9.0 mm. The screen adjustments allow for expansion of the ablation zone out to 9.5 mm. Some experienced refractive surgeons simply enlarge the ablation diameter to 9.0 mm on all myopic treatments. When doing this, one must consider the diameter of the flap that will be created and attempt not to ablate cornea outside the stromal bed. Enlarging the ablation zone is probably an important step that helps minimize complaints of nighttime glare and haloes. The surgeon should personally make this adjustment on all patients without relying on a technician. This forces the surgeon to look at the selected scan and ensures that the quality of the WaveScan images is good and appropriate for each patient to be treated.

PATIENT PREPARATION

The third step in the process is to prepare for surgery using proper alignment and orientation techniques to ensure fidelity in transmitting the custom shape to the cornea. In the absence of the iris registration (IR) upgrade, use a sterile marking pen to mark the limbus at 3 and 9 o'clock, as described in Chapter 1. This will allow an adjustment for cyclorotation of the eye, which can occur when the patient is positioned under the laser.

The FDA has approved IR; however, some surgeons still mark the patient in case the IR fails to capture. If a surgeon plans to use IR, there is a very specific procedure that AMO recommends in order to assure accurate WaveScan capture with proper reference to the pupil centroid. This differs slightly compared to non-IR treatments. Under the current software version, each eye has to be captured for the patient separately as if each is represented as a separate patient. This ensures proper IR identification, capturing the appropriate pupil centroid and iris markings. The method of capturing and saving these IR files is described in detail in the "Alternative Capture Advisory letter" that was published in July 2011. Because it relates the laser to the WaveScan, IR is available only for custom treatments. The fully automated IR system will signal the surgeon if the orientation of the eye or head under the laser is different than during WaveScan acquisition or if the pupil center has shifted. Once iris registration has been achieved, the laser can then compensate for this movement. IR is not an active tracking system. The IR system and the appropriate

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laser compensation are set prior to the ablation and remain fixed until changed by the surgeon. If the eye continues to move, the laser would need to be reset to compensate for this movement. If the eye were to move again, the surgeon would need to stop and reregister. During the VISX clinical trials, the IR system was found to be convenient and reliable, as well as user friendly.

Because it uses iris features to recognize the patient's eye, it also serves as a double check of identity and helps prevent treatment to the wrong eye or patient. Tracking and alignment are even more important for wavefront-guided treatments because the ablations always contain unique features that are not symmetrical, unlike spherocylindrical ablation profiles.

TREATMENT

Most experienced refractive surgeons feel that different microkeratomes will not have significant impact on the results of CustomVue treatment provided that surgeons are consistent with their technique. Remember, as mentioned earlier in the text, that CustomVue treatments will remove more tissue per diopter, so residual bed depth will become more of an issue. The surgeon needs to know the range of flap thicknesses that his or her particular microkeratome will produce. Always check the central pachymetry of the stromal bed to confirm that sufficient RSB is present. If the clinical situation requires a thinner flap, the femtosecond laser may be a more desirable option. When using a femtosecond laser for flap creation, if a significant opacified bubble layer (OBL) is present, some surgeons prefer to wait until this dissipates. If the OBL is in or near the visual axis, it may affect the accuracy of the eye tracker. This has not been well studied and remains slightly controversial. If air should enter the anterior chamber during femtosecond ablation, the bubbles usually collect anterior to the pupil and may also interfere with the active tracker. Should this occur the bubbles will become smaller with time. After a period of observation and confirmation that the tracker can find the pupil, the ablation can proceed.

Align the limbal marks with the reticle hash marks or, if available on your system, engage IR; focus the microscope on the surface of the stromal bed; and center the reticle over the pupil. The pupil centroid through a small pupil is located in a different position than through a dilated pupil. Before engaging the ActiveTrak with automatic centering, reduce the room illumination and the microscope illumination also, if possible, so that the custom treatment will be centered at the same location as the WaveScan. Once centered and tracking is engaged, depress the laser pedal to begin treatment. CustomVue treatments should never be performed without the ActiveTrak engaged. The speed of laser treatment is variable; therefore, the surgeon should not be alarmed by the change in the sound of the laser compared with conventional treatment.

SUMMARY

Careful attention to details and acquisition of reliable data will result in the best possible outcomes. It is important for the surgeon to understand the WaveScan system so that necessary guidance can be provided to staff and potential errors recognized and prevented.

The VISX Star S4 with CustomVue currently has the widest range of approvals for conventional and wavefront-guided treatments and has many features that make it a user-friendly system. Calibration is fast and simple to perform. The user software interface is intuitive. Also, if your laser suite has sufficient room, a femtosecond laser can be in the same room, allowing the surgeon to use the same chair. The autocentering and tracking features are extremely versatile and robust under most lighting and pupillary conditions. Use the minimum lighting that allows the ActiveTrak to autocenter and track the pupil in order to match the lighting conditions during WaveScan acquisition and CustomVue treatment. This better aligns treatment centration.

Iris recognition technology provides surgeons with greater comfort when treating eyes with greater amounts of cylinder and HOAs. Once the surgeon becomes more experienced and has gathered sufficient data, the ±10%

nomogram adjustment and the ±0.75 D physician adjustment can be used to develop individual nomograms. These are very helpful for fine-tuning results for individual patient needs. This laser platform is upgradeable, serviceable, and reliable. The field service, training materials, and customer care center at VISX are also helpful.

Suggested Reading

1. Lindstrom RL, Linebarger EJ, Hardten DR, et al. Early results of hyperopic and astigmatic laser in situ keratomileusis in eyes with secondary hyperopia. *Ophthalmology*. 2000;107(10):1858–1863.

chapter 8

WaveLight Allegretto Wave Eye-Q Laser

VANEE VIRASCH and JONATHAN B. RUBENSTEIN

The WaveLight Allegretto Wave Eye-Q Laser can be used for Wavefront Optimized LASIK treatments and, in conjunction with the WaveLight Analyzer, for wavefront-guided Custom LASIK treatments.

This platform is a scanning flying spot excimer laser that exists at three frequencies, 200, 400, and 500 Hz, with a pulse duration of 12 ns. The ablation times are very rapid with the 200-Hz laser correcting 1 diopter (D) at a 6.5-mm optical zone in about 4 seconds, while the 400-Hz laser can correct 1 D in only 2 seconds. The scanning spot laser overlaps a previous ablation spot every fifth pulse, allowing cooling time between pulse applications and decreasing any theoretical thermal risk.

The system is equipped with an integrated cross-line projector that allows not only horizontal centration, but also vertical, or *z*-axis, centration on the cornea. Correct height alignment is achieved with two precise distance laser diodes. This is an advantage particularly in patients requiring high astigmatic correction. The laser's **PerfectPulse Technology** utilizes a Gaussian beam profile and a 0.95-mm spot size to ensure a smooth and precise ablation of corneal tissue. This is coupled with a high-speed eye-tracking system with a response time of <6 ms for accurate placement of each laser pulse. The pupil-based eye-tracking system can be used with a pupil size ranging from 1.5 to 8.0 mm and does not require pupil dilation. A built-in slit lamp is also provided, which allows the surgeon to inspect both flap alignment and interface clarity while the patient is on the operating table. It can also be used to find the flap edge in a retreat case. Other features of this laser include a bright 110W xenon illumination system and a portable notebook computer that allows the surgeon to program the laser treatments, preoperatively from a separate location. There is an external plume evacuator that removes fumes and odors from the surgical field, thus protecting both the patient and surgeon. The laser is attached to a motorized swiveling bed that also moves the patient under the laser with push button control. The laser is also less sensitive to changes in temperature and humidity, because the optics of the beam formation is protected inside a tube system that is nitrogen gas purged. Only a very short part of the excimer laser beam is exposed to ambient air. The overall fluence is measured by objective calibration and adjusted for the individual room conditions once a day. Temperature and humidity in the laser room should still be controlled in order to manage the response of the patient's cornea. The laser is able to operate at temperatures that range from 65°F to 86°F and 20% to 70% relative humidity.

Wavefront Optimized LASIK

The objective of Wavefront Optimized technology is to preserve the natural asphericity of the cornea. Previous LASIK platforms resulted in non-aspheric ablation profiles, flattening the central cornea more than the peripheral cornea and inducing spherical aberration. These ablation profiles also resulted in larger and more irregular transition zones.

Wavefront Optimized treatment is a novel technology that improves upon previous

ablation profiles by altering the way in which the peripheral cornea is ablated. Due to the angle of incidence of the laser beam, there is increased reflection and energy loss as the treatment beam moves peripherally along the curved cornea. Therefore, with a non-optimized ablation profile, less energy is delivered to the peripheral cornea, which results in a non-aspheric corneal surface. In order to compensate for this, the Wavefront Optimized laser creates an ablation profile that places more laser pulses in the peripheral zone depending upon each individual's degree of corneal steepness (Figs. 8.1A and B).This results in a smoother transition between the central and peripheral cornea and maintains the natural aspheric shape of the cornea. The smoother area between optical zone and transition zone allows for smaller transition zones, larger optical zones, and decreased postoperative spherical aberration. The large optical zones with minimal transition zones also create a lower incidence of halos and glare even for patients with larger pupils.

The laser is approved for LASIK treatments in patients 18 years of age or older for the correction of myopia or hyperopia and in patients 21 years of age or older for the correction of mixed astigmatism. For Standard Wavefront Optimized (non-Custom) LASIK treatments, the laser is approved for myopic treatments up to −12 D sphere and up to −6.0 D of astigmatism at the spectacle plane. It is approved for hyperopic LASIK corrections up to +6.0 D of sphere with or without astigmatic refractive errors up to 5.0 D at the spectacle plane, with a maximum spherical equivalent of +6.0 D. LASIK treatments for mixed astigmatism are approved for up to 6 D of correction at the spectacle plane. All patients must have a stable manifest refraction defined as <0.5 D shift over the year prior to surgery. The target refraction can be varied from −3.00 to +1.00 D for sphere and from 3.00 to 0.00 D for cylinder. It is the surgeon's choice to treat on the manifest, the cycloplegic refraction, or some combination of both.

The WaveLight Allegretto Wave Eye-Q Laser treats spherical and astigmatic errors separately. Spherical errors are corrected first followed by astigmatic correction without interruption. Optical zones are spherical for all treatments. Ablation zones, defined as the optical zone plus the transition zone, are circular for treatment of myopic spheres as well as hyperopic spheres and cylinders. Ablation zones are elliptical for myopic cylinders.

System Setup and Surgical Planning

Each surgical day, a performance test is carried out to ensure that the system is operating within specifications. Using a polymethylmethacrylate (PMMA) target, an ablation depth micrometer is used to assure precise energy calibration. Before each patient's surgery, a

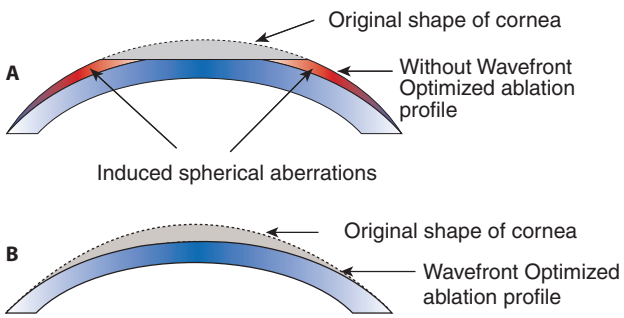

FIGURE 8.1

A: Without Wavefront Optimized ablation, untreated peripheral corneal tissue induces spherical aberrations. **B:** The Wavefront Optimized ablation profile maintains an aspheric shape designed to decrease induced spherical aberrations. (Courtesy of Jonathan B. Rubenstein, M.D.)

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calibration sequence measures the beam location and energy levels to optimize the shot pattern generated for the ablation. Lastly, during the treatment, the energy output is actively monitored with closed loop energy sensors. The laser will not treat a patient unless these tests have been successfully completed.

A notebook computer is provided to enter patient data and plan treatments. This computer can be moved off site to enter patient treatment data preoperatively if the surgeon desires. Parameters to be entered include clinical refraction, vertex distance, keratometry readings, optical zone size, and refractive target. The refractive correction can be entered in either plus or minus cylinder form, and the software will automatically convert the treatment program to minimize the ablation depth.

The default optical zone is 6.5 mm and can be adjusted for mesopic pupil size, if desired. The surgeon must keep in mind that increasing the optical zone will increase ablation depth. The ablation zone size and orientation should be appropriate for the corneal flap size and hinge location to avoid any interference. The ablation should be performed entirely within the stromal bed.

SurgiVision DataLink ALCON Edition offers software and a collective database, that is, pooled data from all of the surgeons that perform LASIK and contribute to the database, that can be used for surgical planning and nomogram adjustment. The software is available online and patient data are entered preoperatively. In addition, after a surgeon has done 20 or more cases, that individual surgeon's data are used to create a personal database. The individual database will then suggest treatment parameters based on that surgeon's previous outcomes. This individualized database is updated on a regular basis. For higher volume surgeons, a personalized nomogram can be built after outcome analyses have been performed on a set number of treatments. The surgeon reviews the recommended treatment parameters from DataLink and must approve these numbers before the technician enters these data into the laser notebook computer.

Wavefront-Guided LASIK

When used in conjunction with the WaveLight Analyzer, the Eye-Q laser can also be used for wavefront-guided Custom LASIK treatments. The WaveLight Analyzer along with the accompanying A-CAT software module were designed for the treatment of eyes with a greater amount of higher order aberrations (RMS > 0.3 μm).

The WaveLight Analyzer measures higher order aberrations using a technique based on the Tscherning principle. In contrast to the Hartmann-Shack principle, the WaveLight Analyzer sends a grid or spot pattern of light rays (10 × 10 mm) on to the cornea that focus in front of the retina forming a pattern. This pattern is captured by indirect ophthalmoscopy and each spot position of the retinal image is compared to its ideal spot position. Any deviations or aberrations from the ideal spot position are then analyzed in order to determine the wavefront error present in the optical system. The Tscherning system's sensors have approximately 10 times higher precision than the Hartmann-Shack sensors.

The data from the analyzer is automatically transferred to the notebook computer containing the A-CAT software. These data are then combined with the input of measured keratometry values and clinical refraction. A wavefront-guided ablation profile is calculated and displayed. Wavefront testing done at the time of surgery allows the surgeon to modify the target refraction and adjust the size of the optical zone and transition zone on the spot.

Treatment Pearls

On the day of treatment, both the technician and the ophthalmologist reexamine the patient. We recheck the manifest refraction and the topography to assure refractive and corneal stability. We base our treatment primarily on manifest refraction, with guidance from the cycloplegic refraction. The refractive and the keratometric values are then sent to SurgiVision DataLink, where they are modified based on the individual surgeon's database.

The technician shows the suggested treatment to the surgeon, who adjusts or approves the values as is before entry into the laptop computer. Next, the patient lies down on the laser bed. Topical anesthetic is instilled, both eyes are prepped with 5% Betadine solution, and gauze sponges are taped over the patient's ears to prevent inadvertent drips. The energy level test is performed. The patient's head is aligned to assure that the eye and laser are in the same plane. The plume evacuator is then brought into position. The LASIK flap is lifted and the nasal-based flap is folded in a taco configuration so that the temporal epithelial edge of the flap is draped over the hinge to protect the hinge from excimer ablation.

The laser is focused by having the patient look at a rapidly blinking green fixation light while the surgeon aligns the two red focusing HeNe beams onto the center of the optical zone. Fine focus is accomplished with a joystick in the surgeon's right hand. It is helpful to turn down the intensity of the field illumination to aid in the patient's ability to fixate on the green light. The eye-tracking system always centers automatically to the pupil center. However, the surgeon using Wavefront Optimized ablation has the choice of manual decentration.

The eye is then tracked with a centering test and the surgeon locks in the tracker with a tap on the foot pedal. The tracker is active for the *x*- and *y*-axes. In the *z*-axis, we focus with the two distance laser diodes. There is no cyclotorsion tracking or iris registration. The Eye-Q uses NeuroTrack to compensate for eye rotation and the cross lines for cyclotorsion alignment.

While holding the patient's head gently with both hands to assure good centration, the foot pedal is depressed, and the laser pulse energy is delivered. Again the treatments are quite rapid with a rate of 4 sec/D with the 200-Hz laser or 2 sec/D with the 400-Hz laser. After the laser treatment is complete, the interface is irrigated and the LASIK flap is repositioned in the usual fashion.

SUMMARY

The advantages of the WaveLight excimer laser in our hands have been:

- Very fast ablations, making treatment easier for the patient and the surgeon, minimizing corneal drying during treatment.
- Accuracy. Excellent clinical results, especially in the treatment of astigmatism.
- Wavefront Optimized protocols, which provide the ability to achieve excellent results with minimally induced higher order aberrations.
- Faster patient flow because of lack of the need for wavefront testing before treatment.

chapter 9

SCHWIND AMARIS Systems

DIEGO DE ORTUETA and THOMAS MAGNAGO

The SCHWIND AMARIS is a sixth generation excimer laser. It has both a 750 Hz and a 500 Hz version. Among the technical advances are:

- An Automatic Fluence Level Adjustment (AFLA). The goal of AFLA is to achieve perfect smoothness with high ablation speed. This has been developed to ensure an ideally balanced ratio between the total number of laser pulses and the energy delivered. The result is that approximately 80% of the laser ablation is performed with a high fluence value, while low fluence is used for the remaining 20%. The ideal smoothing of the surface is achieved by adding low fluence pulses at the end of the treatment.
- The SCHWIND AMARIS laser uses a small spot size of 0.54 mm and a Super-Gaussian beam profile. The improved spot overlap matrix is designed to provide a precise reproduction of the calculated ablation volume avoiding vacancies and corneal roughness.
- The small spot size allows the laser to perform sophisticated ablation profiles with a high-speed ablation time. This reduces the likelihood of significant stromal bed dehydration during a large correction. The 750-Hz laser system at a 6-mm optical zone corrects 1.0 diopter (D) in 1.5 seconds versus 1.0 D in 2 seconds for the 500-Hz laser system.
- The SCHWIND AMARIS laser systems work with an Intelligent Thermal Effect Control (ITEC)[1] that reduces the likelihood of damage to surrounding corneal tissue, even at the extremely high ablation speed. The ITEC algorithm ensures that the temperature rise of the cornea is <5° and significantly <40°, which is considered critical for corneal tissue denaturation.
- The laser systems have an active tracker to monitor the position of the eye 1,050 times/second with an average latency of about 1.6 ms. The total reaction time of the AMARIS is typically <3 ms. The AMARIS 750S laser system continuously tracks and actively compensates for eye movements including dynamic cyclotorsion (DCC), which is the rotating movement of the eye during the laser treatment. The laser detects both the pupil and the limbus. The limbus is used as a reference for ablation because its diameter is stable, meaning that the original ablation center is maintained throughout the treatment. The point selected as the center of the ablation is the same throughout the treatment because the laser system tracks the pupil in relation to the limbus.
- The illumination is automatically adjusted to maintain the pupil diameter at the same size at the beginning of the treatment as it was at the preoperative examination when the diagnostic data were obtained.
- Real-time pachymetry provides information about the corneal thickness throughout the entire duration of the treatment. The changes are measured and displayed on the treatment screen. The measurements can be taken before the preparation and after lifting of the flap, as well as during and after the laser treatment. This

ensures that the surgeon knows exactly how much tissue has been ablated at all times and the thickness of the remaining cornea. Real-time pachymetry allows the surgeon to change the surgical plan intraoperatively if the stromal bed is thinner than expected. Pachymetric data can be printed and saved for future reference in the event that retreatment surgery is needed in the future.

- The microscope for the SCHWIND AMARIS laser delivers good contrast, true color brilliance, and good depth of focus. The diagnostic slit lamp for flap checking is compactly designed and can be moved around two axes across the entire working area.
- With the AMARIS laser systems the laser beam is guided through a completely enclosed beam path in a vacuum. No disturbing elements can impair the quality of the laser beam, and there is no deviation of results to be expected as, for example, could occur with the use of nitrogen (Fig. 9.1).

One of the main differences between the two laser platforms is the speed of ablation, which is described with the model numbers 750S and 500E. The z-tracking is only available for the AMARIS 750S, meaning that the AMARIS 500E works with five dimensions of eye tracking. Also, the 500E has a more compact design without a swivelling laser arm.

Treatment Spectrum

The SCHWIND AMARIS laser systems offer a wide range of applications in refractive and therapeutic corneal surgery with the SCHWIND Custom Ablation Manager (CAM). The software includes modules to treat hyperopia, myopia, and astigmatism. The manifest sphere must be within the range of −15 to +8 D, and the manifest cylinder range must be between −7 and +7 D. The spherical equivalent must be within the range of −9 and +6 D.

Safety and efficacy data support LASIK treatment in the maximum range of −12 D with up to +6 D of cylinder for myopia and up to +6 D for hyperopia with up to +6 D of astigmatism. For photorefractive keratectomy (PRK), the proven maximum spherical correction is −9 D with up to 6 D of cylinder and a maximum of +6 D with up to +5 D of astigmatic correction. As previously stated, higher corrections are possible, but there are no data to support safety and efficacy. Treatment of presbyopia and therapeutic treatments such as pachymetry-assisted laser keratectomy (PALK) or phototherapeutic keratectomy (PTK) are also possible. Supporting multicenter study results have been published.[2–8]

The optimized refractive keratectomy (ORK)-CAM[9] is a planning software tool for refractive laser treatments such as LASIK or Femto-LASIK, and for surface ablation such as LASEK, PRK, Epi-LASIK, and also the transepithelial photorefractive keratectomy (TransPRK) (Fig. 9.2).

For each planned refractive treatment, the SCHWIND CAM calculates the size of the optimal transition zone, depending on the refraction, treatment method, and optical zone. This provides standardized treatment for more predictable outcomes.

FIGURE 9.1

SCHWIND AMARIS 750S. (Courtesy of SCHWIND.)

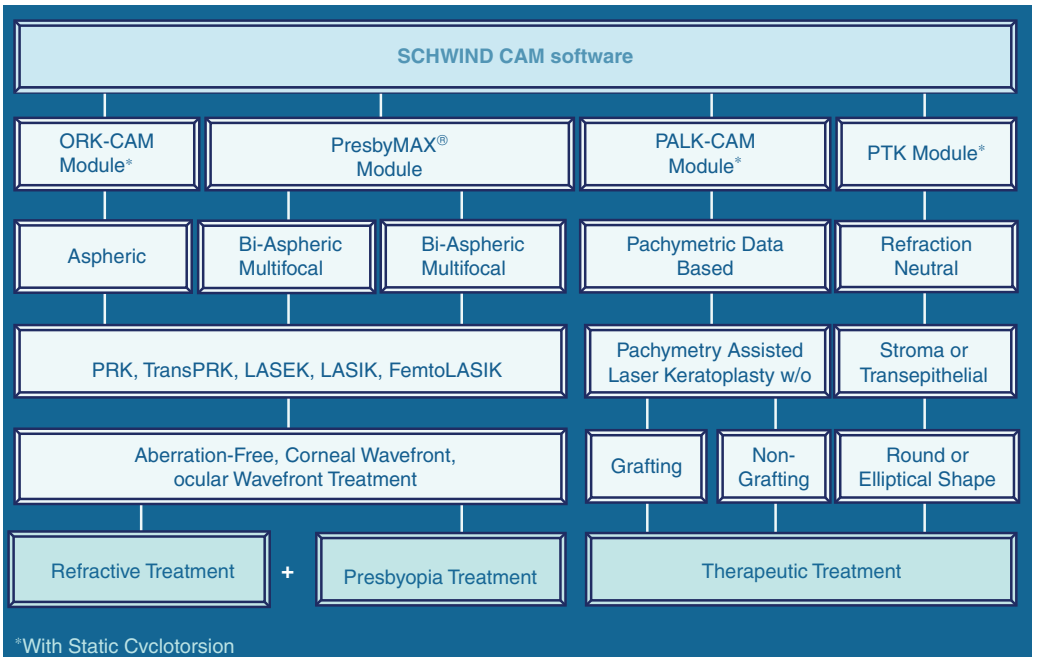

FIGURE 9.2

SCHWIND CAM software. (Courtesy of SCHWIND.)

The optical zone is also the effective optical zone. The optical zone can always be optimized, even if there is limited wavefront information available for a customized treatment, for example, due to small pupils. This optimization is achieved by peripheral aspheric enlargement of the optical zone.

The pulse efficiency of laser ablation depends on the depth of the tissue and the cell structure. A LASIK procedure ablating deeper tissue layers requires different parameters from those needed for a surface treatment. Therefore, the ORK-CAM defines the ablation per pulse, depending on the treatment method. This is one of the reasons why nomogram adjustment is unnecessary.

SCHWIND Diagnostic Technology

OCULAR WAVEFRONT ANALYZER

The Ocular Wavefront Analyzer is a high-resolution Hartmann-Shack aberrometer that measures 1,024 points with a resolution of 230 µm. Each eye is measured three times to ensure good repeatability. The ocular wavefront analyzer determines total higher order aberrations (HOAs) and root-mean-square (rms) error. An integrated infrared pupillometer allows the determination of scotopic pupil size and calculation of the mesopic pupil size based on aberrometry. The device also measures accommodation and keratometry (*K*) and calculates the Seidel refraction. In our experience, the Seidel measurement with a 4-mm pupil is close to the manifest subjective refraction and can be used in place of it. The Seidel refraction incorporates HOAs into the spherocylindrical refractive error and allows one to check the data against the patient's glasses prescription.

CORNEAL WAVEFRONT ANALYZER

Corneal wavefront measurements can be done with the Keratron Scout, Placido disc topographer (Optikon 2000 Industrie, Rome, Italy). This Placido disc–based system measures more than 80,000 points and provides Zernike components up to the eighth order. Ray tracing and a sophisticated eye model calculate corneal topography, which provides *K* readings at 3, 5, and 7 mm as well as the

Maloney Index and simulated *K*-reading. We have found that the Maloney Index is more reliable than standard *K* readings in describing the cornea, because it better reflects the actual flattest and steepest meridians, rather than measuring only the flattest meridian and automatically placing the steepest axis 90 degrees away. The topography system also includes a repeatability test. Four topographies per eye should be measured, and data from the best test can be extracted. Images taken during corneal wavefront measurement can be exported and used for the static cyclotorsion control, ensuring that information about the change from upright to supine positions of the patient is obtained. The laser software can compensate for this cyclotorsion.

The infrared pupillometer calculates the mesopic pupil diameter, which is useful for determining the size of the optical zone to be treated. These data can be exported to create a customized corneal wavefront treatment. In this case, the HOAs determined by corneal wavefront analysis can be used in conjunction with the patient's manifest refraction.

From the topography elevation, tangential and axial maps are generated. The tangential map and the corneal wavefront map are normally used because they provide the most comprehensive information, applying the arc-step algorithm to compute corneal curvature and identify abnormalities of the cornea, such as keratoconus. There is also a software program that calculates a patient's likelihood of developing keratoconus based on asymmetry of the cornea. The difference map is used to track the changes in topography over time.

SCHWIND SIRIUS—SCHEIMPFLUG ANALYZER

SCHWIND SIRIUS offers a combined solution for refractive and therapeutic corneal surgery. The multifunctional diagnostic device combines a rotating Scheimpflug camera and a Placido disc topography device. It provides a quick, three-dimensional analysis of the entire cornea and the anterior segment in one step. The SCHWIND SIRIUS captures the anterior segment in <1 second. The high resolution of only 1 µm and more than 100,000 points detect the smallest irregularities on the anterior corneal surface and therefore offer a precise analysis of the aberrations. This noncontact measurement allows the clinician to analyze the complete corneal wavefront, the topography of the anterior and posterior corneal surface (including the tangential and axial curvature), as well as the anterior chamber. In addition, the SIRIUS calculates the keratometry readings, which can be used for power calculation of intraocular lenses (IOL).

The corneal wavefront analysis documents the type and size of all existing optical errors on the anterior corneal surface with the aid of the ray-tracing method. The Scheimpflug system helps also with its extensive keratoconus screening. The detailed measurements provide the option to generate a corneal pachymetry map for corneal transplants. Combined with ablation using the SCHWIND AMARIS laser, this measurement allows one to perform PALK.

COMBI WAVEFRONT ANALYZER

The Combi Wavefront Analyzer allows one to integrate all the data needed to plan refractive surgery.[10] This device combines ocular wavefront and corneal wavefront measurements, allowing one to determine the best treatment for each patient. The comparison feature of this diagnostic device allows the user to load two wavefront aberration files: two corneal wavefront maps, two ocular wavefront maps, or one corneal and one ocular wavefront map. This direct comparison provides information about the location of the patient's visual deficiency. From the comparison, it is possible to determine whether or not the problem resides on the corneal surface. The Combi Wavefront Analyzer thus helps the refractive surgeon to decide which diagnostic data should be used for optimal treatment results. It combines comprehensive analysis of HOAs and refraction results in a one-step treatment. The Combi Wavefront Analyzer combined with SCHWIND SIRIUS and its Scheimpflug camera provides detailed information about the entire anterior segment and all the necessary information for PALK.

9

The Workflow

PREPARATION OF THE AMARIS

The workflow starts with a checkup before the surgical session begins. About once every 2 weeks a message pops up that the laser needs a gas refill. Refill is done via a fully automatic process that takes about 5 minutes. A calibration (fluence test) of the AMARIS laser system is typically performed in about 3 minutes. Evaluation of the calibration result is carried out automatically, preventing subjective misadjustments. Treatments with the AMARIS laser systems can be performed for up to 2 hours after a fluence test before the next fluence test is required.

ABERRATION-FREE TREATMENTS

The goal of keratorefractive surgery in virgin eyes with good visual acuity is to correct the refractive error without inducing aberrations. For the vast number of such patients, our way of treatment is the SCHWIND aspheric aberration neutral "aberration-free method."[11,12] This provides good results, which can be achieved without having to consider individual wavefront data. Spherical or cylindrical refractive errors are exclusively corrected. Additionally, minimal HOAs are induced during the treatment that may reduce visual acuity or contrast vision.

The aberration-free method is based upon the hypothesis that it is not always advantageous to remove HOAs that existed preoperatively. This is the case in eyes obtaining a good visual acuity without visual complaints. Studies with untreated eyes have shown that patients with above-average visual acuity can have HOAs. It was also observed that patients with the fewest HOAs were not always those who achieved the best visual acuities. Since the brain, with the help of neural compensation, adapts to aberrations, the patient has less need of adapting to a new visual condition. In such a way, there are at least five criteria—native aberrations, neural compensation, chromatic blur, depth of focus, and wide field vision—that favor the goal of leaving minor amounts of clinically irrelevant aberrations.

In conventional spherical and aspherical ablation methods, HOAs are induced during the laser treatment. The aspheric aberration-free profiles of the SCHWIND AMARIS software, however, compensate for HOAs that may result from the flap cut, the change in the corneal shape caused by the laser ablation or from the loss of efficiency by ablation at the corneal periphery. Thus, the goal of this software is to be aberration-neutral, which in practice creates a low amount of HOAs independent of the individual shape of the corneal surfaces to be treated.

For planning, just the keratometry readings are entered into the ORK-CAM software together with the patient's refractive error at the corresponding vertex distance. In all treatments, the ablation is centered using the pupillary offset,[13] which is the distance between the pupil center and corneal vertex normal, as measured by a videokeratoscope, either with the SIRIUS Scheimpflug device (CSO, Rome, Italy) or the Keratron Scout topographer (Optikon 2000 SpA, Rome, Italy). This objectively measured offset is entered into the planning software.

Depending on the refractive values, the ORK-CAM software will propose a specific optical zone (OZ). As long as the patient's pupil diameter under dark mesopic conditions is not larger than the proposed OZ, the default values should be used. This is provided there are no other considerations such as stromal thickness. In a standard fashion, the SCHWIND-CAM provides optimization by calculating the size of the appropriate transition zone for each treatment, depending on the refraction, treatment method, and OZ.

CUSTOMIZED TREATMENTS

Modern refractive surgery should provide customized patient-oriented laser vision correction for each eye based on the patient's history, diagnosis, and visual demands. If the diagnostically determined HOAs impair vision, they should be corrected.[14] We defined the limit of 0.30 µm at 6 mm of pupil diameter as clinically significant.[15] If the aberrations found in the ocular wavefront analysis are significantly higher than in the corneal wavefront, we typically prefer to use the ocular wavefront for the customized treatment.

Topography-guided or corneal-wavefront–guided algorithms allow the surgeon to treat highly aberrated corneas, such as those with decentered ablations or corneal scars. The software system incorporates the impact of HOAs into the refraction so that the expected theoretical objective impact of the HOAs is balanced by the manifest refraction as measured by the surgeon.

Ocular wavefront treatments have the advantage of being based on objective refraction of the complete ocular system, whereas corneal wavefront treatments have the advantage of independence from accommodation effects or light effects on the pupil as well as in retreating corneas that had previously undergone refractive surgery. When evaluating the outcomes of wavefront-customization strategies, wavefront aberration analysis (both total and corneal) is mandatory to determine whether the customization aims can be achieved. Comprehensive diagnostic information can be obtained by:

- SCHWIND SIRIUS Scheimpflug device
- Corneal Wavefront Analyzer
- Ocular Wavefront Analyzer

Customized wavefront treatments are regarded as a suitable method to perform tailor-made visual corrections with optimum results. Individual characteristics of an eye beyond sphere and cylinder are thereby considered in the ablation profile. Nevertheless, aberration-free treatment offers significant advantages for the many patients whose vision is not affected by existing HOAs.

PRESBYOPIC TREATMENTS

The PresbyMAX is an integrated software module of the SCHWIND CAM for the SCHWIND AMARIS laser system platforms. It is intended to be used for planning treatments in which refractive corrections in sphere and cylinder are combined with presbyopia compensation. Ocular or corneal wave aberration information can be taken into account as well. The concept uses bi-aspheric multifocal ablation profiles combining two focus-shifted aspheric profiles with different asphericities. Each concentric area is multifocal with a transition between both providing intermediate visual function. In the case of PresbyMAX, a bilateral treatment is planned with simultaneous correction of the distance refraction based on sphero-cylindrical input (and ocular/corneal wavefront data) and the additional component for near correction designed to alleviate presbyopia with slight myopic defocus and spherical aberrations. A controlled multifocal vision is calculated with the center corrected for near and the periphery for distance, optimized bi-aspheric profile, and a pre-calculated amount of different high order spherical aberrations.

In this way, the software creates a multifocal cornea with a defined amount of identical induced negative spherical aberration for both eyes. The multifocality ensures that the best focusing distance changes across the optical zone. The results of our presbyopia-correction approach show that patients have achieved (both objectively and subjectively) good distance and intermediate vision with excellent near vision.

The current bi-aspheric presbyopic profiles show, on average, good to very good outcomes objectively, but subjective impressions particularly for patients with high adds may be less than satisfactory. Distance function may be less well-tolerated, especially in patients who were myopic preoperatively. A micro-monovision approach is an alternative, which places emphasis on the patient's dominant eye for far distance and on the nondominant eye for near function. No significant compromise in binocular visual perception and stereopsis is seen as a result of the minor differences (-0.75 D anisometropia) in distant target refraction between both eyes (Fig. 9.3).

In all modalities, the presbyopia software PresbyMAX offers a broad treatment spectrum for different indications: treatment of emmetropic, myopic, hyperopic, and astigmatic eyes. From experience we can say that patient selection is an important key factor for success. The characteristics for a candidate for a good PresbyMAX treatment are:

1. Patients with a positive attitude preoperatively knowing that reduced distance vision postoperatively (BCVA pre-op vs. UCVA post-op) may occur.
2. Patients who are willing to accept wearing glasses in case of either distance or near visual performance needs.
3. Photopic pupil size should be within 2.5 and 3.0 mm.

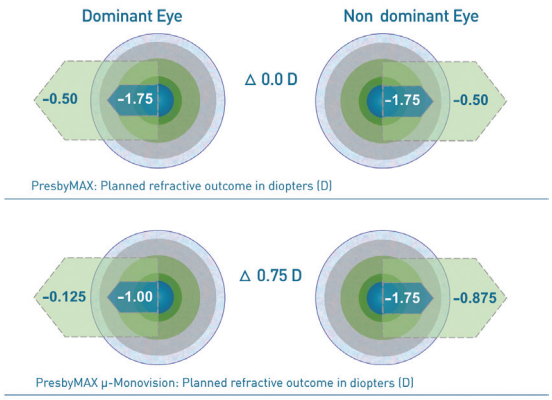

FIGURE 9.3

Central and mid-peripheral targets for PresbyMAX with and without micro monovision. (Courtesy of SCHWIND.)

4. The corneal vertex should be the center of the treatment. Whenever the pupil-to-vertex distance exceeds 200 µm, the offset from corneal vertex to pupil center should be used.
5. Preoperative corneal curvature should be between 40 and 48 D.
6. Preoperative monocular best-corrected distance visual acuity equal or better than 20/25 (0.1 logMAR).
7. Preoperative binocular near visual acuity of J4; 20/32 (0.2 logRAD) or better with addition of +1.50 D.
8. Corneal spherical aberration (C[4,0]) @ 6 mm should be positive (≥0.0 µm).
9. Ocular spherical aberration (C[4,0]) @ 6 mm should be more positive than −0.2 µm.

I find it important to center the aberration-free treatment on the corneal vertex to reduce induced coma aberrations, which disturb vision at all distances.

LASER ABLATION FOR ABERRATION-FREE, CUSTOMIZED, AND PRESBYOPIC TREATMENTS

The procedure using the AMARIS system is very standardized and guided; and the fact that the workflow is the same for each of the various treatments is even more valuable. It starts with the import of the planned treatment file. Despite advanced planning, there is still the option to modify all the parameters directly at the excimer laser. After this data import, there is the option of adjusting the laser profile rotationally by comparing iris landmarks on the actual patient, lying underneath the laser, with the diagnostic data from the upright measurement. This adjustment is helpful whenever the astigmatism is >1.0 D or for customized treatment in order to compensate for possible static cyclorotation, that is, ocular rotation occurring from the upright to the supine position. While most patients have no significant cyclotorsion, there is a substantial outcome enhancement for the ones who do rotate. The debris removal system is brought down and automatically stops 4 cm above the eye, creating a constant airflow, like a jet stream. The eye-tracker automatically locks in all the various dimensions, and treatment starts by depressing the pedal. The dynamic cyclotorsion tracking function continually compensates for rotational ocular movements during the treatment. This occurs independently whether or not the static cyclotorsion was corrected. My keratorefractive treatments are approximately 60% LASIK and 40% surface, usually performed as TransPRK.

TRANSPRK

The so-called TransPRK is an advanced no-touch, all-laser version of surface ablation. The TransPRK does not require contact mechanical epithelial debridement. The laser ablates 55 µm centrally and 65 µm peripherally,

since the epithelium is thicker in the periphery, within an 8.0 mm diameter zone. The extent of epithelial laser removal matches the total zone of ablation, that is, the total of the selected optical zone plus the transition zone. Because the area of epithelial removal is smaller than is required for manual PRK, the healing process is about 1 or 2 days shorter. Additionally, both the epithelium and the stroma are ablated in a single procedure. This shortens the overall treatment time significantly and minimizes the risk of corneal dehydration.

The TransPRK can be combined with "aberration-free" treatment and corneal- or ocular-wavefront–guided treatment as well as PresbyMAX treatment.

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SECTION V

Management of Postsurgical Problems

chapter 10

Retreatment of Patients After Primary Refractive Surgery

MICHAEL ROSENBERG

This chapter will review retreatment of the keratorefractive surgery patient who has symptomatic ametropia following the surgery. The management of other LASIK-related complications is covered in detail in Chapter 11.

Since the initial publication of this book, there have been significant technologic advances in laser refractive surgery. For example, use of the femtosecond laser has increased significantly. The delivery of femtosecond energy has become more efficient, resulting in reduced laser times and decreased postoperative inflammation. There has been a parallel improvement in excimer laser quality and the efficiency of beam delivery for both conventional and custom treatment. This has resulted in better patient outcomes, but perhaps more importantly, it has resulted in raising patient expectations. The promises of the "possibility" of 20/20 vision with newer lasers and laser delivery techniques are likely to be misinterpreted by unsophisticated and sophisticated patients alike as tantamount to a guarantee. The sensible preoperative approach to "underpromise" and "overdeliver" requires a logical postoperative strategy for enhancement surgery.

One of the most important factors determining patient satisfaction after refractive surgery is a realistic expectation of visual function. The patient should be made to understand that refractive surgery is a process rather than a procedure. It is the responsibility of the surgeon to communicate appropriate vision goals of primary surgery as well as retreatment. The preoperative discussion should also include an explanation of the types, frequency, and potential complications of retreatment surgery. The surgeon's philosophy and comfort with enhancement surgery are most important factors in determining the ultimate outcome for any given patient.

Most physicians performing refractive surgery can be generally described as aggressive or conservative with regard to outcomes. Aggressive surgeons will set high postoperative

vision expectations—for example, at least a 98% probability of uncorrected acuity of 20/25 or better. To achieve these results, a relatively higher probability of retreatment must be expected. More conservative surgeons may set lower goals—for example, the ability to pass the driver's test without restriction, or performing the majority of visual tasks without spectacles or contact lenses. Patients willing to accept the less rigorous goals can expect a lower probability of retreatment. Nevertheless, patients who preoperatively seem willing to accept the possibility of a less than ideal outcome are frequently dissatisfied after surgery. Not only do they see worse than they did preoperatively with spectacles or contact lenses, but they have night vision symptoms resulting from residual refractive error. For these reasons, it is imperative that every physician performing refractive surgery be comfortable with the concept of retreatment and be knowledgeable about the various surgical techniques available. Patients who attain the highest level of postoperative visual function will be active ambassadors for the refractive surgeon. This will increase both patient referrals and the overall success of the refractive practice. Patients who achieve less than expected results after surgery are more likely to lack enthusiasm for the procedure and will communicate that feeling to the detriment of their surgeon and the field of refractive surgery. It is hoped that this chapter will allow the reader to become more comfortable if not enthusiastic about retreatment and receive the gratification that comes from patient outcomes that are "wonderful" rather than just "okay."

Indications

The basic indication for retreatment of a patient after primary refractive surgery is patient dissatisfaction due to ametropia, with stable refractive error that can be corrected safely and reliably. The patient must have decreased vision that, when corrected with appropriate refraction, results in good visual acuity. The residual refractive error must be amenable to treatment with an approved laser protocol or by appropriate incisional surgery. The patient should be informed of the potential risks and benefits of the various available retreatment techniques, and the chosen technique should conform to the patient's risk/benefit comfort level.

Residual myopia, hyperopia, and regular astigmatism can be corrected, assuming corneal thickness and keratometry are adequate. Patients with irregular astigmatism, inadequate residual stromal bed, or extremely steep (for hyperopic retreatment) or extremely flat corneas (for myopic treatment) are more problematic. While a post-enhancement residual stromal bed of <250 µm has been a traditional limit that could not be exceeded, many surgeons now prefer to leave at least 275 µm or even more stromal tissue untouched to reduce the long-term risk of ectasia. Most surgeons agree that one should avoid steepening the cornea to ≥50 diopters (D) or flattening the cornea to <35 D.

In some cases, the result following initial surgery may be consistent with the preoperative discussion of expectations, but the patient is still unhappy. This may occur in patients who are given soft outcome predictions. For instance, they may be told "If you have refractive surgery, you will be able to do virtually everything you need to do without glasses, including driving." A soft end point sounds good during the consultation. However, it may not sound so good after treatment, when a patient with preoperative best-corrected visual acuity (BCVA) of 20/20 has a postoperative uncorrected visual acuity of 20/25—and night vision issues. The patient can drive without glasses, but is not comfortable. In these situations, the physician must choose one of several options: remind the patient of the preoperative discussion, convince the patient that all is fine, or proceed with retreatment. A surgeon who fails to present the option of retreatment either because of an unwillingness to do a retreatment or because of a lack of comfort with the techniques will leave the patient with the perception of a less than satisfactory result. This surgeon misses the opportunity to provide the patient with a result perceived to be excellent. The surgeon should present the patient with the option of retreatment rather than waiting for the patient to request the procedure. This will instill confidence and ultimately leave the patient with a very positive experience.

Many refractive surgeons do not believe in encouraging retreatment for a patient with <20/20 visual acuity or some other surgically induced vision abnormality unless the patient expresses discontent. While this patient may not become an ambassador for LASIK surgery, there will also be no added risk due to retreatment. In the unlikely event that a retreatment problem was to develop, a patient might wonder why the surgeon encouraged a second surgery in the absence of a complaint. As surgeons become more comfortable with designing a customized retreatment surgery for their patients, it becomes easier to recommend the additional surgery. The majority of patients do benefit from retreatment when it is properly planned and executed.

Residual refractive errors, which occur during the first 6 months after treatment, result from initial overcorrection, undercorrection, or regression. The likelihood of postoperative ametropia in the immediate postoperative period increases with the degree of correction. Regression refers to minimal or no refractive error in the immediate postoperative period, and late, slow drift in the direction of the primary refractive state. The larger the preoperative correction, the more likely is regression to occur within the first 6 months to a year. A smaller number of patients will develop ametropia years after the initial treatment. This occurs more frequently in patients with larger initial refractive error and in patients initially treated for hyperopia. This is particularly true for a hyperopic patient, in whom the surgeon elected to treat the manifest correction rather than the full amount of hyperopia revealed during cycloplegic refraction. This group of patients should be allowed to adapt to the full correction prior to the initial surgery or be educated about the likelihood that they will need retreatment likely more than a year after the initial surgery.

There are multiple reasons for immediate over- or undercorrection. Inaccurate refraction may result from surgeon or technician error, or inadequate cycloplegia. Failure to calibrate the laser properly may lead to insufficient or excessive laser energy. Overcorrections may result from dehydration of the stromal bed during the procedure, particularly when the ablation time is lengthy. This is potentiated by low humidity in the laser suite or prolonged elevation of a flap during LASIK prior to initiating treatment. Undercorrections may be related to overhydration of the cornea due to high humidity or excessive irrigation prior to initiating treatment. Many early conventional myopia treatment nomograms were geared toward a slight undercorrection. They were designed to avoid overcorrection of myopia at a time when treatment of hyperopia was not available. The advent of customized treatments and improved laser quality combined with strict control of environmental factors has obviated some of these issues.

To optimize postoperative results, it is essential for each surgeon to develop a standardized LASIK technique, and to develop an individual nomogram based on the postoperative results, the equipment being used, and the conditions in the laser suite. This requires tight control and maintenance of both temperature and humidity.

Common Postoperative Vision Problems

There are certain common situations in which patients voice dissatisfaction, despite apparently good outcomes. These include the following:

- Asymmetry of visual acuity
- Night vision symptoms
- Oblique astigmatism
- Unrecognized anisometropia
- Asthenopia in overcorrected pre-presbyopic patients

It should be emphasized that evaluation of the true residual refractive error should always be on the basis of a cycloplegic refraction. Whether the subsequent retreatment is based on the cycloplegic refraction or manifest refraction is the surgeon's decision.

ASYMMETRY OF VISUAL ACUITY

A patient who has very sharp 20/20 visual acuity or better in one eye but weak 20/25 acuity in the other eye will frequently complain about the weaker eye. This is especially significant when the weak eye is the dominant

eye. A patient using binocular vision will choose to derive most visual information from input of the dominant eye and thus the overall satisfaction will be dependent on the acuity in that eye. Generally, no amount of reassurance will satisfy a patient, who is able to alternately cover each eye. This comparison will be done in perpetuity until the weaker eye is corrected. Patients may be convinced not to have retreatment of a mildly myopic nondominant eye, especially if they have early presbyopic symptoms. In the presbyopic patient, it is important to evaluate the uncorrected visual function both at distance and near, prior to retreating myopia. The patient may otherwise not appreciate the benefit of this myopic eye for intermediate or near tasks.

NIGHT VISION SYMPTOMS

Uncorrected refractive error is the most common cause of persistent nighttime haloes and glare. Night vision issues are one of the more significant concerns of patients contemplating refractive surgery, particularly if night driving is important to the patient's lifestyle. Persistent complaints about night vision from a patient with good visual acuity, but a residual refractive error, should be addressed with retreatment. As an example, a patient with a visual acuity of 20/20—who has a refraction of $-0.50 + 1.25 \times 85°$ may have symptoms of star-bursting related to the residual cylinder. This may become more evident at night when the pupil is larger. Effective treatment will reduce the number of patients with night vision problems following laser vision correction.

OBLIQUE ASTIGMATISM

Patients with regular oblique corneal astigmatism frequently complain of subjective visual disturbance out of proportion to visual acuity. The accurate identification and measurement of residual oblique astigmatism requires careful cycloplegic refraction as well as corneal topography and keratometry. Patients with either "with-the-rule" or "against-the-rule" astigmatism will have a vertical or a horizontal border in relative focus, providing sufficient visual clues in a world that is oriented vertically and horizontally. Patients with oblique astigmatism have equal defocus of vertical and horizontal borders, creating a more generalized blur.

UNRECOGNIZED ANISOMETROPIA

Patients with anisometropia will frequently have subjective complaints despite apparently good visual acuity when tested monocularly without cycloplegia. Patients with no ametropia in the dominant eye may have residual ametropia in the nondominant eye, resulting in visual symptoms when using the eyes binocularly. Overcorrected myopes with hyperopia in one eye may read the Snellen chart quite easily until dilated, and may not show a significant refractive error on manifest refraction. A young patient with a postoperative refractive error may have postoperative hyperopia with or without astigmatism of up to +1.00 to +1.25 D and still have 20/15 visual acuity. It is incumbent on the physician to perform a cycloplegic refraction on any patient with unexplained visual complaints, regardless of the uncorrected visual acuity. It is also important to perform at least one cycloplegic examination on every patient at a time when the refractive error is likely stable, and before the patient is released from postoperative care. Symptomatic patients with unrecognized overcorrection may return several years after discharge, with reduced acuity and dissatisfaction creating a situation in which accurate explanation of the issues is awkward, and correction by retreatment is somewhat more difficult.

ASTHENOPIA IN UNCORRECTED PRE-PRESBYOPIC PATIENTS

Patients with symmetric overcorrection and hyperopia may have good acuity and vague symptoms, especially if there is some degree of persistent astigmatism. Timely cycloplegic refraction will identify these patients and permit prompt retreatment.

In summary, the measurement of good uncorrected visual acuity is not the sole factor in identifying patients who are candidates for possible retreatment. Careful consideration

of patient symptoms combined with careful refraction, with and without cycloplegia, is necessary to ensure that patients will have optimal refractive outcomes.

Evaluation

The most important prerequisite for retreatment is refractive stability. The stability of refraction should be determined on the basis of cycloplegic and manifest refraction to avoid undercorrection of accommodating hyperopic patients and the overcorrection of accommodating myopic patients. The surgeon should determine whether the retreatment should be based on the cycloplegic or the manifest refraction. Patients should be followed for at least 5 to 6 weeks after the primary treatment before determining the potential need for retreatment. Moderately myopic patients (up to −6.00 D) may be retreated as soon as two refractions, at least 1 month apart, are stable and as soon as 2 to 3 months after an initial uncomplicated LASIK. In patients with greater amounts of myopia, patients treated for hyperopia, those treated with photorefractive keratectomy (PRK), and patients with complications from the initial treatment (e.g., corneal abrasion), retreatment should be postponed until refractive, topographic, and anatomic corneal stability is observed. For patients with significant confounding abnormalities such as visually significant striae, keratitis, or epithelial ingrowth, appropriate treatment of the pathological condition is required before retreatment with the laser. In many cases, treatment of these problems will correct the residual refractive error.

Prior to potential retreatment, a thorough examination should include monocular uncorrected visual acuity, best spectacle–corrected visual acuity (BSCVA), manifest and cycloplegic refraction, keratometry, slit-lamp examination, central and peripheral pachymetry, corneal topography, and preferably wavefront evaluation. Table 10.1 provides a checklist that summarizes these retreatment examination tasks.

Keratometry should be done to help predict the postoperative contour after retreatment. Caution is advised if the predicted average keratometry value would be >50.00 D in a hyperopic patient or <35.00 D in a myopic patient. Remember, in order to predict postoperative keratometry, use the conversion factor of 0.7 or 0.8 multiplied by the spherical equivalent of the refraction in a myopic patient. The result is subtracted from the average keratometry value. No conversion factor is needed for the hyperopic treatment. The spherical equivalent is simply added to the average keratometry value. Corneal topography must also be used to rule out the corneal ectasia.

The slit-lamp examination is important to rule out corneal pathology that could explain reduced visual acuity, such as surface disruption, striae, interface debris, inflammation, or epithelial ingrowth. The presence of cataract could also explain a change in refractive error, night vision disturbance, or decreased acuity and should be identified before additional cornea surgery is considered.

Wavefront evaluation can be helpful as a technique for determining the residual refractive error. It also determines the type and amount of higher order aberrations (HOAs). It can be used to retreat the patient with a custom ablation. Surgeons using the VISX CustomVue WaveScan system can prepare a PreVue lens, which the patient can use preoperatively to determine the value of a custom retreatment. A Prevue lens is created by applying the planned custom treatment to a plastic lens blank that resembles the individual lenses in a trial lens set. The patient can look through the lens to judge the potential benefit of the proposed treatment. Ultrasonic as well as topographically determined pachymetry is especially important after prior refractive surgery in order to confirm adequate residual stromal bed (RSB). Remember that not all topography units can accurately measure corneal pachymetry. Corneal thickness must be adequate in the areas in which retreatment will occur, the central cornea (myopia), mid-peripheral cornea (hyperopia and astigmatism), or peripheral cornea (if incisional correction is indicated). Ideally, the flap thickness in LASIK patients has been determined by subtraction pachymetry during the initial treatment. If it has not, knowledge of the instrument used

TABLE 10.1 Preoperative Examination Checklist for LASIK Retreatment

Monocular uncorrected visual acuity
BCVA
Manifest refraction
Cycloplegic refraction
Keratometry to be certain cornea will not be too steep (≥50.00 D) or too flat (<35.00 D) after retreatment
Slit-lamp exam to rule out surface disruption, striae, interface debris or inflammation, ingrowth, or cataract
Corneal topography to rule out ectasia or decentered ablation
Ultrasonic pachymetry centrally to determine RSB and peripherally, if LRI considered; alternatively, measured pachymetry from a topography unit that accurately measures thickness can be used;
OCT can be used to measure flap thickness and RSB
Wavefront scan to determine refraction, HOAs, create PreVue lens, or prepare for custom retreatment

to create the flap, the specific microkeratome, and head, or the femtosecond laser flap settings may provide enough information to estimate the adequacy of the remaining cornea. Anterior segment optical coherence tomography (OCT) can also be used to measure post-LASIK flap thickness (see Chapter 3).

Conventional (non-custom) treatment of the undercorrected myopic patient should not be nomogram adjusted; that is, the manifest or the cycloplegic refraction without adjustment is used. Custom retreatment should be surgeon-adjusted as it would be for a primary treatment.

Surgical Techniques for Retreatment

Multiple techniques are available to surgeons for patients requiring retreatment. Surgeons should be well acquainted with both the approved and the off-label treatment range on their available laser, should this be a consideration. Various techniques are listed next, and each technique is discussed in detail in the subsections that follow.

The most common techniques used for retreatment are:

- Laser retreatment beneath a previously made LASIK flap
- Laser surface retreatment after a primary surface ablation
- Surface ablation on a previously made LASIK flap without prior LASIK
- Laser surface retreatment after prior LASIK surgery
- Limbal relaxing incision(s) (LRI)

Less commonly needed techniques used for retreatment are:

- LASIK or surface ablation after previous radial keratotomy (RK)
- LASIK in patients having undergone prior surface ablation

Rarely used techniques include:

- Laser treatment after re-cutting a flap or repeating femtosecond flap

The potential risks and complications of each retreatment technique being considered should be carefully explained to the patient. The obvious benefit is improved visual acuity. Peer-reviewed literature documents good visual results with a low incidence of complications from all of the procedures; however, some procedures may be associated with more severe complications than others.

The most severe potential complications common to all techniques are infection and subsequent ectasia. Infection is quite rare and ectasia is also uncommon, assuming excessive thinning of the stromal bed is avoided. A challenging complication can result from purposefully creating a new (second) flap by recutting with a microkeratome or using the femtosecond laser. This technique may result in the intersection of the two interfaces, the initial and the secondary, leading to marked irregularity of the bed and potentially shredding of tissue and possibly loss of bits of

tissue in the worst cases. Most refractive surgeons try to avoid recutting a previously made LASIK flap, since other safer techniques are most often available.

Manual re-lift of a previously created LASIK flap has the advantage of minimal postoperative discomfort and rapid visual recovery. Assuming the initial flap was well constructed, the likelihood of a defective flap after re-lifting is quite low. The character of the flap is slightly less flexible than is typically experienced during the initial surgery. As a result, if handled carefully, the likelihood of postoperative striae is less than after a primary procedure and repositioning is often easier. Tearing of the flap is rare (See Video 16) and if the re-lift is difficult, the procedure can be aborted. Successful lifting even many years after the initial procedure is not unusual, although re-lift of a femtosecond laser flap may be more difficult than re-lifting a previously made microkeratome flap. In addition, re-lifting a large diameter flap with a flap edge near the limbus may be more challenging than re-lifting a small flap. This author has successfully lifted flaps up to 11 years after the primary procedure, and it continues to be the retreatment procedure of choice because of the rapid visual recovery with minimal, if any, postoperative discomfort. There is a greater incidence of epithelial ingrowth after a re-lift, which can be minimized with meticulous technique. Epithelial ingrowth, when it does occur, is usually peripheral, does not affect acuity, and often becomes inactive, requiring no further treatment.

If re-lifting the flap is not possible, the patient can have surface ablation immediately. In order to do that, the patient should be informed and educated about a surface treatment at the time of the retreatment consultation. The longer recovery time and possible postoperative discomfort must be emphasized.

The advantages of PRK on the flap are elimination of complications related to flap manipulation such as epithelial ingrowth. This technique also does not additionally thin the stromal bed. The disadvantages include prolonged recovery, postoperative pain, which may be more than that experienced after the original LASIK procedure, and potential corneal haze. The risk of postoperative stromal haze following PRK on a flap is greater than that seen following primary PRK, and may occur even after treatment for low corrections. For this reason, many surgeons prefer to use intraoperative mitomycin C to reduce this risk (see Chapter 13) (See Videos 6, 7 & 9). Finally, performing PRK may have risks related to prolonged steroid administration if this is found to be necessary.

Ideally, most patients with ametropia will require only one retreatment, but if adequate corneal thickness is present, additional retreatment is possible.

RETREATMENT PROCEDURE BENEATH A PREVIOUSLY CREATED LASIK FLAP

(See Video 4)

The patient is seated at the slit lamp and topical anesthetic is instilled in both eyes. If the patient is to have a custom retreatment or has a significant amount of astigmatism, a sterile marking pen is used to mark the 3 and 9 o'clock positions at the limbus to facilitate detection of cyclotorsion. The patient should be staring at a distant target while the slit beam is oriented horizontally. Applying the pen several times for each mark ensures that the mark will last. The cornea is then illuminated with a broad, obliquely directed beam. The patient is asked to look toward the direction of the hinge, and the edge of the flap is usually easily identified as a faint gray or white curvilinear opacity. Occasionally, this may be difficult to see, especially if the flap edge is located near the limbus within the vascular arcade, or within a corneal arcus. In this instance, the flap edge can usually be seen elsewhere on the cornea where the edge of the flap is located further from the limbus. The patient may have to look in different directions to enable the surgeon to identify a distinct flap edge. In general, the edge of a femtosecond laser flap is easier to identify than a microkeratome flap edge due to greater scarring in the former case.

Occasionally, the flap is still difficult to discern. Gentle pressure with an instrument on the peripheral cornea near the estimated position of the flap edge will distort the cornea and make the edge evident. The flap edge is scored using the tip of a 25G sterile

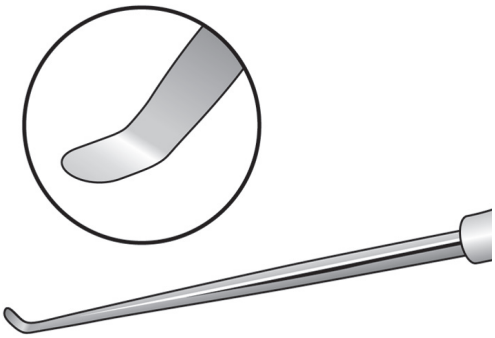

FIGURE 10.1
Machat LASIK retreatment spatula (Asico AE-2830).

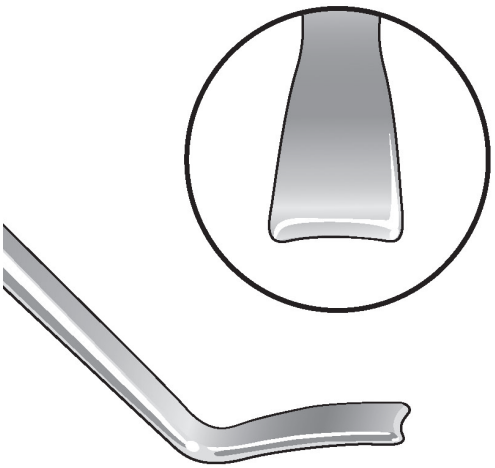

FIGURE 10.2
Rosenfeld glide dissector (Storz E9086).

hypodermic needle bevel up for at least 1 clock hour. Some surgeons prefer a Sinskey hook. A Machat LASIK retreatment spatula (Asico AE-2830) (Fig. 10.1) or a Sinskey hook is positioned at an acute angle to the stroma at the scored flap edge and moved along the flap edge until an easily identifiable area of separation of at least 1 clock hour is created. Some physicians prefer to do the entire procedure under the laser microscope, but the optics of the slit lamp are far superior, and corneal epithelial injury is less likely when the initial flap separation is performed at the slit lamp.

Once the flap is elevated, the patient is positioned, prepped, and draped under the laser microscope. The cornea is marked across the flap edge in the same manner as for a primary treatment to assure accurate flap repositioning. The Machat LASIK retreatment spatula, Sinskey hook, or a Rosenfeld glide dissector (Storz E9086) (Fig. 10.2) is placed in the initial area of separation and passed in circumferential fashion, breaking the epithelium at the flap edge and separating the flap edge from the underlying bed, until the hinge is encountered on each side. It is important to do this slowly enough to avoid tearing the flap edge if an area of slightly greater adhesion is encountered.

After appropriate positioning of the laser, the flap is either grasped and gently lifted using a forceps 180 degrees from the hinge, or a spatula is passed under the flap from one edge to the other at the hinge, sweeping toward the free edge, lifting and folding the flap back at the hinge. If the initial flap was made with a mechanical microkeratome, the lift is usually easy. Only rarely is it necessary to use a spatula to break adhesions under the flap before the lift is made. Surprisingly, some patients who are retreated within the first 6 months have more flap resistance than patients lifted after several years. It is therefore always prudent to lift the flap slowly to avoid inadvertent flap trauma. Remember that if the flap has been made with a femtosecond laser, the epithelium is more adherent at the flap edge. The cornea is therefore more prone to epithelial disruption. Either scoring the flap edge more extensively before lifting or lifting with greater care is advised. It is also advisable to use a spatulated instrument passed across the bed prior to the lift. If there is resistance near the hinge, a dry Merocel sponge can be placed on the undersurface of the flap and it can be "peeled" toward the hinge.

The refractive procedure is performed in the usual manner. As previously stated, no nomogram adjustment should be used for myopia correction. For patients being retreated for hyperopia, whether the result of overcorrection of primary myopia or undercorrection of primary hyperopia, a nomogram adjustment is usually advised based on the surgeon's personal outcome experience.

Before the flap is replaced, a dry Merocel sponge is used to push from the periphery of the stromal bed toward the edge of the bed to remove any epithelial cells inadvertently

introduced onto the bed. The flap is replaced. It is usually repositioned easily and seems to be significantly more resistant to swelling during the procedure. The placement of a bandage contact lens overnight is a good idea to provide increased comfort and promote epithelialization.

In addition, maintaining a secure flap that is resistant to movement by blink or inadvertent patient contact may reduce the incidence of epithelial ingrowth. In the absence of a significant corneal abrasion, the soft contact lens use is not typically associated with an increased risk of diffuse lamellar keratitis (DLK). When the epithelium is minimally disrupted, some surgeons prefer not to use a contact lens.

Postoperative care consists of topical prednisolone 1% and a topical antibiotic four times daily just as is done after primary treatment. Topical ketorolac tromethamine 0.5% (Acular) can be instilled at the end of the procedure and lubricants can also be used for comfort. Patients who have undergone retreatment have less discomfort than was present with the original procedure. However, significant discomfort may occur when epithelial disruption is moderate or marked, or if the contact lens is too tight. Patients typically recognize the visual improvement immediately or shortly after removal of the contact lens.

SURFACE RETREATMENT AFTER PRIMARY SURFACE ABLATION

Retreatment is performed in a fashion identical to the primary treatment. After instillation of topical anesthesia, a 7- or 9-mm optical zone marker (Asico AE 2713) (depending on the maximum diameter of the excimer ablation zone) is placed on the cornea centered on the pupil. The marker is filled with a 20% absolute alcohol solution to loosen the corneal epithelium and is allowed to remain in place for 15 to 20 seconds. Caution the patient about moving the eyes so the solution does not leak beyond the debridement area. The alcohol is removed from the well with a Merocel spear and the cornea irrigated with balanced salt solution. After drying with a sponge, the edge marked by the zone marker is easily visualized, and the reticle of the laser microscope is used to check for adequate centration.

Using a dull retreatment spatula, the epithelium is removed with much less force than with simple mechanical removal. The bed is inspected to ensure that no epithelial remnants are present and the treatment is applied. If more than 1 minute of time is required to remove the epithelium, a moist sponge should be gently wiped across the stromal bed to avoid excessive dehydration. The prior ablation zone will usually appear rougher than the untreated stroma because of the absence of Bowman's layer. Do not mistake this roughened stroma for adherent epithelium. No nomogram adjustment on the cycloplegic refraction is required in a PRK retreatment. If mitomycin C is used, some surgeons will reduce the sphere by 10%; others will treat the full cycloplegic refraction since retreatments are usually small, making significant overcorrection unlikely.

Following the laser ablation, the cornea is irrigated for 1 minute with chilled balanced salt solution and a chilled extend wear contact lens is placed. This is because there is some suggestion that cold will inactivate some of the cytokines released as a result of the laser treatment and, in doing so, reduce postoperative pain. Some physicians advocate chilling the cornea with a "Popsicle" of frozen sterile balance salt. Postoperative medications include a topical antibiotic four times daily, topical prednisolone 1% two to four times daily and may include cyclogyl 1% intraoperatively, ketorolac 0.5% (Acular) four times daily, artificial tears, and dilute anesthetic drops (comfort drops). The anesthetic drops may be prepared by adding topical anesthetic to a bottle of artificial tears to formulate a 10% or 20% concentration, or alternatively it can be obtained from a compounding pharmacy. It should be used only if needed, no more than four times per day, and only during the first 2 to 3 days after treatment. Patients can be given a prescription for an oral analgesic, which may include narcotic. Some surgeons have found oral gabapentin or nonsteroid anti-inflammatory agents pre- and postoperatively to be useful in controlling discomfort.

There is no consensus regarding the use of mitomycin-C for retreatment after primary PRK. If mitomycin-C was used for the primary treatment, it probably should be used again for the retreatment procedure. If significant haze is present, treatment of the haze with topical steroids or superficial keratectomy with mitomycin-C application should precede any laser retreatment (see Chapter 13). Ablative procedures should not be done unless the corneal condition is stable.

LIMBAL RELAXING INCISIONS

(See Video 10)

LRIs are made just inside the limbus. The incisions are usually made on both sides of the axis of the steepest meridian, that is, the axis of plus cylinder. Pachymetry should be performed at the limbus at each end of the steep meridian. The standard LRI is performed using a knife with a 600-µm diamond blade. One of the keys to a successful LRI is achieving the maximum safe depth. Ideally, the LRI blade is adjusted to a blade length 50 to 75 µm less than the corneal thickness as determined by pachymetry at each incision site.

Topical anesthetic is instilled in both eyes and the limbus is marked at 3 and 9 o'clock, as previously noted. The LRI may be done under the laser microscope, under an operating microscope in a minor surgery suite or at the slit lamp. It is generally easier for the patient and the surgeon if the patient is supine rather than sitting up. The patient is then prepped with 5% povidone iodine and draped. A Mendez degree gauge (Asico AE-2765) or equivalent instrument is aligned with the previously made marks at 180 degrees, and a marking pen is used to mark the limbus at each end of the axis of the steep meridian (plus cylinder). An LRI circumferential marker of 30, 45, or 60 degrees is inked and used to mark the cornea so that the center of the marker is bisected by the mark at the end of the steep meridian.

The circumferential size of the marker and number of incisions, one or two, is determined according to the specific astigmatic nomogram used. A number of nomograms exist and many can be found online by searching for "astigmatic nomograms." Nomograms designed to correct astigmatism in patients undergoing cataract surgery are applicable. The Nichamin age and pachymetry adjusted nomogram or NAPA (Table 10.2) is a popular one. Many nomograms are based on treatment with a 600-µm blade. Surgeons using a variable blade may work out their own nomogram. The circumferential mark should be in clear cornea, preferably just central to the normal limbal vessels. The LRI knife is inserted to full depth perpendicular to the corneal surface at one end of the LRI mark and moved to the other end of the mark. The incision is gently spread with a forceps to verify depth and absence of a perforation. The patient should be examined at the slit lamp immediately postoperatively to confirm normal anterior chamber depth and globe integrity. Postoperative drops include topical antibiotic four times a day for 3 to 4 days and prednisolone 1% five times daily for 10 days, the latter to retard wound healing that could potentially lessen the effect of the LRI. The patient should be examined the next day and 1 week later. The effect is usually noted within 1 to 2 days.

LASIK OR SURFACE ABLATION AFTER PRIOR RADIAL KERATOTOMY

(See Video 8)

Patients following previous RK may be good candidates for retreatment if their vision is correctable and the refraction is stable. While acuity may be improved by retreatment, symptoms of glare and night vision problems caused by incisions or scarring within the central corneal cannot be expected to improve. LASIK using a mechanical microkeratome can be considered if the BSCVA is good and the RK incisions are well healed and narrow. Wide scars, a large number of incisions, and epithelial plugging within the incisions increase the risk of instability of the segments of the corneal flap; that is, the flap may break into segments when lifted. The risk of epithelial ingrowth under a LASIK flap may be increased if a large epithelial plug fills one or more incisions and is then transected when the flap is cut. A femtosecond laser should not be used since the corneal scars may cause focal interference with the laser energy, resulting in an

TABLE 10.2 Nichamin Age and Pachymetry-Adjusted Intralimbal Arcuate Astigmatic Nomogram

Pre-op Refractive Cylinder (D)	20–30 y	31–40 y	41–50 y	51–60 y	61–70 y	71–80 y
With-the-Rule (Steep Axis 45°–135°)						
Paired Incisions in Degrees of Arc						
0.75	40	35	35	30	30	
1.00	45	40	40	35	35	30
1.25	55	50	45	40	35	35
1.50	60	55	50	45	40	40
1.75	65	60	55	50	45	45
2.00	70	65	60	55	50	45
2.25	75	70	65	60	55	50
2.50	80	75	70	65	60	55
2.75	85	80	75	70	65	60
3.00	90	90	85	80	70	65
Against-the-Rule (Steep Axis 0°–44°/136°–180°)						
Paired Incisions in Degrees of Arc						
0.75	45	40	40	35	35	30
1.00	50	45	45	40	40	35
1.25	55	55	50	45	40	35
1.50	60	60	55	50	45	40
1.75	65	65	60	55	50	45
2.00	70	70	65	60	55	50
2.25	75	75	70	65	60	55
2.50	80	80	75	70	65	60
2.75	85	85	80	75	70	65
3.00	90	90	85	80	75	70

Note: Blade depth setting is at 90% of the thinnest pachymetry.
Source: Adapted from Nichamin L. Management of astigmatism in conjunction with clear-corneal phaco surgery. In: Gills JP, ed. *A complete surgical guide for correcting astigmatism: an ophthalmic manifesto*. Thorofare, NJ: Slack Inc; 2003:Table 6-2:45. ISBN: 1-55642-612-7.

inconsistent flap. Further, the dissection required for flap elevation may disrupt the RK incisions.

In general, a thicker flap will decrease the risk of instability. It is best to use a spatula under the flap when lifting in order to maintain alignment of the flap segments. It is not unusual to have some slight segment movement on lifting and replacing the flap. If the segments are carefully repositioned and a bandage contact lens applied, healing is usually uneventful.

Patients with multiple incisions or patients in whom the BCVA is obtained only with a contact lens are better candidates for surface treatment, though a surface treatment cannot be expected to improve preexisting irregular astigmatism. Mechanical debridement of the epithelium should be avoided. The use of alcohol and gentle debridement is less traumatic. Mitomycin-C may reduce the incidence of haze following a surface ablation. The treatment may need to be reduced to avoid overcorrection (refer to Chapter 13).

LASIK RETREATMENT AFTER PRIOR SURFACE TREATMENT

This is indicated for PRK patients only when sufficient corneal thickness is present. A typical

patient may have had myopic PRK because LASIK was unavailable at the time of surgery. Another example would be a patient whose central cornea was judged too thin for LASIK, but now requires hyperopic retreatment for an overcorrection and there is sufficient peripheral corneal thickness. Use of a femtosecond laser may provide more reliable control over the thickness of the flap than a more unpredictable microkeratome. In addition, flaps created with the femtosecond laser are not influenced by keratometric values. The excimer procedure is performed exactly as a primary treatment.

SURFACE RETREATMENT AFTER PRIOR LASIK

(See Video 9)

This situation occurs in patients with inadequate corneal thickness for treatment under a flap, or in patients with poor quality flaps that may be further compromised by re-lifting. Access and review of the original preoperative and intraoperative records by the retreating surgeon is important in order to better assess the flap quality and thickness and to determine the risk of further flap compromise. While many surgeons use mitomycin-C routinely for surface retreatment after LASIK, the peer-reviewed literature does not support the clear benefit or necessity of mitomycin-C in these patients. Treatment is performed as described previously for primary PRK, except for the need to protect the flap by avoiding mechanical epithelial debridement. Debridement from the hinge toward the periphery is recommended.

CUSTOM SURFACE OR LASIK RETREATMENT AFTER PRIOR CONVENTIONAL TREATMENT

Some patients continue to complain of poor-quality daytime or nighttime vision after conventional primary treatment despite good visual acuity and minimal to no refractive error. These patients are candidates for custom retreatment if an acceptable treatment plan can be generated after wavefront analysis. The use of a PreVue lens as prepared with the VISX laser or similar laser cut lens in this situation can demonstrate to the patient the potential benefit of custom retreatment. This goes a long way toward alleviating physician and patient anxiety about the results of the proposed treatment.

chapter 11

LASIK Complications and Management

CHRISTOPHER J. RAPUANO

Introduction

The significant advantages of LASIK over photorefractive keratectomy (PRK) are somewhat tempered by the increased complexity of the surgery, which increases the type and severity of complications. While the risk of complications is low, when a complication occurs, it needs to be managed appropriately to achieve the best chance of a satisfactory result. Additionally, surgeons should continue to strive to minimize complications. This chapter will focus on intraoperative and postoperative complications and their causes, prevention, and management. It may be helpful for the reader to refer to Chapter 10 on retreatment as needed for a more detailed discussion of the indications and techniques related to re-lifting a LASIK flap. Use the intraoperative and postoperative planning index to find representative cases that demonstrate each of the complications discussed.

Intraoperative Complications

SHREDDED FLAP

A shredded flap is one of the most feared complications of LASIK. It is typically only recognized after the microkeratome has made its pass and is removed from the eye. The surgeon may notice the flap to be somewhat irregular. Otherwise, it becomes obvious when the surgeon attempts to lift the flap and does not find a standard flap attached at a hinge.

Causes

- **Poor suction or pseudosuction.** Most, if not all, modern microkeratome systems alert the surgeon when the machine senses adequate suction on the eye and will allow the microkeratome to pass only after suction is achieved. However, if the suction port or ports are occluded by conjunctiva, the machine can measure full suction without the intraocular pressure (IOP) being adequately elevated. This situation is termed *pseudosuction*. Patients with redundant or boggy conjunctiva, such as might occur in association with thyroid orbitopathy, after retinal surgery or after multiple attempts at achieving suction, are at greater risk for pseudosuction.
- **Poor blade quality.** If a pass is made with an imperfect blade, the result may be a poor-quality flap. The exact condition of the blade will impact both the nature and the degree of flap damage.
- **Recutting a flap.** Recutting a LASIK flap is a retreatment option, but a second flap may intersect with the first flap, resulting in an irregular flap and an irregular stromal bed. Because of this risk, recutting a flap is considered a less desirable approach to retreatment.
- **Attempting to create a thin flap.** LASIK on the second eye using a microkeratome with the same blade will generally result in a thinner flap. Microkeratomes may cut thinner flaps in thin corneas. The femtosecond laser can also be set to a thickness <100 µm. In any of the above situations, flaps thinner than expected may result and the flap may be of poor quality. A shredded flap is less likely with the femtosecond laser.

Prevention

- **Obtain sufficient exposure.** Poor suction can occur due to difficulty positioning the microkeratome onto the eye. This is more likely to occur when exposure is inadequate. The surgeon may notice a hissing sound, if suction is insufficient.
- **Press the ring firmly against the globe.** Firm posterior pressure on the suction ring presses the redundant conjunctiva against the sclera. This may help reduce the risk of pseudosuction.
- **Triple check the IOP:**
  - First: As the pressure in the eye is increasing, the surgeon should monitor the pupil, which often dilates slightly and then remains enlarged.
  - Second: Once the machine registers full suction, the IOP should be high enough to obstruct blood flow to the eye and the patient will usually notice the vision dimming or even blacking out.
  - Third: Check the IOP. This can be done with a Barraquer tonometer, pneumotonometer, TonoPen, or even with digital palpation. The pressure should be >65 mmHg to obtain a quality flap with a blade microkeratome.
- **Check the blade.** The surgeon or an experienced technician should always check the quality of the blade prior to seating it in the microkeratome.
- **Avoid recutting a LASIK flap for retreatment.** Other retreatment options are reliable and safer.
- **Be cognizant of the risk of creating a very thin flap.** Consider PRK if the cornea is thin. Consider using a new microkeratome blade or a thicker plate on the second eye to avoid the risk of a shredded flap.

Management

- **ABORT THE EXCIMER LASER ABLATION.**
- **Replace flap pieces as best as you can.** The goal is to put all of the pieces of the shredded flap back into their original location. This is often quite difficult because there may be multiple small fragments of essentially clear cornea.
- **Place a bandage soft contact lens (BSCL).** The BSCL is usually removed 1 to 7 days later. Topical antibiotic and topical corticosteroid eyedrops are applied in routine fashion with the lens in place and after the lens is removed.

Long-Term Management

Later options include no refractive surgery, transepithelial PRK with or without mitomycin-C, and LASIK with a femtosecond laser setting a significantly deeper flap depth.

BUTTONHOLE FLAP

Buttonhole flaps (Fig. 11.1) have been described in eyes with normal corneal curvature, but steep corneas appear to be at increased risk, when using a blade microkeratome. The surgeon must always closely examine the quality of the flap as it is being lifted and reflected. Special attention should be paid to the central and paracentral cornea, looking for a full-thickness (easy to detect) or partial-thickness (harder to detect) buttonhole. Buttonholes are easier to detect on the stromal bed appearing as an area of elevation or a smooth island of tissue, but can also be seen as an irregularity or hole in the underside of the flap as it is lifted (Fig. 11.2). Although rare, buttonholes can occur with the femtosecond laser.

Causes

- **Steep cornea** (≥48.00 diopters [D]). The proposed mechanism for steep corneas

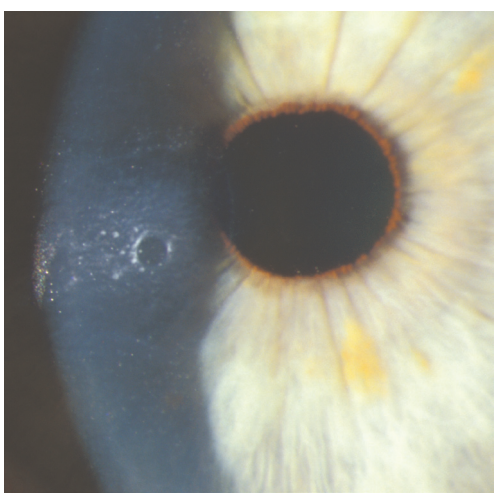

FIGURE 11.1

Flap buttonhole. (Courtesy of Christopher Rapuano, M.D.)

FIGURE 11.2

Smooth, elevated contour of a full-thickness buttonhole noted in the stromal bed, with a corresponding hole noted in the flap.

predisposing to buttonholes is that when suction is applied, the steepness allows a large amount of tissue to be "pushed up," above the plane of the suction ring. As this large area of corneal tissue is deformed by the mechanical microkeratome pass, it buckles posteriorly to the plane of the blade and is left uncut, creating a buttonhole (Fig. 11.3).

- **Localized corneal thinning or scarring**. A localized area of stromal loss or scarring may be covered by thickened epithelium. As the flap is made, there may be a full-thickness stromal defect that is covered only by tenuous epithelium.
- Partial- or full-thickness buttonholes can occur during the femtosecond laser pass as gas passes through a focal area of corneal thinning or scar. Alternatively, it can result from a traumatic flap lift or from debris on the applanation lens that causes focal posterior displacement of the cornea with resultant focal superficial femtosecond laser ablation.

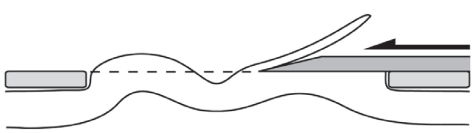

FIGURE 11.3

Proposed mechanism of the buttonhole. It is presumed that an at-risk cornea will buckle in advance of the microkeratome pass, resulting in an isolated area in which the flap is not cut.

Prevention

- **Use an appropriate suction ring** (e.g., use an 8.5-mm suction ring when $K > 45.00$ D). Most microkeratome systems are designed with a variety of suction rings. Smaller rings do not allow as much corneal tissue to protrude anteriorly. Follow the manufacturer's recommendations regarding which suction ring size to use, based on the keratometry readings.
- **Femtosecond laser.** The risk of a buttonhole is less because the applanating lens flattens the cornea within the suction ring and there is no mechanical pass across the cornea to induce a buckling of tissue. Consider using a thicker flap if possible when a scar or corneal facet is present within the margins of the flap. Gentle flap dissection can prevent a traumatic flap dissection. If a gas bubble is seen during the laser pass in an area of scar, extra care should be taken during flap dissection. These are very rare situations. In general, the femtosecond laser is safer than a blade microkeratome for the patient with a steep cornea.
- **Surface ablation.** If steep keratometry readings or areas of corneal scarring/thinning are noted preoperatively, the surgeon may want to avoid the possibility of a LASIK flap complication and perform a surface ablation.

Management

- **DO NOT LASER.**
- **Replace the flap as best as you can.**
- **Place a BSCL, in the event of a full-thickness buttonhole.** The BSCL is usually removed 1 to 7 days later.

Long-Term Management

Later options include no refractive surgery, transepithelial PRK (with or without mitomycin-C), and LASIK (using a microkeratome with a thicker plate or a deeper femtosecond laser ablation) (See Video 20).

SHORT OR DECENTERED FLAP WITH AN EDGE IN LASER TREATMENT ZONE

The LASIK flap needs to be properly centered and large enough to accommodate the entire centered excimer laser ablation. A 6-mm-diameter ablation does not require as large a flap as an 8-mm-diameter wavefront-guided custom ablation or a 9-mm hyperopic correction.

Causes

- **Poor centration of the microkeratome or femtosecond laser.** The suction ring should be centered on the pupil or slightly decentered toward the planned hinge location. It may slip slightly or the globe might rotate under the ring as suction is applied to the eye.
- **Small flap.** The flap may be too small to allow the full laser ablation size. This may be due to inadequate suction prior to the pass or due to a flat corneal contour with keratometry readings ≤40.00 D.
- **Incomplete flap.** Loss of suction during the mechanical microkeratome pass might result in a foreshortened flap. An incomplete flap can occur with the femtosecond laser if suction is lost, if the applanation pressure is light, if fluid is present under the applanation lens, or if the meniscus is too close to the flap edge (See Video 13). Refer to Chapter 5 for a more complete discussion of the femtosecond laser.

Prevention

- **Re-center the suction ring.** If the suction ring is decentered, suction should be released and the ring repositioned properly before the microkeratome or femtosecond laser pass. Some femtosecond lasers (e.g., IntraLase) have a toggling function that allows for minor readjustments of centration; however, the diameter of the flap decreases when this is done. Many femtosecond lasers do not have this capability.

Management

- **Use the reticle.** If the flap has been created, use the excimer laser reticle to determine whether the treatment zone will fit entirely beneath the flap. If the hinge is slightly encroaching within a large (e.g., 8- or 9-mm diameter) ablation zone, then the laser treatment can most likely proceed safely. The hinge should be covered with a hinge protector when the treatment zone is large. Ablation of the hinge should be prevented to avoid a doubly treated area. Laser system software that can design a hinge-sparing ablation may exist on the particular excimer laser being used. Check with the medical director of the laser center.
- **DO NOT LASER if flap size is inadequate.** If the flap does not cover the vast majority of the treatment zone, it is best to abort the excimer laser procedure.
- **Do not attempt another blade microkeratome pass during the same surgery session.** The femtosecond laser is more versatile in this situation. At the first sign of a significant incomplete laser ablation, stop the femtosecond laser. Using the same applanation cone, the laser can be reset, the surface dried, and, if good applanation can be achieved, another laser pass attempted. The pocket should not be cut on the second pass of the femtosecond laser. Usually, an adequate flap can be created with this second pass; however, if the stromal bed appears very irregular, it may be best to abort the excimer laser procedure.
- **Do not try a lamellar dissection to increase flap diameter.** Attempting to increase the flap diameter with a blade is very likely to cause irregular astigmatism and a poor visual outcome. In some cases after a femtosecond laser flap has been created, a small area of incomplete ablation can successfully be bluntly dissected.
- **Replace the flap.** If the flap is inadequate, replace it as one would replace a routine LASIK flap.

Late Management

Later options include no refractive surgery. After waiting for 3 to 6 months, one could attempt to repeat microkeratome or femtosecond LASIK with a larger and thicker flap. Finally, surface ablation with or without mitomycin-C could be considered. Surface ablation over a previous flap increases the risk of haze.

FREE CAP

Automated lamellar keratoplasty, the predecessor to LASIK, and original LASIK techniques were performed by creating a free cap. The current hinged-flap technique improved wound alignment and the safety of the LASIK procedure. While there are reports of free caps occurring in eyes with normal corneal curvature, the risk is increased in patients with flat corneas when using a blade microkeratome.

The presence of a free cap (see Case 66, Fig. 1, Chapter 16) is not always a disaster, particularly if it is discovered right away and prompt, appropriate action is taken. The surgeon must immediately recognize that a free cap was created before the technician removes and disassembles the blade microkeratome, potentially losing the cap. Noting that part of the corneal ink mark is missing following the microkeratome pass and observing an irregular light reflex as the microkeratome is removed from the eye are key findings. The free cap must be gently removed from the microkeratome unit and placed epithelial side down on a thin layer of saline. If the ink marks are disappearing, they may need to be augmented to ensure correct cap placement. If the cap looks like a jigsaw puzzle piece, it should fit perfectly on the stromal bed when it is replaced. If the cap does not fit perfectly, it may be upside down.

Causes

- **Flat cornea ($K \leq 40$ D).** It is suspected that when suction is applied, the flat contour does not allow enough tissue to protrude above the plane of the suction ring. As the blade cuts across, a small free cap is created.
- **Poor microkeratome ring suction.** Poor suction also results in inadequate tissue protruding through the ring.
- Inadequate docking of the femtosecond laser with the suction ring.
- **Improper settings for the microkeratome.** If the settings (e.g., ring size on the console does not match the size used, incorrect hinge width) of the microkeratome are incorrect, there is an increased risk of flap complications.
- **Torn hinge**

Prevention

- **Use a large suction ring on a flat cornea (e.g., 9.5-mm Hansatome ring).** Using a larger suction ring allows a greater amount of tissue to protrude anteriorly, ideally creating a normal-sized, hinged flap.
- **Femtosecond laser.** Successful flap creation with the femtosecond laser system is less dependent on corneal curvature and is, therefore, less likely to create a free cap. Careful attention to the docking procedure and recognition of suction loss is necessary.
- **Surface ablation.** If flat keratometry readings are noted preoperatively, the surgeon may prefer to perform a surface ablation. This is particularly true if a femtosecond laser is not an option.

Management

- **The size and centration of the free cap will determine the ability to perform the laser ablation.** If the free cap is as large as the laser treatment zone, the laser treatment may be safely performed, provided the area of exposed stroma is well centered. If the laser ablation zone is larger than the stromal bed, do not perform the excimer laser treatment.
- **Position the free cap dull side (stroma) posteriorly and shiny side (epithelial) anteriorly.** The ink marks should line up, ensuring correct orientation and that the epithelial side is anterior. Place both a BSCL and a shield. Some surgeons place one or more sutures to secure the flap in position. However, sutures in a small free cap may cause distortion within the visual axis.

INTERFACE DEBRIS

Small amounts of interface debris are common and usually inconsequential. They may create tiny interface scars.

Cause

- **Interface opacities can come from numerous sources,** including makeup, meibomian gland secretions, epithelium, metallic blade fragments, and poor cleaning of the microkeratome.

Prevention

- **Instruct the patient to avoid face or eye makeup** on the day of surgery.
- **Careful removal of makeup** the night before surgery.
- **Cleansing the eyelids of residual makeup.**
- **Treating meibomian gland dysfunction (MGD) and blepharitis preoperatively.**
- **Meticulous cleaning of equipment and use of disposable equipment** may help decrease interface debris.
- **Aggressive irrigation of the flap interface with balanced salt solution,** using irrigating cannulas, such as the Viduarri (BD Visitec No. 585216) or the Manche cannula (Asico AE-7281).
- **Use of an aspirating eyelid** speculum such as the Lieberman speculum (Asico AE-1040A).

Management

- **Irrigate significant interface debris before leaving the laser room.** Check the interface under high magnification under the laser. A light pipe, with the laser microscope light off, can help highlight debris. Significant debris, especially if located in the visual axis, should be removed. Minor amounts are often difficult to remove and may be left in place.
- **Check the patient at the slit lamp.** Bring the patient back under the laser microscope to remove significant interface debris as needed.
- **Debris near the edge of the flap that is seen at the slit lamp can be removed with a fine spatula.**

EPITHELIAL LOOSENING OR DEFECT

The microkeratome pass can cause the epithelium to loosen, dislodge, or even slough. The management of this problem begins with the preoperative recognition of predisposing factors, the choice of equipment designed to minimize these problems, proper intraoperative management of the corneal surface, and postoperative care. One key to intraoperative management is identifying the abnormality to be at the level of the corneal epithelium and not the flap interface.

Predisposing Factors

- **Epithelial basement membrane (EBM) dystrophy.** One of the most common risk factors for epithelial problems during and after LASIK is EBM dystrophy.
- **Recurrent erosion history.** A history of recurrent erosions should alert the surgeon that the patient probably has corneal epithelial adhesion problems and may be at risk for such difficulties during and after LASIK.
- **Older patient (≥45 years).** Several studies have demonstrated older age to be a risk factor for epithelial problems with LASIK.
- **Poor-quality blade.**
- **Large flap diameter.**
- **Excessive topical anesthetic.** Topical anesthetic is toxic to the epithelium. The anesthetic drop should be instilled just prior to placement of the eyelid speculum.
- **Pivoting microkeratome.**

Prevention

- **Avoid LASIK in patients with excessive risk of epithelial problems.**
- **Minimize the use of topical anesthetic.**
- **Lubricate the eye before the microkeratome pass.** The Zero Compression Head on the Hansatome has greatly reduced epithelial disruption compared to the standard head.
- During femtosecond laser flap dissection, be certain the dissector is actually in the interface and not just subepithelial.

Management

- **If the flap stroma is normal, you can proceed with the excimer laser ablation.**

- **Realign all loose epithelium and replace all the epithelial tags** in their original position as much as possible.
- **Check the stromal bed carefully for epithelial fragments, which must be removed.**
- **Consider placing a BSCL,** although this may increase the risk of diffuse lamellar keratitis (DLK).
- **Use preservative-free lubricants frequently.**
- **Follow closely as there is an increased risk of DLK with epithelial defects, even when they occur months or years after LASIK surgery.**
- If there is a large area of severe epithelial loosening or sloughing, **consider debriding the abnormal epithelium and consider postponing surgery on the fellow eye.** Surface ablation, if possible, would be a better choice.

LIMBAL BLEEDING

Bleeding at the edge of the flap is not uncommon. If it is anticipated and managed appropriately, the excimer laser ablation can be performed without problem.

Causes

- **Limbal neovascularization.** It is most common in previous long-term contact lens wearers. Patients with atopic keratoconjunctivitis, acne rosacea, blepharitis, and/or meibomianitis may be left with corneal neovascularization even after the external disease has been medically controlled. The more extensive the neovascularization, the more likely bleeding is to occur. Patients with blood vessels in the ablation zone are poor candidates for LASIK surgery. Superficial vessels within the hinge will generally not bleed.
- **Large, peripheral flaps are associated with an increased risk of transecting peripheral blood vessels.**
- **Decentered flaps are closer to the limbus on one side and therefore at greater risk of bleeding.**

Prevention

- **Avoid superior flap decentration** so that the flap edge will be less likely to transect the more common superior vessels.
- **Make a smaller flap** either with a smaller diameter microkeratome ring or with smaller diameter settings using the femtosecond laser.
- **AVOID TOPICAL BRIMONIDINE (e.g., ALPHAGAN) as a means to constrict blood vessels.** Brimonidine use can make postoperative flap dislocation more likely.
- **Consider using a femtosecond laser.** Significant bleeding from perilimbal corneal neovascularization is much less likely when the flap is created with a femtosecond laser than when a mechanical microkeratome is used.

Management

- **Wait 30 to 60 seconds after the flap is made before lifting.**
- **Place a sponge (e.g., Chayet sponge) at the edge of the flap** to collect the blood before it migrates onto the stromal bed.
- **Direct, gentle pressure at the site of hemorrhage with a Merocel sponge** can help achieve adequate hemostasis more quickly.
- **A drop of phenylephrine can slow the bleeding but will also dilate the pupil, which may impact excimer laser ablation centration.**
- **It is critical to prevent the blood from reaching the ablation zone during the excimer laser treatment because it will mask the laser ablation and predispose to irregular astigmatism.** Interrupt the ablation to remove accumulating blood that is entering the treatment zone. This must be done quickly to avoid excessive drying of the flap bed, which can lead to overcorrection.
- **Irrigate any blood from the interface at end of surgery.** Blood in the interface increases the risk of DLK.

POORLY ADHERENT FLAP

A poorly adherent flap noted immediately after surgery is more likely to become displaced postoperatively. It is wise to make sure the flap is well aligned and in stable position prior to the patient leaving the laser center.

Causes

- **Overhydration of the flap.** Excessive irrigation of the flap interface and lifting and replacing the flap multiple times increases flap hydration and can lead to poor adherence.
- **Trauma to the flap from the eyelid speculum.** During speculum removal the flap can be displaced, requiring careful repositioning. Care should be taken to lift the eyelid speculum away from the cornea during removal to prevent hitting the flap.
- **Endothelial dysfunction** (e.g., Fuchs' corneal dystrophy). Reduced endothelial pump function may decrease flap adherence. A thick cornea, central pachymetry ≥650 µm, noted preoperatively should prompt a further evaluation with specular microscopy to rule out a low endothelial cell count. A thick cornea due to endothelial dysfunction may result in postoperative flap instability after LASIK surgery.

Prevention

- **Keep the flap irrigation and manipulation to a minimum.**
- **Remove the eyelash drapes and eyelid speculum very carefully, avoiding contact with the flap edge.**
- **Avoid topical Brimonidine,** which can increase the risk of flap displacement.
- **Avoid LASIK in patients with endothelial dysfunction.**
- Some feel that the femtosecond laser with its ability to create a more perpendicular side cut or even a reverse bevel cut (see Fig. 5.1) makes flaps that are more resistant to flap displacement.

Management

- **Let the flap "dry" in good position for a few minutes prior to carefully removing the eyelid speculum.**
- **Consider placing a BSCL on the eye if the flap does not appear secure.**
- **Insist that the patient wear protective glasses and nighttime goggles postoperatively and avoid touching or rubbing the eyes.**
- **Instruct patient on safe eyedrop instillation.**

Postoperative Complications

Complications that usually occur soon after surgery include a displaced flap, infection, DLK, central toxic keratopathy, and flap striae. Other complications that occur later include dry eye syndrome/neurotrophic keratopathy, epithelial ingrowth, pressure-induced stromal keratitis (PISK), pressure-induced interface fluid, and ectasia. Postoperative vision complaints that may be considered complications by patients include poor unaided visual acuity due to inadequate correction of refractive error or regression of refractive effect; poor night vision due to glare, haloes, or decreased contrast sensitivity; photophobia; and ghosting. Refer to Chapter 10 for a more detailed discussion of the management of patients with these complaints.

FLAP DISPLACEMENT

A displaced flap can occur any time after surgery from the first day to years later. The most common symptoms of a dislodged flap are acute pain and decreased vision, which may be mild to severe, depending on the severity of the displacement. It can range from a small area of folding at the flap edge to a completely dislodged flap, only adherent at the hinge. Rarely, the flap can be entirely avulsed. In general, a femtosecond laser flap becomes more resistant than a mechanical microkeratome to flap displacement because of the scarring that occurs with the former.

Causes

- **Trauma is the main cause of a dislodged flap.** The sooner after surgery, the less trauma it takes to displace a flap. In fact, in the first few days postoperatively, the patient may not recall any trauma. The injury could be as minor as rubbing the eye. After months or years, it typically requires a distinct and memorable jab to the eye.
- **There are anecdotal reports of a very arid environment, such as a sauna, associated with flap dislocation soon after LASIK.**

Prevention

- **Remind patients to be cautious about rubbing or getting hit or poked in the eye.**

- **Patients should wear eye protection (glasses and nighttime goggles),** especially during activities where there is risk of ocular trauma.

Management

- **A dislodged flap should be repositioned as soon as possible.** A small fold at the flap edge that occurred a few hours prior may be simply repositioned at the slit lamp, for example, with a cellulose sponge or a fine spatula. A more extensive displacement or one that occurred days before most likely requires repositioning under an operating microscope. The displaced flap should be folded back, and the underside of the flap AND the stromal bed need to be scraped carefully but aggressively (e.g., with a Tooke knife or Beaver No. 15 blade) to remove any epithelial cells that may have grown in. If flap folds or macrostriae are present, they should be stretched out as much as possible. The flap is repositioned and the interface irrigated. Alignment marks placed prior to flap realignment should appear offset after proper realignment. Let the flap adhere for at least 5 minutes, because it is often edematous and prone to slippage. Consider placement of a BSCL. Do not be alarmed if even after stretching the flap, faint macrostriae still appear at the slit lamp postoperatively. They will more than likely disappear by the next day.
- **The flap can be sutured in place if it is not adhering well; alternatively, fibrin tissue glue placed at the edge of a well-aligned flap can help keep the flap from moving.**

INFECTION

Infection is one of the most dreaded postoperative complications of LASIK. Symptoms include pain, redness, and decreased vision. The symptoms may be acute or gradual in onset and they may begin days, weeks, or even months after surgery. Infection can originate on the ocular surface or within the flap interface. It typically begins with an infiltrate that may be single or multiple and can become confluent (Fig. 11.4). There may also be an anterior chamber reaction.

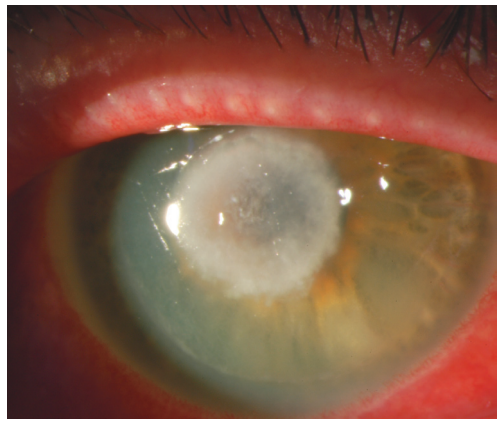

FIGURE 11.4

Fungal infection of a LASIK flap. (Courtesy of Christopher Rapuano, M.D.)

Causes

- **Bacteria.** Typically early onset, within 3 to 5 days, usually begins as a single superficial infiltrate. Epithelial defects, contact lens use, epithelial ingrowth particularly with a fistulous track to the surface, poor flap adherence, and blepharitis likely predispose the patient to bacterial infections.
- **Atypical mycobacteria.** Usually later onset, after 2 to 4 weeks; may have multiple discrete infiltrates initially, often in the interface.
- **Fungus.** Typically later onset, after 2 to 4 weeks; may be associated with prolonged steroid use.
- **Recurrent HSV.** May present as an epithelial dendrite or stromal inflammation.
- Hospital workers colonized with methicillin-resistant Staphylococcus aureus (MRSA) may be at greater risk of infection with this organism.

Prevention

- **Treatment of underlying blepharitis** prior to surgery may decrease the risk of infection or sterile inflammation.
- **Preoperative and postoperative topical antibiotics** also may decrease the risk of infection.
- **Povidone iodine prep before surgery.**
- **Preoperative and postoperative treatment of dry eye syndrome** also may decrease the risk of infection.

- **Limiting the duration of topical steroid use** increases the resistance to infection.
- Consider removing long-standing epithelial ingrowth particularly when extensive or when associated with a fistulous track to the surface.

Management (See Video 19)

- **Small peripheral superficial infiltrates can be treated with frequent broad-spectrum topical antibiotics** (e.g., fluoroquinolone or fortified antibiotics). Larger, deeper, or more central surface infiltrates should be cultured directly and treated aggressively.
- **Infiltrates in the flap interface require lifting of the flap, culture of the infiltrate in the interface, irrigation of the interface with antibiotics, and replacement of the flap.** The patient should receive frequent broad-spectrum topical antibiotics. Depending on the particular situation, the antibiotics should also be effective against atypical mycobacteria (e.g., amikacin or clarithromycin).
- **Close follow-up is required for all suspected infections.**
- **Remove the flap if the condition is not responding to antibiotics or if the flap becomes necrotic.** The flap may be a barrier to antibiotic treatment of a deeper infection.
- **Infection needs to be differentiated from DLK** (see next section).

DIFFUSE LAMELLAR KERATITIS

DLK is also known as diffuse interface keratitis, diffuse interstitial keratitis, and "sands of the Sahara" syndrome. It is a nonspecific sterile inflammatory response to a corneal insult. The insult can vary greatly from apparently uncomplicated LASIK flap creation with a microkeratome or femtosecond laser to foreign material in the interface or an epithelial defect. The onset of DLK is typically within a few days of surgery. Corneal trauma, epithelial erosion, or corneal infection months or years after LASIK can also induce DLK. Symptoms range from none to mild photophobia and/or mild decreased vision to more severe decreased vision. Signs include diffuse haze at the flap interface that usually begins peripherally or paracentrally, and migrates centrally. It often appears "wave-like." There is minimal to no anterior chamber reaction. As DLK progresses, the interface inflammation can coalesce into clumps of inflammatory material. The view of iris details can become obscured. Ultimately, melting of the flap overlying the opacity can occur.

Causes

The cause is multifactorial and includes:

- **Bacterial endo/exotoxins from a sterilizer,** which can cause epidemics of DLK.
- **Meibomian secretions.**
- **Machine cleaner/oils from microkeratome.**
- **Epithelial defect,** either from the surgery or later from trauma or recurrent erosion syndrome.
- **Excessive femtosecond laser energy.**
- **Infectious keratitis, either related to the surgery or occurring months or years later.** Bacterial, adenoviral, and HSV keratitis can cause a secondary sterile interface inflammation (DLK) in addition to the active infection.

Prevention

- **Appropriate sterilization techniques, including proper management of the microkeratome.**
- **Appropriate cleaning of microkeratome equipment.** Disposable microkeratomes may decrease the risk of DLK.
- **Treat and control eyelid margin inflammation and acne rosacea preoperatively.**
- **Avoid intraoperative epithelial defects** (see earlier section).
- **Avoid postoperative trauma.**
- **Properly adjust the energy level of the femtosecond laser.**

Grading and Treatment

The severity of DLK varies from mild to severe and has been divided into grades. Treatment depends on the severity of the inflammation. Needless to say, if the underlying cause is known, it should be addressed. The general principles of treatment are use of corticosteroids (topical and/or oral), coverage with topical antibiotics, lifting the flap in more severe cases to remove inflammatory material, and close

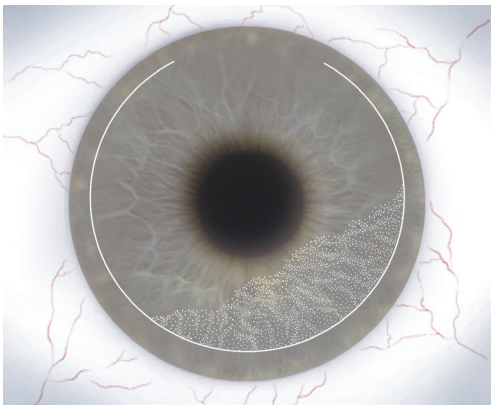

FIGURE 11.5

DLK grade 1: fine cell in flap interface not involving visual axis.

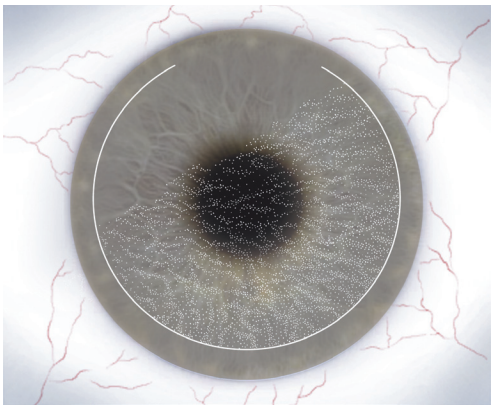

FIGURE 11.6

DLK grade 2: fine interface cell involving the central cornea.

follow-up in all cases. DLK generally resolves over several days to a few weeks. Except for the very mild cases, the condition usually progresses before resolving, despite the use of steroids. The surgeon is advised to have a low threshold for lifting the flap, scraping the interface and undersurface of the flap, and irrigating. This is an effective treatment and should not be considered a last resort. If one is thinking about lifting the flap, do it. Remember that the goal of any treatment of DLK is not simply to clear the inflammation, but also to preserve the refractive correction. Delay in treatment can result in stromal loss with a hyperopic shift and rarely corneal scarring. It is important to explain to the patient the potential seriousness of this condition and the need for aggressive treatment and careful follow-up. The various grades, an illustration of each, and the suggested treatment at each grade follow:

- **Grade 1** (Fig. 11.5): Mild keratitis, typically peripheral, minimal to no symptoms. Treatment: Topical prednisolone 1% every 1 to 2 hours while awake. Follow up within 1 to 2 days.
- **Grade 2** (Figs. 11.6 and 11.7): Moderate infiltration, extending to the central cornea, decreased visual acuity, and/or photophobia. Treatment: Topical prednisolone 1% every hour. Consider adding oral prednisone 60 mg/day. Consider flap lift and interface washout if infiltration is heavy or if DLK is progressing quickly. Follow up in 1 day.
- **Grade 3** (Figs. 11.8 and 11.9): Significant infiltration, central involvement, clumping of inflammation obscuring iris detail, further decrease in visual function. Treatment: Topical prednisolone 1% every hour, oral prednisone 60 mg/day, lift flap and brush stromal bed and undersurface of the flap with a Merocel sponge or gently scrape with a blunt Machat PRK/LASIK spatula (Asico AE-2769), irrigate interface copiously, obtain culture if considering infection. Follow up in 1 day.
- **Grade 4** (Fig. 11.10): Dense white infiltrate centrally with or without melting, marked loss of visual function. Treatment: Lift flap, scrape interface debris, culture, and irrigate. Place a drop of steroid on the stromal bed. Apply topical prednisolone 1% every hour. Continue oral steroids. Follow up in 1 day.

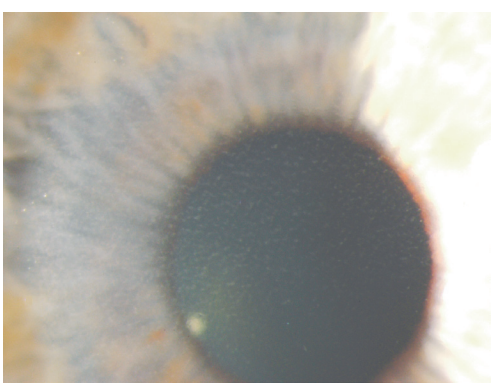

FIGURE 11.7

Clinical appearance of DLK grade 2. (Courtesy of Christopher Rapuano, M.D.)

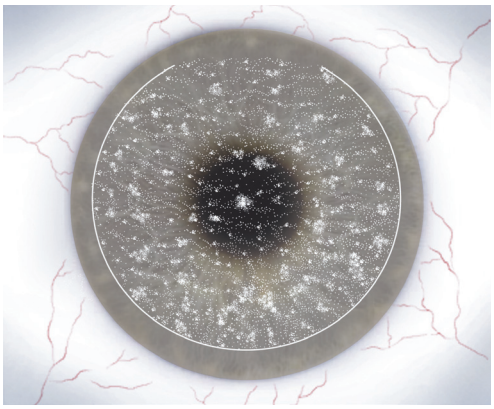

FIGURE 11.8

DLK grade 3: clumping of cellular material within part or the entire interface.

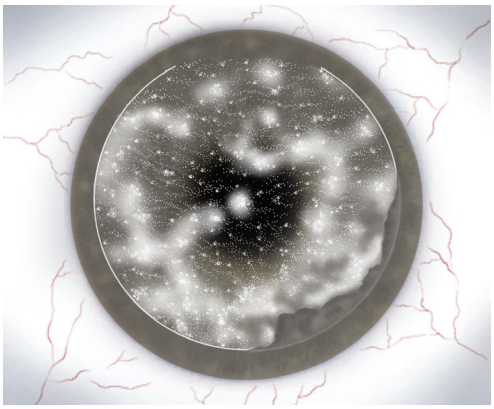

FIGURE 11.10

DLK grade 4: dense infiltrate prevents view of underlying iris detail. Keratolysis can also be seen as illustrated in this drawing.

CENTRAL TOXIC KERATOPATHY

Central toxic keratopathy (CTK) was originally thought to be a severe inflammatory form of DLK, but it is now believed to be a rare noninflammatory condition of unknown etiology. While most commonly reported after LASIK, it has also been seen after PRK and other laser surgeries such as selective laser trabeculoplasty.

Symptoms of poor vision and photophobia generally begin a few days after surgery. Signs include mild to severe central corneal opacification, corneal thinning and flattening (causing a hyperopic shift), and anterior corneal striae (Figs. 11.11A and B).

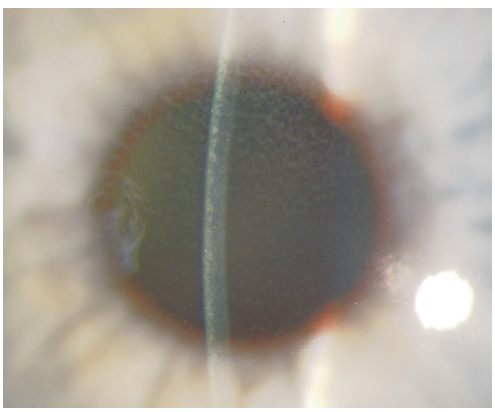

FIGURE 11.9

Clinical appearance of DLK grade 3. (Courtesy of Christopher Rapuano, M.D.)

Cause

- **Unknown**

Prevention

- **Unknown**

Management

- **Steroids are not thought to be helpful.** The induced hyperopia and central opacity tend to improve or resolve over 6 to 18 months. It is important not to proceed with enhancement surgery too soon as the refractive error tends to improve on its own over time.

PRESSURE-INDUCED STROMAL KERATITIS

After LASIK, elevated IOP can cause a sterile PISK that can mimic DLK. The typical history is that the patient was initially placed on topical steroids to treat DLK. The IOP is not routinely measured. A few weeks go by and the stromal keratitis worsens. The IOP is still not measured and the steroids are increased to treat the misdiagnosed "DLK."

Cause

- **Elevated IOP, often a steroid sensitive response.** A fluid cleft may develop in the flap interface (See Fig 3.3 and 3.5, page 44). This fluid cleft causes a falsely low IOP measurement with Goldmann applanation tonometry.

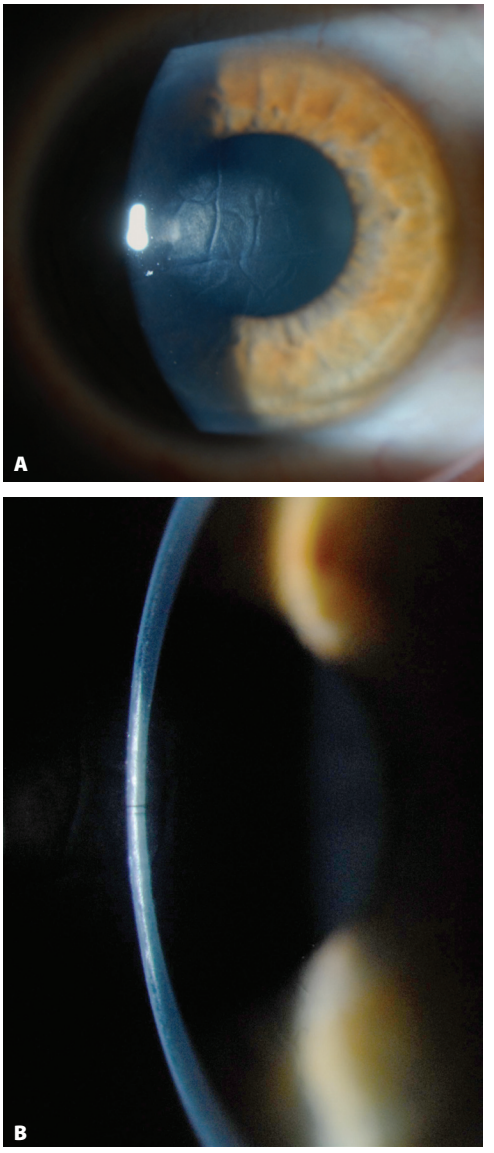

FIGURE 11.11

Severe CTK can be seen in this right eye 11 days after LASIK for –4.5 D. **A:** A broad-beam view highlights the very localized superficial central stromal folds and haze. **B:** The slit-beam view illustrates the central corneal thinning and that the corneal opacity is at the level of the flap interface. (Courtesy of Christopher Rapuano, M.D.)

Prevention

- **Routinely check the IOP approximately 1 week after LASIK,** especially if the patient is using topical steroids, and definitely if DLK is not responding as expected.
- **Consider checking the IOP with a Tono-Pen centrally and peripherally.** A Goldmann tonometer placed outside the flap may also reveal elevated IOP.

Management

- **Taper and stop the topical steroids quickly.**
- **Treat the elevated IOP.** The stromal keratitis should resolve soon after the IOP returns to normal. If course has been protracted, check for afferent pupil and obtain visual fields, stereo disc photos, and optical coherence tomography (OCT) retina/nerve fiber layer if available.

MICROSTRIAE

When a LASIK flap is created, it fits perfectly on the stromal bed beneath it. However, after the excimer ablation of the stroma, the flap and the bed no longer have the exact same curvature, and the flap must conform to a new underlying stromal contour. This can result in the formation of tiny folds within the flap called microstriae. They are commonly seen after LASIK, especially after treatment of high refractive errors, where the "mismatch" is greatest. Microstriae can also occur as a result of excessive flap hydration, which can alter flap-bed alignment. Microstriae can still be seen even when mark alignment is proper and the flap-edge gutter is symmetrical. They often have a "cracked mud" appearance best seen with indirect or retro-illumination (Fig. 11.12) or after instillation of fluorescein. Occasionally, they can also appear as fine parallel lines. The microstriae may be missed immediately after surgery, particularly if the cornea is excessively wet. Microstriae may have little effect on visual acuity or the affected patient may complain about the quality of vision.

Causes

- **Mild flap-bed mismatch once the flap is replaced after the laser ablation.**
- **Epithelial defects may cause flap swelling,** which can accentuate the mismatch and increase the risk of microstriae.
- **Excessive flap hydration.**

Prevention

- **Impossible to completely prevent.** Make sure the flap is well seated after it is replaced.

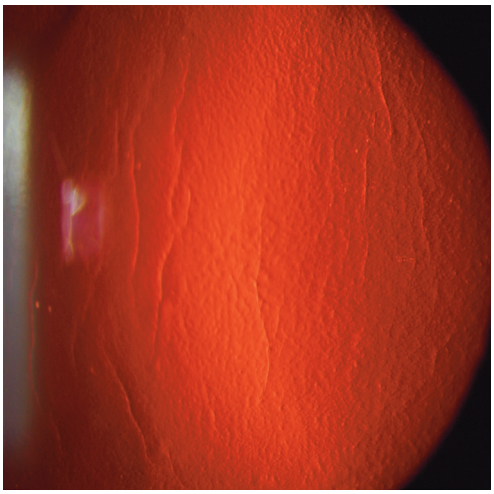

FIGURE 11.12

Microstriae demonstrated on retro-illumination in patient 10 days postoperatively to correct –9.50 + 0.50 × 180. (Courtesy of Robert S. Feder, M.D.)

Check both the ink mark alignment and the gutter width around the entire flap.

- **Prevent epithelial defects as discussed earlier.**
- **Avoid excessive flap hydration during the procedure.**

Management

- **Usually none required because microstriae usually do not affect vision.** However, if central striae are seen at the slit lamp immediately after surgery, refloating the flap is advisable. If vision is affected, see the next section on Macrostriae.
- If the patient is bothered by the quality of vision, even if the visual acuity is good, relifting and stretching the flap can reduce central microstriae and may help relieve these symptoms.

MACROSTRIAE

In contrast to microstriae, macrostriae (also called flap folds [Figs. 11.13A and B]) can significantly decrease visual acuity as well as the quality of vision and typically require treatment. They result from a grossly misaligned flap and can cause a significant irregularity in the tear film, thereby affecting visual function.

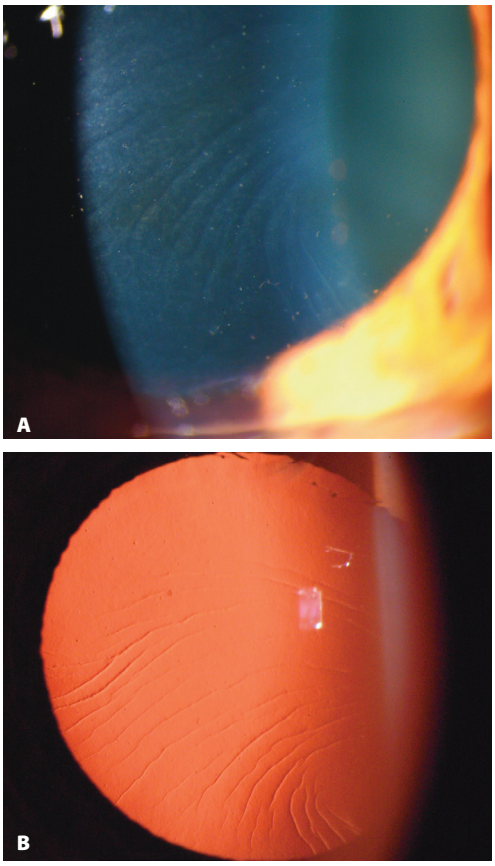

FIGURE 11.13

Macrostriae. **A:** Macrostriae are seen on direct slit-lamp illumination in a patient with BCVA20/30–. **B:** The same cornea in retro-illumination. (Courtesy of Paul J. Bryar, M.D.)

Causes

- **Poor flap alignment at the time of surgery.**
- **Minor trauma after surgery.** May be associated with eyedrop instillation, wiping the eye, or bumping the eye.
- **Poor flap adherence.**
- **Idiopathic.** Occasionally, striae that appear as microstriae on slit-lamp examination cause some irregular astigmatism to occur for unknown reasons.

Prevention

- During surgery, **make certain that the flap is well positioned, marks are well aligned, and the edge gutters are symmetrical.**

- As the eyelash drapes and eyelid speculum are removed, **encourage the patient to continue looking at the fixation light to avoid contact of the drape or speculum with the flap edge.** Lift the speculum upward during removal to prevent bumping the cornea and displacing the flap.
- **Instruct the patient how to safely instill drops, use eye protection, and avoid eye rubbing and trauma.**

Management (See Video 18)

- **Lifting and realigning the flap into proper position** works well when it occurs at the time of surgery or is noted and fixed soon after surgery.
- **Re-lift and stretch the flap** with sponges under an operating microscope, if symptomatic macrostriae are noted on postoperative day 1. Folds noted at the slit lamp immediately after the procedure will usually be gone the next day. Some surgeons will attempt to smooth out striae at the slit lamp. This can be effective right after surgery, but is increasingly less effective over time. Use of hypertonic and hypotonic solutions to dehydrate or hydrate the flap prior to "ironing it out" has been advocated by some surgeons.
- **Suturing the flap** in conjunction with a re-lift may help to reduce macrostriae. The flap is lifted, stretched, and then sutured into position with approximately 6 to 8 interrupted 10-0 nylon sutures. Care should be exercised to avoid inducing new flap misalignment. Some surgeons use a running suture. Sutures should be left in place for 4 to 6 weeks.
- **Removal of the central 4 to 5 mm diameter of epithelium** may be helpful, because the epithelium may be "holding" the striae in position. This may be associated with slow reepithelialization and DLK.
- **Excimer laser phototherapeutic keratectomy (PTK),** in which a masking agent fills the troughs within the folds and the peaks are ablated, has been used to treat visually significant micro- and macrostriae, where the flap does not appear grossly displaced. This procedure may result in a hyperopic shift in refractive error.

DRY EYE SYNDROME/NEUROTROPHIC EPITHELIOPATHY

Irritation, dryness, grittiness, and foreign body sensation are common symptoms after LASIK surgery, particularly when the flap is created with the femtosecond laser. The symptoms can last from several days to months, but usually return to baseline by 3 to 6 months. Rarely, patients can be very unhappy due to prolonged and/or severe symptoms.

Causes

- **During LASIK, the corneal nerves are transected, creating a neurotrophic cornea, which can result in a neurotrophic epitheliopathy.**
- **This neurotrophic effect decreases the feedback loop to the lacrimal glands and can cause a secondary decrease in tear production and a dry eye condition.**
- **The surface of the reshaped cornea may not hold the tear film as well as before, causing secondary wetting problems.**
- **The microkeratome may damage the goblet cells and microvilli, causing a corneal surface problem.**
- **In rare cases, there may be a neuropathic origin to the painful symptoms.**

Predisposing Factors

- **An abnormally low Schirmer's test result, low tear break-up time (TBUT), excessive tear film debris or mucus, and conjunctival and corneal staining with fluorescein, rose bengal, or lissamine green** are indicative of a possible preoperative dry eye syndrome, which predisposes the patient to such problems postoperatively.
- **Low ambient humidity** such as occurs in desert climates or during winter months in northern climates.
- **Wide palpebral fissures, eyelid retraction, or prominent globes** allow for increased tear evaporation.
- **Reduced blinking** resulting from consistent long hours of reading or driving may be associated with increased evaporation.
- **Blepharitis** and **meibomianitis** may also predispose to surface problems after LASIK surgery due to disruption of the tear film.

Prevention

- **Treat dry eye syndrome preoperatively with a combination of artificial tear supplements, topical cyclosporine 0.05% (Restasis), punctal plugs, and nutritional supplements.**
- **Treat blepharitis preoperatively.**
- **Consider performing a nasal hinge LASIK flap,** because theoretically it transects fewer corneal nerves than a superior hinge.
- **Consider a surface ablation procedure,** because it induces less neurotrophic effect and consequently is less likely to compromise tear function.
- **Consider avoiding keratorefractive surgery** in a patient with a high risk of significant postoperative dry eye problems, when the surface problems cannot be satisfactorily improved prior to surgery.

Management

- **To control the commonly encountered superficial punctate keratopathy (SPK) and dry eye symptoms during the first few months after LASIK, patients should all receive frequent preservative-free tears to use during the first postoperative month.** The tears can be changed to minimally preserved tears and their frequency decreased as the SPK and dry eye symptoms improve.
- **Artificial tear gels and ointments may be required** if the tear supplements are not enough.
- **Cyclosporine 0.05% (Restasis) drops twice daily can be very effective in improving tear production and symptoms in patients with dry eyes after LASIK.** While the effect of the cyclosporine can take up to 1 month to observe, the onset of beneficial effects from the vehicle is much quicker.
- **Punctal plugs** can be inserted to improve SPK and symptoms.
- **A personal humidifier at the workstation** can be helpful for patients who spend hours staring at the computer. A humidifier in the bedroom may also be helpful.
- **Encourage good hydration in patients who exercise heavily.**
- **Avoid dehydration in patients on oral diuretic agents and, if possible, reduce the dose of oral allergy medications or other drugs that have anticholinergic side effects.**
- **Rarely, neuropathic pain medications such as gabapentin and pregabalin can be helpful.**
- A temporary lateral tarsorrhaphy can dramatically reduce surface exposure in a patient with a wide palpebral fissure and severe dry eye symptoms and signs. This is rarely, if ever, necessary because such patients are usually counseled to avoid LASIK surgery.
- **Fortunately, the symptoms improve with time in most patients.**

GLARE/HALOES

Glare, haloes, or starbursts around lights, especially in dim illumination, are common for 2 to 6 weeks after LASIK. These symptoms are most frequently noted during nighttime driving. The symptoms generally improve after 6 weeks and then return to "baseline." Patients often have similar symptoms prior to LASIK, but may not notice them until after surgery.

Predisposing Factors

- **High degrees of myopia** are often treated with smaller effective optical zones to preserve residual stromal bed that can increase the likelihood of symptoms.
- **High degrees of astigmatism** may also shrink the optical zone and increase glare and halo symptoms.
- **Large pupils in dim illumination,** generally >6.5 mm, may also increase the chance of glare and haloes. The scientific data on this issue are conflicting. Many surgeons do not believe this is a significant risk factor for nighttime symptoms.
- **Highly anxious patients** may be more likely to complain of glare and haloes at night.
- **Older age** may increase the risk of these symptoms.
- **Residual refractive error** causes defocus that may mimic or worsen glare and halo symptoms. This is a major cause of night vision problems.

- Other factors may be involved but have yet to be identified.

Prevention

- **Inquire during the initial consultation if glare and haloes are experienced at night, particularly when driving at night.** Encourage the patient to pay attention to the quality of vision at night prior to surgery. Awareness of night vision preoperatively can help form a basis for comparison after surgery. If they do have symptoms, have them draw a representation of the visual symptoms and put this drawing in the chart.
- **In patients at higher risk for these symptoms or with significant concerns, consider performing unilateral surgery on the nondominant eye.** If the patient is happy with the result, the dominant eye can be treated.
- **When treating astigmatism, mark the 3 and 9 o'clock axes on the eye preoperatively to help compensate for intraoperative cyclotorsion.** This will help to properly align the astigmatic treatment. Laser software with iris registration should improve the alignment of astigmatism correction.
- **Use of a blend zone (e.g., 8.0 mm) with or without an enlarged optical zone can reduce postoperative night vision problems.** Many surgeons use the largest treatment zone that anatomical constraints will allow in every patient in order to minimize night vision problems.
- **Custom LASIK may reduce the preexisting higher order aberrations (HOAs) thought to be associated with night vision symptoms.** Custom LASIK also may induce fewer HOAs than conventional LASIK.

Management

- **Treat ametropia.** Whether due to initial undercorrection or overcorrection, or due to regression, defocus is a common source of vision problems at night. Treatment can be as simple as a pair of glasses worn only for night driving. An enhancement procedure once the refractive error has stabilized will have a beneficial effect at night to the extent that defocus is improved or eliminated (see Chapter 10).
- **Preventing excessive pupil enlargement in dim light with topical Brimonidine drops or shrinking the pupil size with dilute pilocarpine (1/2% to 1/32%)** can significantly improve symptoms in some patients.
- **A wavefront- or topography-guided peripheral blend or optical zone enlargement** may improve glare and halo symptoms, particularly if HOAs are high. If a custom PreVue lens (VISX) is available, the patient can use this at night to determine the potential value of a custom retreatment.
- **The symptoms often improve with time.** Whether this is due to cornea remodeling, neuroadaptation, a gradual decrease in pupil size over time, or a combination of all of these factors, is unknown.

EPITHELIAL INGROWTH

Epithelial ingrowth occurs when epithelial cells grow under the LASIK flap (see Cases 68 and 69 in Chapter 16). It is commonly noted at the flap edge, advancing inward <0.5 mm. It typically grows centrally and/or circumferentially from a fistulous epithelial track at the flap edge. It can also be seen as an island of epithelium, presumably implanted at the time of surgery. When it is extends beyond 1 to 2 mm from the flap edge, it can cause problems. If it reaches the paracentral cornea, it can cause elevation of the flap and irregular astigmatism. If the epithelium reaches the central cornea, it can actually block the vision. Epithelial ingrowth is often self-limited, remaining stable, but occasionally it can be slowly progressive. Rarely, it can progress relatively rapidly. The sheet of epithelium in the interface can also impede nutrients from reaching the flap. This lack of nutrients can cause SPK or even flap necrosis. This situation is not usually serious at the flap edge, but more centrally it can have a profound impact on vision. Epithelial ingrowth is rather uncommon after primary procedures, but occurs with increased frequency after enhancement surgery or traumatic flap dislocation.

Cause

- **Epithelium under the flap from a fistulous track at the flap edge or implantation of epithelial cells at the time of primary or enhancement surgery or traumatic flap dislocation.**

Predisposing Factors

- **An undetected underturned flap edge that is not remedied immediately following surgery.**
- **An intraoperative epithelial defect,** especially at the flap edge, increases the risk that epithelium will grow under the flap and not over it.
- **Epithelial basement membrane dystrophy** increases the risk of loose epithelium and epithelial defects during surgery.
- **A flap buttonhole** can allow epithelium to grow under the flap.
- **Flap dehiscence patients are at high risk of epithelial ingrowth** because epithelium grows over the stromal bed during the time the flap is out of position. If it is not thoroughly removed from both the stromal surface and the underside of the flap prior to replacement of the flap, it will continue to grow in the flap interface.
- **Free cap.**
- **Flap-lift enhancement surgery** increases the risk of epithelial ingrowth because when the flap is lifted, the epithelial edges are ragged. These ragged edges tend to heal somewhat more slowly, increasing the risk that some cells will grow under the flap.
- **Hyperopic ablations tend to be wider than myopic ablations,** and occasionally the laser treatment spills out onto the epithelium outside the stromal bed. This epithelial damage may cause difficulty with healing, thereby increasing the risk of ingrowth.
- **Older patients have been shown to have a higher tendency toward epithelial ingrowth,** perhaps because the epithelium is often less adherent.
- **Microkeratome flaps** are more prone to epithelial ingrowth than femtosecond laser flaps due to the construction of the side cut (see Fig. 5.1).

Prevention

- **Use a bandage contact lens to facilitate rapid healing** if epithelial irregularities occur during surgery. While most surgeons will use a contact lens to facilitate healing, it has been suggested that a bandage contact lens may actually increase the incidence of epithelial ingrowth.
- **Take steps to avoid epithelial defects and buttonholes.** See earlier sections.
- **Meticulous epithelial tag replacement at the time of enhancement surgery.**
- **Educate the patient regarding avoiding trauma to the flap.**
- **Careful but aggressive removal of all epithelium from the stromal bed surface and the underside of the flap prior to replacement of a dehisced flap.**
- **Create large flaps for hyperopic treatment to avoid ablating the epithelium.**

Management (See Video 17)

- **Treatment is required when the epithelial ingrowth is causing problems either with flap health (SPK, epithelial defect, flap necrosis), vision (irregular astigmatism or central opacity), or chronic irritation.** Serious consideration should be given to treating ingrowth progressing ≥2 mm from the flap edge.
- **Surgical treatment of primary epithelial ingrowth:**
  - At the slit lamp, mark the involved area with a sterile surgical marking pen and lift the edge of the flap with a Sinskey hook or Machat LASIK enhancement spatula (Asico AE-2830).
  - Under the laser microscope, mark the flap edge for later realignment, gently open the edge of the flap with a Rosenfeld Glide Dissector (Storz E9086) or other blunt instrument designed for this purpose, and lift the flap with a cyclodialysis spatula.
  - Aggressively, but carefully, remove all epithelial cells from the stromal bed and underside of the flap. A Tooke knife or sharp blade is very helpful, but special care must be taken when scraping the underside of the flap to avoid damaging

it. A Machat PRK/LASIK spatula (Asico AE 2769) also works well.
  - Replace the flap, remove redundant epithelium from the flap edge, irrigate the interface, and line up all the epithelial tags. Consider placing a BSCL, especially if the epithelial edges are ragged.
- **Surgical treatment of recurrent epithelial ingrowth:**
  - Repeat the lift and scrape procedure described above.
  - Consider suturing the flap. The technique is identical to the one just described with the addition of interrupted or a running suture to secure the flap edge.
  - Fibrin glue can be placed at the flap edge to seal the flap and prevent recurrent epithelial ingrowth.
  - Some surgeons use absolute alcohol or PTK to eliminate residual epithelial cells; however, these can damage the cornea.

CORNEAL ECTASIA

Corneal ectasia is a thinning and protrusion of the cornea, similar to what is seen in keratoconus, which can occur after LASIK or PRK. It leads to irregular astigmatism and may be progressive.

Cause

- **LASIK surgery weakens the corneal stroma,** leading to progressive corneal thinning and protrusion.

Predisposing Factors

- Randleman and colleagues[1] evaluated 171 ectasia cases (96% LASIK) that developed following excimer ablation. Regression analysis was used to determine the most significant factors that distinguished these patients from uncomplicated controls. **These factors in declining order of significance were abnormal preoperative topography, residual stromal bed thickness, patient age** (younger being more risky), **and preoperative corneal thickness.**
- Abnormal corneal topography. **Forme fruste keratoconus, also called subclinical keratoconus, and pellucid marginal degeneration greatly increase the risk of progressive ectasia following LASIK.** Inferior steepening, superior flattening, skewing of radial axes, paracentral islands of elevation, and eccentric areas of corneal thinning are abnormal findings that may increase the risk of post-LASIK ectasia. For in-depth discussion, refer to Chapters 1, 2, and 12.
- **A residual stromal bed thickness <250 µm is likely to weaken the cornea excessively and increases the risk of ectasia.** The stromal bed thickness is related to the thickness of the flap and the amount of tissue removed with the excimer laser. The safety of this 250-µm barrier has not been proven. Some patients may require a thicker barrier. Some surgeons prefer a residual stromal bed thickness of 300 µm.
- **Treatment of high myopia and use of thick flaps decrease the residual stromal bed thickness.**
- **A residual stromal bed thickness of <50% of the original corneal thickness may also excessively weaken the cornea and predispose to ectasia.**

Prevention

- **Review the preoperative corneal topography,** carefully looking for preexisting irregularity in contour and/or elevation, mild keratoconus, and pellucid marginal degeneration.
- **Measure the corneal thickness preoperatively after a period of contact lens abstinence.** Calculate the expected residual bed thickness for each patient.
- **Always use the refraction prior to nomogram adjustment to calculate ablation depth and do not use the ablation depth calculated by the laser.** This is known as the nomogram-adjusted ablation depth.
- **Consider measuring the flap thickness intraoperatively using the subtraction technique (see section on Flap Thickness, Chapter 1) to be sure there is adequate residual stromal bed thickness for the planned ablation**.

- **Consider a surface ablation procedure or consider an alternative to keratorefractive surgery if there is an increased likelihood of ectasia.**
- **Adhere to a guideline** that is relatively safe based on the recommendations of experienced surgeons and one that is compatible with the risk tolerance of the individual patient and surgeon. Be aware that some patients will not develop ectasia even when their clinical characteristics suggest increased risk. The challenge is in knowing preoperatively how a given patient will respond in the long term. Recognize that even when the surgeon follows the suggested guidelines, the rare patient may still develop the clinical signs of ectasia. Examples of such guidelines are listed below:
  - Avoid LASIK if the Randleman risk ectasia score is >2 (see Chapter 1, Tables 1.6 and 1.7)
  - Avoid LASIK, if the corneal thickness is <500 µm, and avoid PRK when <475 µm
  - Consider alternatives to LASIK if residual stromal bed is predicted to be <250 µm (some surgeons prefer to use 275 µm or even 300 µm) or <50% of original thickness
  - Avoid LASIK, if corneal topography out of contact lenses is consistently abnormal
  - Avoid LASIK on a patient with a normal cornea if there is ectatic disease in the fellow eye. Some surgeons also avoid LASIK in patients who have parents or siblings with a corneal ectatic disease such as keratoconus or pellucid marginal degeneration.
- If there is heightened risk of ectasia, be certain to **discuss** this with the patient preoperatively **and document** the discussion with the patient.

Management

- **A rigid gas-permeable contact lens is often able to restore excellent vision in eyes with ectasia.** The fitting may be challenging just as it is in keratoconus patients.
- **Intrastromal ring segments (e.g., Intacs) may be successful in improving vision or contact lens wear in some eyes with ectasia.** However, they may not stop progressive ectasia.
- **There may be a role for corneal collagen cross-linking in the treatment of post-LASIK ectasia (see Chapter 12 and Cases 87 and 88).**
- **Cornea transplant may be required to restore vision in contact lens–intolerant cases.**

CENTRAL ISLANDS

A central island is a small, localized area of steep corneal curvature within the central cornea, which is identified after excimer laser ablation. A central island is not unique to LASIK and is, in fact, more common after surface ablation. It causes decreased uncorrected and best-corrected vision, ghosting, and haloes due to irregular astigmatism. It is usually noted a few days to a few weeks postoperatively, when the vision is not as good as expected and corneal topography is obtained. Topography demonstrates a central area of steepness on the order of 1.5 to 3.0 D and measures 1.5 to 2.5 mm in diameter.

Cause

- The cause of central islands is multifactorial and includes **beam profile abnormalities, ablation plume blocking subsequent central laser pulses, and unequal central stromal hydration during the ablation.** Material in the treatment zone such as epithelium, blood, or fluorescein on the pachymeter tip may also interfere with the ablation.

Predisposing Factors

- **More common after PRK than LASIK.**
- **Broad-beam excimer laser ablations are more commonly associated.**
- **More common in high myopic treatments and with larger ablation zones.**
- **A persistent postoperative epithelial defect also increases the risk of central islands.**

Prevention

- **Many laser ablation profiles have incorporated anti–central island patterns.**
- **Prevention of persistent epithelial defects may also help.**
- **Use a pachymeter tip dedicated to the laser suite that is used only for intraoperative pachymetry.**
- **Make certain the interface is clean and smooth before proceeding with the laser ablation.**

Management

- **After PRK, most central islands resolve without additional laser treatment over 3 to 12 months.**
- **After LASIK, central islands tend not to resolve spontaneously.** If they do not resolve after 3 months, they can be treated with a small-diameter (2- to 3-mm), low-myopic PRK treatment. A wavefront-guided custom ablation may also be an option. A custom PreVue lens (VISX) may help determine if the custom ablation would relieve symptoms.

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chapter 12

Collagen Cross-Linking for Ectasia Following Keratorefractive Surgery

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Post-LASIK Ectasia: Background and Clinical Presentation

LASIK surgery is generally considered to be safe and effective for the treatment of myopia when patients are carefully screened for risk factors. The incidence of complications is fortunately quite low, and most problems are relatively easy to handle. In contrast, the management of progressive corneal thinning and ectasia following keratorefractive surgery has become a major postoperative challenge and remains of great concern. Clinically, eyes with iatrogenic ectasia develop progressive steepening centrally or inferiorly, leading to significant and progressive increase in myopia, irregular astigmatism, increase in high order aberrations (coma), loss of uncorrected visual acuity (UCVA), and corneal thinning. Central ectasia can usually be adequately corrected with glasses or contact lenses, but inferior ectasia is often associated with loss of best-corrected visual acuity (BCVA). Ectasia can occur from a few weeks to 45 months after the primary surgery.[1] The median time of diagnosis of postoperative LASIK ectasia was reported to be 13 months.[2]

Corneal ectasia after LASIK was first described in 1998[3]; more than 200 cases have now been reported in the literature. The incidence of post-LASIK ectasia has been estimated to be between 0.04% (1:2,500)[4,5] and 0.66% (1:150).[6] Fortunately, however, the predicted epidemic of iatrogenic ectasia 20 years after LASIK has not occurred.[7]

Why Does Ectasia Occur?

In LASIK both the lamellar cut and the tissue ablation contribute to a reduction in the biomechanical strength of the cornea.[6] This is because the LASIK flap no longer contributes to the load-bearing function of the cornea and the posterior stroma is significantly less stable biomechanically.[8] Both LASIK and radial keratotomy (RK) patients seem to be predisposed to the development of iatrogenic ectasia[9–11] while it is less likely following photorefractive keratectomy (PRK).[12] Using the Ocular Response Analyzer (ORA), a decrease in mean corneal hysteresis (CH) from 11.52 to 9.48 mmHg and in mean corneal resistance factor (CRF) from 11.68 to 8.47 mmHg has been found following LASIK surgery.[13,14] Also, the effect of creating flap without stromal ablation reduces CH by 1 mmHg and CRF by 1.8 mmHg.[15] Clinically, the LASIK flap can still be lifted after many years. Histopathologically, only epithelial thickening at the flap edge and a hypocellular primitive scar without myofibroblasts[16] composed primarily of large proteoglycans and a disorganized network of interspersed smaller than normal diameter collagen fibrils have been found.[17,18] Measurements of the tensile wound strength of the flap margin at its peak of healing had a tensile strength of 28% of normal controls, while the central and paracentral flap scar

showed an average of only around 2% to 3% of normal controls.[19] In porcine eyes with 300-µm thick flaps, a significant decrease in CH from 8 to 5.1 mmHg and CRF from 8.2 to 4.1 mmHg was measured, whereas there were no significant changes in 100-µm thin flaps, demonstrating that thick LASIK flaps have a more profound biomechanical insult.[20] Similar to keratoconus, the decreased biomechanical strength eventually can lead to a so-called "interfiber fracture" with interlamellar and interfibrillar slippage,[21] while simple stretching of the fibrils could not be confirmed. Breaks of Bowman layer are rare in post-LASIK ectasia.[22]

Risk Factors for Post-LASIK Ectasia

While the risk factors for ectasia have been presented elsewhere in this handbook (Chapters 1 and 11), these issues are of such significance that they are again presented here to provide context and completeness for the discussion of collagen cross-linking (CXL). It is hoped that it will be particularly helpful for readers who use the book as a "go to" reference and not an inconvenience for those reading cover to cover.

Risk factors for the development of post-LASIK ectasia include young age, high myopia (>8 diopters [D]), reduced corneal thickness, low residual stromal bed (RSB) thickness, preexisting keratoconus, pellucid marginal degeneration or forme fruste keratoconus, greater residual myopia, and greater stromal ablation.[1,2,4–6,23,24] A practical scoring system with a cumulative risk score has been proposed by Randleman, taking into account the following five factors: topography pattern, RSB thickness, age, preoperative corneal thickness, and preoperative spherical equivalent manifest refraction (see Chapter 1 [Tables 1.6 and 1.7] and Chapter 11).[20] Anterior bulging of the posterior corneal surface has been described as an early indication of imminent corneal ectasia.[21] This can be seen on a posterior elevation map, the so-called "posterior float." When the posterior float is created on an Orbscan (Bausch & Lomb, Rochester, NY), the maximum elevation above a best fit sphere should not exceed 50 µm centrally because this might indicate forme fruste keratoconus.[5,25] Caution is advised when this Orbscan value is >40 µm. Using the Pentacam (Oculus, Lynnwood, WA), it has been recommended that the maximum central elevation for a pre-LASIK cornea should not exceed 11 µm anteriorly or 20 µm posteriorly. A LASIK screening algorithm based on corneal topography indices and Orbscan II analysis measuring the posterior float has been proposed to exclude keratoconus suspects from LASIK.[25] A more detailed discussion of corneal topography can be found in Chapter 2.

Although it is still somewhat controversial, it has been suggested that one leave a residual stromal bed thickness of ≥250 µm or ≥50% of the total preoperative corneal thickness.[5] The total corneal thickness should generally not be <500 µm.

Rare cases of post-LASIK ectasia in the absence of the typical preoperative risk factors and only low to moderate myopia have been described and are alarming.[5,26] Therefore, potential risk factors like young age or an innate biomechanical weakness of the cornea of the individual have been suggested.[5] The concept of a chronic disease process due to an increased activity of degradative proteolytic enzymes, subclinical interface inflammation, and loss of keratocytes in the anterior flap instead of a purely mechanical process has been hypothesized as well.[27]

In addition, the accuracy of the flap thickness, especially with mechanical microkeratomes, can vary significantly with diameter deviations of up to 300 µm and thickness standard deviations of up to 30 µm.[1,5,28–31] Thick flaps can lead to a greater decrease of the biomechanical strength. Therefore, thin flaps using a femtosecond laser may be advantageous.[20] Dehydration of the stromal bed caused by prolonged exposure during surgery can increase the ablated tissue mass, leading to more ablation than calculated.[5]

Post-LASIK Ectasia Management

Management of these patients is directly related to the degree of ectasia and the level of

visual disability. Careful documentation of the refractive status, including cycloplegic refraction, slit-lamp examination, and corneal contour mapping, including power, elevation, and pachymetry maps, is essential. Optical coherence tomography (OCT) imaging, if available, can be helpful as well (see Chapter 3). This careful evaluation and documentation enables the clinician to adequately follow the patient and determine the rate of progression. These patients are often confused and frightened, and a clear, calm explanation of both the condition and an appropriate management strategy will be much appreciated. Improving visual function will, however, be the most helpful way of reducing anxiety.

The refractive consequences of post-LASIK ectasia usually can be corrected effectively with rigid gas-permeable contact lenses, but best-corrected visual acuity is often significantly worse than it was preoperatively, and about 20% of the cases may require deep anterior lamellar keratoplasty (DALK) or penetrating keratoplasty due to contact lens intolerance.[32,33] Secondary glaucoma, graft rejection, or other untoward effects do occur and must be explained. The keratoplasty rate has been reported to be 10% to 35% in post-LASIK ectasia patients,[2,32] just as in progressive keratoconus. Alternatively, intrastromal corneal ring segments (ICRS), inserted into a corneal tunnel, may improve visual acuity in iatrogenic ectasia. The ring segments induce central corneal flattening by occupying peripheral space in the stroma. The magnitude of flattening is directly proportional to the thickness of the implant and inversely proportional to its diameter. They are placed on the steep keratometric axis or around the cone. Possible problems are patient discomfort, infection, ring segment extrusion, anterior stromal necrosis, intrastromal deposits, and regression of the refractive effect.[34–36]

Cross-Linking Treatment of Post-LASIK Ectasia

Photochemical corneal cross-linking treatment of progressive keratoconus, similar in many respects to post-LASIK ectasia, was introduced in 2003 by Wollensak, Spoerl, et al. and has proved to be successful in halting and partially reversing corneal ectasia in progressive keratoconus.[37,38] In standard CXL, the epithelium is removed and 0.1% riboflavin–20% Dextran T500 solution is instilled onto the cornea preoperatively every 3 minutes for 30 minutes and intraoperatively every 3 minutes. Ultraviolet-A (UVA) light irradiation of 370 nm is then applied for 30 minutes with a surface irradiance of 3 mW/cm^2 (equal to a dose of 5.4 J/cm^2). Postoperatively, a bandage contact lens, antibiotic, and non-steroid anti-inflammatory drops (NSAID) are administered until healing of the epithelial defect.[37,39]

CXL is based on the production of reactive oxygen species (ROS) by UVA light A light of 370 nm wavelength and the photosensitizer riboflavin, inducing covalent intra- and interfibrillar collagen and proteoglycan cross-links in the anterior 300 µm of the cornea.[39] Ex vivo biomechanical measurements in human corneas have shown an increase in corneal tensile strength by about 300% after CXL. Keratocyte apoptosis 24 hours after cross-linking and subsequent keratocyte repopulation and corneal remodeling has been observed in the anterior stroma both on histology and confocal microscopy. The stromal thickness should be no less than 400 µm to avoid the cytotoxic endothelial dose of 0.36 mW/cm^2.[39]

Because of the great similarities between progressive keratoconus and post-LASIK ectasia, it is only logical to use CXL treatment to stop the "freefall" of iatrogenic ectasia. Cross-linking experiments in organ-cultured bovine corneas with anterior flaps showed a threefold increase of the adherence of the flap using extensometer measurements pulling and detaching the flap from the underlying stromal bed. The effect was strongest immediately after cross-linking but decreased slightly after 4 weeks.[40] Although cross-linking does not increase the interlamellar cohesive force,[41] cross-linking of the flap including the hinge stabilizes both the flap against wrinkling and displacement and the underlying stroma against ectasia, creating inter- and intrafibrillar collagen cross-links (Fig. 12.1).

Starting in 2005,[42] patients with post-LASIK ectasia have been treated (Table 12.1). Data from several studies including a controlled prospective randomized study with

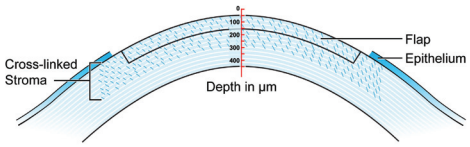

FIGURE 12.1

Scheme of the cross-linked corneal stroma after LASIK. Note that 150 µm of the remaining stroma beneath the flap gets cross-linked.

1 year of follow-up are already available.[44,50–54] All studies have shown a stabilization of corneal ectasia after cross-linking treatment but the effect seems to be less robust than in keratoconus because of the persistent lack of biomechanical contribution by the severed flap to the stromal biomechanical stability.[44] Interestingly, a pregnancy-related exacerbation of post-LASIK ectasia despite stabilization by CXL for 22 months was possibly observed in one case.[45] Similarly, pregnancy has also been shown to trigger post-LASIK corneal ectasia,[55] and estrogen treatment of organ-cultured porcine corneas has been shown to induce a reduction in corneal stiffness by 36%,[56] similar to cortisol.[57] While long-term data are not yet available, cross-linking may one day be a proven modality in the surgeon's armamentarium for treating this rather desperate situation.

Risks of Cross-linking Treatment

Corneal cross-linking is a safe and efficacious treatment modality when performed according to the standard rules. Early benign transitory haze of the anterior stroma due to lacunar

TABLE 12.1 Studies on Collagen Cross-Linking for Post-LASIK Ectasia

Authors	Country	Design (*n*)	Follow-up	Outcome
El Wahab and El Fayoumi[43]	Kuwait	Prospective, non-randomized (20)	24 mo	BCVA improved from 0.4 to 0.64; Kmax decreased from 50.1 to 49.11 D; anterior float decreased from 38.51 to 31.45
Hersh et al.[44]	USA	Controlled prospective randomized (28)	1 y	Decrease of Kmax by 1 D, improvement of UDVA from 20/112 to 20/89, slight improvement in CDVA from 20/37 to 20/31, no change in corneal thickness, corneal hysteresis, and corneal resistance factor
Hafezi and Iseli[45]	Switzerland	Case report (2)	29 mo	Decrease of Kmax by 2.7 D within 2 y, increase of Kmax in the 6th mo of pregnancy in one eye
Hafezi et al.[46]	Switzerland	Case series (10)	Up to 25 mo	Decrease of Kmax in five eyes by ≥2 D, increase in BCVA
Kohlhaas et al.[42]	Germany	Case report (2)	18 mo	Stabilization of Kmax and astigmatic axis
Kymionis et al.[47]	Greece	Prospective comparative case series (5)	1 y	Wound healing response like in keratoconus on confocal microscopy
Salgado et al.[48]	Germany	Prospective, non-randomized (22)	1 y	Stabilization of Kmax, UCVA, BCVA
Vinciguerra et al.[49]	Italy	Prospective, non-randomized (13)	3–12 mo	Stabilization of steepest meridian keratometry, Klyce and Ambrósio indices, slight increase in BSCVA from 20/35 to 20/25

Abbreviations: CDVA, corrected distance visual acuity; BSCVA, best spectacle–corrected visual acuity; UDVA, uncorrected distance visual acuity.

edema can be found in most cases leading to some glare in the first 3 months postoperatively.[39,54] In rare cases, infectious keratitis, Herpes reactivation, scarring, sterile infiltrates, and acute melting with perforation due to endothelial damage have been reported.[39] It is therefore mandatory to perform a preoperative pachymetry. Corneas with <400 µm stromal thickness endangering the integrity of the endothelium should only be cross-linked after appropriate preoperative and intraoperative stromal swelling induced by the application of hypo-osmolar riboflavin drops that must be continued throughout the UVA irradiation.[58,59] The standard 0.1% riboflavin–20% Dextran T 500 solution can lead to a corneal thinning effect of about 75 µm.[60] Diffuse lamellar keratitis has been reported in one case after CXL treatment for post-LASIK ectasia.[61]

Future Directions

CROSS-LINKING COMBINED WITH REFRACTIVE CORRECTION

The future of cross-linking treatment of iatrogenic ectasia may lie in the correction of both the biomechanical and refractive sequelae of ectasia using cross-linking combined with refractive corrections. Cross-linking plus insertion of intracorneal ring segments has been reported with the application of cross-linking 1 day or 1 month after the Intacs operation achieving UCVA of 20/30 eight months after the combination procedure.[36,62] If cross-linking is performed first, the power of the femtosecond laser has to be modified and ICRS insertion is more difficult.[63] Therefore, it seems preferable to first insert the rings and then perform cross-linking with better refractive effect in concurrent ICRS insertion compared to a two-step, sequential procedure.[64] Cross-linking plus topography-guided PRK has been successfully used in a patient with post-LASIK ectasia, leading to an increase of UCVA from 20/100 preoperatively to 20/40 12 months postoperatively.[65] Cross-linking plus conductive keratoplasty seems to be less promising because the refractive effect lasts only for a few months.[66] Suturing and tightening the flap with the addition of cross-linking has also been proposed to induce stabilization of the suture effect following suture removal.[67] Also, if the thin flap technique with the femtosecond laser has been used, this may provide additional stabilization.[20,68]

POSTERIOR CROSS-LINKING

A potential problem with cross-linking treatment of post-LASIK ectasia is that most of the cross-linking effect occurs in the anterior stroma,[39,69] a region that has become biomechanically decoupled from the posterior stroma following creation of the LASIK flap as seen on anterior segment OCT.[70] An alternative approach of lifting the flap and performing cross-linking of the posterior stroma might be preferable, although it is more risky for the endothelium. Using this approach, it would probably be good to swell the posterior stroma before and during the procedure using hypo-osmolar riboflavin solution without dextran.[58,59] This technique might also be more efficacious because the posterior stroma is biomechanically about 50% weaker than the anterior stroma.[8]

PROPHYLACTIC TREATMENT

A new approach to the problem of post-LASIK ectasia might be the prophylactic cross-linking treatment of LASIK patients either as a two-step procedure before LASIK or right after LASIK in one session. If cross-linking is performed before the LASIK procedure, alterations like an increased flap thickness or a slightly different ablation rate have to be taken into account.[71] In the one-step procedure, routine LASIK would be performed first followed by immediate accelerated cross-linking because an additional 30 minutes of standard cross-linking would be hard for the patient to bear. In this variation, the riboflavin solution can be administered into the flap interface without de-epithelialization. Also, the irradiation time and dose level are changed from the standard 3 mW/cm^2 and 30 minutes of irradiation to an equivalent dose of 7 mW/cm^2 for 15 minutes[72] or even 30 mW/cm^2 for only 3 minutes, for example. First studies have been started, but so far no long-term data are available.

In summary, post-LASIK ectasia is due to both the surgical lamellar cut and the ablation

of stromal tissue weakening the corneal biomechanical strength. Risk factors for the development of post-LASIK ectasia include high myopia (>8 D), reduced corneal thickness, low residual stromal bed (RSB) thickness, preexisting keratoconus or forme fruste keratoconus, greater residual myopia, and greater stromal ablation. To reduce the risk for the development of post-LASIK ectasia, an RSB thickness of ≥250 μm or ≥50% of the total preoperative corneal thickness should be left intact.

Thin flap LASIK using the femtosecond laser may reduce the risk for post-LASIK ectasia. Visual rehabilitation of post-LASIK ectasia includes the use of rigid contact lenses, insertion of intracorneal ring segments, deep anterior lamellar keratoplasty, or penetrating keratoplasty.

Stabilization of post-LASIK ectasia can be achieved using corneal cross-linking. Additional refractive corrections by topography-guided keratectomy or insertion of intracorneal rings are possible and should preferably be performed in one concurrent operation. Prophylactic cross-linking treatment right after LASIK using accelerated cross-linking with a shorter irradiation time and a higher-than-standard dose may be the future technology in LASIK patients with significant ectasia risk factors. Cases 87 and 88 are representative of CXL for post-LASIK ectasia.

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SECTION VI

Other Surgical Considerations

chapter 13

Role of Mitomycin-C in Keratorefractive Surgery

PARAG A. MAJMUDAR

Mitomycin-C (MMC) is an antibiotic derived from *Streptomyces caespitosus,* and its cross-linking properties enable it to bind to DNA and prevent replication. For that reason, this alkylating agent was originally used as a systemic chemotherapeutic agent. In a manner similar to the way in which MMC prevents replication of neoplastic cells, it can prevent fibroblastic proliferation as well. This property was recognized to be beneficial in prolonging the success of glaucoma filtration surgery, and its use in this capacity is commonplace. In addition, MMC has also proven to be helpful in the management of corneal intraepithelial neoplasia and pterygium. More recently, MMC has become increasingly accepted for use in refractive corneal surgery as a modulator of wound healing following excimer laser surface ablation.

A well-recognized, but perhaps poorly understood, complication of corneal surface ablation with the excimer laser is the development of corneal haze. Its incidence has fortunately diminished with the advent of more sophisticated excimer laser technology. The improved technology has allowed for a more homogeneous distribution of laser energy, which may result in smoother ablation of the corneal stroma and may prevent activation of stromal keratocytes. These activated keratocytes deposit ground substance and abnormal collagen, which is thought to cause clinically significant haze. Nonetheless, corneal haze is still seen following surface excimer laser procedures. Despite the initial promise of laser-assisted subepithelial keratectomy (LASEK), haze can be seen following this procedure as well.

In 1991, Talamo et al.[1] described an animal model of photorefractive keratectomy (PRK) haze and analyzed the effects of MMC on haze prevention. Their results showed that eyes treated with MMC developed significantly less corneal haze. Our group described the first human series of eyes to receive treatment with MMC for post-PRK corneal haze. In those

early cases, recurrent corneal haze resulted in severe visual disability and patients were contemplating corneal transplantation. We postulated that the antiproliferative effect of MMC on the activated stromal keratocytes might prevent further haze formation, and developed the protocol for the treatment of corneal haze following surface excimer laser ablation, which is widely accepted today.

Because MMC was successful in preventing recurrence of existing haze, the protocol was expanded for prophylactic use in patients predisposed to the development of corneal haze following primary surface ablation for high myopia, and surface ablation over irregular LASIK flaps, such as buttonholes. Although this application of MMC remains controversial, there is evidence that it can be safe and effective (See Videos 6 & 7).

Treatment of Existing Corneal Haze with Mitomycin-C

The technique of superficial keratectomy with MMC for existing corneal haze is described in this section. It is important to note that MMC in no way eradicates corneal haze; rather, MMC prevents the stromal keratocytes from depositing additional scar. Therefore, it is imperative that the scar be completely removed. Two methods are used to remove scar tissue: mechanical debridement using a 64 Beaver blade or a diamond-dusted burr, like that used for pterygium removal and excimer laser phototherapeutic keratectomy (PTK). Both methods may work equally well. In either case, multiple intraoperative slit-lamp examinations may be required in order to gauge the efficacy and determine the end point of the keratectomy. When using PTK, care must be taken to vary the distribution of pulses throughout the corneal surface in order to reduce the likelihood of unwanted hyperopic shifts.

Once the scar has been removed, it is of the utmost importance to follow the protocol for MMC application meticulously in order to prevent potential complications. This begins with procurement of the medication. Significant deviation from the concentration and duration of exposure can lead to vision-threatening adverse events. Our protocol is to have MMC 0.2 mg/mL (0.02%) prepared by an independent compounding pharmacy in order to minimize errors in dilution. A common area of confusion is the unit of measure for the MMC; 0.02% is equivalent to 0.2 mg/mL, but there have been anecdotal case reports of 0.2% being used. This is 10 times the suggested concentration and results in severe endothelial toxicity.

Once the MMC has been correctly prepared, 1-mL aliquots may be frozen for several weeks until ready for use. The MMC is thawed prior to surgery and placed in an empty disposable contact lens well. Proper application of MMC to the corneal surface is best achieved by using a 6- to 8-mm circular Merocel sponge (Beaver-Visitec International, Inc., Waltham, MA), commonly used in the operating room to shield the retina from microscope-induced phototoxicity. The advantage of the corneal light shield over a spear is that the light shield achieves better contact with the corneal surface and, more importantly, prevents excess MMC from coming into contact with the limbus. Limiting the spread of MMC is critical in reducing potential postoperative complications. The corneal light shield is placed in the MMC solution at the beginning of the case and is left in the solution until needed.

During application of MMC, care should be taken to ensure that the shield is wet but not dripping with MMC. It is placed on the central cornea, and the surgeon must meticulously monitor the surface to prevent MMC from coming into contact with the limbus and conjunctiva. The duration of exposure is exactly 2 minutes. After the allotted exposure time, the MMC-soaked sponge is carefully removed and discarded, a cellulose sponge is used to remove any excess MMC left on the cornea, and the surface of the eye is vigorously irrigated with 30 mL of balanced salt solution. These steps remove excess MMC from the corneal stroma, and will also help to minimize potential complications.

Typical post-keratorefractive surgery medications are administered—topical antibiotics, corticosteroids, and nonsteroidal anti-inflammatory agents—and a therapeutic bandage contact lens is placed. The cornea is carefully

monitored for reepithelialization, which typically occurs in 3 to 5 days. The patient should be forewarned that visual recovery may be slow, and that the final refractive error is difficult to predict. The possibility of the future need for refractive treatment should be explained.

Despite advances in the prophylactic use of MMC in which shorter applications of MMC may be preferred (as described below), when faced with existing scar, the therapeutic dose of MMC remains at 0.2 mg/cc for 2 minutes. While attempts at shorter durations have resulted in recurrent haze, a randomized clinical trial has not been designed to address this issue. Given its success, the 2-minute application remains the preferred dose for management of existing stromal haze.

Prophylactic Treatment with Mitomycin-C

Mitomycin-C may be used selectively in primary surface ablation cases, in order to prevent the development of corneal haze in predisposed patients. The definition of the high-risk patient following surface ablation has evolved, especially after the introduction of the newer generation excimer lasers. Early in the PRK experience, it was felt that the threshold for developing haze was a surface ablation to correct more than 6.00 diopters (D) of myopia. Patients were often counseled that in ablations > −6.00 D, the risk of haze was significant. However, assigning a haze potential to a particular dioptric level of correction appears arbitrary. This became very evident with the introduction of the flying spot lasers, which not only removed more tissue per diopter of correction, but also gave surgeons the ability to expand the treatment zone. Munnerlyn's formula, $S = d^2 \times D/3$, where S is ablation depth, d is ablation diameter, and D is correction in diopters, dictates that with expanded optical zones, the depth of ablation is directly correlated with the square of the ablation diameter. Patients began to develop haze following surface ablation for as little as −4.00 D of myopia if a larger optical zone, such as 8 mm, was selected. Intuitively, the potential for haze is correlated with the total amount of energy delivered to the cornea, and this in turn is directly related to the depth of ablation.

Our definition of high risk has changed to incorporate the total depth of ablation, not just the dioptric level. Because a −6.00 D myopic ablation with a first-generation broad-beam laser with a 6-mm optical zone equates to a depth of ablation of 72 µm, our criteria for the use of prophylactic MMC is 75 µm of excimer ablation, regardless of the actual dioptric correction.

An important issue in the prophylactic use of MMC is potential overcorrection following surface ablation. This effect may be due to MMC-induced inhibition of the compensatory wound healing following surface ablation procedures. This may result in persistent hyperopia and, therefore, we currently use a nomogram adjustment, in which the spherical portion (when written in plus cylinder notation) and not the spherical equivalent is reduced by 10% to 15% based on the patient age and refractive error. For example, for a 35-year-old patient with a refraction of −8.00 + 2.00 × 90, the treatment would be adjusted so that the sphere would be reduced by 10% to −7.20 + 2.00 × 90.

Initially, an exposure time of 2 minutes was used in prophylactic cases of MMC. In 2002, our group began evaluating shorter exposure times of MMC in prophylactic cases, in an attempt to further minimize potential toxicity. There was no difference in rates of haze formation between exposure times of 12 seconds (10% of the original exposure) and 60 seconds. A shorter exposure time is obviously preferable because it would further reduce potential dose-dependent MMC complications. When retreatment is required after PRK with MMC, we usually use MMC again with a 12-second exposure.

Other Applications of Prophylactic Mitomycin-C

Beyond its prophylactic use in PRK, mitomycin-C has been shown to be effective in other clinical situations. Surface ablation following prior radial keratotomy (RK), penetrating

keratoplasty, and following prior LASIK can all result in the development of clinically significant haze. Following LASIK surgery, many contemporary practitioners are electing not to lift the flap for enhancement beyond 3 years postoperatively. It has the advantage of avoiding a deeper ablation of the residual stromal bed and reducing the risk of epithelial ingrowth, more common after flap lift retreatment. More patient discomfort, a slower time for vision rehabilitation, increased risk of DLK and stromal haze are disadvantages. Surface PRK on the LASIK flap with an application of prophylactic MMC 0.2 mg/cc for 12 seconds has been effective in preventing haze. While the conservative approach would be to adjust the spherical correction by 10% to reduce the chance of overcorrection, some surgeons do not adjust the correction if the amount of retreatment is small (See Video 21).

Safety of Mitomycin-C

There is considerable evidence of the toxicity of MMC in the literature. Corneal edema, glaucoma, corneal perforation, iritis, and photophobia following the use of MMC in pterygium surgery have been described by Rubinfield et al.[2] All of these adverse effects were due to prolonged topical administration of MMC. However, a single dose of MMC has been reported by Dougherty et al.[3] to produce a corneoscleral melt in a patient undergoing pterygium surgery.

We feel that our protocol is fundamentally different from previous ophthalmic applications of MMC. In pterygium surgery, the MMC is often used chronically in the postoperative course. Our protocol abandoned this concept because MMC penetrates an intact epithelium poorly, and because we felt that chronic instillation would result in prolonged contact with other ocular surface structures, the most important of which is the limbus. The majority of complications that have been reported occurred following limbal application of MMC for indications such as pterygium surgery. Because the limbus is a highly vascular region, the complications seen are likely to be due to ischemia of the limbal vessels, which may initiate an inflammatory cascade that could potentially lead to release of proteolytic enzymes, and result in a corneoscleral melt. In addition, MMC contact with the stem cell population at the limbus might result in delayed reepithelialization, which is another risk factor for corneal melt. Our protocol involves application to only the central, avascular cornea, and meticulous care to prevent MMC contact with any other ocular structure. MMC is delivered via a corneal light shield, which serves to limit the contact of MMC to only the central 6 mm of the cornea. A Merocel spear is not recommended for MMC application due to its propensity to allow MMC to leak onto the limbus and conjunctiva. Copious irrigation of the ocular surface with 30 mL of balanced salt solution is likely to remove any residual MMC.

Furthermore, it is imperative to utilize the correct concentration of MMC. In our series, a single intraoperative dose of 0.2 mg/cc MMC was utilized for exactly 2 minutes, followed by copious irrigation. Our experience with patients who received MMC treatment for post-PRK haze removal has shown no long-term adverse effects over 8 years, and no patients in the prophylactic group experienced any toxic adverse effects related to MMC administration. Reepithelialization was complete in all eyes by the fifth postoperative day, which is similar to our experience with other PRK and LASEK patients who were not treated with MMC. Morales et al.[4] performed PRK in 18 eyes of 9 patients and compared endothelial cell counts using either MMC 0.2 mg/cc applied for 30 seconds or balanced salt solution. The study showed an 18.2% cell loss at 3 months ($p= 0.002$), in the MMC group only. PRK with MMC is widely used internationally to prevent haze and postoperative corneal edema appears to be extremely rare, however, the long-term safety of MMC in this setting has yet to be determined. Lower doses of MMC have been evaluated, but largely abandoned due to lack of efficacy in the higher degrees of myopia.

Patients should be advised that the use of MMC to prevent or treat corneal haze is off-label. The long-term effects are not well known. The benefits and risks should be included in

the informed consent and the discussion well documented in the chart.

The role of MMC has expanded recently in refractive surgery. Its first major application was in preventing haze recurrence after PRK and RK. Use of MMC in conjunction with transepithelial PTK/PRK has also proven to be effective in treating patients with complicated LASIK flaps. The results of our case series demonstrate that MMC is effective in reducing the incidence of haze in those eyes that are most likely to develop this visually disabling complication. Certainly, longer follow-up and treatment of greater numbers of patients will help support the validity of this technique.

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Suggested Readings

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chapter 14

Cataract Surgery After Keratorefractive Surgery

CHRISTOPHER J. RAPUANO

LASIK surgery is not typically performed in the presence of a visually significant lens opacity since cataract surgery can both eliminate the opacity and also resolve most refractive errors. LASIK can be performed in a patient with a tiny, off-axis lens opacity if after an adequate period of observation there is no evidence of progression. Caution is advised if the patient is on chronic medication known to cause cataract.

Aging is probably the most likely cause of progressive cataract following LASIK or surface ablation. There are, however, a few specific causes of cataract to look out for in patients after keratorefractive surgery.

Causes

- An **oil-drop cataract**, which may also appear as "white nuclear sclerosis," is not uncommon in relatively young high myopes. The oil-drop cataract causes a myopic shift and may be mistaken for refractive regression[1] (Fig. 14.1).
- **Posterior subcapsular cataract** (PSC) can be seen in patients using chronic systemic steroid medication to control systemic inflammatory disorders. It is also seen after long-term topical steroid use to treat such conditions as diffuse lamellar keratitis after LASIK or for the management of haze after surface ablation.
- **Cortical spokes.** Diabetic patients without significant retinopathy may be candidates for LASIK surgery and over time may develop typical cortical spokes.

Detection

Mild myopic regression after refractive surgery is not rare and is occasionally due to a small lens opacity. A cataract should be suspected in an eye that develops any significant myopic shift some time after refractive surgery, particularly if the patient is over 40 years of age and especially if the refractive surgery was many years prior.

All patients complaining of decreased vision after refractive surgery should undergo a dilated posterior segment examination. At the same time, the lens needs to be carefully evaluated. The oil-drop cataract may easily be

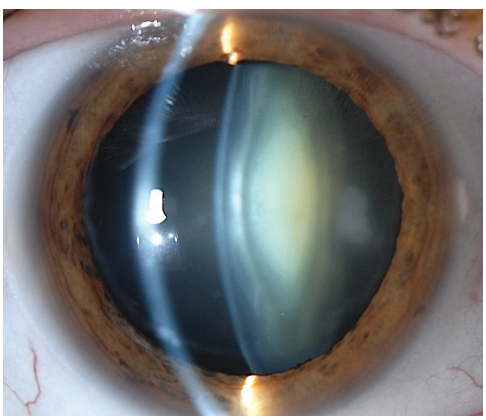

FIGURE 14.1

Slit-beam view of a "white nuclear sclerotic" cataract 10 years after LASIK in this right eye. It has caused 4 D of myopic shift over the previous year. There is also a small degree of old, stable epithelial ingrowth nasally. (Courtesy of Christopher J. Rapuano, M.D.)

overlooked. Both the oil-drop cataract and the PSC are often best seen in retro-illumination. Small nuclear cataracts can also be seen by placing a fine slit beam through the center of the lens. Retinoscopy may also highlight an oil-drop cataract.

Management

If a visually significant cataract is identified and the patient feels functionally impaired, cataract surgery should be considered. A few important issues need to be emphasized in the setting of the post-keratorefractive patient. One is the concept of accommodation. Patients who have become accustomed to excellent uncorrected distance and near vision must be educated about the impact of cataract surgery on accommodation. It is possible that lens-induced myopia has helped to preserve uncorrected near function. Patients who retain reasonable accommodation need to understand that it will disappear after standard cataract surgery. Potential solutions should be discussed, for example, monovision, accommodating and multifocal intraocular lenses (IOLs).

The second issue to discuss is the impact of refractive surgery–induced higher order aberrations and decreased contrast sensitivity on the IOL choice. Since multifocal IOLs also decrease contrast sensitivity, their use after keratorefractive surgery is controversial. The potential benefit of continued spectacle independence must be tempered by the risk of decreasing the quality of vision after cataract surgery. The pros and cons of multifocal IOLs need to be discussed with patients and thoroughly understood before proceeding.[2,3]

The third issue involves the possibility of surprise astigmatism appearing postoperatively. Corneal refractive surgery is based on refraction and not on corneal astigmatism. This means that the refractive surgery may have corrected lenticular astigmatism even in the absence of corneal astigmatism. Refractive astigmatism should be anticipated to return in this situation following cataract extraction because of the original astigmatism correction that now resides in the cornea. This astigmatism can be anticipated if the cataract surgeon reviews the pre-LASIK medical record just prior to the initial surgery. Specifically compare the refractive astigmatism to the corneal astigmatism as measured by keratometry or corneal topography. The difference is lenticular astigmatism, which will disappear after cataract surgery. This potential problem can be resolved by inserting a toric IOL or by performing limbal relaxing incisions at the time of cataract surgery in order to correct regular corneal astigmatism. See Chapter 10 for additional information and (See Video 10). Residual astigmatism can also be managed postoperatively using limbal relaxing incisions, surface ablation, or LASIK.

The fourth challenge in managing the post-refractive surgery cataract is the fact that IOL power calculations are less accurate after keratorefractive surgery than in unoperated eyes.[4] This is because our current methods of measuring the corneal power are not as accurate after corneal refractive surgery. Standard biometry performed on a myopic LASIK patient will underestimate the IOL power and if used, would result in postoperative hyperopia and an unhappy patient. Alternative strategies are necessary for predicting proper IOL power (see below). Patients need to understand the inherent difficulty in predicting IOL power after keratorefractive surgery and that they may need further correction postoperatively to achieve their best visual function. In addition to glasses or contact lenses, they may need to consider either more refractive surgery, such as surface ablation or LASIK, or lens-based surgery, such as a piggyback lens implant or an IOL exchange in order to achieve better uncorrected vision.[5,6]

IOL Calculations After Keratorefractive Surgery

A wide variety of methods have been developed to improve the accuracy of IOL calculations after refractive surgery; however, none of them is perfect. When preoperative information, such as manifest refraction and keratometry readings prior to LASIK surgery, and a stable refraction several months after the refractive surgery are available, then the "clinical history method" can be used.

CLINICAL HISTORY METHOD

In this situation, the difference between the pre- and postoperative spherical equivalent refractions (each corrected to the corneal plane) is subtracted from the preoperative average keratometry reading. This new keratometric value is then used for the IOL power calculation. For example:

Preoperative average keratometric value: 45.00 diopters (D)
Preoperative spherical equivalent refraction (vertex distance 12 mm): −7.00 D
Preoperative refraction at the corneal plane: −7.00 D / (1 − [0.012 × −7.00 D]) = −6.46 D
(Alternatively, can be derived using a distometer wheel)
Stable postoperative spherical equivalent refraction (vertex distance 12 mm): −1.00 D
Stable postoperative refraction at the corneal plane:
−1.00 D / (1 − [0.012 × −1.00 D]) = −0.99 D
Change in manifest refraction at the corneal plane:
−6.46 D − (−0.99 D) = −5.47 D
Postoperative estimated keratometry: 45.00 − 5.47 D = 39.53 D
This value 39.53 D is then used with the axial length to predict the IOL power.

FEIZ-MANNIS METHOD

When preoperative keratometry is unavailable, but there is access to the pre-refractive surgery and a stable post-refractive surgery spherical equivalent prior to development of lens change, a theoretical nomogram can be used (Table 14.1). A common one was developed by Feiz and associates[7,8] based on the formula that they derived:

IOL power underestimation = −0.231 + (0.595 × Change in SE)

To use this nomogram method, biometry is first performed in standard fashion. Based on the difference in spherical equivalent resulting from refractive surgery selected from the left-hand column of Table 14.1, the corresponding IOL power adjustment is selected from the right-hand column. This value is added to the appropriate biometrically determined IOL power. It is this adjusted dioptric power that is selected for use during cataract surgery.

TABLE 14.1 Nomogram for Intraocular Lens Power Adjustment for Emmetropia After Myopic Excimer Ablation

Change in SE(D) at the Spectacle Plane Induced by LASIK or PRK	Increase in Intraocular Lens Power (D)
1.00	0.36
1.50	0.66
2.00	0.96
2.50	1.26
3.00	1.55
3.50	1.85
4.00	2.15
4.50	2.45
5.00	2.74
5.50	3.04
6.00	3.34
6.50	3.64
7.00	3.93
7.50	4.23
8.00	4.53
8.50	4.83
9.00	5.12
9.50	5.42
10.00	5.72
10.50	6.02

Source: This table is modified from Feiz V, Mannis MJ, Garcia-Ferrer F, et al. Intraocular lens power calculation after laser in situ keratomileusis for myopia and hyperopia: a standardized approach. *Cornea.* 2001;20:792–797. The copyright is held by the publisher Lippincott Williams & Wilkins.

According to the authors, using this nomogram adjustment, 63.2% of eyes were within 0.5 D of the intended spherical equivalent, 84.2% were within 1.0 D of the intended spherical equivalent, and 100% were within 1.5 D of the intended spherical equivalent. In comparison, the clinical history method was accurate in predicting the correct IOL power in only 37.5% of cases.

A nomogram (Table 14.2) has also been developed for IOL power adjustment following hyperopic LASIK. In this case, the nomogram

TABLE 14.2 Nomogram for IOL Power Adjustment for Emmetropia After Hyperopic LASIK

Change in SE Induced by LASIK (D)	Decrease in IOL Power (D)
1.00	0.00
2.00	0.97
3.00	1.84
4.00	2.70
5.00	3.56
6.00	4.42

Source: From Feiz V, Mannis MJ, Garcia-Ferrer F, et al. Intraocular lens power calculation after laser in situ keratomileusis for myopia and hyperopia: a standardized approach. *Cornea.* 2001;20:792–797; LWW.

adjustment in the right-hand column is subtracted from the IOL power predicted with standard biometry.

CONTACT LENS METHOD

When no preoperative information is available, the "rigid contact lens method" can be used to calculate the corneal power. The best-corrected vision needs to be at least 20/80 for this technique to work. First, a manifest refraction is performed. Then, a plano rigid contact lens of known base curve expressed in diopters is placed on the eye and a second manifest refraction (over-refraction) is performed. If the second manifest refraction is identical to the first, then the corneal power is the same as the contact base curve expressed in diopters. If not, then the power of the contact lens is adjusted by the difference between the two refractions. If the second refraction is more myopic than the first, then the contact lens is steeper (more powerful) than the cornea, so the amount of change in refraction is subtracted from the contact lens curvature (D). The reverse is true if the second refraction is more hyperopic than the first. For example:

Current spherical equivalent refraction: −2.00 D
A plano rigid contact lens of known base curve (8.7 mm/ 37.00 D) is placed.
Result of contact lens over-refraction: +1.00 D
Difference in refraction: +1.00 D − (−2.00 D) = +3.00 D
Modification in corneal power from rigid contact lens (added since over-refraction was hyperopic): 37.00 D + 3.00 D = 40.00 D
This new value, 40.00 D, is used to calculate the adjusted IOL power.

DIRECT MEASUREMENT OF CORNEAL POWER

The central corneal power, which is poorly measured by manual keratometry and Placido disc-based topography, can be more accurately measured by newer corneal imaging technology. Scanning slit units, single and dual Scheimpflug topography devices, and optical coherence tomography units all hold promise of being able to measure central corneal power with greater accuracy, but unfortunately, none are perfect.[9–14]

ASCRS IOL CALCULATOR WEBSITE

The American Society of Cataract and Refractive Surgery (ASCRS) has developed an extremely useful tool for post-refractive surgery IOL power calculations. It is available at http://iol.ascrs.org and is continually updated. The surgeon inputs as much pre-refractive surgery and current information as is available into the IOL Calculator display. It then shows the results of IOL power calculations using a variety of formulas from which the surgeon can choose. Many formulas are listed, and by clicking on a particular formula, an explanation with appropriate reference appears. The highest and lowest IOL powers as well as the mean power are also illustrated on the screen. As a rule of thumb, it is generally better to err on the side of making the patient slightly myopic (i.e., using an IOL power at the higher end of the range), rather than risking a hyperopic outcome. Patients are generally happier with mild myopia and myopia is somewhat more easily retreated with corneal refractive surgery than is hyperopia. Most surgeons will evaluate all the results displayed by the IOL Calculator and mentally "discard" the outliers. They will then select an IOL power at the higher end of the range to achieve the slightly myopic refractive outcome.

The cataract surgeon is strongly advised to review several methods of adjusting the predicted lens implant power before selecting the IOL for surgery. McCarthy et al.[4] retrospectively reviewed records on 173 pseudophakic eyes that had previously undergone keratorefractive surgery for myopia and determined the top five corneal power adjustment techniques/formula combinations for best predictability and least hyperopic surprises. The Masket with the Hoffer Q formula, the Shammas.cd with the Shammas-PL formula, the Haigis-L, the Clinical History Method with the Hoffer Q, and the Latkany Flat-K with the SRK/T were best. In this study, up to 85% of eyes evaluated had visual outcomes within 1.0 D of the desired refraction.

Patient Management

It is not generally necessary to alter the routine cataract surgery technique after LASIK surgery. Care does need to be taken not to disturb the LASIK flap. There may be some peripheral scarring near the edge of the flap, perhaps from some epithelial ingrowth, which may mildly impede visualization during surgery. Surgeons, and patients, need to understand that even small-incision cataract surgery can worsen dry eye symptoms, which may have persisted after keratorefractive surgery.

A critical aspect of cataract surgery following keratorefractive surgery is management of patient expectations. These patients may be more demanding, and realistic goals for uncorrected distance, intermediate, and reading vision need to be clearly understood by both the patient and the surgeon. Patients need to comprehend that the IOL power calculations are more challenging to determine and may not be perfect. They need to understand that if they are dissatisfied with the postoperative refraction once stabilized there are treatment options. Stabilization may take days in a patient with a history of surface ablation or LASIK, but can take weeks or months after radial keratotomy. Finally, it must be understood that the surgeon will guide the patient through the process and will attempt to do all that is reasonably possible to achieve satisfaction. Evidence of a detailed discussion of appropriate goals and risks of surgery including the possible need for additional surgery should be well documented in the chart.

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chapter 15

Alternatives to LASIK Refractive Surgery

LAWRENCE GANS

Introduction

Excimer laser refractive surgery, and LASIK in particular, is the most popular refractive procedure worldwide. However, alternate procedures are available for favorably modifying the refractive properties of the eye, and when laser vision correction is not appropriate, these procedures become valuable tools for the refractive surgeon. This chapter is an introduction to help the reader understand the role that these alternatives can play in helping the patient achieve better uncorrected vision.

Surface Ablation: PRK/ASA/ LASEK/Epi-LASIK

The various names for keratorefractive surface ablation with the excimer laser are derived from the technique used to handle the epithelial layer. The first FDA-approved refractive surgery procedure using the excimer laser was photorefractive keratectomy (PRK). This procedure involves the mechanical removal of the epithelium followed by excimer ablation of the underlying surface stroma. Although the mechanical removal was initially done with a blade, a battery-operated rotating brush was developed to facilitate epithelial removal (See Video 5). Later, the use of dilute ethanol (20%), or isopropyl alcohol (35% to 70%) was introduced to facilitate mechanical epithelial removal. The alcohol pretreatment effectively loosens the adhesion of the basal epithelial cells so the layer can be gently swept aside. An alternate technique uses the excimer laser to partially remove the epithelium prior to the refractive ablation. This requires the mechanical removal of the remaining epithelium from the ablation zone and was, therefore, termed laser-scrape.

Surface ablation, in the early years of laser vision correction, was performed with broad-beam lasers and lacked the more recent advances of medications to control postsurgical discomfort, and medications like mitomycin-C to reduce the potential for stromal haze with deeper ablations. That led many surgeons to rename the procedure advanced surface ablation (ASA) to differentiate the more modern technique.

With any technique that involves the removal of the epithelium, there is associated postoperative discomfort and delay of vision recovery until the epithelial layer is healed and optically smooth. In the hopes that preserving the epithelium and returning it to the surface following the laser ablation would minimize the soreness and hasten the visual recovery, techniques were developed that allowed the epithelial surface to be lifted as a sheet and then replaced over the treated surface. When this is performed with chemical loosening of the epithelium and mechanical lifting of the flap, it is called LASEK (laser-assisted subepithelial keratectomy). When it is performed using an epithelial keratome, it is known as Epi-LASIK. The epithelial keratome uses an oscillating blunt dissector to separate the sheet of epithelium from Bowman layer. The advantage of retaining the epithelial flap for either pain control or more rapid visual rehabilitation has been difficult to scientifically establish, and it is no longer a popular common practice.

Several advantages make surface ablation an important alternative to LASIK. The long-term postoperative results of surface ablation surgery are comparable to those of LASIK, particularly for myopic corrections of ≤ −5.00 diopters (D). Because no stromal flap is created, risks such as striae, flap displacement, loss of suction during flap creation, diffuse lamellar keratitis (DLK), and epithelial ingrowth are eliminated. This is also true of the risk of flap segmentation or wound disruption problems, which can occur after LASIK in post-radial keratotomy or penetrating keratoplasty patients.

Laser refractive surgery is increasingly being performed to modify the refractive results from lens implantation. As premium lens implantation becomes more popular, patients' expectations for perfect refractive results necessitate that surgeons have the capability to use the excimer laser to correct astigmatism or unintended spherical refractive error. Surface ablation avoids concern that the microkeratome or femtosecond laser could disturb the cataract incision or limbal relaxing incision during flap creation.

An important advantage of PRK is that more stromal tissue is available for safe laser ablation. If a typical LASIK flap measures 100 to 160 μm in thickness including the 50- to 60-μm epithelial layer, a surface procedure can be performed with an additional 40 to 100 μm of stromal tissue available for ablation. This is particularly helpful in treating patients with relatively thin corneas or patients with higher myopic refractive errors. Because customized wavefront-based LASIK surgery requires the ablation of more stromal tissue, surface ablation may be needed in order to leave sufficient residual stromal bed thickness.

Less severe and less prolonged dry eye problems are encountered after surface treatment, which is advantageous in patients who have preexisting tear film problems. When there is no suction ring to raise the intraocular pressure, there is less concern for ischemic complications to the optic nerve, and this may be more suitable for patients with risk factors for glaucoma or other optic nerve diseases. A suction ring cannot be used on a patient with a filtering bleb, while surface ablation might be safely performed in this circumstance.

The cost per case is considerably lower for surface ablation procedures than for LASIK performed with either the microkeratome or femtosecond laser.

The three major disadvantages of surface ablation are postoperative discomfort, slow visual rehabilitation, and the risk of stromal scarring. The removal of surface epithelium by any technique is associated with postoperative pain. This can range from mild to severe and may last for several days until the epithelium has healed. Pain can be minimized with bandage contact lenses topical cycloplegics, oral analgesics, cold compresses, oral and topical nonsteroidal anti-inflammatory medications, and even dilute topical anesthetics. Immediately following surface ablation, the vision can be quite good with uncorrected visual acuity (UCVA) in the range of 20/30 to 20/60. As the epithelium heals during the next few days and the central optical zone becomes rough and irregular, the vision becomes hazier. The initial epithelial layer is somewhat thickened, but gradually smooths out to achieve better optical quality in the subsequent weeks after surgery. The UCVA after the first week is typically 20/30 to 20/40 and may take a few weeks to achieve 20/20 or better visual acuity. Retreatment should not be considered for 6 months after PRK, because of the time necessary for complete healing and refractive stability to occur.

Stromal scarring in the form of reticular haze occurs with increasing frequency and severity with myopic corrections above −5.00 D and ≥75-μm ablation depth, and was generally more common with broad-beam laser procedures. It is less frequent with modern spot lasers but can still occur with higher corrections. The haze usually peaks between 1 and 3 months. Several measures can minimize the incidence and severity of this scarring even at higher corrections. These include intraoperative application of topical mitomycin-C after ablation, lowering the cornea temperature with chilled balanced salt solution (BSS) after the ablation, the use of oral ascorbic acid (1,000 mg daily), reducing sunlight exposure after surgery, and the use of a topical steroid for at least a month following surgery. Prolonged topical steroid use should be monitored as it

increases the risk of IOP elevation that can become quite severe. Of the various modalities used to prevent postoperative haze the use of mitomycin-C, 0.2 mg/cc is most effective and has become routine for many surgeons performing surface ablation procedures (see Chapter 13 for a more detailed discussion). Enhancements after surface surgery require the patient to go through the same process with discomfort and slow return of useful vision. During the enhancement procedure, the surgeon should be prepared for greater epithelial adhesion and a rougher appearance of the stroma within the previous ablation zone.

The technique for ASA involves loosening the epithelial cells with alcohol solution applied to the corneal surface within a circular well of the desired diameter or by placing a round cellulose sponge dampened with the solution on the surface (See Videos 6-9). The time of contact with the alcohol varies from 15 to 45 seconds depending on the alcohol concentration used, and the condition of the epithelium. Longer contact time may be required to loosen epithelium for enhancement of a previous surface ablation. Limiting the duration of alcohol contact with the epithelium, removing the alcohol, and copiously irrigating the corneal surface with BSS will minimize stromal penetration and possible toxicity. If a rotating epithelial brush is used (See Video 5), the alcohol solution is not required. If an epithelial flap is to be prepared, the edges are bluntly dissected centrally to create an intact epithelial layer that is reflected away from the treatment zone. The laser ablation is performed. For procedures with ablation depths >75 µm, mitomycin-C 0.2 mg/cc on a cellulose sponge can then be applied to the stromal surface for 12 to 30 seconds. The surface is irrigated again with chilled BSS. A bandage contact lens is placed on the cornea and the procedure is complete.

Various oral analgesics (e.g., celecoxib, gabapentin, and pregabalin) are commonly prescribed for use beginning the day prior to surgery and continuing for 1 to 2 days after surgery to help minimize discomfort. Cold compresses can be used as well. Oral ascorbic acid 1,000 mg/day, if used, is begun the day of surgery and is continued for 1 month. Topical antibiotic and steroid eye drops are used four times daily. The antibiotic can be discontinued once the epithelium is healed, but the steroid is continued for at least 1 month. The bandage contact lens is removed when the epithelium is intact, usually on the fourth postoperative day.

Bilateral simultaneous surgery is commonly performed, but the patient must be thoroughly prepared preoperatively for the visual disability that will likely occur during the first week after surgery. Many patients will, therefore, opt for sequential surgery, which is less convenient but reduces the transient visual disability that occurs during the first postoperative week.

Incisional Procedures

ASTIGMATIC KERATOTOMY AND LIMBAL RELAXING KERATOTOMY

Astigmatic keratotomy (AK) is an extension of the relaxing incision procedure long used by corneal transplant surgeons to correct postkeratoplasty astigmatism. Straight or arcuate tangential incisions are made in the steep meridian to cause an axial change in the astigmatism. The number and pattern of these incisions, along with their distance from the visual axis, determine the amount of correction obtained. In addition to flattening the steep meridian, these incisions also produce a steepening in the orthogonal meridian (90 degrees away), resulting in what is termed coupling. The ratio of the amount of flattening in the steep meridian where the incision is placed to the amount of steepening in the orthogonal meridian is termed the *coupling ratio.* The coupling ratio varies with the type of incision produced and is an important predictor of the spherical equivalent change that will result from the astigmatic surgery. A coupling ratio of 1:1 will have no change in the spherical equivalent. For example, an eye that begins at $-4.00 + 4.00 \times 90°$ (spherical equivalent of −2.00 D) and undergoes successful AK should end up at approximately −2.00 D. Short and straight tangential incisions tend to produce less orthogonal steepening than do longer or arcuate incisions.

The procedure (See Video 10) is performed with a thin diamond blade that has a rectangular or trapezoidal tip with cutting edges at the base and the sides to allow the knife to slide predictably at the same depth along the curved circumference of the cornea. The guarded edge is set with a micrometer or is set at a fixed length to produce an incision 90% to 95% of the corneal pachymetry for mid-peripheral incisions (AK), and arbitrarily at 600 µm for limbal relaxing incisions (LRIs). The 3 and 9 o'clock limbus is marked at the slit lamp so that adjustment for intraoperative cyclotorsion movements can be made. The steep meridian is confirmed with intraoperative keratoscopy or a Mendez gauge, and the incision track is marked on the corneal surface. Incisions are commonly performed in pairs with one on either side of the visual axis and both centered on the steep meridian. The incisions are generally made at the edge of a 7-mm optical zone to minimize visual symptoms, but can be made at a smaller optical zone for greater amounts of correction.

Astigmatic keratotomy can correct mild to moderate cylinder reliably with few objectionable symptoms. When performed at the time of cataract surgery with a standard lens implant, the LRI procedure helps produce an emmetropic result for patients with corneal astigmatism. When the attempted correction exceeds 2 D, the number of incisions and the need to be closer to the optical zone result in objectionable visual symptoms. LRI is an effective way to treat low degrees of post-LASIK mixed astigmatism. Because of the coupling effect, both the sphere and the cylinder are corrected. This can be done without incurring the risk of flap re-lift or the expense of excimer laser retreatment (see Chapter 10).

RADIAL KERATOTOMY

Radial keratotomy (RK) was the first surgical procedure widely performed in the United States for the correction of myopia. The early popularity of this procedure led to the evolution of refractive surgery as a means to reduce or eliminate the need for corrective lenses. The procedure has largely been abandoned because of the short- and long-term corneal instability encountered, particularly when larger degrees of correction are attempted. It is important to understand the fundamentals of this procedure, because these patients present to the refractive surgeon and the cataract surgeon with progressive symptoms that require management.

Radial incisions in the peripheral cornea correct myopia by producing a peripheral bulge and central flattening of the anterior refractive surface. This central corneal flattening was used to correct mild to moderate degrees of myopia. The amount of correction could change throughout the day possibly related to diurnal variations in intraocular pressure. By altering the length and number of incisions created, the surgeon attempted to control the amount of refractive correction produced.

A wide range of factors influenced the effectiveness of the surgery. These included the age of the patient (older patients experience greater effects for the same amount of surgery), gender (some have said women experience greater effects), the depth, and the incision profile at the central end of the incision. The surgeon would select the number of incisions and the optical zone, which is the clear, unincised area of central cornea, based on the characteristics of the particular eye. RK surgeons developed personal nomograms to help produce consistent results with their individual technique. Radial keratotomy has the potential to correct myopia from −0.50 to as high as −8.00 D or more, but in practice it was only useful up to about −4.00 D, after which disturbing visual symptoms interfered with the refractive correction.

The surgery was performed with the patient recumbent. Topical anesthesia was applied and the patient instructed to fixate on a target. An ink mark was made with an optical zone marker to delineate the optical zone centered on the entrance pupil of the eye. The surgeon would stabilize the globe with a forceps or fixation ring and create the incisions using a guarded diamond knife blade. The exposed portion of the blade was set with a micrometer to ideally create incisions that were 85% to 95% of the corneal thickness as determined by pachymetry. Commonly four to eight radial incisions were created.

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Radial keratotomy has several inherent side effects that make photoablative surgery much more desirable. The incisions weaken the peripheral cornea to cause the bending that flattens the central curvature to correct myopia. From morning to evening that bending may vary to produce the diurnal fluctuation mentioned earlier. It is not uncommon for RK patients to be relatively hyperopic in the morning and more myopic by evening. The fluctuations increase with higher attempted corrections using more numerous and longer incisions. The incisions can heal with epithelial plugs growing into the depths of the incisions. Some incisions may not be created perpendicular to the corneal surface. In each of these situations, the incisions can become opaque, resulting in glare. In the avascular cornea, these incisions are never completely healed and can split open with ocular trauma, during penetrating keratoplasty or during LASIK flap creation. Infection, if it occurs near an RK wound, can rapidly progress toward the posterior stroma.

One of the most disturbing aftereffects of RK is the long-term instability, with some eyes becoming significantly hyperopic in future years. Former RK patients are presenting to refractive surgeons for correction of progressive hyperopia. LASIK can be done if the incisions are fine, that is, without large epithelial plugs. A microkeratome flap that requires no dissection would be preferred over a femtosecond laser flap because the necessary dissection might open the fragile RK wounds. PRK is another option (See Video 8), but it can result in haze. Mitomycin-C 0.2 mg/cc solution applied to the treatment zone after the PRK ablation can reduce this risk (see Chapter 13). Conductive keratoplasty is not recommended for consecutive hyperopia after RK. Intraocular lens (IOL) procedures such as refractive lens exchange are additional alternatives. Despite the hyperopic correction, the risk of retinal detachment in these previously myopic patients must be considered if clear lens exchange is planned. Irregular astigmatism and continued progressive effect make some of these patients difficult to treat.

Thermal Procedures

The use of heat to change the shape of the cornea is more than 100 years old, but only recent advances in technology have allowed the controlled application of heat to predictably change the corneal shape without causing necrosis and scarring. The goal is to apply heat to the mid-peripheral cornea to induce shrinking, which secondarily steepens the central cornea, correcting hyperopia.

CONDUCTIVE KERATOPLASTY

Conductive keratoplasty (CK) is a non-laser procedure that uses radiofrequency (RF) energy to create the thermal shrinking of collagen that alters the corneal contour. RF energy can be controlled very precisely to produce a safe, predictable effect in the tissue. The ViewPoint CK System (Refractec, Inc., Irvine, CA) is relatively inexpensive and includes the RF generator with an eyelid speculum and probe tip to perform the surgery. The probe, or Keratoplast, has a metal tip that is 90 μm wide and has a guard that allows exposure of 450 μm to penetrate the corneal stroma. The RF energy pulse moves from the exposed portion of the metal tip inserted into the corneal stroma and passes through the tissue back into the eyelid speculum that acts as the return path for the current to the generator box. The resistance of the tissue to the passage of the RF energy produces the heat that causes a column of contraction around the Keratoplast extending posteriorly to reach a depth of 450 μm.

CK is performed in the office with topical anesthesia. A corneal marker defines a pattern of eight spots in a series of rings with diameters of 6.0, 7.0, and 8.0 mm centered on the entrance pupil. The number of rings used for treatment defines the intended correction. The surgeon inserts the Keratoplast at each spot on the cornea and depresses a foot pedal to get the CK unit to deliver the energy. It typically takes about 2 minutes to perform each ring.

CK is capable of inducing up to 3 D of increased power to the cornea. This procedure can be used for the correction of a corresponding amount of hyperopia, or to induce correction

of presbyopia. The latter is termed NearVision CK (NVCK) and is typically performed on the nondominant eye in a plano-presbyope to provide "blended vision," where both eyes are used together for distance and near. With the CK technique, a single 8-mm ring will produce 1 D of steepening and two rings at 7 and 8 mm give slightly more than 2 D.

The advantage of CK over hyperopic LASIK is that it is less expensive to perform and does not involve surgery on the central cornea. In the FDA trials of CK, the efficacy data were similar to that of LASIK, and the safety variables were superior. As an off-label use, the surgeon can vary the pattern of spots to correct astigmatism by applying more spots, or moving them closer to the visual axis, in the flatter meridian.

The correction of corneal astigmatism cannot be predicted accurately using CK, but intraoperative keratoscopy can confirm the astigmatic effect at the time of the surgery. The FDA limits the ViewPoint CK System RF generator to a fixed energy level in the United States, but the generators available outside of the United States allow manipulation of the energy for treatment spots.

CK can be performed after myopic LASIK or PRK to treat overcorrections. The effect of CK spots is dramatically increased in eyes that have had laser vision correction, and thus the diameter of the CK treatment ring can be increased to 9 mm or more and still produce steepening of a diopter or more. Because the peripheral cornea is not thinned significantly by myopic laser correction, there should generally be sufficient thickness (>450 μm), but peripheral pachymetry should be used to confirm this.

CK can produce a lasting effect to steepen the central cornea, but many patients will need additional treatment after a variable period of time because of a further loss of accommodative amplitude with age, a hyperopic refractive shift, or a loss of the steepening gained from the initial treatment. Additional CK treatment can restore the correction, or it is possible to perform LASIK, or ASA, on these eyes. Femtosecond laser flap creation should not be considered because the puncture wounds left after the CK treatment may lead to vertical gas breakthrough during the laser pass (see Chapter 5).

NVCK can be used in patients who became plano-presbyopes because of laser vision correction. The patient who had LASIK years ago to eliminate the need for glasses at age 38 was happy until age 44 and now needs reading glasses. NVCK is an alternative to LASIK enhancement to induce myopia in the eye preferred for reading to produce monovision. There is a significant difference in the result of NVCK performed after LASIK surgery from the results in eyes that have not had prior refractive surgery. In the FDA studies for NearVision CK in patients with no prior surgery, two-thirds of patients retained an uncorrected distance acuity of 20/30 in the treated eye, while achieving J3 or better near vision. This does not occur with NVCK in eyes that have had prior LASIK. After laser refractive surgery, the effect of CK is more like monovision contact lenses where the reading-corrected eye loses significant distance acuity.

The data in the FDA studies of CK showed similar refractive efficacy to that of LASIK for previously untreated eyes, and the safety variables were superior. Eyes with peripheral thinning from marginal degenerations or keratoconus should not be treated with CK.

Augmentation Procedures

INTRASTROMAL RING SEGMENTS

Intrastromal ring segments, Intacs (Addition Technology, Des Plaines, IL) and Ferrara rings (Ferrara Ophthalmics/Ltda., BeloHorizonte, Brazil) are used to treat low amounts of spherical myopia, to delay the need for keratoplasty in keratoconus, and to treat laser-induced corneal ectasia. These semicircular (Intacs = 150-degree arc; Ferrara rings = 160-degree arc) ring segments made of PMMA are placed within a stromal pocket or channel created in the mid-periphery of the cornea (Fig. 15.1). The amount of correction produced is determined by the thickness of the segments, which steepen the peripheral cornea to flatten the optical zone.

Intacs were first FDA-approved for the correction of spherical myopia up to −3.00 D.

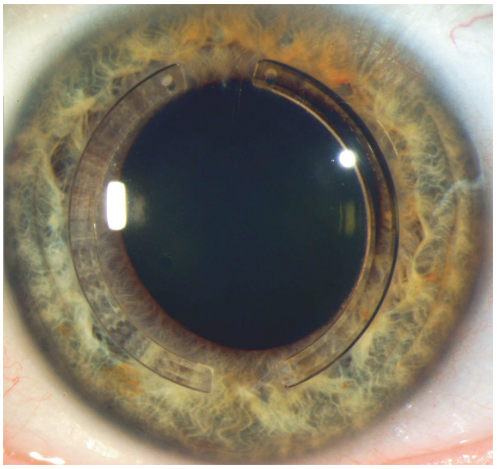

FIGURE 15.1

Intrastromal ring segments (Intacs). (Courtesy of Addition Technology, Inc.)

The stromal pockets were originally prepared with a special set of instruments to create a lamellar channel at about two-thirds stromal depth having a 7.5-mm diameter around the geometric center of the cornea. Ferrara rings are placed at a 5-mm diameter for greater myopic correction. The procedure is performed with topical anesthesia. A 1.0-mm radial incision is made at 68% of the pachymetry reading where the insertion is to be started. A suction ring is applied to stabilize the globe at the appropriate pressure and to guide the tip of the dissector as it creates the channels in each direction away from the starting incision. The ring segment will then slide into place through the lamellar channel, and the radial incision is secured with a single nylon suture.

Alternatively, the lamellar channels can be created with a femtosecond laser, for example, IntraLase, which simplifies the preparation. Using a femtosecond laser to create narrower intrastromal channels can also increase the amount of correction; however, it has the potential to make the ring segments more difficult to insert. Setting a channel width with an inner diameter of 6.6 mm and an outer diameter of 7.4 mm seems to strike a good compromise between maximizing effect and jeopardizing the ease of insertion.

Visual outcomes with Intacs for low levels of myopia are similar to those achieved with conventional LASIK. Above −2.25 D of correction, patients are more likely to complain of glare, photophobia, and polyopia. The advantage of Intacs over LASIK is that the ring segments can be easily removed or exchanged to modify the refractive result, and the central cornea is untouched by the procedure.

The disadvantages of Intacs have kept it from becoming popular. They can only correct low levels of myopia without astigmatism. It requires expensive equipment and special training to create the lamellar channels. There is a small risk of the ring dissecting out of the channel anteriorly or posteriorly during insertion. It can be associated with complaints of chronic postoperative discomfort and/or glare. The ring segments are visible with close observation, which is a cosmetic objection to some. Finally, white channel deposits adjacent to the Intacs can occur that may also be cosmetically significant.

Ring segments have some specialized uses beyond the correction of low myopia. They can be used to correct small amounts of residual myopia following LASIK, where the remaining central stromal bed is too thin for further laser ablation. Ring segments are also used for patients with keratoconus to improve uncorrected acuity, to facilitate contact lens correction. This can delay the need for corneal transplantation in some patients but does not arrest the progression of the disease. Ring segments in combination with collagen cross-linking have been used to treat keratoconus.

CORNEAL INLAYS

Corneal inlays involve the placement of a small lens, or lenticule, within the central stroma to alter the refractive property of the cornea. Keratophakia is a procedure in which a refractive lenticule was placed within the corneal stroma to steepen the anterior refracting surface to correct hyperopia and aphakia. The lenticule was created from homoplastic donor corneal tissue prepared on a cryolathe, where it was ground into the shape of a plus power lens. Synthetic materials were developed as an alternative to the use of donor corneal tissue, but these interfered with corneal metabolism and created interface opacity. This technique never developed the safety,

efficacy, or cost-effectiveness to gain general acceptance as an alternative to refractive lens implantation.

By reducing the size of the synthetic material, it is possible to form a small area of central steepening to produce a multifocal effect without disturbing corneal metabolism. One such design is the Vue+ (formerly Presbylens from ReVision Optics, Inc., Lake Forest, CA). This 2.0-mm diameter lenticule fits under a corneal flap or within a central pocket centered over the pupil. Another design is the InVue intracorneal microlens (Biovision AG, Bruggs, Switzerland), which is a 3.0-mm diameter hydrogel microlens about 15- to 20-µm thick placed in a central stromal pocket 200-µm deep. Corneal inlay procedures offer the potential to reverse or modify the presbyopic refractive correction by removing or exchanging the lenticule.

Another concept under development as an alternative to monovision LASIK for presbyopes is the aperture corneal inlay such as KAMRA (AcuFocus Inc., Irvine, CA). While the Vue+ and InVue create a localized central steepening to focus for reading, the aperture inlay is very thin and does not significantly change the corneal curvature. The inlay is a 3.8-mm polyvinylidene fluoride disc with a 1.6-mm central aperture that will increase depth of focus by its pinhole effect. Microperforations in the material allow passage of fluid to maintain stromal metabolism. The inlay can be placed within a LASIK flap after correction for ametropia. The depth of field created by the aperture should not change with the aging progression of presbyopia.[1,2] At this time, none of these corneal inlay devices have been approved for use in the United States.

ORTHOKERATOLOGY

Orthokeratology is a nonsurgical alternative to correct low levels of spherical myopia. A rigid gas permeable contact lens (Paragon CRT, Paragon Vision Sciences, Mesa, AZ) with a flatter base curve than the corneal curvature is worn during sleep to produce a temporary correction of myopia when the lens is removed on awakening. It is most appropriate for individuals adverse to surgery with spherical myopia up to −2.50 D. Orthokeratology effect is temporary, and vision will blur with regression, but the lenses can be reinserted to restore the correction. Most patients complain of discomfort with these lenses. Its effective range is similar to that of Intacs and shares the advantage over LASIK of potential reversibility. These lenses have also been reported to improve vision in eyes with undercorrected LASIK surgery. There have been reports of bacterial keratitis with the use of these lenses.

LENS IMPLANTATION: CLEAR LENS EXCHANGE OR REFRACTIVE LENS EXCHANGE

With the evolution of cataract surgery to include astigmatism-neutral incisions and highly accurate biometry came the expectation that surgeons could reduce the patient's dependence on glasses with lens implant surgery. Thus cataract surgery has become a refractive procedure as well as one for visual rehabilitation. Safety issues associated with peribulbar and retrobulbar injections are avoided with topical anesthesia. Foldable IOLs can be implanted through small, self-sealing clear corneal incisions so that the recovery of useful vision occurs soon after the completion of the procedure. The relatively high degree of safety and the relative simplicity of the process for the patient have led to the use of clear lens extraction with IOL implantation (clear lens exchange) for purely refractive purposes.

Clear lens exchange may be an option when contraindications to keratorefractive surgery exist, such as when the cornea is too thin or if the degree of refractive error is beyond the limit of safety and predictability for excimer laser ablation. The exchange of the patient's clear lens with an IOL of appropriate power can correct a wider range of refractive conditions than the laser, and it is not dependent on the corneal thickness. It requires equipment and skills that most refractive surgeons already possess, and the start-up costs are significantly less than is required for excimer laser surgery.

Refractive astigmatism will be adequately corrected if its source is lenticular in nature. Astigmatism may potentially increase

postoperatively if corneal astigmatism is unmasked by extraction of the lens. Because the purpose of the surgery is refractive in nature, the surgeon must have a plan for dealing with astigmatism. Astigmatism ≤1 D may be corrected by placing the wound in the axis of plus cylinder. LRI or toric IOL implantation may be required for greater astigmatic corrections. Toric IOLs are discussed in a later section. For correction of greater degrees of astigmatism, a keratorefractive procedure may be considered (see later section on Bioptics). Patients with large spherical corrections preoperatively may not be as bothered by small amounts of residual correction after surgery.

A plan for near vision correction must be developed preoperatively. Pre-presbyopic patients must understand that extraction of the crystalline lens will be associated with loss of accommodation and near acuity. The preservation of accommodation is an advantage of phakic IOL surgery. The clear lens exchange patient has several options available including the use of reading glasses, monovision using monofocal IOLs to create low myopia in the nondominant eye, multifocal IOL insertion, and use of the accommodating IOL. These more sophisticated IOLs are discussed in the next section.

The patient must understand that when performed to remove a cataract, this surgery is performed as a bilateral procedure that is done sequentially and not simultaneously. The risks associated with intraocular surgery must be explained and the patient should understand the more invasive nature of this surgery. The risk of IOL power miscalculation should be addressed, especially if the patient has had prior keratorefractive surgery. Patients with a history of iritis, glaucoma, or risk factors for retinal detachment may not be ideal candidates for this surgery.

The surgery is essentially the same as for cataract removal, though the accuracy of the biometry and lens power calculation is most critical to produce the ideal refractive result. Noncontact techniques such as emersion A-scan ultrasonography and optical biometry with the IOL Master (Carl Zeiss Meditec Inc., Dublin, CA) or LENSTAR (Haag-Streit USA, Mason, OH) can be more accurate than traditional contact ultrasonography. The IOL Master or LENSTAR are of particular value in eyes that have had previous refractive surgery.

Hyperopic patients may have a crowded anterior chamber and may get the added benefit of deepening their chamber angle after surgery. Particular caution is advised when treating myopic patients, because of the risk of retinal detachment. This risk increases with the degree of myopia, the number of years after surgery, and after YAG laser posterior capsulotomy.

Advanced Technology Intraocular Lenses

TORIC INTRAOCULAR LENSES

The AcrySof Toric IOL (Alcon Laboratories, Inc., Fort Worth, TX) and the STAAR Toric IOL (STAAR Surgical, Co., Monrovia, CA) are designed for the correction of astigmatism following lens extraction. The AcrySof lens is a one-piece, flexible-loop, acrylic IOL, while the STAAR lens is a foldable, plate haptic, silicone IOL. After insertion, the lens is rotated to the axis of plus corneal astigmatism. Marks on either side of the optic (Fig. 15.2B) indicate the axis of the cylindrical IOL power. The axis and power of the cylindrical correction required are based on keratometry and topography, and not on refraction because the crystalline lens will be removed during surgery. The precision of the alignment along the steep corneal meridian may be within 10 degrees of ideal and still provide excellent refractive results at lower levels of astigmatism correction. The AcrySof toric lenses are available in a wide range of spherical powers from +6.00 to +30.00 with available cylindrical power correction from +1.5 to +6.00 D. The IOLs can correct up to 4.1 D of astigmatism at the corneal plane. The STAAR toric lenses are more limited in astigmatism correction. Both lenses are intended for implantation in the capsular bag and should not be implanted in the event of zonular disruption or posterior capsular rupture. Patients should be warned about the chance of IOL rotation postoperatively and the potential need to reposition the lens.

MULTIFOCAL INTRAOCULAR LENSES

The ReZoom lens (Abbott Medical Optics, Santa Ana, CA) is a second-generation, zonal

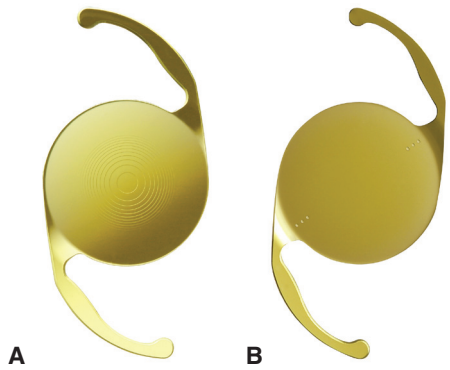

FIGURE 15.2

A: AcrySof ReSTOR is an apodized diffractive, acrylic multifocal IOL. **B:** AcrySof Toric IOL can correct up to 4.1 D at the corneal plane. The alignment dots on either side of the optic are aligned with the axis of corneal astigmatism. (Courtesy of Alcon Laboratories, Inc.)

refractive multifocal acrylic IOL (Fig. 15.3). It is distance dominant, but has five expanded optical zones. Zones 1, 3, and 5 are for distance correction, while 2 and 4 are for near correction. The transition areas between zones correct vision at the intermediate distance. This 13.00-mm modified C-style PCIOL has a 6.0-mm optic and produces about 2.8 D of accommodative effect. This multifocal lens is an improvement over the Array lens because patients supposedly have a broad range of quality vision correction and experience less glare and fewer haloes and starbursts.

The AcrySof ReSTOR (Alcon, Fort Worth, TX) is also a foldable, acrylic multifocal IOL (Fig. 15.2A). In contrast to the ReZoom IOL, the central 3.6-mm of the ReSTOR is an apodized diffractive lens. Apodization technology is used to smoothen the step heights of this diffractive IOL to improve image quality through enhanced light utilization, thereby reducing visual disturbances. The incidence of bothersome postoperative glare and haloes is reportedly 5%. It is recommended that this lens be placed bilaterally to obtain the optimal effect. The peripheral part of the 6.0-mm optic is a refractive distance lens. The lens is distance dominant at night when the pupil is enlarged; however, adequate near correction is maintained. When the pupil is smaller, the light focus is split between distance and near.

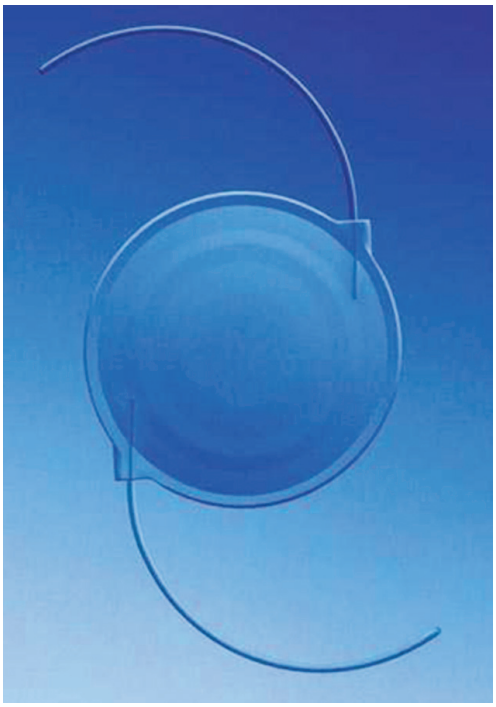

FIGURE 15.3

The ReZoom zonal refractive multifocal acrylic IOL. (Courtesy of Abbott Medical Optics.)

Therefore, the lens function is less dependent on pupil size than a zonal refractive IOL. The lens has an add power of 3.2 D at the spectacle plane. Intermediate correction with the ReSTOR is not as robust as distance and near correction.

ACCOMMODATIVE INTRAOCULAR LENSES

Unlike the multifocal lenses, an accommodative IOL depends on movement of the lens optic within the eye to achieve a change in refractive power. The Crystalens (Bausch & Lomb, Rochester, NY) is the first accommodative IOL available in the United States. Others are being investigated. The Crystalens AO (Fig. 15.4), the most recent iteration of the lens, has a biconvex silicone optic measuring 5.0 mm. The redesigned Crystalens has a broader T-shaped polyamide portion at each end of the lens to ensure good capsular bag fixation with less chance of decentration. The lens powers range from +10.00 to +33.00 D in +0.50 D steps. The Crystalens AT52SE is available in powers as low as +4.00 D. The overall

FIGURE 15.4

The Crystalens AO accommodating IOL. (Courtesy of Bausch & Lomb.)

length of the lens is 11.5 mm for powers of +17.0 to +33.0 D and 12.0 mm in length for powers below +17.0 D. These lenses must be placed entirely in the capsular bag and should not be used in the event of capsular or zonular rupture. Because of its posterior location within the eye, there does not appear to be more glare than would occur with a standard 6.0-mm optic. It has a modified plate haptic IOL with a grooved hinge on either side of the optic that allows the lens to flex and the optic to move anteriorly when the ciliary muscle contracts. This movement increases the effective lens power, thereby achieving its accommodative effect. It is estimated that 1 mm of anterior displacement results in 2 D of accommodative power.

The lens is placed in the eye with an inserter. The capsulorrhexis must be ≥5.5 mm for the lens to function properly. The anterior capsule ledge should ideally cover both hinges. Care should be taken to prevent a postoperative wound leak in order to keep the lens from prematurely shifting anteriorly. Reading glasses are dispensed for use in the first 2 weeks to reduce accommodation, allowing the IOL to settle in to the proper position within the contracting capsular bag. Reading capability may continue to improve over the first 6 months. Many surgeons will use a slightly myopic target in the nondominant eye to ensure good near function.

The risk of ghosting, glare, or multiple images that exists with a multifocal IOL must be weighed against the risk that a Crystalens patient may require glasses for certain activities. Toric multifocal lenses and a toric Crystalens are currently investigational. Until these toric IOLs become available, a plan for managing astigmatism in excess of 0.75 D should be developed and discussed with the patient preoperatively.

PHAKIC INTRAOCULAR LENSES

Phakic intraocular lenses (PIOLs) are a generally accepted alternative for the correction of myopic patients who are not appropriate candidates for LASIK surgery. In the United States, only myopic PIOLs are currently approved, but worldwide, PIOLs are available for a wider range of refractive correction including hyperopia and astigmatism. PIOLs, when compared to LASIK, offer rapid visual recovery and equivalent or superior visual quality, particularly in low contrast situations. They are removable and can provide a broader range of refractive correction. Insertion of a PIOL carries the risks of intraocular surgery, and it lacks the fine-tuning capability of LASIK surgery.

Patients may not be suitable for LASIK surgery if the cornea is too flat, too steep, or too thin to accommodate the desired refractive correction. The refractive correction may exceed the approved treatment range on the available laser. Tear deficiency or corneal neovascularization may also disqualify the patient for LASIK. Keratorefractive surgery may be ill-advised if the resultant keratometry measurements are <35.00 or >50.00 D. Laser refractive surgery may be contraindicated in patients having risk factors for postsurgical ectasia. The patient may be a candidate for a PIOL in each of these situations. Therefore, the PIOL has the potential to extend the limits of refractive surgery beyond what LASIK can safely treat.

Unlike a clear lens exchange procedure with a monofocal IOL, the patient retains accommodation. This is particularly important for the younger pre-presbyopic patient. The PIOL is removable if IOL exchange or cataract surgery becomes necessary. The surgical skills

required are similar to those used in small incision cataract surgery and the start-up costs involved are far less than those required for the purchase of an excimer laser.

Patients should be informed that, in contrast to LASIK surgery, this is intraocular surgery with all of its associated risks. Patients with iritis, rubeosis iridis, glaucoma, cataract, endothelial dystrophy, and other anterior segment pathology are poor candidates for this procedure.

PIOLs are positioned in three possible locations: the anterior chamber angle vaulting over the iris and crystalline lens, fixated to the iris surface, and positioned in the ciliary sulcus between the iris and the crystalline lens. To date in the United States, only two PIOLs, the Verisyse lens (distributed by Abbott Medical Optics, Inc., Santa Ana, CA) known outside the USA as the Artisan lens (Ophtec BV, Groningen, The Netherlands) and Visian Implantable Collamer Lens (ICL) (STAAR Surgical, Inc., Monrovia, CA), have received FDA approval for myopic corrections.

The Verisyse lens is an iris-supported lens that has the advantage of being a one-size-fits-all IOL (Fig. 15.5). The main disadvantage of the currently approved PMMA lens is that it requires a large incision for insertion, which could induce astigmatism. It also requires an anterior chamber depth of ≥3.2 mm for safe insertion. The technique of needle enclavation, in which a small knuckle of iris is incorporated into the claw-like haptics on either side of the lens, is a specialized surgical skill that must be mastered. Fixation in this way allows the pupil to move freely. Ophtec has developed an instrument that uses suction to draw the knuckle of iris into the haptic claws to make fixation easier.

In Europe, the Artisan lens is available for hyperopia and astigmatism correction. This lens design has a long track record of safety and has also been used internationally for many years as a popular lens for secondary implantation to correct surgical aphakia. Because the iris supports the lens, and the pupil is constricted pharmacologically during implantation, there is little risk of cataract from trauma to the crystalline lens. The needle enclavation technique is challenging, however,

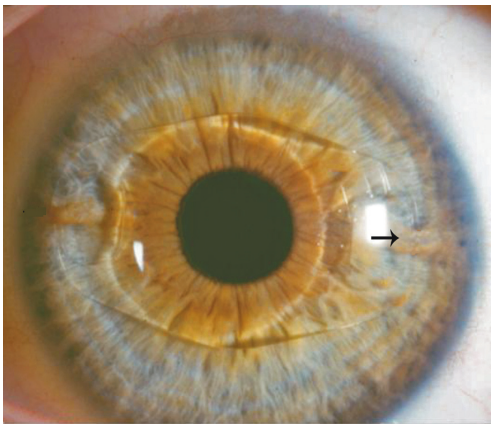

FIGURE 15.5

The Verisyse (also known as Artisan) iris-supported phakic IOL. The *arrow* indicates a knuckle of iris enclavated within lens haptics. (Courtesy of Abbott Medical Optics, Inc.)

and it is critical to achieve a stable, secure, and accurate position for the lens implant.

In 2010, Ophtec received approval in Europe for the Artiflex and Artiflex Toric lenses. These are foldable silicone versions of the Artisan lenses. They are becoming very popular because they only require a 3.2-mm incision for implantation compared to the 6-mm wound required for the PMMA Artisan lens. The Artiflex toric lens is available for the correction of up to 8.0 D of astigmatism and as much as 15.0 D of myopia. The astigmatic axis is aligned with the haptic claws, so the surgeon positions the lens in alignment with the plus refractive cylinder and enclavates the lens with that orientation. Potential complications with iris-supported PIOLs include progressive endothelial cell loss, pupil ovalization, and iris pigment loss with deposition of pigment on the lens. Nonpigmented lens deposits are also seen and can produce glare.

Anterior chamber, angle-supported, PIOLs (ACPIOLs) are still being developed but several early designs have been abandoned over concerns with endothelial cell loss. The PMMA angle-supported NuVita Baikoff MA20 (Bausch & Lomb, Rochester, NY) is designed with flexible haptics providing four points of angle fixation. The Kelman Duet implant (Tekia, Irvine, CA) has a three-point angle-fixated PMMA haptic and a biconcave silicone

optic that are implanted separately. The lens can be implanted through a 2.0-mm incision. The haptic is snaked into the anterior chamber while the folded optic is injected through a 2.0-mm cartridge. The optic is then attached to the haptic with tabs. The Duet is available outside of the United States in powers extending from −6.0 to −20.0 D with haptic lengths of 12.0, 12.5, and 13.0 mm. One of the newest concepts is the Vision Membrane Multifocal (Vision Membrane Technologies, Inc., Carlsbad, CA). This very thin, flexible silicone lens has a 7-mm diffractive optic and is foldable and able to fit through a very small incision.

Angle-supported lenses and posterior chamber lenses are dependent on accurate sizing to achieve a proper fit. Anterior segment OCT (e.g., Visante, Carl Zeiss Meditec, Inc., Dublin, CA, refer to Chapter 3) and high-frequency ultrasound biomicroscopy (e.g., UBM, Paradigm Medical Industries, Salt Lake City, UT) give more precise biometry allowing these and other phakic lens implants to be sized more accurately. The risks associated with angle-supported lens implantation include endothelial cell loss, pupil ovalization, and pupillary block.

The posterior chamber PIOLs (PCPIOLs), for example, the FDA-approved Visian ICL (Fig. 15.6) and the PRL (CIBA), are flexible and can also be inserted through a small clear cornea incision. In the United States, the myopic ICL is approved in the range of −3.00 to −15.00 D corrections. The Visian ICL is available outside the United States in a toric version (TICL) capable of correcting up to 6 D of astigmatism with myopia correction in the range of −3.00 to −23.00 D. The ICL is made of foldable Collamer, a proprietary compound made from porcine collagen, and is inserted through a 3.2-mm incision (See Video 11). The lens fits in the posterior chamber with the haptics in the ciliary sulcus and the optic vaulting the crystalline lens (Fig. 15.7). Ideal vault for this lens is from 350 to 800 µm.

Unlike the Artiflex Toric lens, the TICL is not fixed to an intraocular structure to prevent rotation. Lenses are manufactured with the cylinder oriented within the optic so the lens is implanted horizontally regardless of the refractive cylinder axis. The surgeon receives a guide along with the TICL specifically ordered from the patient's refractive cylinder that specifies the correct orientation for the implant. The surgeon is required to rotate the lens no more than 22.5 degrees (three-fourths of a clock hour) above or below the horizontal meridian to achieve an accurate astigmatic correction.

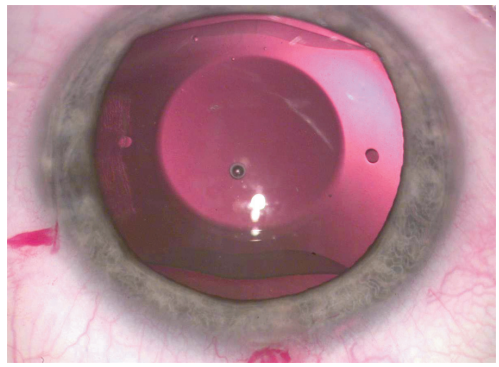

FIGURE 15.6

The Visian ICL in position in the ciliary sulcus anterior to the crystalline lens. (Courtesy of STAAR Surgical.)

Prophylactic peripheral iridotomies are recommended for all the PIOL types to reduce the risk of pupillary block. These may be performed preoperatively with the Nd:YAG laser, or at the time of implantation. Laser iridotomies are often performed in pairs to avoid the potential for a single small opening to be blocked with pigment during lens positioning.

In the last decade, the US Military has become one of the largest providers of refractive surgery worldwide. They have studied phakic lens implantation as an alternative to laser vision correction in military personnel. The United States Army Warfighter Refractive

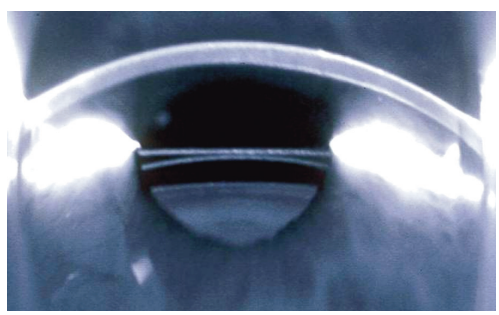

FIGURE 15.7

Scheimpflug photography shows PIOL optic (Visian ICL) in the posterior chamber vaulting over the crystalline lens. (Courtesy of STAAR Surgical.)

Eye Surgery Program (WRESP) offers Visian ICL corrective surgery to servicemen and women requiring corrective eyewear who are not ideal candidates for laser vision correction because of thin corneas, abnormal topography, or significant dry eye disease. Their report of 3-month outcomes concluded that the ICL provided excellent refractive and visual results.[3] The U.S. Naval Medical Center, San Diego, prospectively compared 43 TICL eyes with 45 PRK with MMC eyes treated with the VISX Star S3 laser. Their conclusions were that the TICL performed better than PRK in all measures of safety (BSCVA), efficacy (UCVA), predictability, and stability.[4]

The complications of ICL surgery were recently reviewed.[5] Phakic lens implantation has risks in common with all intraocular surgery such as infection, and while it has been reported, endophthalmitis is extremely rare. The risk of retinal detachment is expected to be significant because the majority of PIOL procedures are performed in patients with high axial myopia. The most significant risk is that of cataract development, which occurs in about 5% of eyes. Some of these are produced by surgical trauma and have an early onset. Others may be due to inadequate vault (<200 µm), which have a more delayed onset. While this represents a significant complication, it can be corrected with explantation of the ICL and surgical treatment of the cataract. With greater surgical experience and more accurate sizing of ICLs, this risk can be reduced. Glaucoma can result from postoperative steroid therapy, just as it can with laser vision correction, but more dangerous is pupillary block glaucoma resulting from an incomplete or blocked iridotomy. Visual complaints include monocular diplopia or ghost images from large iridotomies and glare with large pupils in low light conditions.

BIOPTICS

Zaldivar described the combined use of lens implantation followed at a later time by laser refractive surgery and used the term *bioptics*.[6] Originally, bioptics referred to insertion of a PCPIOL followed by LASIK. Güell used the term *adjustable refractive surgery* (ARS) to describe his technique of creating a LASIK flap and then inserting an iris-fixated PIOL.[7] He would later perform the excimer procedure as an enhancement, if needed. This flap-first technique was designed to reduce the risk of corneal endothelial trauma caused by using a microkeratome in the presence of an iris-fixated PIOL. Over time, *bioptics* has come to mean the combination of any two refractive procedures. Bioptics is particularly useful for expanding the range of refractive lens surgery, adding additional myopic, hyperopic, and astigmatism correction beyond the available lens implant powers. It also adds the fine-tuning capability of a keratorefractive procedure to accommodative or multifocal lens implants used for refractive lens exchange. Keratorefractive surgery can be done with less risk of ectasia in patients with high myopia or thin corneas when phakic lens implantation eliminates the major myopic component. Interestingly, the highly myopic patients can increase lines of BCVA presumably due to image magnification.

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SECTION VII

Study Section

chapter 16

Case Studies

The heart and soul of *The LASIK Handbook* are the 105 cases, which are presented for study. The cases represent a broad array of pathology and experience. They are indexed by findings or characteristics with the intention of making them easily accessible for reference when a patient with similar findings presents for refractive surgery. The indexes can be found at the beginning of the book. The cases have been prepared by the editor and the contributors, and reflect the opinions and preferences of the individual author. The reader is presented with one way—but not necessarily the only way—to work the case. Each of your patients is unique and surgery should always be designed with your specific patient in mind.

Easier cases will appear at the beginning of the study section. Preoperative decision-making is emphasized in the first half of this section. The later cases emphasize intraoperative and postoperative management. In addition to print illustrations, some cases will have references directing the reader to illustrative or instructional videos.

It can be assumed in each case that the risks of surgery have been presented to the patient, that they were understood, and that the patient wishes to proceed with surgery. Unless otherwise indicated, the patient has been out of contact lenses long enough for the given refractions to be stable. That said, not every patient presented is a candidate for LASIK surgery. The reader will need to make that determination.

For the sake of discussion, a preoperative estimate of residual stromal bed (RSB) for microkeratome cases is determined as preoperative pachymetry minus both the plate thickness and the non–nomogram-adjusted estimate of the stromal ablation. Depending on the specific microkeratome, the actual flap thickness may be greater or less than the plate would indicate. The reader should be aware that this is only an estimate made to determine a patient's suitability for surgery and is not a substitute for direct measurement or knowledge of specific microkeratome performance for a specific surgeon. Many factors previously discussed (see Chapters 1 and 4) will impact the actual flap thickness and residual stromal bed (RSB) thickness.

Over the many years during which these cases have been collected, some trends have changed. For example, there is little, if any, scientific basis for the belief that pupil size is a

factor causing postoperative nighttime glare and haloes. Many surgeons use the largest treatment zone that anatomical constraints will allow regardless of pupil size. Some accomplished surgeons do not even measure pupil size. Other surgeons prefer to tailor the treatment zone to the pupil size among other factors. Another example of a management change is that over time many surgeons have found no difference in night vision with either a 6.0- or 6.5-mm treatment zone as long as a blend zone to at least 8.0 mm is performed. They prefer to use the smaller treatment zone to conserve stromal tissue. Finally, there has been a heightened sensitivity about avoiding ectasia, and to that end surgeons are more conservative about preserving the RSB. While 250 µm was considered adequate thickness in years past, some surgeons now routinely prefer 275 µm or even 300 µm; and some are more likely to advise against LASIK for even minor topography abnormalities. While the scenarios presented in these cases are timeless, opinions about the optimal management strategies should be expected to change over time.

The best learning experience for case study will occur if the reader, with paper and pencil in hand, actively studies each case history and examination and develops an independent surgical strategy before reading the discussion and treatment plan. The reader should work the case as if the patient had presented in the office. One should identify the variables or challenges that must be considered when developing a surgical plan. The key questions to be answered in each case include: Is this patient a good candidate for LASIK surgery or is another approach better or safer? What correction should be treated? How should the flap be created? What treatment zone is most appropriate? What is the approximate ablation depth? What is the overall plan for surgery in the language the scrub technician and laser engineer can use? For example, specify the microkeratome ring and plate sizes or femtosecond flap thickness and diameter, as well as the strategy for excimer ablation. Are there any special considerations in the case?

Each case is followed by a narrative discussion and most cases provide a tabular summary of a proposed surgical plan. The equipment used to carry out the plan is specified. At the conclusion of each case, a series of take-home points is listed.

While one could work the cases in order, an alternative way to proceed is to use the various case indexes. Two charts are provided: one for preoperative patient characteristics and one that contains intraoperative and postoperative conditions. Readers can match the variables observed in a proposed patient with those variables in the index and find the relevant cases in the handbook. For example, a reader concerned about the management of a patient with corneal neovascularization can locate this variable in the index and be directed to all of the cases in which corneal neovascularization is discussed. These indexes will hopefully allow the reader to easily access those specific cases and discussions that will be most relevant. It is our hope that studying these cases will be a satisfying experience, both challenging and rewarding.

Preoperative Decision Making

CASE 1

A 35-year-old woman with a history of myopia and a 20-year history of soft contact lens wear expresses interest in LASIK surgery. Assume she has been out of her contacts long enough for the refractions to have stabilized.

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W	OD – 6.25 20/20+ OS – 6.25 20/20–	**Uncorrected Va** 20/400 OU
M	OD – 5.50 + 0.50 × 40° 20/15 OS – 5.25 20/15–	
C	OD – 5.25 20/15 OS – 4.75 20/15–	
K	OD 44.50 × 180°/44.87 × 90° OS 44.50 × 180°/44.75 × 90°	

Pachymetry	**Topography**	**Scotopic Pupils**
OD 541 μm OS 531 μm	No cone OU	OD 5.0 mm OS 5.0 mm

Additional Examination

Excellent exposure with a normal slit-lamp examination, intraocular pressure (IOP), and fundus examination.

Discussion

This is a fairly straightforward patient with myopia. While astigmatism appears in the manifest refraction, the cycloplegic (C) refraction will be used in determining the laser treatment. Many surgeons prefer not to change the cylinder from the manifest refraction. Alternatively, the patient could have a post-cycloplegic refraction prior to surgery to check the astigmatism.

The small scotopic pupil allows the surgeon to choose a small treatment zone. This will help preserve corneal tissue. Many surgeons, however, do not believe that pupil size is a significant risk factor affecting the quality of night vision and choose to use the largest treatment zone possible, given anatomical constraints. Because there is no peripheral pathology and the corneal diameter is presumably of normal size, a larger ring can be used. This will create a larger flap that may be desirable in the event future retreatment is necessary. Notice that this patient appears to be moderately overcorrected in her present spectacles. Relaxing accommodation may take some time. It is helpful to warn the patient preoperatively that the full vision correction will not occur instantaneously, but may occur over several days to a couple of weeks.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	8.5 or 9.5 mm	8.5 or 9.5 mm	If perilimbal neovascularization or a small corneal diameter, choose 8.5-mm ring
Plate size	160 or 180 μm	160 or 180 μm	Hansatome flap may be thinner than plate size
Ablation zone	6.0 mm	6.0 mm	Ablation zone > scotopic pupil
Cycloplegic RX	–5.25 diopters (D)	–4.75 D	

Surgical Plan (Continued)

	Right Eye	Left Eye	Comments
Calculations: Sphere in cycloplegic refraction is reduced by the VISX nomogram Adjusted correction is entered into VISX laser	−5.25 × 6% = −0.315 −5.25 + 0.32 = −4.93 −4.93 D	−4.75 × 6% = −0.285 −4.75 + 0.29 = −4.46 −4.46 D	Refer to Chapter 7 on the VISX laser and the nomogram (Table 7.1, page 75) for the amount of reduction
Ablation depth use non–nomogram-adjusted spherical equivalent	From Table 7.3: 66 µm Using calculation: −5.25 D × 12 µm/D = 63 µm	From Table 7.3: 60 µm Using calculation: −4.75 D × 12 µm/D = 57 µm	Most cases will use the calculation method for ablation depth
Residual stromal bed (RSB)	541 µm − 160 µm − 66 µm = 315 µm >250 µm	531 µm − 160 µm − 60 µm = 311 µm >250 µm	Intraoperative pachymetry best for RSB calculation

Take-Home Points

1. Always use the cycloplegic refraction before making the nomogram adjustment in calculating the ablation depth.
2. Using an ablation zone slightly larger than the scotopic pupil minimizes tissue removal. Be aware that there is a trend toward relying less on pupil size to determine treatment zone, given the lack of scientific evidence to support pupil size as a factor related to postoperative night vision disturbance.
3. A larger flap is desirable in case a retreatment requires a larger treatment zone. However, when the flap edge is near the limbus, the flap may be more difficult to relift.
4. Warn the patient overcorrected in spectacles or glasses about the possibility of a slower postoperative visual recovery.

CASE 2

A 38-year-old woman has worn rigid gas-permeable (RGP) hard contact lenses for 15 years and presents for LASIK evaluation. The patient is highly myopic and feels vulnerable and disabled without her contact lenses. The past ocular history has been completely uneventful. There has specifically been no history of corneal ulceration, abrasion, or keratitis. Her general health is excellent. After consultation and detailed explanation of the risks of surgery, the patient is anxious to proceed with LASIK. She is kept out of contact lenses until the corneal contour and refraction stabilize.

W	OD − 10.25 + 1.25 × 4° 20/25− OS − 10.25 + 0.75 × 150° 20/30−	**Uncorrected Va** CF 3′ CF 3′
M	OD − 9.50 + 0.50 × 180° 20/15− OS − 9.75 + 0.75 × 135° 20/15	
C	OD − 9.75 + 0.50 × 160° 20/15 − Vertex distance 12 mm OS − 9.50 + 0.50 × 120° 20/20 Vertex distance 12 mm	
K	OD 44.87 × 90°/44.50 × 180° OS 43.87 × 40°/44.50 × 130°	

Pachymetry	**Topography**	**Scotopic Pupils**
OD 564 µm OS 555 µm	Against-the-rule astigmatism OU; no cone OU	OD 5.0 mm OS 5.0 mm

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Additional Examination

The external eye appears healthy. The lids are lax and the palpebral fissure is wide. The exposure is excellent. The slit-lamp examination shows subepithelial haze OD with minimal thinning near the limbus superiorly extending for 1 clock hour. There is no active keratitis and no corneal neovascularization. The anterior segment is otherwise normal in both eyes. The lids and lashes are normal with no evidence of blepharitis or meibomian gland disease. The IOP and dilated fundus examinations are normal.

Discussion

The treatment of high myopia requires an adequate corneal thickness and corneal steepness in order to ensure that the cornea will not be too thin or flat postoperatively. If the corneal thickness is inadequate, the cornea is too flat, or the degree of myopia is too great, consider an alternative to LASIK such as insertion of a phakic IOL (see Chapter 15 on alternatives to LASIK). Clear lens exchange in an extreme myope may have an unacceptably high risk of retinal detachment over the long term.

The highly myopic patient may have excessive myopic correction in spectacles or contact lenses, which can only be uncovered with a full cycloplegic refraction. It is also important to measure the vertex distance. Most excimer lasers have a default vertex distance at the spectacle plane. If the measured vertex distance is different than the default, an adjustment is required. For greatest accuracy, central pachymetry should be measured at the time of surgery. Do not rely on the pachymetry performed on a different day to calculate flap thickness. Many factors including contact lens wear, time of day, and ambient humidity can impact corneal thickness.

To estimate the postoperative corneal contour, multiply the spherical equivalent by 0.7 or, to be even more conservative, 0.8. Subtract this product from the average of the preoperative keratometry values. If the result is <35.00 D, the cornea may be too flat after surgery. Highly myopic patients are more likely to regress postoperatively; therefore, in anticipation of possible regression, it is useful to make certain that there is sufficient corneal steepness and thickness to support retreatment. If there is not much room for retreatment, the patient must be warned of the limitation on enhancement and the consequence of untreated regression. Because the pupil is rather small in this case, a smaller ablation zone can be used. This will mean the ablation will not be as deep and will leave more residual stroma.

This patient has an old scar in the right cornea. She denies inflammation, infection, or erosion. Because the scarring is superficial and well out of the ablation zone, it is not a contraindication to surgery. The surgeon should always attempt to determine the cause of such a scar by obtaining a complete history and performing a thorough examination.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	9.5 mm	Hansatome
Plate size	160 µm	160 µm	Hansatome flap is usually thinner than the plate thickness, especially on the second eye
Ablation zone	6.0 mm	6.0 mm	VISX STAR S4
Calculations with nomogram correction (enter into VISX)	−9.50 D × 11% = 1.05 −9.75 + 1.05 = 8.70 −8.70 + 0.50 × 180	−9.25 × 11% = 1.02 −9.50 + 1.02 = 8.48 −8.48 + 0.50 × 135	Use cylinder axis of the manifest or split the difference between M and C

Surgical Plan (Continued)			
	Right Eye	**Left Eye**	**Comments**
Ablation depth	9.50 D × 12 µm/D = 114 µm	9.25 D × 12 µm/D = 111 µm	Always use non–nomogram-adjusted spherical equivalent to calculate ablation depth
RSB	564 µm – 128 µm – 114 µm = 322 µm >250 µm	555 µm – 123 µm – 111 µm = 321 µm >250 µm	RSB calculated using the central flap thickness measured in surgery

Take-Home Points

1. Make certain the patient will have enough RSB for retreatment and will have adequate corneal curvature to support good visual function.
2. Always use the non–nomogram-adjusted spherical equivalent to calculate the ablation depth. Do not rely on the ablation depth calculated by the laser for conventional LASIK.
3. Measure pachymetry intraoperatively. Do not rely on a central pachymetry measurement made on a different day.
4. Do not compromise on patient safety. Consider alternatives to LASIK when necessary. Straight talk with the patient is always the best approach.

Proceed to Case 74 to find out what happened to this patient.

CASE 3

A 40-year-old woman comes desiring refractive surgery. She has worn rigid gas-permeable contact lenses (RGPCLs) for more than 15 years and is becoming increasingly intolerant to her contact lenses. She stopped wearing her RGPCLs 4 weeks ago in preparation for her refractive evaluation. She has been treated in the past for Graves' disease. She currently takes levothyroxine (Synthroid) and occasional artificial tears.

W	OD – 4.25 + 1.00 × 78° OS – 2.50 + 0.50 × 125°	**Uncorrected Va** 20/400 20/200
M	OD – 4.75 + 1.25 × 70° 20/20 OS – 3.25 + 0.75 × 135° 20/20	
C	OD – 5.00 + 1.50 × 75° 20/20 OS – 3.00 + 0.50 × 125° 20/20	
K	OD 41.00 × 170°/43.00 × 80° OS 42.12 × 35 °/43.75 × 125°	
Pachymetry OD 548 µm OS 552 µm	**Topography** Regular astigmatism OU	**Scotopic Pupils** OD 6.9 mm OS 6.8 mm

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Additional Examination

Her corneas are clear without staining. Her eyelids show 2-3+ blepharitis with meibomianitis. Changes are seen on her eyelids and face, consistent with acne rosacea. There is mild upper lid retraction OU without proptosis. The remainder of her ocular examination is normal.

Discussion

This patient's case illustrates a number of important clinical points. This patient has been a long-time RGPCL wearer. These rigid contact lenses may alter the shape of the cornea and mask astigmatism and myopia. Therefore, the surgeon must be sure that the refraction is stable and accurate. The magnitude and axis of the astigmatism must be consistent between the manifest refraction, cycloplegic refraction, and the corneal maps. The corneal maps should show regular astigmatism and no signs of corneal warping. If there is any doubt as to whether the contact lenses have altered the refraction and corneal shape, the patient should stay out of the contacts for a longer period of time and return for repeat refraction and maps until they are all stable and consistent.

This patient is also at risk for postoperative dry eyes. A 40-year-old woman is undergoing early hormonal changes that decrease tear production. She also has increased corneal exposure due to lid retraction resulting from thyroid disease. Lastly, she has posterior blepharitis and abnormal meibomian glands that produce an abnormal lipid component to her tear film and therefore tear film instability. The decreased tear production that normally accompanies a denervated post-LASIK cornea may further contribute to this patient's postoperative dry eye. The patient should be treated aggressively after surgery if signs of dry eye and corneal staining occur. This treatment could include frequent nonpreserved artificial tears and/or topical cyclosporine. Punctal occlusion should be avoided until the posterior blepharitis is treated.

Lastly, this patient has posterior blepharitis as a result of the acne rosacea. This increases the chance for diffuse lamellar keratitis (DLK). The rosacea should be treated with eyelid hygiene twice a day, combined with oral doxycycline or minocycline. LASIK should be delayed until the lids show clinical improvement.

This patient is a good candidate for custom ablation. Her refractive error falls well within the range for custom ablation and her refraction from the wavefront aberrometer is consistent with her manifest and cycloplegic refraction. She shows enough spherical aberration and coma to benefit from the wavefront-guided treatment. Her corneas are mildly flat and therefore a 9.0-mm suction ring is chosen on the Becton Dickinson K-3000 microkeratome. A 160-µm plate is used to create a slightly thinner flap to avoid any possible masking effects that a thicker flap would have on a custom ablation.

Surgical Plan

	Right Eye	Left Eye	Comments
Considerations	Evaluate for dry eye, treat for rosacea. Proceed only if surface is healthy		
Ring size	9.0 mm	9.0 mm	BD K-3000
Plate size	160 µm	160 µm	Actual flap thickness is usually thinner
Ablation zone	6.5 mm with blend zone	6.5 mm with blend zone	Alcon laser Pupils >6.5 mm
Spherical equivalent	–4.25 D	–2.75 D	

Surgical Plan (Continued)			
	Right Eye	**Left Eye**	**Comments**
CustomCornea treatment based on Alcon wavefront measurements	–4.39 D sphere 1.30 D × 66°	–2.95 D sphere 0.69 D × 132°	The Alcon CustomCornea suggests a 6% reduction of sphere and cylinder; treatment is based on the wavefront data
Nomogram adjustment (6%) at corneal plane in minus cylinder	–2.76 – 1.19 × 156°	–2.04 – 0.65 × 42°	
Ablation depth	80 µm	56 µm	The Alcon software calculates the ablation depth
RSB	548 µm – 160 µm – 80 µm = 308 µm	552 µm – 160 µm – 56 µm = 336 µm	>250 µm

Take-Home Points

1. Be sure that the patient has been out of RGPCLs long enough to allow the cornea to assume its normal shape.
2. Look for factors that could predispose a patient to postoperative dry eyes and pretreat the patient appropriately.
3. Treat a patient with rosacea with preoperative oral tetracycline and lid hygiene.
4. Consider wavefront-guided ablation if the wavefront-derived refraction is consistent with the manifest refraction and the patient demonstrates higher order aberrations (HOAs).

CASE 4

A 38-year-old police detective had worn RGPCLs for 15 years. He was eager to become less dependent on his contact lenses and glasses prompting a LASIK consultation. He understood the future need for reading glasses and the other associated risks of surgery. After 1 month, his refractive error had stabilized and surgery was planned.

W	OD – 2.50 20/20– OS – 2.50 20/20–	**Uncorrected Va** 20/200 20/200
M	OD – 3.75 + 1.25 × 87° 20/15 OS – 3.25 + 0.75 × 85° 20/15–	
C	OD – 3.50 + 1.00 × 85° 20/15– OS – 3.25 + 0.75 × 90° 20/15	
K	OD 42.75 × 177°/43.75 × 87° OS 43.00 × 180°/44.00 × 90°	
Pachymetry OD 513 µm OS 509 µm	**Topography** Regular with-the-rule astigmatism OU	**Scotopic Pupils** OD 7.0 mm OS 7.0 mm

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Discussion

While the pupils are somewhat large and the cornea somewhat thin, the correction is low enough such that there is room for a large zone with a blend to extend the treatment to 8.0 mm. This patient, due to his profession, should be specifically warned about the possibility of night vision problems and the effect of a traumatic injury to the flap. He should also be considered for a custom procedure, which may reduce the likelihood of postoperative glare and haloes.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	9.5 mm	
Plate size	160 µm	160 µm	Hansatome flap usually thinner than 160 µm
Ablation zone	6.5 mm with blend (6.0 mm with blend is an alternative)	6.5 mm with blend (6.0 mm with blend is an alternative)	VISX laser 7.0-mm pupil
Calculations with nomogram correction (enter into VISX laser)	3.00 D × 7% = 0.21 D 3.50 D – 0.21 D = 3.29 D –3.29 + 1.00 × 85	2.88 D × 7% = 0.20 D 3.25 D – 0.20 D = 3.05 D –3.05 + 0.75 × 90	
Ablation depth	45 µm + 8 µm = 53 µm	43 µm + 8 µm = 51 µm	
RSB	513 µm – 160 µm – 53 µm = 300 µm >250 µm	509 µm – 160 µm – 51 µm = 298 µm >250 µm	If actual flap is thinner than 160 µm, RSB will be even greater

Take-Home Points

1. Emphasize those risks that are relevant to a given patient based on the patient's work and leisure activities.
2. Design the surgery to minimize those risks. In this case, use a treatment zone larger than the scotopic pupil, use the largest zone permissible given the anatomical constraints, and/or consider a custom treatment.

Proceed to Cases 61 and 62 to find out what happened to this patient.

CASE 5

A 33-year old woman with an 18-year history of soft contact lens wear presented with a 6-month history of contact lens intolerance. She complained of itching, tearing, and burning in both eyes for the previous 6 months. She could not wear contact lenses because of discomfort and wished to consider refractive surgery.

W	OD –6.50 + 0.50 × 95 OS –6.25 + 0.50 × 85	**Uncorrected Va** 20/400 OU
M	OD –6.00 sphere OS –6.50 + 0.50 × 80	
C	OD –5.75 sphere OS –6.25 + 0.50 × 80	
K	OD 42.50 × 180/43.25 × 90 OS 42.50 × 180/43.25 × 90	
Pachymetry OD 556 µm OS 549 µm	**Topography** OD 0.75 D regular cyl at 90; normal elevation OS 1.00 D regular cyl at 80; normal elevation	**Scotopic Pupils** 6.0 mm OU

Additional Examination

The bulbar conjunctiva showed 1+ injection and the superior palpebral conjunctiva showed 2-3+ injection both eyes. Her corneas were both clear and her tear film appeared adequate.

Discussion

This 33-year-old female is, in general, an excellent candidate for refractive surgery. Her contact lens intolerance is largely related to her chronic allergic conjunctivitis. Contact lens wear can exacerbate the signs and symptoms of allergy. Therefore, removing the need for contact lenses with refractive surgery is desirable. Before contemplating laser surgery, she will require treatment for her allergic conjunctivitis. Topical mast cell stabilizers and antihistamines can help to control the inflammation in her conjunctiva. It is optimal to have a quiet and calm eye before performing refractive corneal surgery.

When using the WaveLight laser, the patient's data is entered into the SurgiVision DataLink program. The planned correction is based on the manifest (M) refraction, cycloplegic (C) refraction, and data obtained by the Alcon wavefront aberrometer. The aberrometer has proven to be an excellent auto refractor and is a useful guide in treatment planning when combined with the manifest and cycloplegic refractions. Once the surgeon's treatment plan is calculated, the degree of spherical and cylindrical refractive error is entered into the SurgiVision program. The DataLink program then modifies the treatment based on the patient's age, refraction, keratometry, and the doctor's individual nomogram. The suggested DataLink treatment plan is then programmed into the laser.

Surgical Plan
Ziemer Femto LDV flap diameter: OD 9.0 mm OS 9.0 mm
Flap thickness: OD 110 µm OS 110 µm
Ablation zone: 6.5-mm optical zone with a 1.25-mm transition zone and a total ablation area of 9.0 mm OU
Ablation depth: OD 84.17 µm OS 91.08 µm

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Surgical Plan (Continued)
Original planned treatment: OD −6.00 + 0.50 × 110 OS −6.50 + 0.50 × 85
DataLink-adjusted treatment: OD −5.75 + 0.50 × 110 OS −6.25 + 0.50 × 85
Measured RSB: OD 360 µ OS 346 µ

Take-Home Points

1. Allergic conjunctivitis is a common cause for contact lens intolerance. Care should be taken to adequately treat the allergic conjunctivitis until the conjunctiva and ocular surface looks quiet. Attention should also be paid to avoid treating seasonal allergy patients during their high allergy season.
2. The Alcon WaveLight laser platform works well with the integrated SurgiVision DataLink program. The DataLink program uses the surgeon's specific nomogram to adjust treatment parameters before entering this data into the laser. The entered data is therefore based upon analyzed outcomes from the surgeon's specific databank.

CASE 6

A 28-year-old woman presents for laser vision correction. Her past medical history is negative, and her past ocular history is significant for 15 years of soft toric disposable contact lens wear. There is no history of prior ocular trauma, infection, or prior surgery. She is not currently pregnant or nursing. She takes no systemic or ocular medications and has no known drug allergies. She last wore her contact lenses 3 weeks ago.

W	OD – 4.50 + 0.50 × 90° 20/25 OS – 4.75 + 0.75 × 90° 20/30	**Uncorrected Va** 20/400 20/400
M	OD – 4.75 + 0.50 × 90° 20/20 OS – 5.25 + 0.75 × 85° 20/20	
C	OD – 4.75 + 0.50 × 90° 20/20 OS – 5.25 + 0.75 × 90° 20/20	
K	OD 40.50 × 90°/40.00 × 180° OS 41.50 × 90°/40.50 × 180°	
Pachymetry OD 535 µm OS 540 µm	**Topography** Regular bow-tie OU	**Scotopic Pupils** 7.0 mm OU

Additional Examination

The patient does not have deep-set eyes. The palpebral fissure is wide OU. The slit-lamp examination reveals a normal cornea OU with no evidence of guttata or keratoconus (KC). The lenses are clear, and the IOP is 16 mmHg OU by applanation tonometry. The dilated funduscopic examination is unremarkable. Orbscan evaluation reveals posterior elevation of 22 µm in the right eye, and 26 µm in the left eye.

Discussion

This patient is a very good candidate for laser vision correction, especially LASIK, provided that several points are considered. From a historical perspective, the patient has no other complicating medical or ophthalmic conditions. The length of time that she has been out of her toric contact lenses is adequate with the minimum being 2 weeks. The refractive error is within the range for LASIK, and more importantly has been stable over the past year. Stability is defined as a <0.5 D change over the previous 12 months. The corneal thickness is adequate for LASIK at this level of myopia. The topographical analysis is normal in each eye. Orbscan measurements of the posterior elevation may help identify corneas that have forme fruste keratoconus (FFKC). Remember that posterior elevation in an untreated cornea of 50 µm (0.050 mm) or greater above a "best-fit sphere" are strongly suggestive of FFKC (see discussion of topography in Chapter 2). Values between 40 and 50 µm are suspicious and other criteria should be used to determine whether or not a patient is a candidate for LASIK. A posterior elevation of 22 and 26 µm as in this case is not a reason for concern.

Several issues regarding this patient need to be addressed. The patient's keratometry values are fairly flat. In general, 1 D of excimer ablation will result in flattening of the keratometry by 0.7 to 0.8 D. Although controversial, it is wise to keep the corneal curvature above 35.00 D following LASIK surgery. In this case, the expected postoperative keratometry values should be approximately 36.50 D. Another problem with flat corneal contour relates to the creation of the corneal flap. With a very flat cornea, there is a higher incidence of a small flap or possibly a free cap. To minimize this possibility, a larger diameter suction ring should be used, such as a 9.5-mm ring. The femtosecond laser is a useful alternative, because its use is not dependent on corneal contour.

Another issue is the large pupil size. The Bausch & Lomb (B&L) laser has the capability of treating a wide ablation zone, larger than the scotopic pupil size, and this may help reduce the incidence of glare, haloes, and starbursts. The optical zone determines the depth of ablation, according to Munnerlyn's formula and, therefore, caution is urged in selecting the appropriate zone. The optical zone can be set from 4.5 to 8.0 mm plus a blend zone of 3 additional mm. Therefore, a 6-mm optical zone provides an ablation of 9 × 9 mm, larger than almost all scotopic pupil size. It is the most commonly used optical zone size. In this patient, with 7-mm scotopic pupils, we would select a 6-mm optical zone because the total ablation area is larger than the scotopic pupil size. The selection of a larger optical zone would probably not provide additional benefit and only consume more corneal tissue.

The B&L laser is very accurate. We do not adjust the desired refraction with any nomogram, but each surgeon should make this determination after a careful analysis of their data. We often adjust the target refraction in patients <30 years of age to +0.50 D.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	9.5 mm	Flat contour; use 9.5 to prevent free cap
Plate size	160 µm	160 µm	Hansatome usually cuts 100–120 µm flap
Optical zone	6.0 mm	6.0 mm	B&L laser
Transitional zone	9.0 mm	9.0 mm	Total ablation larger than scotopic pupil
Enter into B&L laser, no nomogram adjustment needed	−5.25 + 0.50 × 90°	−5.75 + 0.75 × 85°	Target + 0.50 D postoperatively

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Surgical Plan (Continued)

	Right Eye	Left Eye	Comments
Ablation depth RSB	95 µm 535 µm – 160 µm – 95 µm = 280 µm >250 µm	103 µm 540 µm – 160 µm – 103 µm = 277 µm >250 µm	

Take-Home Points

1. Use a 9.5-mm ring for flat corneas in order to prevent free flaps.
2. Select the appropriate optical zone size in order to provide adequate coverage of the scotopic pupil.
3. Always measure intraoperative pachymetry.

CASE 7

A 38-year-old man is interested in refractive surgery. He occasionally wears soft contact lenses. His refraction has been stable for over a year. He has no health problems.

W	OD – 3.75 + 1.75 × 89° 20/20+ OS – 4.75 + 2.00 × 81° 20/15	**Uncorrected Va** CF 5′ CF 5′
M	OD – 3.75 + 1.75 × 100° 20/15 OS – 4.50 + 2.00 × 90° 20/15	
C	OD – 3.75 + 2.00 × 100° 20/15 OS – 4.50 + 2.00 × 85° 20/15–	
K	OD 39.50/41.00 × 94° OS 39.12/41.37 × 94°	
Pachymetry OD 550 µm OS 550 µm	**Topography** No cone OU	**Scotopic Pupils** OD 6.0 mm OS 6.0 mm

Additional Examination

The patient has slightly deep-set eyes, with lax lids and a wide palpebral fissure. The remainder of the examination was normal.

Discussion

Based on the information given, this patient appears to be a good candidate for LASIK. The presence of astigmatism reduces the laser ablation depth by decreasing the spherical equivalent. In future cases, the ablation depth will be determined by the calculation method.

Remember that the width of the astigmatic treatment zone in a conventional treatment with the VISX laser is 4.5 to 5.0 mm, depending on whether the overall treatment zone is 6.0 or 6.5 mm. If the pupil is large and the degree of astigmatism is large, for example, >2 D, nighttime vision issues are possible. The cornea is somewhat flat, so a larger ring is necessary to make an ample size flap. The risk of an inadequately small or free cap is greater when the corneal contour

is quite flat. If the cornea is very flat, for example, keratometry values <39.00 D, and the degree of correction is low, a surface ablation procedure is a consideration. In this case, there is ample tissue, which allows the surgeon the flexibility to choose a 160- or 180-µm plate on the Hansatome. The size of the treatment zone is selected to be slightly larger than the diameter of the scotopic pupil. A slightly deep-set eye would not pose a serious problem, particularly if the lids are lax and the palpebral fissure is wide. However, patients with deep-set eyes will be more challenging for beginning LASIK surgeons.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	9.5 mm	Flat contour
Plate size	160 or 180 µm	160 or 180 µm	Actual Hansatome flap likely thinner than the plate
Ablation zone	6.5 mm	6.5 mm	6.0-mm pupils
Spherical equivalent	–2.75 D	–3.50 D	Treat cycloplegic refraction
Calculations: sphere in cycloplegic refraction reduced by nomogram adjustment, then enter into VISX laser	–2.75 × 7% = –0.19 –3.75 – (–0.19) = –3.56 –3.56 + 2.00 × 100°	–3.50 × 7% = 0.25 –4.50 + 0.25 = –4.25 –4.25 + 2.00 × 90° (Use axis from manifest refraction or choose an axis in the middle)	Make sure to reduce the sphere from the cycloplegic refraction by the nomogram adjustment (see discussion on VISX laser in Chapter 7)
Ablation depth Use non–nomogram-adjusted cycloplegic refraction	Using Table 7.4, page188 = 34 µm Calculation method: 2.75 D × 15 µm/D = 41 µm	Using Table 7. 4, page188 = 42 µm Calculation method: 3.50 D × 15 µm/D = 53 µm	To be conservative, choose the larger of the two values for ablation depth
RSB	550 µm – 160 µm – 41 µm = 349 µm >250 µm	550 µm – 160 µm – 53 = 337 µm >250 µm	RSB > 250 µm; intraoperative measurement is recommended

Take-Home Points

1. Astigmatism reduces the ablation depth by decreasing the value of the spherical equivalent.
2. High astigmatism correction as part of a conventional myopic astigmatic correction may contribute to night vision issues. This is because of the smaller width of the minor axis of the astigmatic treatment zone. For astigmatism >2.00 D, the patient should be advised.
3. A larger microkeratome ring is required if the cornea is flat, and if very flat, avoid using a blade microkeratome. Either use the femtosecond laser for flap creation or do a surface ablation procedure.

CASE 8

A 40-year-old physician has worn RGP hard contact lenses for about 29 years without difficulty. She is very interested in LASIK surgery because she is leaving on a 1-year stay in Nepal, where she will be volunteering in a medical clinic. She sees much better in her contact lenses than in glasses, and desperately wants to avoid the need for contact lenses while she is in remote Nepal.

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She was just chosen for this post and is leaving in 2 to 3 weeks and is anxious to proceed with evaluation and the surgery as soon as possible. She has done a lot of research on LASIK and is confident about basic understanding of the risks.

W	OD – 4.50 20/40 – HCL OD 20/20 OS – 4.50 20/25 – HCL OS 20/20	**Uncorrected Va** CF 5′ CF 5′
M	OD – 3.75 + 0.50 × 90° 20/25 OS – 4.00 + 0.75 × 85° 20/25–	
C	OD – 3.50 + 0.50 × 85° 20/30– OS – 4.00 + 0.75 × 85° 20/25	
K	OD 43.75 × 177°/44.25 × 87° OS 43.50 × 180°/44.00 × 90°	
Pachymetry OD 554 μm OS 557 μm	**Topography** Regular with-the-rule astigmatism OU	**Scotopic Pupils** OD 5.0 mm OS 5.0 mm

Additional Examination

Additional examination includes a normal external examination with excellent exposure and tear meniscus, a normal slit-lamp examination, IOP, and fundus examination.

Discussion

Patient desperation and demand for surgery ASAP combined with the inability to adequately follow the patient should raise a red flag that this patient might be a poor candidate for LASIK on the basis of the psychosocial criteria laid out earlier in the basic LASIK section, Chapter 1. There are more red flags that should have been detected. This physician has worn rigid lenses for almost 30 years. The corneas will almost certainly not have enough time to stabilize even if she stops lens wear on the day of examination. She may have an element of irregular astigmatism, which explains why she cannot be refracted to 20/20 or better. While this physician may be familiar with the basic risks of LASIK, she is depending on her refractive surgeon to carefully look at the risks she would face if LASIK were performed under these specific conditions. Despite her desperation, it would be ill-advised to rush into LASIK before her departure. She would be worse off in Nepal with poor uncorrected acuity and inadequate best-corrected acuity.

Treatment Plan

Have the patient stop wearing contact lenses. Refract the patient several days prior to departure and if her acuity is better than with her own glasses, give her a prescription for new spectacles.

Take-Home Points

1. Beware of the patient who is desperate for surgery, overly confident about the risks, and anxious to proceed.
2. Avoid surgery if the patient will not get adequate follow-up care.
3. Allow adequate time for the corneas to stabilize, particularly when the patient cannot be refracted to 20/20 and there is no other cause.

CASE 9

A 51-year-old man with history of myopic astigmatism has had a stable refraction for 1 year. He has a history of contact lens intolerance in the past. He is left eye dominant.

W	OD – 1.50 + 0.50 × 8° 20/20+ OS – 2.75 20/20 + Add + 2.00 OU	**Uncorrected Va** 20/100 20/200
M	OD – 1.00 + 0.50 × 8° 20/20 OS – 2.75 20/20	
C	OD – 1.25 + 0.25 × 175° 20/15 OS – 2.75 20/15 –	
K	OD 40.00 × 180°/41.50 × 90° OS 41.00 × 10°/41.75 × 100°	

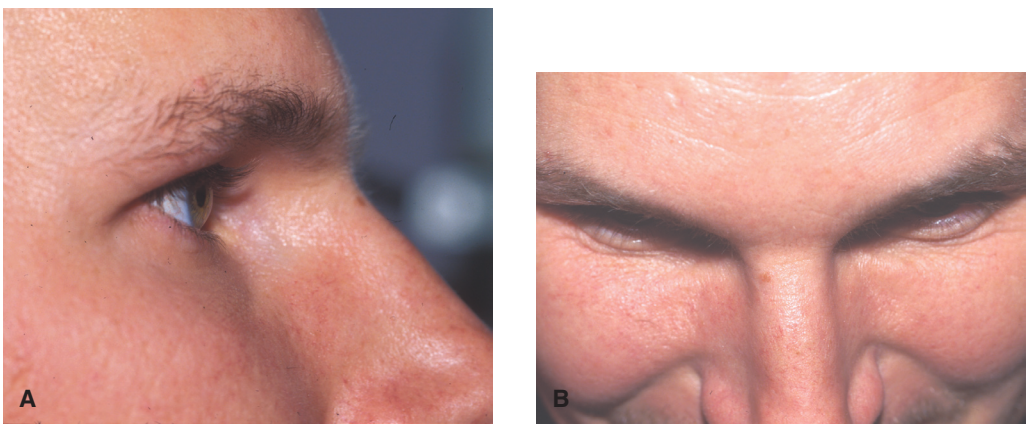
Pachymetry	**Topography**	**Scotopic Pupil**
OD 573 μm OS 572 μm	No cone OU	OD 6.0 mm OS 6.0 mm

Additional Examination

Deep-set eyes (Case 9, Figs. 1A and B). The examination is otherwise normal.

Discussion

There are several points worth considering in this case. First, at age 51, this patient is highly likely to experience presbyopic symptoms following bilateral treatment for distance. This patient might do very well if only the dominant left eye is treated for distance. The untreated right eye might serve his intermediate and near vision reasonably well. As a rule, patients in this setting are better served with sequential surgery rather than bilateral simultaneous surgery. This allows the patient an opportunity to experience monovision, leaving open the option to subsequently



CASE 9, FIGURE 1

A, B: Deep-set eye. (Courtesy of Robert S. Feder, M.D.)

treat the nondominant eye. A preoperative trial of monovision using a contact lens in the dominant eye is often helpful. Second, the corneal contour is relatively flat. Remember that there is an increased risk of a small flap or free cap when the corneal contour is flat. A larger ring is needed to ensure that the flap will be large enough to accommodate a larger treatment zone. Finally, the periorbital anatomy may pose a problem. Remember to check prominence of the brow, relative height of the palpebral fissure, lid laxity, and degree of enophthalmos in determining whether exposure will be adequate. If exposure is an issue, consider going with a more sturdy speculum such as the Murdock speculum (ASICO AE-183); going without a speculum and the standard ring; using a micro-ring, which has a smaller outer diameter; using a single-piece microkeratome such as the Amadeus or the Nidek, which creates a nasal hinge; or the femtosecond laser which does not depend on the translation of a blade across the cornea. One could also consider a surface ablation procedure. Adequate preoperative sedation can help achieve adequate exposure by relaxing periorbital muscles and reducing blepharospasm.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	9.5 mm	*K* < 45.50 D
Plate size	160 µm	160 µm	
Ablation zone	6.5 mm	6.5 mm	Pupils <6.5 mm
Spherical equivalent	–1.13 D	–2.75 D	
Calculations using nomogram correction	–1.13 D × 7% = –0.08 D –1.25 D + 0.08 D = –1.17 D –1.17 + 0.25 × 175°	–2.75 D × 8% = –0.22 D –2.75 D + 0.22 D = –2.53 D –2.53	Reduce the nomogram adjustment from the sphere in the cycloplegic refraction
Ablation depth	1.13 D × 15 µm/D = 17 µm	2.75 D × 15 µm/D = 41 µm	Use non–nomogram-adjusted cycloplegic refraction to calculate ablation depth
RSB	OD: 573 µm – 160 µm – 17 µm = 396 µm OS: 572 µm – 160 µm – 41 µm = 371 µm RSB > 250 µm OU		
Special consideration	Because this patient is of presbyopic age, give strong consideration to treating only the dominant left eye. Right eye can always be treated later		

Take-Home Points

1. Consider sequential rather than simultaneous treatment if the patient is of presbyopic age and the refractive error of the nondominant eye is suitable for near vision correction.
2. Consider the risk of inadequate flap diameter or free cap if the cornea is flat.
3. Flaps are more difficult to make if the eye is deep set. Remember the various treatment options available in this setting. Discuss the surface ablation option preoperatively.

CASE 10

A 63-year-old man is highly motivated to have refractive surgery to improve his vision. He currently does not wear glasses or contact lenses and functions well. He works full time as an architect. He enjoys fishing and hunting. He drives occasionally and without difficulty during the day but does notice some glare while driving at night.

W None		**Uncorrected Va** 20/25+ dist; 14 pt near 20/200 dist; 4 pt near
M	OD – 0.25 + 0.50 × 180° 20/20 OS – 2.00 20/20	
C	OD pl + 0.50 × 180° 20/20 OS – 1.75 20/20–	
K	OD 42.62 × 179°/42.00 × 89° OS 43.00 × 180°/43.00 × 90°	
Pachymetry OD 520 μm OS 520 μm	**Topography** No evidence of keratoconus	**Scotopic Pupils** OD 5 mm OS 5 mm

Additional Examination

The patient has excellent exposure. The slit-lamp examination, fundus, and IOP are normal.

Discussion

Occasionally, a presbyopic-age patient will present with naturally occurring monovision who is highly motivated to have refractive surgery. Although his motivation is high, this man currently functions well during work and leisure activities without correction. Although the patient would be willing to have refractive surgery to correct the left eye, surgery would be ill-advised. Because of the loss of near vision postoperatively, this patient would perceive a significant loss of visual function even if the postoperative result were 20/15 OS. While his night driving might improve, he only drives occasionally. His work as an architect would require full-time spectacle use. He would also need reading glasses for fishing. The slight correction in the right eye is too low to treat. This presbyopic patient is not a good candidate for refractive surgery, but might benefit from glasses for night driving.

Take-Home Points

1. Avoid refractive surgery in presbyopic patients who function well without glasses or contact lenses during work and leisure activities.
2. Motivation for refractive surgery does not make a patient a candidate for refractive surgery.
3. The preoperative evaluation is an opportunity to understand the patient's motivations for surgery, determine if the patient will achieve a net gain from the surgery, and educate the patient.
4. A patient properly advised against surgery can be a potential referral source, while a patient made unhappy with surgery will usually speak negatively about the surgeon and the office.

CASE 11

A 27-year-old woman presented with a history of myopic astigmatism. She states she wants to be able to drive, water-ski, and work at a computer without contact lenses. She has a history of

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"lazy eye" OD as a child with no history of strabismus surgery or patching. She also has a history of corneal neovascularization OU. She wears SCL, 2-week disposables, but has tolerated RGP lenses in the past. The patient denies diplopia while wearing contact lenses. Currently, she uses no ocular medications.

W	OD – 6.25 + 1.00 × 96° 20/20 OS – 6.25 + 0.25 × 179° 20/30	**Uncorrected Va** OD CF OS CF
M	OD – 6.00 + 1.25 × 90° 20/20+ OS – 7.25 20/15–	
C	OD – 5.75 + 1.00 × 85° 20/15 OS – 6.75 20/15	
K	OD 44.75 × 7°/44.75 × 97° OS 44.50 × 3°/45.00 × 93°	
Pachymetry OD 549 μm OS 547 μm	**Topography** OD regular astigmatism OS no cone	**Scotopic Pupils** OD 7.5 mm OS 7.5 mm

Additional Examination

There appears to be good exposure. There is a 4 PD esophoria in primary position only. There is also superior and inferior pannus <2.0 mm OU and anterior stromal scarring OD without significant thinning extending <1.5 mm from the superior limbus. The refraction is stable out of contact lenses. Mild blepharitis is present in all four lids.

Discussion

This patient is an acceptable candidate for LASIK surgery. The cornea is thick enough to allow the surgeon to use a 180-μm plate; however, a 160-μm plate would leave more room for retreatment if it became necessary. The esophoria is small; however, if the patient developed a large anisometropia postoperatively, fusion may become more challenging for the patient. The large pupil will require a larger treatment zone. With the VISX laser one could use either a 6.0 or 6.5 treatment zone with the 8.0 mm blend zone. The myopia OS is within the acceptable range for VISX custom OS for high myopia.

The corneal pannus raises an important concern—namely, the risk of intraoperative bleeding. A flap that is large may cut into the vessels resulting in hemorrhage. (See Chapter 1 on ring placement for management of intraoperative hemorrhage.) A smaller flap would help avoid the vessels, but may not accommodate the full treatment zone. Because the keratometry indicates that the cornea is not flat, an 8.5-mm ring would probably be adequate to create the necessary flap size, reducing the risk of bleeding. Ring decentration to avoid isolated vessels risks a significant flap decentration. The femtosecond laser is advantageous in a case like this, because the flap diameter is more predictable. Also the laser process is less likely to induce problematic bleeding into the interface.

The scarring noted in this patient would likely be in the hinge of a superior-hinged flap and not cause a problem. Whenever scarring is present, even if it is peripheral, the surgeon

should attempt to rule out previous herpes simplex disease or other source of chronic keratitis. The blepharitis in this case should be treated and controlled preoperatively and the lids reexamined prior to surgery.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	8.5 mm	8.5 mm	Smaller ring to avoid bleeding
Plate size	160 µm	160 µm	More room for retreatment
Ablation zone (VISX laser)	6.5 mm with blend or custom	6.5 mm with blend or custom	Pupils >6.5 mm 6.0 mm zone could also be used
Spherical equivalent	–5.25	–6.75	
Calculations with nomogram correction (enter into VISX)	–5.25 × 6% = –0.32 –5.75 + 0.32 = –5.43 –5.43 + 1.00 × 85	–6.75 × 7% = –0.47 –6.75 + 0.47 = –6.28 –6.28	Reduce the sphere of the non–nomogram-adjusted cycloplegic refraction
Ablation depth	5.25 D × 15 µm/D = 79 µm + 8 µm for blend zone = 87 µm	6.75 D × 15 µm/D = 101 µm + 8 µm for blend zone = 109 µm	Remember to add 8 µm additional for blend zone in patient with <10 D; depth with custom may be more
RSB	549 µm – 160 µm – 87 µm = 302 µm	547 µm – 160 µm – 109 µm = 278 µm	RSB > 250 µm OU

Take-Home Points

1. Perform a motility examination routinely. Abnormalities should be explained to the patient. Patients who are asymptomatic in contact lenses should do well unless significant anisometropia or distortion has developed that interferes with fusion. Any potential risks should be explained and documented in the chart.
2. When pannus or neovascularization is present, consider flap diameter and its implications. Balance the need to protect the peripheral cornea with the need to accommodate a large treatment zone. IntraLase, if available, can be helpful.
3. Treat blepharitis preoperatively and examine patient before surgery to be certain that the condition is controlled.

CASE 12

A 23-year-old woman presented for LASIK consultation complaining that her contact lenses had become increasingly uncomfortable and as a result her wear times had been declining. She is an accomplished skier and diver and is unable to wear glasses during these activities. She is in good health. She recently saw her eye doctor and was told her eyes were healthy.

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W	OD – 6.50 + 2.25 × 115° OS – 5.50 + 2.00 × 85°	**Uncorrected Va** CF 5′ CF 5′
M	OD – 6.25 + 2.00 × 115° 20/20 OS – 5.75 + 2.50 × 80° 20/20	
WR	OD – 6.75 + 2.30 × 120° OS – 5.71 + 2.45 × 84°	
C	OD – 6.50 + 2.25 × 120° 20/20 OS – 5.75 + 2.50 × 85° 20/20	
K	OD 43.00 × 35°/45.75 × 125° OS 42.75 × 175°/45.50 × 85°	

Pachymetry	**Topography**	**Scotopic Pupils**
OD 546 µm OS 548 µm	Regular astigmatism OU	OD 8.7 mm OS 8.8 mm

Additional Examination

The external examination was normal, revealing excellent exposure. The tear function was normal. The slit-lamp examination was unremarkable. The IOP was 12 mmHg OU and the fundus was normal OU. WaveScan measurement showed 9.2% HOA and RMS 7.64 OD; and 3.4% HOA and RMS 5.29 OS.

Discussion

Review of old records revealed refractive stability for at least 2 years. She had a relatively high RMS (see discussion of custom VISX in Chapter 7) and had pupils that put her into a high-risk category for night vision complaints when combined with her refractive error. After consultation regarding the options, the patient elected to undergo CustomVue LASIK with IntraLase.

The manifest and WaveScan refractions were well matched so no physician adjustment was used. The high RMS value does not influence the treatment plan in this patient. Clinically, any adjustments are based on comparisons of manifest, cycloplegic, and WaveScan refractions.

The flaps and ablations were well centered, and surgery was uncomplicated. The surgeon needs to remember that the clinical situation may vary depending on the method of flap creation. In this case, the IntraLase femtosecond laser was used to create the flap. Rarely when using the IntraLase, a period of waiting is required until the intrastromal gas dissipates enough to allow the tracker to recognize the pupil. If a significant amount of opaque bubble layer is obscuring the view of the pupil, then it is best not to lift the flap immediately, but to instead wait until the gas dissipates. At the 3-month postoperative visit, the patient had a UCVA of 20/15 with plano refraction OU. The patient had no complaints of nighttime glare or haloes.

Surgical Plan

With planned ablation depths of 101 and 83 µm, IntraLase flaps of 120 µm and 9.0 mm in diameter were selected. The CustomVue treatment was set for a 7.0-mm × 6.0-mm optical zone and 9.0-mm ablation zone OU. The 9.0-mm ablation zone was selected to cover the relatively large mesopic pupils.

Take-Home Points

1. The CustomVue platform allows for adjustment of the treatment zone for patients with large pupils. Some surgeons use the largest feasible treatment zone regardless of pupil size.
2. The CustomVue treatment reduces the risk of night vision problems for patients at risk for such problems or in patients who would be bothered by these symptoms. It induces less new HOAs than many other excimer lasers.

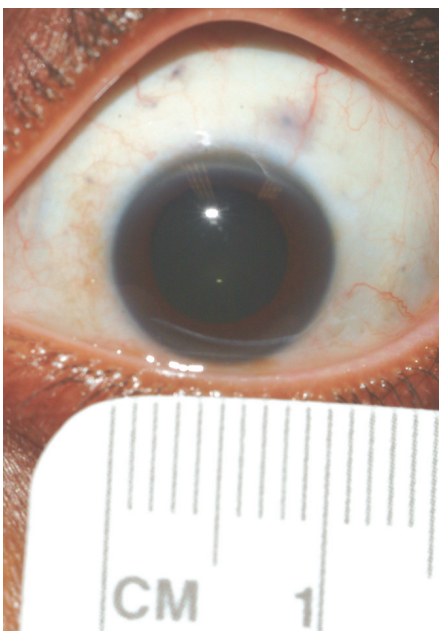
CASE 13

A 32-year-old woman presents for LASIK consultation with the hopes of being less dependent on her glasses. She does not wear contact lenses.

W	OD – 4.50 20/20– OS – 4.50 20/20–	**Uncorrected Va** CF 5′ CF 5′
M	OD – 4.75 + 0.75 × 87° 20/15 OS – 4.50 + 0.50 × 85° 20/15–	
C	OD – 4.50 + 0.75 × 85° 20/15– OS – 4.25 + 0.50 × 85°20/15	
K	OD 46.75 × 177°/47.25 × 87° OS 46.50 × 180°/47.00 × 90°	
Pachymetry OD 504 μm OS 507 μm	**Topography** Regular with-the-rule astigmatism OU	**Scotopic Pupils** OD 7.5 mm OS 7.5 mm

Additional Examination

The external examination reveals excellent exposure with a corneal diameter of 10 mm (Case 13, Fig. 1). The slit-lamp examination shows a clear cornea and the anterior chamber is deep and



CASE 13, FIGURE 1
Small corneal diameter. (Courtesy of Robert S. Feder, M.D.)

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quiet. The lens appears normal and there is no cataract. The IOP and fundus examinations are normal.

Discussion

The important findings in this case are the small cornea with relatively steep curvature. The corneas are rather thin and the pupil is large. The key decision is the recognition that the use of a mechanical microkeratome might be problematic. The flap must be large enough to accommodate a large treatment zone, yet not so large that it extends into the limbus. One could consider using a small ring diameter for the microkeratome to keep the flap from being too large. However, with only slight flap decentration, there is a significant risk of limbal invasion and hemorrhage, because the cornea is small and steep. Other options are probably safer. The most conservative refractive procedure would be PRK in which there is no flap-related risk. A large zone with an added blend could be used and excellent centration should not be difficult to achieve. The patient would need to understand the advantages and disadvantages of sequential and simultaneous surgery.

Another option to consider would be to use the femtosecond laser to make the flap. Remember that the flap diameter with this laser is not dependent on corneal curvature and the diameter can be preset. In addition, with this patient's thin cornea, the laser would provide more control over the actual flap thickness. Centration is a concern, however. If the applanation lens was not well centered and the cursor was used to center the ablation, the resultant flap might be too small to accommodate the entire ablation. If the flap edges were too close to the limbus, limbal bleeding might occur or air bubbles might extend into the anterior chamber. Despite these possible risks, the femtosecond laser, if available, would be a much better choice than a microkeratome for flap creation.

Surgical Plan

	Right Eye	Left Eye	Comments
The patient opts for PRK OU			
Ablation zone	6.5 mm with blend	6.5 mm with blend	VISX STAR S4 laser
No nomogram correction for PRK (enter into VISX)	−4.50 + 0.75 × 85°	−4.25 + 0.50 × 85°	
Ablation depth	4.13 D × 15 µm/D = 62 µm + 8 µm = 70 µm	60 µm + 8 µm = 68 µm	Discuss the risk of haze and the need for topical steroids postoperatively
RSB	504 µm −70 µm = 434 µm 434 µm	507 µm − 68 µm = 439 µm 439 µm	

Take-Home Points

1. Recognize the special challenge posed by the patient with microcornea.
2. PRK remains an important keratorefractive option in selected cases.
3. The femtosecond laser is safer than the microkeratome in the patient with a small, steep cornea because it offers more control over the flap diameter.

CASE 14

A healthy 31-year-old woman with no significant past medical history had previously worn soft contact lenses for 2 years. She has not worn lenses for 1 month and presents for LASIK consultation.

W	OD – 5.50 + 1.00 × 93° 20/15– OS – 4.50 + 0.50 × 75° 20/15	**Uncorrected Va** 20/400 20/400
M	OD – 5.00 + 1.00 × 90° 20/15 OS – 4.50 + 0.50 × 75° 20/15	
C	OD – 5.00 + 1.00 × 90° 20/15 OS – 4.25 + 0.75 × 65° 20/15	
K	OD 42.00 × 180°/45.50 × 90° OS 42.25 × 180°/45.50 × 90°	
Pachymetry OD 528 µm OS 537 µm	**Topography** OD +3.5 D at 94° regular OS +3.0 D at 89° regular	**Scotopic Pupils** OD 7.5 mm OS 7.0 mm

Additional Examination

There is excellent exposure and the examination is normal except for mild blepharitis and moderate acne rosacea.

Discussion

There are several items of note on the examination. First is the pupil diameter. While some believe pupil size and night vision are not related, many surgeons believe that the treatment diameter should be larger than the pupil size measured in the dark. In this case, the VISX laser would treat out to 8.0 mm if a blend zone were to be used. With CustomVue LASIK, the treatment zone could be expanded further if desired. Second, notice that there is substantially more with-the-rule astigmatism on topography and with keratometry than is seen in the cycloplegic refraction. How is this possible? More than likely there is lenticular astigmatism that cancels out some of the corneal astigmatism. If this patient requires cataract surgery in the future, untreated corneal astigmatism may be unmasked. Never treat the astigmatism from keratometry or topography. Some surgeons will choose to use the axis of astigmatism in the manifest refraction, while some will choose an axis midway between the cycloplegic and manifest refractions. Finally, the acne rosacea should be treated with a course of doxycycline, provided the patient is not allergic. She should be warned about sun sensitivity, yeast vaginitis, reduction in the effectiveness of oral contraceptives, and risk to the baby if she becomes pregnant. Also it is important to treat significant blepharitis prior to laser surgery.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	9.5 mm	
Plate size	160 µm	160 µm	Actual Hansatome flap often thinner than the plate
Ablation zone	6.5 mm with blend or custom	6.5 mm with blend or custom	Pupils >6.5 mm 6.0 mm with blend can also be used

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Surgical Plan (Continued)

	Right Eye	Left Eye	Comments
Spherical equivalent (SE)	−4.50 D	−3.87 D	
Calculations with nomogram correction (enter into VISX)	−4.50 D × 6% = 0.27 D −5.00 + 0.27 = −4.73 −4.73 + 1.00 × 090	−3.87 D × 6% = 0.23 D −4.25 + 0.23 = −4.02 −4.02 + 0.75 × 065	Reduce sphere of cycloplegic refraction by the calculated nomogram adjustment
Ablation depth	4.50 D × 15 µm/D = 68 µm+ 8 µm blend = 76 µm	3.87 D × 15 µm/D = 58 µm + 8 µm blend = 66 µm	Calculate ablation depth using the non–nomogram-adjusted SE
RSB	528 µm − 160 µm − 76 µm = 292 µm >250 µm	537 µm − 160 µm − 66 µm = 311 µm >250 µm	Intraoperative pachymetry is the most accurate way to determine RSB

Take-Home Points

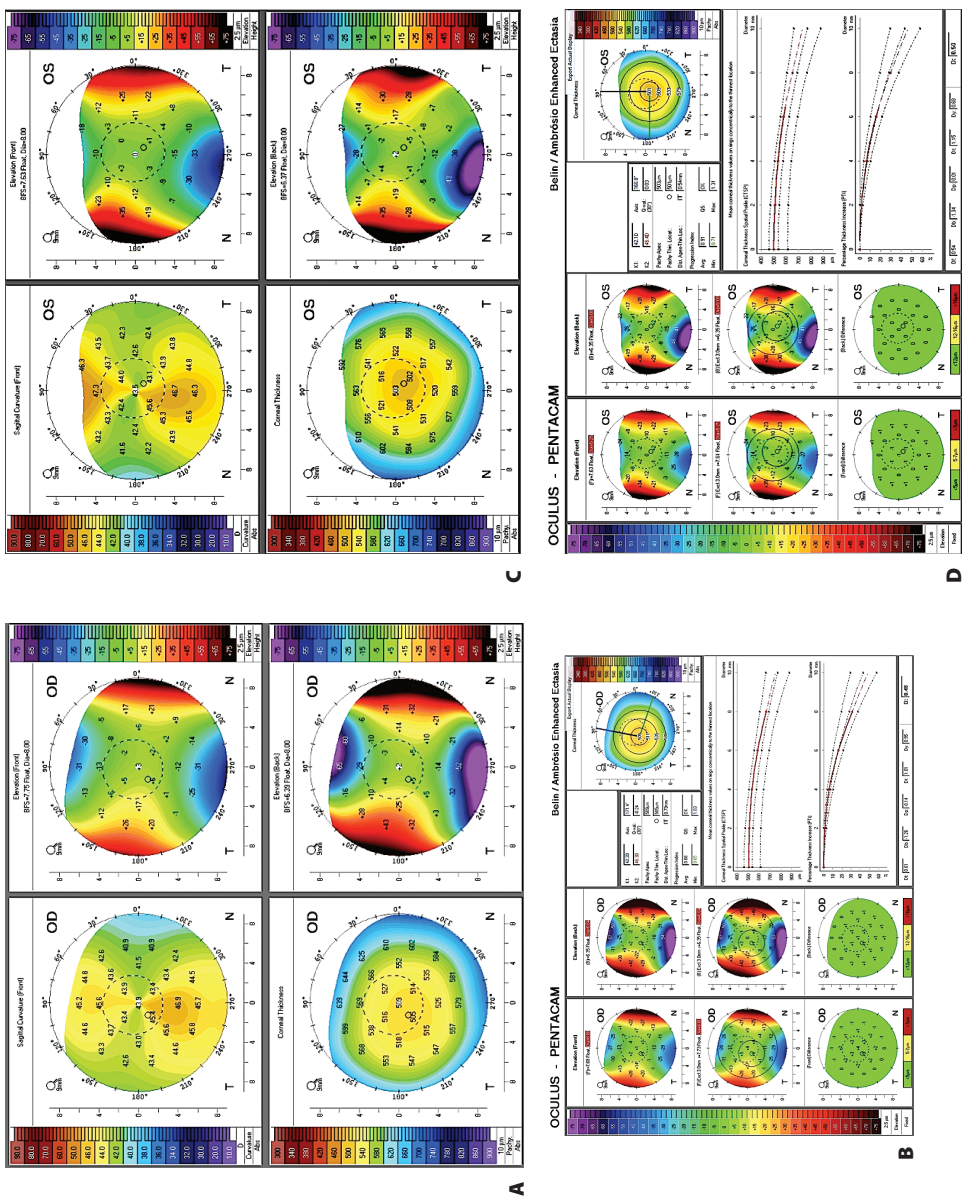
1. A large treatment zone is preferable when the pupil diameter is large. However, some surgeons routinely use the largest zone that anatomical constraints will allow regardless of pupil size.
2. It is worthwhile to note disparities between refractive astigmatism and corneal astigmatism measured with topography and keratometry, but base the treatment on the refractive astigmatism.
3. Treat blepharitis and rosacea prior to surgery.

CASE 15

A 27-year-old Asian woman was interested in refractive surgery because she could not see well in glasses and was increasingly uncomfortable in contact lenses. She enjoyed scuba diving and had difficulty using contact lenses underwater. She once tried a prescription mask, but it did not work well. She had a long history of high astigmatism just like her father and her correction had been stable for the past 2 years. She had worn contact lenses for 10 years and had been out of them for 3 weeks.

W	OD −5.00 + 4.75 × 73° 20/20 OS −6.25 + 6.00 × 80° 20/25±	**Uncorrected Va** 20/80 20/80
M	OD −5.00 + 4.75 × 75° 20/20 OS −5.50 + 4.00 × 75° 20/20	
C	OD −4.75 + 4.75 × 75° 20/15- OS −4.75 + 4.00 × 80° 20/20	
K	OD 42.62 / 45.75 × 70° OS 42.62 / 45.75 × 70°	

Pachymetry	Topography	Scotopic Pupils	Dominant Eye
OD 502 µm OS 506 µm	OD See below OS See below	OD 7.8 mm OS 7.6 mm	OS



CASE 15, FIGURE 1

A: Pentacam OD 4 maps refractive view. **B:** Pentacam OD Belin/Ambrosio Enhanced Ectasia view. **C:** Pentacam OS 4 maps refractive view. **D:** Pentacam OS Belin/Ambrosio Enhanced Ectasia view.

Additional Examination

The palpebral fissures were small and the lids were somewhat tight. The corneal diameter was 11 mm OU. The IOP was 12 mmHg OU. The slit-lamp and fundus examinations were completely normal.

Discussion

Careful evaluation of corneal topography is essential in a patient with high astigmatism and relatively thin corneas in order to rule out the presence of preexisting ectatic disease (refer to Chapter 2). The power and elevation maps demonstrate high astigmatism, which appears to be regular and symmetrical with none of the topographic findings one might see in FFKC. It is worth noting that the pachymetry maps reveal the thinnest portion of the cornea to be displaced inferotemporally in the right eye (Case 15, Fig. 1A lower left map) and slightly displaced inferotemporally in the left (Case 15, Fig. 1C lower left map). In this patient, with better than 20/20 best-corrected acuity, stable refraction for 2 years, and normal power and elevation maps, the pachymetric findings alone are probably not sufficient for the surgeon to reject this patient as a candidate for refractive surgery. However, a younger patient with more significant borderline topographic findings may naturally progress to FFKC or even manifest ectasia. As always, it is the surgeon's judgment and responsibility to determine on which patient to operate. The enhanced ectasia views (Case 15, Figs. 1B and D) do not show an abnormal area of elevation, that is, both lower left maps are green. The pachymetric curves follow the mean and standard deviation curves indicating that the corneal pachymetry increases appropriately as one progresses from the thinnest portion of the cornea to the periphery.

Realistic vision expectations should be presented to the patient. The patient's unaided postoperative acuity often exceeds 20/40, but is not usually 20/20. It is also possible to lose some of the best-corrected acuity. Near vision is often significantly improved even in young patients who suffer from a high preoperative astigmatic correction. This is an unexpected benefit of surgery that patients frequently discover after refractive surgery. It is important to inform the patient with high astigmatism of the increased risk of nighttime vision symptoms. Some would say the large pupil in this case was a further risk, while others would say the pupil size is not relevant.

In this case, custom treatment on the VISX laser was not an option because of the high cylinder, but in general, the iris registration feature available with custom treatment on the VISX Star 4 laser is helpful in aligning astigmatic treatment. Conventional treatment of myopic astigmatism is approved for up to +5.00 D of cylinder. In this patient with thin corneas, tight lids, small palpebral fissure, and a small cornea, PRK seemed to be a better option than LASIK. The femtosecond laser with adjustable flap diameter does allow predictably thin flaps to be made on small thin corneas. Careful consideration must be given to the predicted residual stromal depth if LASIK is performed in this situation. Remember that ablation depth on the VISX laser is calculated using the spherical equivalent so that high astigmatism will reduce the ablation depth related to the myopic portion of the refraction. When the patient is treated with PRK, it is reasonable to give the patient the option of sequential surgery with the nondominant eye first or simultaneous treatment. Some patients want to get the surgery over at one time. They need to be warned that vision will be poor as the healing epithelial defect is approaching fixation.

Treatment

The patient opted for simultaneous PRK, which was performed based on the cycloplegic refraction. A 6.5-mm zone with a blend zone to 8.0 mm was used. A 9.0-mm epithelial defect was created using 20% alcohol applied for 20 seconds. The calculated ablation depth was 44 μm OD and

49 µm OS. Nine months following surgery, the uncorrected acuity was 20/20+ OD and 20/25 OS with a refraction of plano OD and −0.50 + 0.50 × 145 OS. She noted some glare at night, but on balance was quite pleased.

Take-Home Points

1	Careful analysis of corneal topography, power, elevation, and thickness, is especially important in a highly astigmatic patient to rule out signs of preexisting ectasia.
2	Highly astigmatic patients should be presented with realistic vision expectations and warned about possible nighttime visual symptoms.
3	Successful correction of high astigmatism has the potential to improve near as well as distance vision even in a young person.

CASE 16

A 43-year-old woman, with an 8-year history of biopsy-proven sarcoidosis, presents with interest in refractive surgery. She was treated for iritis 3 years ago, but there have been no recent episodes of ocular inflammation since that time. She wore soft contact lenses steadily until 2 years ago, when the lenses became increasingly irritating. She now uses them only for sports and social occasions. Last month the patient contracted the flu that was going around her office, but now feels fully recovered. She occasionally uses an oral decongestant for sinus congestion.

W	OD – 5.75 20/30– OS – 5.50 + 1.25 × 86° 20/20–	**Uncorrected Va** OD CF 5′ OS CF 5′
M	OD – 5.50 + 0.50 × 65° 20/20+ OS – 5.25 + 1.00 × 92° 20/15–	
C	OD – 5.25 + 0.75 × 75° 20/20+ OS – 5.25 + 1.25 × 92° 20/15–	
K	OD 43.12 × 175°/44.00 × 85° OS 42.62 × 180°/43.75 × 90°	
Pachymetry OD 550 µm OS 550 µm	**Topography** No cone OU	**Scotopic Pupils** OD 6.5 mm OS 7.0 mm

Additional Examination

There is excellent exposure with a wide palpebral fissure, prominent globes, and lax lids. There is punctate fluorescein staining inferiorly on the cornea of each eye. The anterior segment, IOP, and fundus examinations are otherwise normal.

Discussion

The refractive surgery evaluation should always include the patient's past medical and ophthalmologic history. Both may impact the decision to perform LASIK. In this case, the patient has sarcoidosis. There have been no recent episodes of iritis and the fundus examination is normal, however, the patient has become contact lens intolerant. Patients often do not offer

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a history of dry eye even when specifically asked. The clinician must discern whether tear deficiency is present and whether it might affect the surgical outcome. Several of the factors in this case should signal a potential problem with tear function postoperatively. First, sarcoidosis can cause reduction in lacrimal gland tear production. This may have been a factor causing her contact lens intolerance. Second, tear deficiency is more common in middle-aged and older women. Third, she is using oral decongestants, which can dry the mucous membranes. The history of the flu might suggest that the consultation is taking place during winter when the ambient humidity is decreased. Next, the wide fissure and prominent globes will undoubtedly increase the likelihood of evaporation from the ocular surface. Finally, the patient works as a copyeditor, requiring her to read all day, further drying the eyes due to exposure.

In short, this patient has many risk factors for dry eye and potential for problems postoperatively. Add to these factors the neurotrophic corneal changes that can result from severing the corneal nerves during flap creation, and the potential for protracted surface irregularity becomes clear. Further evaluation is important in this case. The risk of a postoperative surface abnormality must be explained to the patient. It is prudent to document this in the chart.

The Schirmer's test is part of the dry eye evaluation, but it is not the only determinant that should be used. The presence of symptoms particularly at the end of the day, injection of the bulbar conjunctiva within the palpebral fissure, mucous discharge, debris in the tear film, a decreased tear meniscus, and punctate fluorescein staining on the cornea and the conjunctiva are all important factors. Clinical judgment is necessary to determine whether a tear deficiency state can be adequately controlled preoperatively. If various treatment regimens such as tear supplements, topical cyclosporine, punctal plugs, humidifiers, and adequate oral hydration successfully reverse the signs and symptoms of dry eye, it may then be safe to proceed with surgery. Remember that a patient with evaporative dry eye due to exposure or poor blink may not respond to tear supplements or plugs as well as the patient with reduced tear production.

Given this patient's presbyopic age and profession, it is important to discuss the need for reading glasses or monovision correction. If monovision is considered, remember to try this option in contact lenses preoperatively. The nondominant eye is usually the near eye.

Surgical Plan

	Right Eye	Left Eye	Comments
Considerations	Evaluate for dry eye, consider punctal plugs or other measures, and reevaluate. Proceed only if surface is healthy		
Ring size	9.5 mm	9.5 mm	Hansatome
Plate size	160 or 180 µm	160 or 180 µm	Actual flap thickness may be thinner or thicker
Ablation zone	6.0 or 6.5 mm with blend or custom	6.0 or 6.5 mm with blend or custom	VISX STAR S4 Pupils >6.5 mm
Spherical equivalent	−4.88 D	−4.63 D	
Calculations using nomogram adjustment (enter into VISX laser)	4.88 × 8% = 0.39 −5.25 + 0.39 = −4.86 −4.86 + 0.75 × 75°	4.63 × 8% = 0.37 −5.25 + 0.36 = −4.89 −4.89 + 1.25 × 92°	Some surgeons use cylinder axis from cycloplegic refraction, some use an axis midway between C and M, some use the axis of the M

Surgical Plan (Continued)

	Right Eye	Left Eye	Comments
Ablation depth	4.88 D × 15 µm/D (Use 12 µm/D for a 6.0 mm ablation zone) = 73 µm + 8 µm (for blend) =81 µm	4.63 D × 15 µm/D (Use 12 µm/D for a 6.0 mm ablation zone) = 70 µm + 8 µm (for blend) = 78 µm	Use non–nomogram-adjusted SE to calculate ablation depth
RSB Intraoperative pachymetry is recommended for RSB calculation	550 µm – 160 µm – 81 µm = 309 µm >250 µm	550 µm – 160 µm – 78 µm = 302 µm >250 µm	If Hansatome flap is thinner than 160 µm, the RSB will be greater

Take-Home Points

1. Complete past medical and ocular history is an important part of the preoperative evaluation.
2. Be suspicious for a tear deficiency condition and evaluate properly. Treat the dry eye and reevaluate. Operate only if the surface condition can be normalized. Remember that even if it can, the patient may still experience dry eye symptoms for months or years after surgery.
3. Discuss this condition with the patient and document the discussion in the chart.

CASE 17

A 58-year-old woman presents for LASIK consultation, expressing a goal of reducing her dependence on glasses and contact lenses. She wore monovision in contact lenses with the left eye being the near eye. She cannot remember what the monovision correction in the left eye was or where she got the lens. She has not had a problem with dry eye and wears contact lenses comfortably. She has been diagnosed as a glaucoma suspect and uses timolol 0.5% gel-forming solution each morning in both eyes. She was recently evaluated for a thyroid disorder and the laboratory results were normal. She attended her son's graduation from college 3 weeks ago in Arizona and had no problem with her eyes.

W	OD – 6.50 + 1.25 × 4° 20/25– OS – 6.25 + 0.75 × 103° 20/30–	**Uncorrected Va** CF 5′ CF 5′
M	OD – 5.25 + 1.00 × 12° 20/15– OS – 6.00 + 1.50 × 128° 20/15	
C	OD – 5.00 + 1.00 × 13° 20/15– OS – 5.75 +1.50 × 130° 20/20±	
K	OD 43.87 × 175°/44.00 × 85° OS 43.87 × 20°/44.75 × 110°	
Pachymetry OD 506 µm OS 508 µm	**Topography** Regular with-the-rule astigmatism OU	**Scotopic Pupils** OD 6.5 mm OS 7.0 mm

Additional Examination

Additional examination reveals an ample tear meniscus without punctate fluorescein staining on the cornea. Upper lid retraction with lagophthalmos was noted primarily OD. The motility

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function was normal. The slit-lamp examination was normal. The IOP was 20 mmHg by applanation OU. The cup-to-disc ratio was 0.3 OU and the rest of the fundus examination was normal. Old records were obtained and IOPs had been measured in the high 20s by applanation. Visual fields were obtained and were normal. Stereo disc photographs were obtained for baseline.

Discussion

Monovision should only be considered in presbyopic patients. Before surgery, patients who have never used monovision should have a contact lens trial. This should include both work and leisure activities. If the patient cannot tolerate contact lenses, single-vision monovision spectacles can be prescribed. If contact lens monovision was successful in the past, try to obtain the contact lens prescription. It is important to know how old the patient was at the time of success with monovision and how large a difference was tolerated.

A careful motility examination should be performed prior to surgery. Monovision can disrupt fusion and cause decompensation of a phoria and possible diplopia. Monovision can also have a negative impact on night vision due to defocus in the nondominant eye. This, however, can be corrected with spectacles. The possible negative effect of monovision on night vision should be discussed preoperatively.

Regression of a myopic correction in one eye can result in a form of monovision that the presbyopic patient might find desirable. If monovision correction fails, enhancement surgery can correct the problem. Careful planning before surgery can avoid a failure. CustomVue LASIK (VISX) cannot be performed on the undercorrected eye because the difference between the required treatment and the refraction will be too large. While unilateral custom treatment is usually not recommended when bilateral surgery is being performed, it is not unreasonable to use custom treatment in the distance eye.

This patient was found to have elevated IOP on examinations before the LASIK evaluation. She has thin corneas, so these IOP measurements are significant. However, there was no evidence of glaucomatous nerve damage. The elevated IOP occurring during flap creation would be unlikely to damage a nerve with a 0.3 cup-to-disc ratio. Baseline stereo disc photographs and fields are essential in a case like this, because accurate IOP measurements cannot be made after myopic LASIK. Topical brimonidine (e.g., Alphagan) should be avoided, because it can increase the likelihood of flap displacement.

Women over the age of 50 years are the most likely to develop problems with tear deficiency following LASIK surgery. Tear function should be carefully evaluated in this group, particularly. Lid retraction and lagophthalmos can increase evaporation and complicate a tear deficiency state. Surgery performed in a season or geographic area in which higher ambient humidity is present may be an advantage for patient at risk for dry eye after surgery.

Surgical Plan

	Right Eye	Left Eye	Comments
IntraLase flap diameter	9.0 mm	9.0 mm	Larger flap diameter in case retreatment needed
IntraLase flap thickness (actual flap thickness variance less with laser than microkeratome)	110 µm	110 µm	IntraLase usually creates a flap not greater than 120 µm when set at 110 µm; preferred for patient with thin cornea
Ablation zone	6.5 mm with blend (6.0 mm with blend is an option to conserve tissue)	6.5 mm with blend (6.0 mm with blend is an option to conserve tissue)	VISX STAR S4

Surgical Plan (Continued)

	Right Eye	Left Eye	Comments
Calculations with nomogram correction (enter into VISX)	−4.50 D × 9% = 0.41 −5.00 + 0.41 = −4.59 −4.59 + 1.00 × 13°	−3.00 D × 9% = 0.27 −3.75 + 0.27 = −3.48 −3.48 + 1.50 × 130°	Myopic sphere OS is reduced by 2.00 D to achieve monovision
Ablation depth	4.50 D × 15 µm/D = 68 µm	3.00 D × 15 µm/D = 45 µm	
RSB	68 µm + 8 µm blend = 76 µm 506 µm − 120 µm − 76 µm = 310 µm >250 µm	45 µm + 8 µm blend = 53 µm 508 µm − 120 µm − 53 µm = 335 µm >250 µm	Especially important to measure the bed thickness to be certain adequate room for ablation

Take-Home Points

1. Monovision treatment is good for presbyopic patients who have previously been successful with monovision. The potential impact on fusion and night vision should be explained preoperatively.
2. A glaucoma suspect patient may have LASIK, but baseline fields and stereo disc photos are important to establish a baseline. IOP measurements are inaccurate after myopic LASIK.
3. Postoperative dry eye is a concern, particularly in women over 50 years of age. Increased tear evaporation associated with lid retraction, lagophthalmos, and low ambient humidity can increase the risk of postoperative dry eye symptoms.

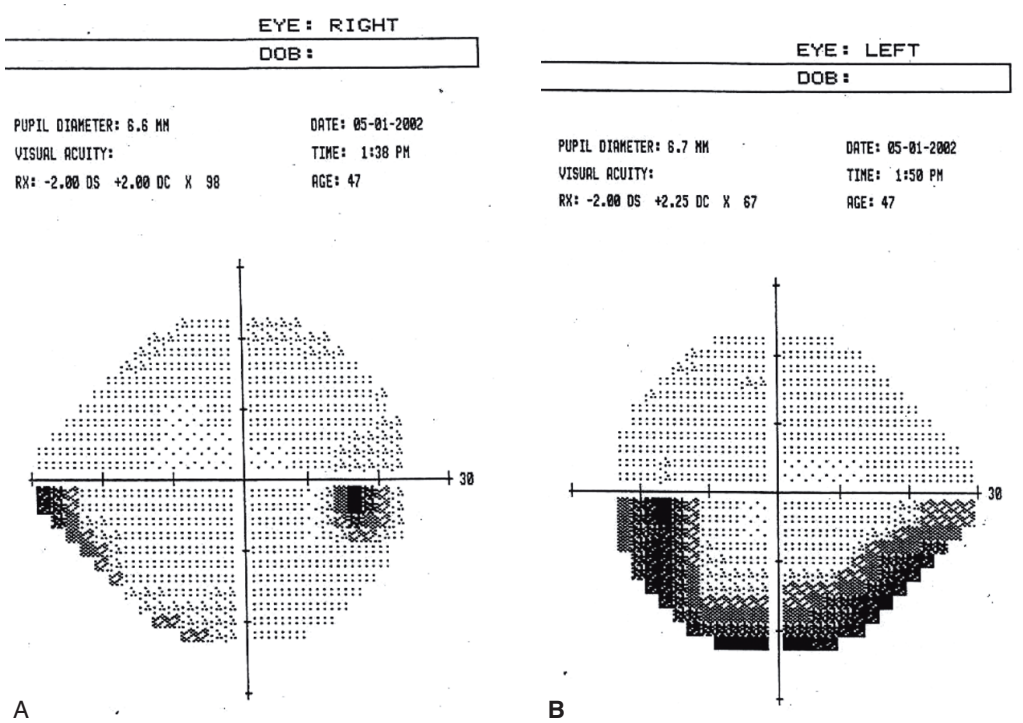
CASE 18

A 47-year-old woman with a history of myopic astigmatism presents for LASIK consultation. Her refraction has remained stable for over 1 year. She has worn RGPCLs for more than 25 years. She is taking bupropion HCl (Wellbutrin) and sertraline HCl (Zoloft). She is currently not using any eyedrops.

W	OD − 5.25 + 2.00 × 98° 20/25 OS − 5.25 + 2.25 × 67° 20/30−	**Uncorrected Va** OD CF OS CF
M	OD − 5.50 + 2.00 × 100° 20/20− OS − 5.25 + 2.00 × 75° 20/20−	
C	OD − 5.25 + 2.25 × 90° 20/15− OS − 5.25 + 2.25 × 70° 20/20+	
K	OD 45.62 × 175°/48.25 × 85° OS 46.00 × 170°/47.00 × 80°	
Pachymetry OD 489 µm OS 495 µm	**Topography** No cone OU	**Scotopic Pupils** OD 5.0 mm OS 5.0 mm

Additional Examination

The IOP by applanation is 16 mmHg in both eyes. On fundus examination, the patient was found to have prominent bilateral optic disc drusen. Visual fields are shown in Case 18, Figures 1A and B.



CASE 18, FIGURE 1

A: Visual field OD. B: Visual field OS. (Courtesy of Robert S. Feder, M.D.)

Discussion

Optic disc drusen may be associated with optic nerve dysfunction. When there is a question of optic nerve dysfunction, always get a baseline visual field to document a possible preoperative field defect. The preoperative fields in each eye appear in Case 18, Figures 1A and B. This patient did have an inferior arcuate defect in the left eye and a subtle inferonasal defect in the right. It is not known with certainty the effect IOP elevation might have on the optic nerve during flap creation. Therefore, it is prudent to discuss this with the patient and the option of an alternative refractive procedure including a surface ablation procedure.

This patient has thinner than average corneas. Some surgeons choose not to perform keratorefractive surgery when the central corneal thickness is <500 µm and some choose to avoid keratorefractive surgery when the RSB will be <50% of the preoperative thickness. Some surgeons will not do LASIK surgery if the RSB is <300 µm, while others will use 250-µm as their minimum RSB. When the cornea is thin relative to the degree of treatment required, it is important to carefully explain the risk of ectasia. It is also important to explain the limitations on retreatment should this become necessary. In this case, the moderate astigmatism will reduce the amount of tissue ablation required. The small pupil will for some surgeons allow a smaller treatment zone, which will also reduce the amount of ablation. Choosing a thinner plate will likely ensure a thinner flap, although thin flaps often occur in thin corneas. Using very thin plates in thin corneas may result in unacceptably thin or even shredded flaps. The variance of flap thickness is less with the femtosecond laser, which can help the surgeon make a flap that is neither too thick nor too thin. However, the suction ring is generally applied for a longer time with the laser than with a mechanical microkeratome. Finally, when LASIK is performed on a patient with a thin cornea, measuring the stromal bed with ultrasonic pachymetry and subtracting this value from the central corneal thickness measured at the time of surgery is necessary to determine the actual flap thickness.

A surface ablation procedure is a preferable option here because the cornea is thin, there is optic nerve dysfunction, which potentially could be affected by the increased IOP during LASIK, and the ablation depth is only 50 µm, which would limit the risk of haze. If LASIK was to be considered in this case, it would be wise to get a neuro-ophthalmology consultation to assess the potential effect of the procedure on the nerve function, discuss the added risk with the patient, and make certain this is documented in the chart. Some surgeons avoid refractive surgery on patients with significant visual field deficits.

Finally, when performing surface ablation or LASIK, remember to mark the patient at the slit lamp, when astigmatism is present, in order to identify and compensate for cyclotorsion.

This patient had bilateral PRK OU and the 3-year postoperative visual acuity was 20/20 OU with no progression of visual field defects.

Surgical Plan: LASIK and PRK

	Right Eye	Left Eye	Comments
Ring size	N/A for PRK 8.5 mm for LASIK	N/A for PRK 8.5 mm for LASIK	PRK requires 7.0-mm epithelial debridement
Ablation zone	6.0 mm	6.0 mm	Pupils <6.5 mm
Spherical equivalent	–4.125	–4.125	
Calculations for LASIK with nomogram correction (enter into VISX)	4.125 × 8% = 0.33 –5.25 – 0.33 = –4.92 –4.92 + 2.25 × 90°	4.125 × 8% = 0.33 –5.25 – 0.33 = –4.92 –4.92 + 2.25 × 70°	Make sure to subtract corrected values from sphere of cycloplegic refraction
For PRK (enter cycloplegic refraction into VISX)	–5.25 + 2.25 × 90°	–5.25 + 2.25 × 70°	No need for nomogram correction if doing PRK
Ablation depth	4.125 D × 12 µm/D = 50 µm	4.125 D × 12 µm/D = 50 µm	No nomogram adjustment for PRK. Always use non–nomogram-adjusted cycloplegic refraction to calculate ablation depth for LASIK
Plate size for LASIK	160 µm	160 µm	If flap too thin on first eye, increase plate thickness or change blade for second eye
RSB (LASIK)	489 µm – 50 µm – 160 µm = 279 µm	495 µm – 50 µm – 160 µm = 285 µm	>250 µm

Take-Home Points

1. Patients with abnormal optic discs, including cupping or disc drusen, require preoperative evaluation, including baseline visual fields.
2. High IOP, which occurs during flap creation, may be undesirable in a patient with optic nerve dysfunction.
3. Thinner flaps result when creating microkeratome flaps on thin corneas.
4. PRK is the preferable keratorefractive option when the cornea is thin or increased IOP is undesirable.
5. In addition to the general risks of refractive surgery, always discuss those specific risks that are unique to the individual patient and document the discussion in the record.

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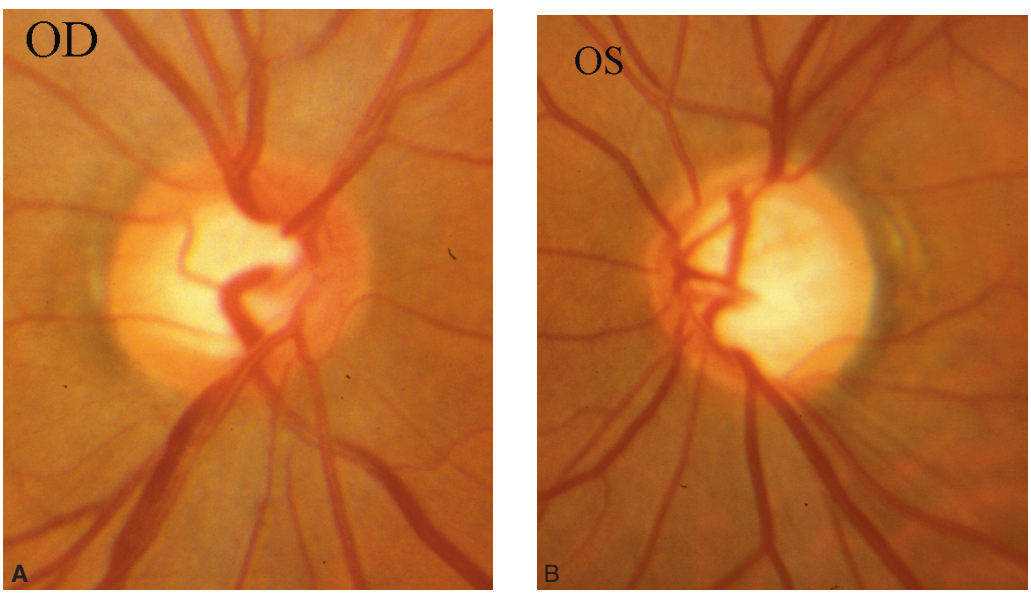
CASE 19

A 35-year-old neurologist presents for LASIK consultation. He enjoys all water sports and is a self-proclaimed "surfer in exile." He wishes to be less dependent on glasses and contact lenses and has worn soft lenses for 15 years. He is in good health and is on no medications. His family history is noncontributory. He mentioned that 6 years ago an eye doctor noted disc asymmetry. Since that time he has received eye care from an optometrist who supplies his contact lenses.

W	OD – 5.50 20/25+ OS – 6.50 20/25–	**Uncorrected Va** OD CF 5′ OS CF 5′
M	OD – 5.00 20/20 OS – 6.00 20/20–	
C	OD – 5.25 + 0.50 × 90° 20/15 OS – 6.00 20/15–	
K	OD 43.25 × 180°/44.00 × 90° OS 43.12 × 30°/44.00 × 120°	
Pachymetry OD 513 μm OS 512 μm	**Topography** Regular astigmatism OU	**Scotopic Pupils** OD 7.5 mm OS 7.0 mm

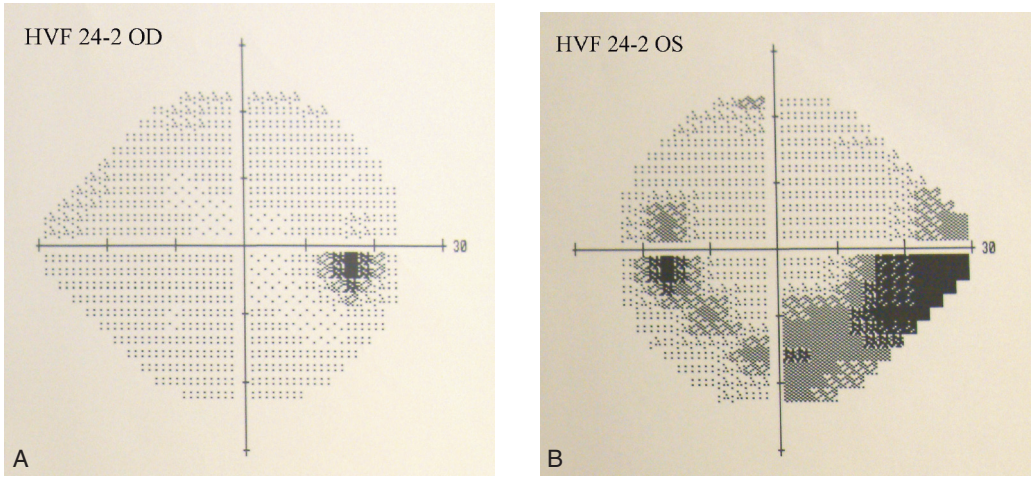
Additional Examination

The external examination was normal with lax lids and a wide palpebral fissure. There was early escape of the pupil response to light OS. Color vision on Ishihara plates was normal in each eye. The slit-lamp examination was entirely normal OU. The IOP was 15 mmHg OD and 14 mmHg OS. The disc photos are shown in Case 19, Figures 1A and B, and the visual fields in Case 19, Figures 2A and B.



CASE 19, FIGURE 1

Optic disc photos: **(A)** right disc and **(B)** left disc. (Courtesy of Robert S. Feder, M.D.)



CASE 19, FIGURE 2

Humphrey 24-2 visual field: **(A)** Visual field OD and **(B)** Visual field OS. (Courtesy of Robert S. Feder, M.D.)

Discussion

Extensive glaucomatous cupping OS was seen on the disc photos. There is an inferior arcuate field defect OS. The pupillary escape noted OS is another indication of optic nerve dysfunction OS. This patient has normal tension glaucoma. Diurnal pressures were obtained and the maximum measured pressure was 19 mmHg OS. Should refractive surgery be offered to this patient? Several important issues must be carefully considered before answering this question. If LASIK were to be performed, a significant elevation in IOP would be required in order to create a flap. It is possible for further nerve damage to occur during this period. While the pressure elevation associated with the femtosecond laser is somewhat less than with a microkeratome, it is not uncommon for the IntraLase ring to cause a transient loss of vision during flap creation. Further, the suction ring must remain in place on the eye for a longer duration with IntraLase than with the microkeratome. If one were to reject LASIK for this reason, would there be additional risks associated with PRK? Measurement of IOP is not reliable after PRK or LASIK. The actual IOP can be significantly higher than the measured reading. Some advocate measuring the pressure from the peripheral cornea using the TonoPen.

This patient's large pupil and −6.00 D correction necessitate a large ablation zone with a blend resulting in an ablation significantly >75 µm. This carries an increased risk of postoperative haze. Unless mitomycin-C (MMC) was applied during surgery, the patient would require several months of topical prednisolone 1%. Glaucoma patients are more likely to experience a steroid-induced IOP rise, which might be more difficult to detect postoperatively. If haze were to develop after surgery, visual fields might be less reliable. In short, this patient's glaucoma may worsen and be more difficult to follow after keratorefractive surgery. As a neurologist, this patient has more insight than the average patient concerning his glaucoma and optic atrophy. Nevertheless, after the risks had been explained, he preferred to have LASIK OD and continue to wear his contact lens OS. He understood that he would no longer have binocular vision in spectacles following surgery. He also understood that if glaucoma developed OD, IOP measurement would be less reliable after LASIK.

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Surgical Plan

	Right Eye	Left Eye	Comments
IntraLase diameter	9.5 mm	No treatment	IntraLase preferred to create a reliably thinner flap with less IOP elevation
IntraLase depth	110 µm	None	Usually creates a 120-µm flap
Ablation zone	6.5 mm + blend zone 6.0 mm + blend acceptable	None	VISX STAR S4
Calculations with nomogram correction (enter into VISX)	−5.00 D × 6% = −0.30 D −5.25 + 0.30 D = −4.95 D −4.95 + 0.50 × 90°		
Ablation depth	−5.00 D ×15 µm/D = 75 µm		
RSB	75 µm + 8 µm = 83 µm 513 µm − 120 µm − 83 µm = 310 µm >250 µm		Intraoperative pachymetry is recommended to determine RSB

Take-Home Points

1. A complete eye examination is an important part of the LASIK evaluation.
2. Keratorefractive surgery may make glaucoma more difficult to manage because IOP measurement is unreliable and PRK haze may make fields unreliable; also, steroid-induced IOP elevation may be difficult to detect.
3. It is possible for IOP rise during flap creation to cause further damage to a nerve with extensive glaucomatous damage.

CASE 20

A 32-year-old man presents for LASIK evaluation. His past medical history is negative, but the past ocular history is significant for a 10-year history of disposable soft contact lens wear. His refraction has been stable for at least the past year. There is no history of prior ocular trauma, infection, or prior surgery. He takes no systemic or ocular medications, and has no known drug allergies.

W	OD − 4.50 + 0.50 × 90° 20/25+ OS − 4.75 + 0.75 × 90° 20/30	**Uncorrected Va** OD 20/400 OS 20/400
M	OD − 4.75 + 0.50 × 90° 20/20 OS − 5.25 + 0.75 × 85° 20/20	
C	OD − 4.75 + 0.50 × 90° 20/20 OS − 5.25 + 0.75 × 90° 20/20	
K	OD 43.5 × 90°/43.0 × 180° OS 43.5 × 90°/42.5 × 180°	
Pachymetry OD 475 µm OS 480 µm	**Topography** Regular astigmatism OU	**Scotopic Pupils** OD 6.5 mm OS 6.0 mm

Additional Examination

The patient does not have deep-set eyes. The palpebral fissure is wide OU. The slit-lamp examination reveals normal corneal structure without evidence of guttata or KC. The lenses are clear, and the IOP is 13 mmHg OU by applanation tonometry. Dilated funduscopic examination is unremarkable. Orbscan evaluation reveals posterior elevations of 28 µm in the right eye and 33 µm in the left eye.

Discussion

With the exception of a thin cornea, this patient has no other contraindications to laser refractive surgery. There are those who believe that a cornea with central thickness of <500 µm is inherently abnormal. Even with an estimated RSB of 270 µm, such as in this case, a better solution may be surface ablation. If the refractive error were significantly higher, a phakic IOL could be considered.

Surface ablation may have a higher risk of inducing corneal haze in patients who have an ablation depth of 75 µm or greater. The prophylactic use of MMC 0.02%, using the proscribed protocol (refer to Chapter 13), may help prevent such an outcome. In this patient, after careful discussion and informed consent regarding the use of MMC, surface ablation with MMC was performed.

When using MMC in the context of refractive surgery, several considerations are important. First and foremost is the accurate compounding of MMC. Since there is a fairly narrow therapeutic window, it is imperative that the correct concentration be used. In most series to date, 0.02% (0.2 mg/mL) of MMC is used.

When planning the entered refraction into the laser, it is important to reduce the spherical correction by approximately 10% in order to compensate for the effect of MMC in corneal wound healing, which may result in postoperative hyperopia. (See Chapter 13 for discussion on nomogram adjustment by age and refractive error.) A postulated mechanism for this is that MMC may prevent the compensatory wound healing that typically reverses the initial hyperopic "overshoot" after myopic surface ablation.

Another important concept is the meticulous adherence to the established protocol for the use of MMC. By doing so, the possible complication rate is dramatically reduced. This involves limiting the exposure of MMC to the central cornea, and away from the limbus, stem cells, sclera, and fornices. This is best accomplished by the use of a corneal light shield, a 6- to 8-mm disk-shaped Merocel sponge. Careful irrigation of any excess MMC from the surface of the eye with 30 mL of balanced salt solution (BSS) will also help reduce the likelihood of complications.

A bandage contact lens is placed on the eye, and topical antibiotics and steroids are used qid for 1 week. Steroids are then tapered over the subsequent 3 weeks. With this technique, reepithelialization is not delayed, and is usually completed within 3 to 5 days, similar to cases of surface ablation in which MMC is not used.

Take-Home Points

1	Avoid LASIK on very thin corneas. Surface ablation or phakic IOL insertion may be a better long-term solution.
2	Consider MMC prophylaxis in higher myopic surface ablations, when the estimated ablation depth is 75 µm or greater.
3	Follow the MMC protocol for preparation and application meticulously.
4	Adjust the entered refraction according to the nomogram (see Chapter 13) to take into account the effect of MMC on wound healing.

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CASE 21

A 40-year-old woman with congenital nystagmus and mild amblyopia OU presented for LASIK consultation in the hope that the surgery would improve her visual acuity. The patient had become intolerant to the soft daily wear contact lenses she had used for the previous 15 years. Her past ocular history was otherwise noncontributory and her general health was excellent. The risks of LASIK surgery were explained in detail. It was explained that surgery was unlikely to improve her visual acuity beyond what she could do in glasses or contact lenses.

W	OD – 3.00 + 2.00 × 89° 20/40 OS – 3.25 + 1.75 × 100° 20/40	**Uncorrected Va** 20/100 20/200
M	OD – 3.25 + 2.25 × 91° 20/40+2 OS – 3.00 + 2.00 × 95° 20/30–1	
WR	OD – 2.22 + 2.19 × 91° OS – 1.98 + 1.93 × 96°	
C	OD – 2.75 + 2.25 × 90° 20/30– OS – 2.50 + 2.00 × 95° 20/30–	
K	OD 42.00 × 180°/44.25 × 90° OS 41.75 × 188°/44.00 × 98°	

Pachymetry	**Topography**	**Scotopic Pupils**
OD 550 μm OS 557 μm	No cone OU	OD 5.9 mm OS 6.3 mm

Additional Examination

Exposure was excellent. There was no detectable tropia. The slit-lamp examination, IOP, and dilated fundus examination were normal. WaveScan measurement showed HOA 8.8% and RMS 2.88 OD, and HOA 8.8% and RMS 2.89 OS.

Discussion

This case brings up two important issues for discussion. First is amblyopia or reduced best-corrected acuity. The nature of the reduced acuity must be elucidated. LASIK is a surgical procedure designed for a healthy eye. Any corneal abnormality causing reduced acuity would likely lead to an unpredictable result after LASIK surgery and would, therefore, be a contraindication. Decreased acuity due to a potentially progressive cataract would be another contraindication. However, mild amblyopia in an otherwise healthy eye is not a contraindication provided the patient has reasonable expectations. The limitations on postoperative acuity need to be carefully explained and understood before surgery. In most cases, the reduced amblyopic target acuity is easier to achieve with LASIK. If, however, a significant tropia is associated with amblyopia, caution is advised. Improving the unaided acuity may affect suppression and result in diplopia.

The second issue is nystagmus. It is potentially difficult to obtain a WaveScan in a patient with a moving eye. Large-amplitude nystagmus might be difficult for the laser to track and it also may

be difficult to center a microkeratome, because the eye is moving as suction is being applied. Finally, registration could be an issue. It is difficult to mark such a patient at the slit lamp for alignment with the laser. Accurate registration is an important step in any custom LASIK surgery or in conventional surgery to correct significant astigmatism.

In this case, the patient was marked, the WaveScan refraction was double-checked, and the tracker was tested with the patient before any treatment commenced. The flaps and ablations were well-centered and the surgery proceeded without complication.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring diameter	9.5 mm	9.5 mm	Hansatome
Plate thickness	160 µm	160 µm	Usually creates a 120-µm flap
Ablation zone	6.0 mm with transition to 8.0 mm	6.0 mm with transition to 8.0 mm	VISX STAR S4 CustomVue
No nomogram adjustment needed (enter into VISX)	−2.22 + 2.19 × 91° Physician adjustment of −0.50 D −2.72 + 2.19 × 91°	−1.98 + 1.93 × 96° Physician adjustment of −0.50 D −2.48 + 1.93 × 96°	Spherical portion can be adjusted ±0.75 D. In US cylinder, power and axis is fixed
Ablation depth RSB	Low ablation depth with ample corneal thickness. RSB adequate OU	Low ablation depth with ample corneal thickness. RSB adequate OU	Ablation depth is calculated by WaveScan unit

At 2 months postoperatively, the patient had an uncorrected acuity of 20/50 OD and 20/30–2 OS. The manifest refraction was OD −0.50 + 0.25 × 90° and OS +0.50 + 0.25 × 105° with best-corrected visual acuity (BCVA) of 20/30–2 and 20/25–2, respectively. Although the patient still has some residual refractive error, the BCVA showed a one-line improvement over the preoperative BCVA.

Take-Home Points

1. Mild amblyopia, in and of itself, is not a contraindication to LASIK surgery, provided the patient has reasonable expectations.
2. Nystagmus can pose a problem for marking and registration, WaveScan acquisition, microkeratome centration, and laser tracking.
3. The patient should be evaluated before surgery to determine if the laser can track the eyes. A robust tracker can increase the safety of LASIK in the nystagmus patient.

CASE 22

This 34-year-old man with myopic astigmatism desired LASIK so that he could drive, play golf and tennis, and watch TV without glasses. He had no significant ocular history. He admitted to being very squeamish about his eyes, and had some difficulty focusing straight ahead during his LASIK consultation.

W	OD – 4.75 + 1.50 × 90º 20/20 OS – 5.50 + 1.75 × 90º 20/20	**Uncorrected Va** 20/400 20/400
M	OD – 5.00 + 1.50 × 90º 20/15 OS – 6.00 + 2.00 × 90º 20/15	
C	OD – 4.75 + 1.75 × 90º 20/20 OS – 5.50 + 1.75 × 90º 20/20	
K	OD 43.50 × 180º/45.50 × 90º OS 43.75 × 178º/45.75 × 88º	
Pachymetry OD 560 µm OS 557 µm	**Topography** With-the-rule astigmatism OU	**Scotopic Pupils** OD 6.0 mm OS 6.0 mm

Additional Examination

There was nothing unusual about the slit-lamp examination of the anterior segment. His ability to cooperate for the eye examination was suboptimal. He was a "squeezer" who was photophobic and had difficulty maintaining fixation for the examination. There was concern about this patient's ability to cooperate for the laser ablation, especially maintaining fixation. In addition, he had a moderate amount of astigmatism so proper alignment of the laser on his cornea was critical for effective laser correction.

Discussion

This patient was an acceptable, although not ideal, candidate for LASIK surgery. He had a thick cornea and was expected to have a generous RSB after myopic ablation. The main concern was about his ability to cooperate for the laser ablation. As usual, the 12 and 6 o'clock axes were marked at the slit lamp with a sterile marking pen, prior to bringing the patient into the LASIK suite to be prepped and draped. Despite the availability of the VISX S4 excimer laser tracking system, the Moria suction ring on a low-vacuum setting was used during laser ablation to help stabilize the globe. Proper alignment of the globe was important because of the dangers of a misaligned treatment of moderate astigmatism.

After making the cutting pass on high vacuum with the Moria CB microkeratome, the device was switched to low vacuum. The microkeratome was reversed and removed, but the suction ring remained on the eye. The low-vacuum setting enabled the suction ring to maintain a firm grasp on the globe, but at a much lower and safer level of IOP. While holding the metal suction ring handle with the left hand, the globe could be stabilized while performing the laser ablation. The ablation went smoothly, and the patient felt relieved that the potential fixation problem was overcome by using the low-vacuum technique.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	0	0	Moria CB
Microkeratome head	130 µm	130 µm	Typically cuts 160-µm flap
Ablation zone	6.5 mm with blend zone	6.5 mm with blend zone	VISX STAR S4

Surgical Plan (Continued)

	Right Eye	Left Eye	Comments
Cycloplegic Rx	−3.25 − 1.50 × 180°	−3.75 − 1.75 × 180°	Minus cylinder form
Calculations using Dr. Rosenfeld's nomogram correction (VISX)	−2.93 − 1.50 × 180°	−3.38 − 1.75 × 180°	10% reduction of sphere using the cycloplegic examination in minus cylinder form
Flap thickness	160 µm	160 µm	
Ablation depth	56 µm	62 µm	
RSB	344 µm	335 µm	>250 µm OU

Take-Home Points

1. The low-vacuum setting on the Moria microkeratome permits exquisite control of the globe during laser ablation.
2. Proper alignment of the axis of astigmatism is critical for treating moderate to high levels of astigmatism.

CASE 23

A 46-year-old dental hygienist with a 30-year history of hard PMMA contact lens wear was seen for refractive consultation. She had early symptoms of presbyopia and had begun to wear near correction over her contact lenses. Her past ocular history was otherwise negative. Her past medical history was significant for medically controlled hypertension.

W	OD − 6.50 + 0.50 × 72° OS − 6.00 + 0.50 × 64°	**Uncorrected Va** 20/400− 20/400−
M	OD − 6.75 + 0.50 × 110° 20/20 OS − 6.00 + 1.00 × 70° 20/20 with + 1.25 add → 20/20 near OU	
C	OD − 6.75 + 0.25 × 120° 20/20 OS − 6.00 + 0.75 × 70° 20/20	
K	OD 45.50 × 90°/44.50 × 180° OS 46.50 × 77°/45.25 × 167°	

Pachymetry	Topography	Scotopic Pupils
OD 500 µm OS 495 µm	+0.75 D x 90° OD +1.00 D x 77° OS	OD 6.5 mm OS 6.5 mm

Additional Examination

Her corneas, tear film, lids, and conjunctiva were normal. Her corneal maps were regular without signs of contact lens–induced warpage.

Discussion

This patient was a long-time rigid PMMA contact lens wearer. This type of patient represents a challenge in two ways. First, the surgeon must be sure that there are no signs of contact

lens–induced effects on the cornea. These include contact lens warpage, which can induce irregular astigmatism, masked astigmatism, and/or myopia that is hidden by the flattening effects of the rigid contact lens. The corneal maps must look smooth and regular and the principal astigmatic axes must be 90° apart. The magnitude and direction of the topographic astigmatism should closely match the refractive astigmatism, although there is usually 0.25 to 0.50 D more astigmatism seen on the maps compared to the refraction. Second, patients who are long-time rigid contact lens wearers have higher visual expectations than patients who wear soft lenses or spectacles. The rigid lenses mask any irregular astigmatism on the patient's cornea and produce an artificially regular surface. These patients should be counseled that their postoperative vision may never be as good as their vision with their rigid lenses.

This patient at age 46 is already experiencing presbyopic symptoms; therefore, careful and complete counseling about presbyopia should be undertaken. Monovision correction for this dental hygienist would be ill-advised because of the effect on stereopsis.

Finally, this patient has thin corneas with a relatively high refractive error. Therefore, the corneas are too thin for LASIK. The risk of haze after surface ablation in this case is significant. This should be discussed with the patient. Consideration of adjunctive MMC treatment would be advisable. The techniques for surface ablation (PRK, Epi-LASIK, and LASEK) should be discussed. See Case 51 to find out what happened in this case.

Surgical Plan

	Right Eye	Left Eye	Comments
Considerations	Do not perform LASIK if the cornea is too thin. Be sure that there are no effects from the rigid contact lens		
Ring size	None in PRK	None in PRK	Cornea too thin
Plate size	None in PRK	None in PRK	Cornea too thin
Ablation zone	6.5 mm with blend	6.5 mm with blend	Pupil = 6.5 mm OU
Spherical equivalent	–7.50 D	–6.25 D	
Conventional surface treatment based on manifest and cycloplegic refractions Treatment is entered in minus cylinder form	–6.75 + 0.50 D × 110° – 6.25 – 0.50 × 20°	–5.75 + 0.75 D × 70° –5.00 – 0.75 × 160°	There is no nomogram adjustment with PRK
Ablation depth	120 µm	98 µm	The Alcon software calculates the ablation depth
RSB	500 µm – 120 µm = 380 µm	495 µm – 98 µm = 397 µm	

Take-Home Points

1. Be sure the patient stays out of her rigid contact lenses until the refraction and topography become stable. The stable topography should be consistent with the refraction.
2. Warn patients in their mid-40s about the effect of myopic LASIK on presbyopia and discuss treatment options. Avoid monovision in patients who require excellent stereopsis to perform their jobs.
3. Avoid LASIK if the cornea is too thin.

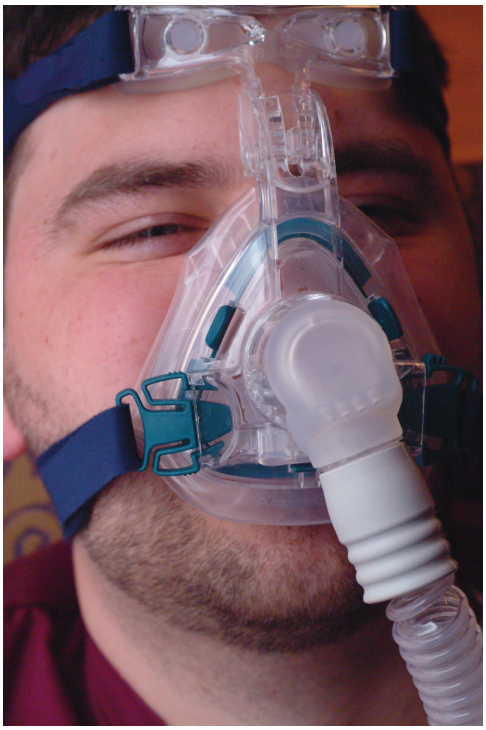
CASE 24

A 46-year-old man presents for LASIK consultation. He is hoping to be less dependent on distance glasses and understands he will need to wear reading glasses. He is not interested in monovision. The patient explains he could never wear contact lenses because he is an intense "eyelid squeezer." He has a history of hypertension and hypercholesterolemia. He also has sleep apnea and wears a continuous positive airway pressure (CPAP) mask every night to assist his breathing during sleep (Case 24, Fig. 1).

W	OD – 8.25 + 1.00 × 72° 20/30+ OS – 6.00 + 0.75 × 77° 20/30–	**Uncorrected Va** CF 3′ CF 3′
M	OD – 7.50 + 1.00 × 85° 20/25– OS – 5.50 + 0.75 × 85° 20/20–	
C	OD – 7.50 + 1.00 × 90° 20/25+ OS – 5.50 + 0.75 × 85° 20/20–	
K	OD 41.62 × 179°/43.25 × 89° OS 42.00 × 180°/42.87 × 90°	
Pachymetry OD 556 μm OS 550 μm	**Topography** No evidence of ectasia OU	**Scotopic Pupils** OD 6 mm OS 6 mm

Additional Examination

Intense blepharospasm is noted when attempting tonometry, but IOP is measured and is normal. A 12Δ right exotropia is noted. The slit-lamp and fundus examinations are normal.



CASE 24, FIGURE 1

Donning the CPAP mask risks bumping the eye and displacing the flap. Air flow over the flap may cause excessive dryness. (Courtesy of Robert S. Feder, M.D.)

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Discussion

Although this patient is highly motivated to have LASIK surgery, he is a poor candidate. Intense blepharospasm can be associated with an incomplete or partial flap intraoperatively. It can also be associated with a displaced flap postoperatively. In addition, this patient wears a CPAP mask at night (refer to Case 24, Fig. 1). The proximity of the mask edge to the eye may also increase the risk of flap displacement.

While LASIK is a poor choice, a surface ablation procedure is a viable option for this patient. The surgeon must carefully explain how surface ablation is different from LASIK. A patient expecting the rapid visual rehabilitation and minor irritation commonly experienced after LASIK surgery will be disappointed with the increased discomfort and slow return of vision after PRK. With the VISX STAR S4 laser and a 6.5-mm optical zone, the estimated ablation depth would be 105 µm OD and 77 µm OS if the nonadjusted refraction is used for the calculation. Alternatively, a 6.0-mm optical zone with a blend to 8.0 mm could be used to conserve tissue. Many surgeons feel that ablation depths of 75 µm or more are associated with significantly more postoperative haze and recommend using topical MMC 0.2 mg/mL applied to the stromal bed with a 6.0- or 7.0-mm foam corneal protector to reduce the risk of haze. (Refer to Chapter 13 on use of mitomycin-C.) The exact amount of time the MMC is applied varies by the surgeon from 12 seconds to 2 minutes. If MMC is used, it is important to reduce the spherical portion of the treatment by 10% to 12%. It is also important to inform the patient that MMC has not been FDA-approved for this purpose, MMC may permanently affect the healing ability of the cornea, and long-term studies on its use to prevent corneal haze have yet to be done.

Remember to always check the keratometry readings in any high myopia case. To estimate the expected postsurgical corneal curvature, multiply the spherical equivalent of the cycloplegic refraction by 0.7 or 0.8 (depending on how conservative the surgeon is) and subtract the product from the average of the presurgical keratometric values. If the result is <35.00 D, there is an increased risk of poor visual function and keratorefractive surgery may not be advisable. In this case, the result of the curvature calculation is significantly >35.00 D, leaving room for retreatment if necessary. The small risk of postoperative diplopia related to the preexisting exotropia should be discussed. Finally, this presbyopic patient must be educated about monovision and the need for reading glasses if full correction is achieved.

Take-Home Points

1	Blepharospasm is a risk factor for partial or incomplete flap intraoperatively.
2	Wearing a nighttime CPAP mask may increase the risk of both flap displacement and dryness.
3	Surface ablations deeper than 75 µm are more likely to develop stromal haze postoperatively.
4	The use of topical MMC 0.2 mg/mL may reduce the risk of postoperative stromal haze, but requires a 10% to 12% reduction in spherical myopic power. The use of MMC requires significant patient education.
5	Do not forget to calculate the postoperative corneal curvature in any high myopia patient to be certain the new corneal contour will not be <35.00 D, possibly too flat to support good visual function.
6	Warn the patient with a tropia about the possibility of diplopia postoperatively, if the ability to suppress the wandering eye is disturbed.
7	Make sure the myopic patient of presbyopic age being treated in both eyes for distance really understands the impact this will have on unaided near vision.

CASE 25

A 32-year-old man presents for LASIK evaluation. His past medical history is negative. The past ocular history is significant for a 10-year history of disposable soft contact lens wear, but no

history of prior ocular trauma, infection, or prior surgery. He takes no systemic or ocular medications, and has no known drug allergies. His refraction has been stable for more than 1 year.

W	OD – 4.50 + 0.50 × 90º 20/25 OS – 4.75 + 0.75 × 90º 20/30	**Uncorrected Va** 20/400 20/400
M	OD – 4.75 + 0.50 × 90º 20/20 OS – 5.25 + 0.75 × 85º 20/20	
C	OD – 4.75 + 0.50 × 90º 20/20 OS – 5.25 + 0.75 × 90º 20/20	
K	OD 43.00 × 180º/43.50 × 90º OS 42.50 × 180º/43.50 × 90º	

Pachymetry	**Topography**	**Scotopic Pupils**
OD 475 μm OS 480 μm	Regular bow-tie OU	OD 6.5 mm OS 6.5 mm

Additional Examination

The patient does not have deep-set eyes. The palpebral fissure is wide OU. The slit-lamp examination reveals normal corneas without evidence of guttata or KC. The lenses are clear, and the IOP is 13 mmHg OU by applanation tonometry. The dilated funduscopic examination is unremarkable. Orbscan evaluation reveals posterior elevation of 47 μm in the right eye and 49 μm in the left eye. The anterior elevation, keratometry, and pachymetry maps of the Orbscan are normal. Specifically, there is no inferior steepening on the keratometry map, and although the overall pachymetry is low, there is no focal area of thinning on the pachymetry map, either centrally or inferiorly, corresponding to the area of highest posterior elevation.

Discussion

This patient is a good candidate for laser vision correction by surface ablation (PRK), except for the abnormal posterior elevation on Orbscan (See Chapter 2 on corneal topography). The Orbscan uses a scanning slit to image the cornea, and by compiling the images, it can reconstruct the anterior and posterior curvature of the cornea. Analysis is made with reference to a "best-fit sphere" and, therefore, any curvature above or below that sphere is given a positive or negative elevation value. Some believe that the earliest corneal changes in ectasia occur in the posterior cornea; therefore, if a patient has significant posterior elevation of the cornea, it may be an early indicator of FFKC. Although no absolutes can be given, it is generally accepted that values above 50 μm (0.050 mm) of posterior elevation are highly suspicious, and values between 40 and 50 μm should at least prompt a discussion with the patient of the potential for ectasia.

Surface ablation techniques may be a safer alternative to LASIK in this setting. Although one cannot unequivocally state that the risk of ectasia after surface ablation is zero, the risk is probably much less than with LASIK. In the setting of high myopia or in cases of higher risk for the development of haze, the judicious use of prophylactic MMC may be beneficial. There are many good reasons to avoid any elective corneal surgery in patients with KC or FFKC. Even a relatively "safer" procedure such as PRK with MMC is not recommended at this time due to unknown effects of laser ablation on these corneas, and the unknown effect of MMC on keratocytes in patients with KC or FFKC. The procedure has the potential to cause acceleration of the ectatic process.

Take-Home Points

1	Analysis of the posterior corneal surface with the Orbscan may be beneficial in identifying patients with FFKC or KC.
2	Use caution in performing LASIK in patients with posterior elevation above 40 µm.
3	Avoid LASIK in patients with posterior elevation above 50 µm.

CASE 26

A 31-year-old woman with a history of soft contact lens wear for 15 years presents for LASIK consultation. The patient has a history of migraines. There is no history of other eye problems. The patient states she has not needed new glasses in the past year. Medications include Imitrex and Prozac.

W	OD – 5.75 20/20 OS – 5.75 20/40+ (old R×)	**Uncorrected Va** OD CF OS CF
M	OD – 6.75 20/20 OS – 6.25 + 1.50 × 35° 20/20–	
C	OD – 6.25 20/15 OS – 6.00 + 1.50 × 45° 20/15–	
K	OD 45.50 × 180°/45.50 × 90° OS 45.50 × 142°/46.50 × 52°	
Pachymetry OD 529 µm OS 501 µm	**Topography** Preoperative: Case 26 Figures 1, 2, and 3	**Scotopic Pupils** OD 6.0 mm OS 6.0 mm

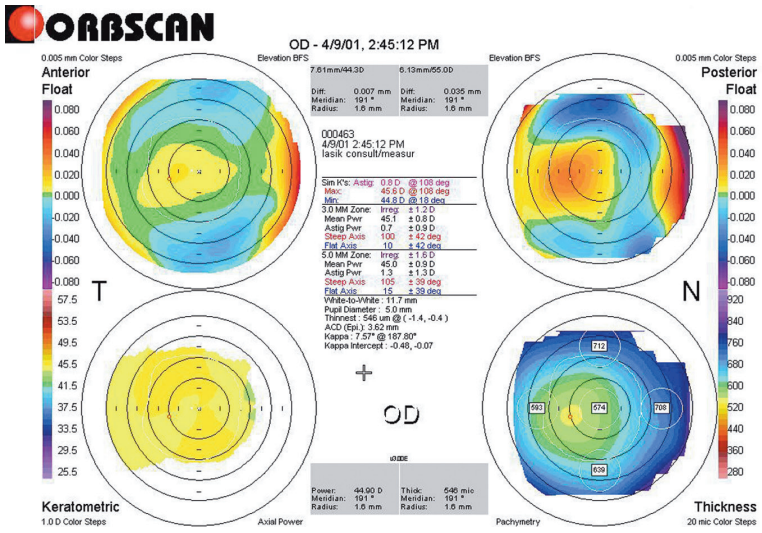
Additional Examination

After 3 weeks out of contact lenses, the cycloplegic refraction remained stable. IOP and fundus examinations were normal. Corneal topography was obtained at that time. See Case 26, Figures 1 and 2, OD and OS, respectively. Normal band view of OS is seen in Case 26, Figure 3.

Discussion

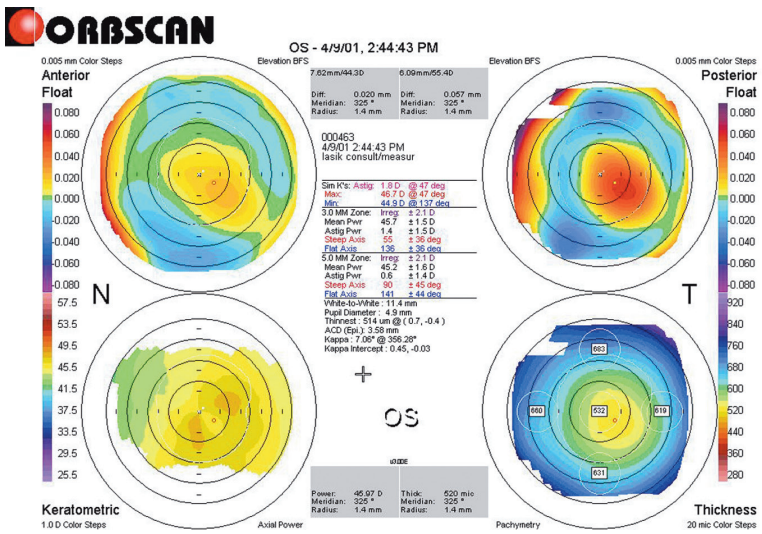
A critical review of the preoperative topography maps is essentially normal in the right eye (Case 26, Fig. 1); however, the power map of the left eye (Case 26, Fig. 2) in the lower left corner deserves special consideration. Notice the dumbbell appearance and particularly how the superior portion is skewed to the right. Rabinowitz refers to this finding as skewed radial axes and has suggested that a deviation >21 degrees is an important index in screening patients for the diagnosis of KC. Refer to the discussion on corneal topography in Chapter 2. In this patient, the central corneal power value is <47.2 D cutoff described by Rabinowitz, but the Sim-K astigmatism of 1.8 D is >1.5 D index.

Another way to look at this patient is to examine the Orbscan II topography using the normal band scale (Case 26, Fig. 3). This was discussed in the section on topography in Chapter 2. Remember that if orange is present in two maps, surface ablation would be a better option than LASIK, provided the risk of ectasia has been explained. Review of this map shows orange in the posterior elevation map upper right and a small orange spot in the power map on the lower left.



CASE 26, FIGURE 1

Preoperative topography OD. (Courtesy of Robert S. Feder, M.D.)

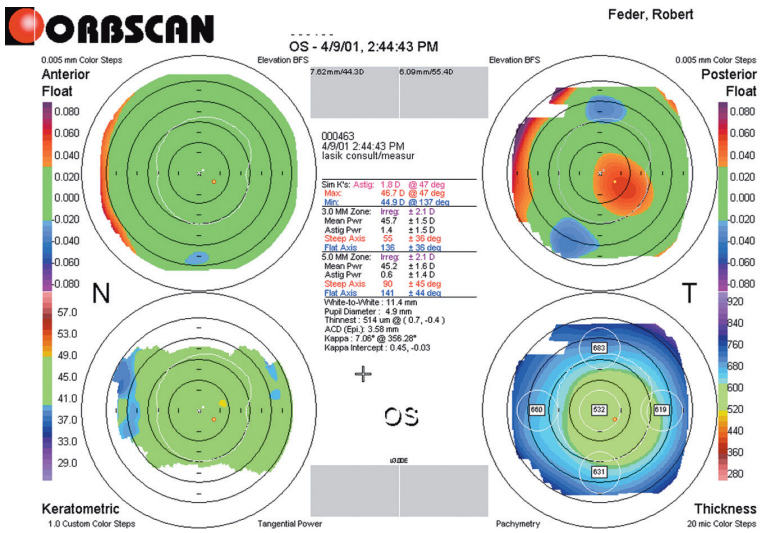


CASE 26, FIGURE 2

Preoperative topography OS. (Courtesy of Robert S. Feder, M.D.)

The presence of orange in two maps is one indicator of a higher risk of ectasia with LASIK. PRK is the preferable choice provided the patient is informed of the ectasia risk.

Another useful index found on the Orbscan II unit is the posterior elevation difference with best-fit sphere. This value is found when the curser is placed on the highest part of the posterior elevation map. The value in the gray box to the left should ideally be <0.04 mm. In this patient, who was treated prior to our awareness of this index, the value was >0.05 mm. Caution is also recommended when the irregularity at the 3.0-mm zone is ±2.0 D or the irregularity at the 5.0-mm zone is ±2.5 D. A more conservative approach would be to use ±1.5 D at 3.0 mm and ±2.0 D at 5.0 mm. The value in this case is ±2.1 D at both diameters. Finally, if the cornea is >20 µm thinner in the periphery than in the center, the postoperative ectasia risk may be increased. No



CASE 26, FIGURE 3

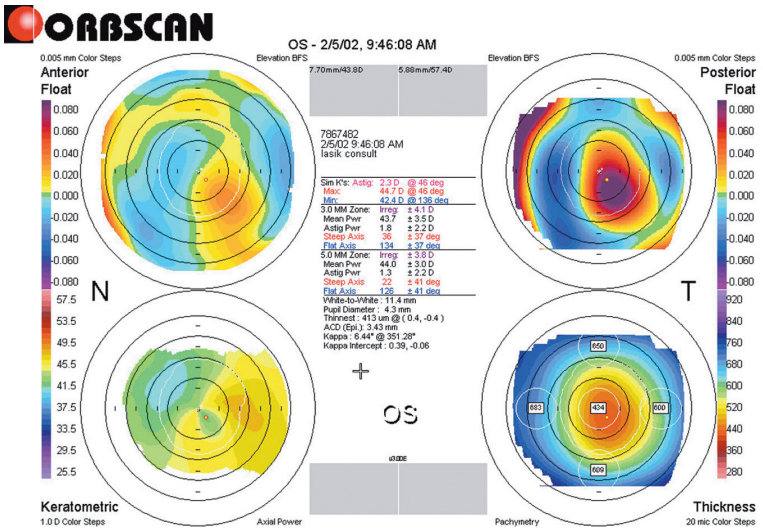
Preoperative normal band view OS. (Courtesy of Robert S. Feder, M.D.)

set of indices is foolproof in preventing postoperative ectasia. It is recommended that several indices and analyses be used to determine whether a particular patient is suitable for keratorefractive surgery. The risks should be carefully and completely explained to the patient and the discussion should be documented in the chart. Some surgeons have the patient sign the record to acknowledge an understanding of the unique risks in the specific case.

In this case, notice also that there is a significant difference in corneal thickness between the two eyes, with the eye suspicious for FFKC being 28 µm thinner than the fellow eye by ultrasonic pachymetry measurement. The patient is eager to have LASIK surgery in both eyes despite the increased risk of postoperative ectasia in the left eye. The options in this case are to avoid corneal refractive surgery, consider PRK in the left eye, or proceed with LASIK. Because LASIK would involve ablation at a deeper layer of the cornea, PRK would be preferable. Conservative surgeons would avoid surgery particularly in the OS, given a picture suggestive of FFKC.

Surgical Plan: LASIK OD and PRK OS

	Right Eye	Left Eye	Comments
Ring size	8.5 mm	N/A	$K > 45.50$
Plate size	160 µm	N/A	Usually thinner flap occurs in thin corneas
Ablation zone	6.5 mm (alternatively, a 6.0-zone plus blend)	6.5 mm (alternatively, a 6.0-zone plus blend)	Pupils ≤6.0 mm
Spherical equivalent	−6.25 D	−5.25 D	
Calculations with nomogram correction (enter into VISX)	−6.25 × 6% = 0.375 −6.25 + 0.38 = −5.87 −5.87	−6.00 + 1.50 × 45°	Some surgeons prefer to use the axis from the manifest refraction
Ablation depth	6.25 D × 15 µm/D = 94 µm	5.25 D × 15 µm/D = 79 µm	The risk of haze may be increased, due to an ablation depth >75 µm
RSB	529 µm − 160 µm − 94 µm = 275 µm >250 µm	501 µm − 79 µm = 422 µm	This patient may require an RSB >300 or more to prevent ectasia



CASE 26, FIGURE 4

Postoperative topography OS. (Courtesy of Robert S. Feder, M.D.)

Postoperatively, this patient achieved an uncorrected acuity of 20/20 OD and 20/30 OS. Her refraction 6 months after surgery was plano OD and −0.50 + 1.50 × 50° 20/25 OS. She is aware that her acuity is better OD, but is overall quite happy with the refractive outcome. The postoperative topography map 6 months after surgery OS is shown in Case 26, Figure 4. The left eye shows further skewing of the radial axes with the development of superotemporal flattening. The posterior float, upper left, is much steeper OS (PRK eye) than it was OD despite the much greater RSB OS. Whether there will be continued progression is not known, but further close follow-up is warranted.

Take-Home Points

1	Reduced best-corrected acuity and significantly decreased central thickness relative to the fellow eye are signs that may be present in association with FFKC.
2	Review preoperative topography carefully for signs of KC or pellucid marginal degeneration (PMD). Different indices provided on most topography units can help determine the presence of subclinical KC, but may not detect PMD.
3	If corneal ectasia is present, the patient should not have corneal refractive surgery. If a patient does not seem to understand the risk that may be present in any case, do not do refractive surgery.
4	In borderline cases, PRK might be a better choice than LASIK to maximize the RSB. If the ablation depth is >75 µm, the use of topical MMC is a consideration to reduce the risk of haze. However, the long-term effects of MMC, particularly in cases such as this are not known.
5	Even when PRK is performed and the RSB is >300 µm, progressive ectasia may occur.

CASE 27

A 35-year-old woman comes in for LASIK consultation. Her husband had successful LASIK surgery 1 year previously and she wondered if she could be a candidate.

She tried contact lenses, but could never wear them comfortably. If she had to, she could see without glasses, but she would get a headache. She wears glasses full time at work and for leisure activities, both for near and distance.

W	OD + 3.25 20/20–3 OS + 3.50 20/25–	**Uncorrected Va** 20/30 18 pt 20/80 24 pt
M	OD + 3.75 20/15 OS + 4.25 + 0.50 × 55° 20/20+	
C	OD + 4.50 20/15 OS + 5.50 + 0.50 × 60° 20/15 slow	
K	OD 43.25 × 15°/44.00 × 105° OS 43.50 × 12°/44.00 × 102°	
Pachymetry OD 544 μm OS 537 μm	**Topography** Regular with-the-rule astigmatism	**Scotopic Pupils** OD 5.0 mm OS 5.0 mm

Additional Examination

The external examination shows good exposure with no evidence of dry eye. The motility examination does not reveal a tropia or phoria. The slit-lamp examination, IOP, and fundus are normal.

Discussion

The key finding in this case is the discrepancy between the spectacle correction and the cycloplegic correction. The difference is +1.25 D OD and over +2.00 D OS. Given this degree of hyperopia, it is not a surprise that she has difficulty functioning without correction despite her pre-presbyopic age. The question is on which refraction should the treatment be based? If you treat on the cycloplegic refraction, she will be quite myopic initially and this might be difficult for her to tolerate. Further, adding the required overcorrection of 25% of the spherical equivalent (see the hyperopia nomogram, Table 7.2, page 77, which is based on age and spherical equivalent) to the sphere portion of the treatment boosts the sphere to +7.19 D. This is well above the approved range for hyperopia with the VISX STAR S4. On the other hand, treating on the manifest refraction will leave her significantly undercorrected and symptomatic as she gets older. What to do? The first step with this easygoing individual is to explain the situation. Good communication, including the patient in the decision-making process, is especially helpful in situations such as this. The best approach is to gradually increase the glasses correction, allowing her sufficient time to adapt to a spectacle correction that is close to the cycloplegic refraction. This process may occur over several weeks or even months; therefore, patience on the part of the doctor and the patient will be required.

Once the patient is comfortable with the full correction, the question of how to deal with the large degree of hyperopia moves to the forefront. Treatment of the right eye is within the approved parameters for LASIK, while the left eye exceeds the upper limit. Because she cannot wear a contact lens, both eyes must be corrected. The options for the left eye include insertion of a phakic IOL (not yet approved in the United States for hyperopia) and clear lens exchange with insertion of an accommodating IOL or multifocal implant. The multifocal IOL is a less desirable option when used as a unilateral treatment. Another option is PRK. PRK for hyperopia does not require a nomogram adjustment and the treatment would, therefore, be within the approved range. It has the advantage of not being an intraocular procedure, but the disadvantage of postoperative discomfort and slower visual rehabilitation. Finally, with large hyperopic keratorefractive procedures, it is important to apply the keratometric conversion factor adding the spherical equivalent in diopters to the preoperative average keratometry value to confirm that the proposed treatment will not induce corneal steepening >50.00 D.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	None for PRK	
Plate size	160 µm	None for PRK	Hansatome flap usually thinner than 160 µm
Ablation zone	9.0 mm	9.0 mm	Hyperopic protocol
Calculations with nomogram correction (enter into VISX)	+4.00 × 25% = 1.00 +4.00 + 1.00 = +5.00 +5.00 D	+5.50 + 0.50 × 60°	No nomogram adjustment for PRK OS
Ablation depth	5 D × 8 µm/D = 40 µm	5.75 D × 8 µm/D = 46 µm	
RSB	544 µm – 160 µm – 40 µm = 344 µm >250 µm	537 µm – 160 µm – 46 µm = 331 µm >250 µm	Hyperopic ablation is not deepest centrally, so RSB is significantly >250 µm

Take-Home Points

1. If the manifest and cycloplegic refractions are significantly different, explain this to the patient and help the patient adapt to a correction similar to the cycloplegic before surgery.
2. PRK on the VISX STAR S4 does not require a nomogram adjustment and this can allow an appropriate large treatment to be done within the approved range.
3. Calculate an expected postsurgical keratometry value by adding the spherical equivalent of the proposed treatment in diopters to the average keratometry. The expected postoperative keratometry (allowing some room for retreatment) should ideally be >35.00 D and <50.00 D. Remember that for myopia the conversion factor for calculating the expected postoperative keratometry is 0.7 or 0.8 multiplied by the spherical equivalent added to the average keratometry.

CASE 28

A 56-year-old man with a history of hyperopia presents for LASIK consultation. He states that he could not tolerate contact lens wear. He has a history of bipolar disorder and anemia. His current medications include Effexor, Buspar, Wellbutrin, and Xanax. He has fainted several times in the past when he has had a blood test.

W	OD + 3.00 20/25+ OS + 2.75 + 0.50 × 90° 20/15 Add + 2.75 OU	**Uncorrected Va** 20/100 18 pt @14″ 20/100 18 pt @14″
M	OD + 3.25 20/20– OS + 3.50 20/15	
C	OD + 3.00 20/20 OS + 3.50 20/15	
K	OD 43.75 × 180°/43.75 × 90° OS 44.00 × 180°/44.25 × 90°	
Pachymetry OD 551 µm OS 551 µm	**Topography** Regular astigmatism	**Scotopic Pupils** OD 4.0 mm OS 4.0 mm

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Additional Examination

Exposure is excellent, the refraction is stable, and the rest of the examination is normal.

Discussion

The clinician must assess this patient's candidacy for LASIK from both the anatomical and the psychosocial perspectives. Is the patient's psychiatric illness stable and might he be expected to have difficulty adapting to the changes that will occur following surgery? LASIK for hyperopia is quite different than for myopia. Regression is expected and, therefore, a significant age-dependent overcorrection must be built into the treatment. It can take as long as 6 months for the refractive error to stabilize. Initial myopia requiring distance glasses with transition over time to a need for reading glasses must be carefully explained and understood. The history of anemia should be investigated and addressed if necessary. Significant anemia may increase the risk for retinal and optic nerve ischemia while IOP is elevated. The history of vasovagal reaction should also not be overlooked. Whereas surgery with a patient in the supine position is beneficial, pretreatment with an intramuscular injection of 1 mL of atropine 0.4 mg/mL given 30 minutes prior to surgery can help block a vasovagal reaction. The hyperopic profile with the VISX laser requires a 9.0-mm ablation zone, so a large flap is necessary. The maximum ablation depth of 8 µm/D of correction occurs at a 5-mm diameter ring around the center of the ablation. Therefore, the cornea would have to be quite thin before the ablation depth made surgery unsafe.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	9.5 mm	Large flap required for hyperopic LASIK
Plate size	160 or 180 µm	160 or 180 µm	Hansatome
Ablation zone	Hyperopic LASIK profile	Hyperopic LASIK profile	VISX STAR S4
Cycloplegic refraction used for treatment	+3.00 D	+3.50 D	Make sure full cycloplegia
Calculations using the hyperopic nomogram correction (see Table 7.2, page 77) (enter into VISX)	+3.00 × 30% = 0.90 +3.00 + 0.9 = +3.90 +3.90 D	+3.50 + 30% = 1.05 +3.50 + 1.05 = +4.55 +4.55 D	Increase the correction to compensate for the expected postoperative regression; +4.55 D is close to the maximum +5.00 D approved for VISX
Ablation depth	3.9 D × 8 µm/D = 31 µm	4.55 D × 8 µm/D = 36 µm	Deepest ablation, 8 µm/D, occurs in a 5-mm diameter ring around the center of the ablation zone
RSB	551 µm – 160 µm – 31 µm = 360 µm	551 µm – 160 µm – 36 µm = 354 µm	Hyperopic ablation is not deepest centrally, so RSB is significantly greater

Take-Home Points

1. Remember both the psychosocial as well as the anatomical criteria for LASIK surgery.
2. Pretreatment with 1 mL of atropine 0.4 mg/mL by intramuscular injection can help prevent a vasovagal reaction. May also be necessary for retreatment.
3. Significant anemia is a risk factor for ischemic injury related to increased IOP from the suction ring.

4 Overcorrection is necessary to compensate for the postoperative regression that often occurs with hyperopic LASIK.

5 Hyperopic patients need to be educated about the possible need for distance glasses after surgery and that it may take up to 6 months for the refraction to stabilize.

CASE 29

This 34-year-old woman presented for LASIK consultation. She had heard about customized treatment for correction of hyperopia and wondered if she was a candidate. She has become increasingly contact lens intolerant over the years and would like to decrease her dependence on glasses and contact lenses. She is in good health and has had no eye problems in the past. She takes birth control pills, but no other medication. Her grandmother had an attack of glaucoma in her 70s that was successfully treated with laser.

W	OD + 3.50 sph 20/25– OS + 3.75 sph 20/25–	**Uncorrected Va** 20/100 20/200
M	OD + 4.00 + 0.55 × 60° 20/20–1 OS + 4.00 + 0.75 × 127° 20/20	
WR	OD + 4.17 + 0.65 × 55° OS + 3.74 + 0.73 × 141°	
C	OD + 4.25 + 0.50 × 60° 20/20 OS + 4.00 + 0.62 × 130° 20/20	
K	OD 40.62 × 147°/41.12 × 57° OS 40.12 × 45°/40.87 × 135°	
Pachymetry OD 562 μm OS 570 μm	**Topography** Regular astigmatism	**Scotopic Pupils** OD 7.5 mm OS 7.2 mm

Additional Examination

The external, slit-lamp, and fundus examinations are normal. The angle is wide open and the IOP is 15 mmHg OU. WaveScan measurement showed 7.8% HOA and RMS 6.99 OD, and 6.4% HOA and RMS 7.73 OS.

Discussion

While pachymetry is a major concern in treating high myopia, it is somewhat less of a concern in high hyperopia, because the maximum ablation depth is less per diopter and the deepest ablation does not occur at the thinnest part of the cornea. For the high hyperopia treatment, corneal curvature becomes a more important concern. The resulting corneal curvature should ideally not exceed 50.00 D on keratometry. Adding the spherical equivalent of the correction to the preoperative average keratometry value provides an estimate of this value.

In this case, the cornea is flat so there is plenty of room to steepen the cornea without exceeding the limit just discussed. However, creating a flap with the microkeratome can be an issue in a patient with a flat cornea. There is increased risk of a free cap being created or a flap that is too small to accommodate the larger hyperopic ablation zone. A larger-diameter ring on the

microkeratome should be used. The femtosecond laser is an excellent alternative because the flap diameter created is independent of corneal curvature.

Often patients who have a higher level of hyperopia can have a latent component. The key here, as in myopic patients, is clinical correlation with the manifest, the cycloplegic, and the WaveScan refractions. Patients who have significant deviation should not be treated with the CustomVue platform.

Surgical Plan

The manifest, cycloplegic, and WaveScan refractions were well-matched, so no physician adjustment was used. Surgery was planned using the Hansatome (160-µm head and 9.5-mm ring) and CustomVue with the VISX STAR 4 laser. The surgery proceeded in an uncomplicated fashion.

Follow-Up Evaluation

At 3 months postoperatively, the patient presented with some overcorrection (myopic shift) OD > OS resulting in compromised uncorrected acuity, although best-corrected acuity remained unchanged from preoperative measurements.

Manifest Refraction	Uncorrected Va
OD −1.25 + 0.25 × 90° 20/20	20/50
OS −0.75 + 0.50 × 75° 20/20	20/30

In general, CustomVue hyperopic treatments tend to result in refractive errors near plano in the early postoperative period. The amount of overcorrection that resulted in this case occasionally occurs in high hyperopic corrections. This may be the result of the longer treatment time. Over time, the overcorrection tends to regress. If this persists at the 6-month postoperative visit and is stable, then a CustomVue enhancement can be considered in the same manner as a myopic enhancement case. In general, hyperopic CustomVue treatments tend to be closer to emmetropia earlier when compared with conventional treatments and therefore regress less.

Take-Home Points

1. Low hyperopia cases treated with CustomVue typically end up near plano postoperatively, but high hyperopic cases may be prone to overcorrection. This may be related to the longer treatment time.
2. Careful clinical correlation of manifest and wavefront refractions is extremely important in treating hyperopic patients.
3. Avoid cases when the estimated average postoperative keratometry is >50.00 D.
4. If the preoperative cornea is flat, use a large microkeratome ring or femtosecond laser.

CASE 30

A 49-year-old woman with a history of hyperopic astigmatism presents for consultation. She has worn toric soft contact lenses for many years and her refraction has been stable for more than 1 year. She had crossed eyes as a child and was treated with glasses only. Without glasses she currently is unable to see distance or near. She is right eye dominant.

W	OD + 2.50 + 1.25 × 94° 20/25– OS + 3.75 + 1.50 × 86° 20/30	**Uncorrected Va** CF distance; 18 pt near CF distance; 18 pt near
M	OD + 3.00 + 1.25 × 90° 20/15 OS + 4.75 + 2.00 × 85° 20/20	
C	OD + 3.00 + 1.50 × 90° 20/15 OS + 5.00 + 2.00 × 85° 20/20	
K	OD 41.50 × 6°/42.75 × 96° OS 41.75 × 178°/42.75 × 88°	
Pachymetry OD 505 μm OS 501 μm	**Topography** Regular astigmatism OU	**Scotopic Pupils** OD 7.0 mm OS 7.0 mm

Additional Examination

The patient has a prominent brow, but lax lids and a wide palpebral fissure. The corneal diameter is 12 mm OU. The motility examination reveals an 8Δ esophoria at distance. The IOP and fundus examination are normal.

Discussion

Several useful teaching points are demonstrated in this case. In the evaluation, the pushed plus manifest refraction uncovered nearly all of the hyperopic correction noted in the cycloplegic refraction. The +3.75 D spherical equivalent and the +1.25 D of astigmatism in the right eye are well within the approved range for hyperopic LASIK even when 23% of the spherical equivalent is added to the sphere (per the nomogram for hyperopic LASIK on the VISX laser, Table 7.2, page 77).

This is not the case for the left eye. The nomogram percentage adjustment is 28% for a +6.00 D spherical equivalent in a 49-year-old, which would add 1.68 D to the spherical portion of the refraction. This would exceed the approved range for hyperopic correction with the VISX laser, which would require off-label use of the laser. Most surgeons would not advise off-label use of the laser and would instead look for alternatives. Some surgeons prefer to avoid keratorefractive surgery near the approved upper limits for myopia and hyperopia. The patient should be informed that at the upper extremes of approved treatment, a loss of best-corrected acuity or reduced night vision might occur. Clear lens extraction with a toric IOL or LRI would be an alternative for the hyperopic patient, whereas a phakic IOL might be a better choice for the high myope due to the risk of retinal detachment. In this case, a surface ablation procedure would be an alternative to LASIK for the left eye. PRK does not require a nomogram adjustment. The surgeon can use the cycloplegic refraction if it is close to the manifest refraction.

A large flap is required for hyperopic LASIK in order to accommodate the 9.0-mm treatment zone. In this case, the keratometry values are >45.00 D, so an 8.5-mm Hansatome ring would be an acceptable choice. Because of the prominent brow, the surgeon should be prepared to position the patient in the chin-up position to achieve better exposure. The corneas are somewhat thin, but this should not pose a problem for this hyperopic patient. Keep in mind that a thin flap is likely to occur with a microkeratome and with the same blade the flap in the second eye would be even thinner. The femtosecond laser is less dependent on corneal thickness in creating flaps of a desired thickness.

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As with any hyperopic patient, it is important to discuss the slower visual rehabilitation and the possible need for distance glasses. If the PRK option is selected for the left eye, the rehabilitation will be even slower. The epithelial debridement will need to be large enough to accommodate the 9.0-mm ablation zone and will therefore take the surface longer to heal and stabilize. The final point is to explain in lay language to this esophoric patient that in the event of postoperative anisometropia, added strain on fusion might result in symptomatic diplopia.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size for LASIK	8.5 mm	9.0-mm epithelial debridement	Steep small cornea; 8.5-mm ring is the better choice OD
Plate size for LASIK	160 µm or 180 µm	Not applicable	Thin flaps result from mechanical microkeratome flaps in thin corneas
Ablation zone	9.0 mm	9.0 mm	VISX STAR S4
Spherical equivalent	+3.75 D	+6.00 D	
Calculations with nomogram correction	+3.75 × 23% = 0.86 +3.00 + 0.86 = +3.86	+6.00 × 28% = +1.68 +5.00 + 1.68 = +6.68 (see comment)	+6.68 (sphere + nomogram adjustment) exceeds the FDA-approved limit. With PRK, treat on cycloplegic refraction
(enter into VISX)	+3.86 + 1.50 × 90°	+5.00 + 2.00 × 85°	
Ablation depth	4.61 D × 8 µm/D = 37 µm	6.00 D × 8 µm/D = 48 µm	
RSB	505 µm − 160 µm − 37 µm = 308 µm >250 µm	501 µm − 160 µm − 48 µm = 293 µm >250 µm	Hyperopic ablation is not deepest centrally, so RSB is greater

Take-Home Points

1. If the spherical equivalent plus the nomogram adjustment exceeds the approved limit for the laser, consider using PRK, which does not require a nomogram adjustment.
2. Explain to patients that at the extremes of approved hyperopic treatment, a loss of best-corrected postoperative visual acuity can occur.
3. Clear lens extraction with a toric IOL to correct astigmatism, a multifocal IOL (provided both eyes will ultimately be treated), or an accommodating IOL with LRI are additional options when the amount of hyperopic correction is excessive.

CASE 31

A 66-year-old woman had eight-cut RK in the left eye 10 years ago. She continued to wear a soft contact lens in the right eye. Over the years, she developed decreasing vision in the left eye and symptoms of eyestrain. She wondered if laser surgery could improve her symptoms. She was not interested in monovision and was made aware she would need reading glasses following surgery. She understood the risks of surgery. After being out of her contact lens, her refraction was followed until stable. Old records were obtained and the refraction in the OS was stable over the previous 18 months.

W	OD – 4.50 20/20–3 OS + 3.00 + 1.25 × 30° 20/20+	**Uncorrected Va** OD CF OS 20/400
M	OD – 4.75 20/15 OS + 3.00 + 0.75 × 40° 20/20+	
C	OD – 4.50 + 0.50 × 175° 20/15– OS + 3.00 + 0.75 × 40° 20/20±	
K	OD 44.75 × 15°/45.00 × 175° OS 37.12 × 12°/38.50 × 102°	
Pachymetry OD 510 μm OS 498 μm (≥537 μm in midperiphery)	**Topography** Regular OD Central flattening OS	**Scotopic Pupils** OD 5 mm OS 5 mm

Additional Examination

The keratometry reading OS prior to RK was 44.00 D × 44.25 D @ 180°. The RK incisions are thin without noticeable epithelial plugs. There is no corneal neovascularization. The cornea is otherwise clear. There is no cataract. The IOP and fundus are normal.

Discussion

LASIK surgery can be safely performed following RK, provided the conditions are optimal. The RK scars should be thin and free of large epithelial plugs. Ideally, there should be at most only minimal irregular astigmatism; that is, the patient should be correctable to 20/20. If the BCVA is <20/20, the postoperative LASIK result is less predictable.

The cornea is somewhat thin centrally. This was presumably present preoperatively, because RK would not thin the uninvolved central cornea. The thin cornea does not preclude hyperopic LASIK, because the deepest ablation is at 5 mm and is only 8 μm/D. Although the central cornea is flat, the microkeratome will engage the cornea in the periphery where the cornea is not so flat. The risk of a free flap is small. Base the ring diameter on the preoperative keratometry. When the flap made with the microkeratome is lifted, care is required to avoid disrupting the incisions. A thicker flap is usually an advantage to avoid separation. If the incisions do separate, the excimer procedure can still be done, but the pieces should be meticulously replaced at the end of the procedure and a bandage soft contact lens (BSCL) placed. The risk of epithelial ingrowth is probably increased if this occurs. Femtosecond laser should not be used following RK because the required flap dissection could potentially disrupt the RK incisions. In addition, the waste gases from photodisruption can push anteriorly through the RK incisions, so-called vertical gas breakthrough, and form a small buttonhole.

The hyperopic nomogram adjustment is different following RK (see Table 7.2, page 77) and in a 66-year-old woman, a 2% addition is suggested. For patients under age 50, in contrast to standard hyperopia, a reduction in the hyperopic correction is suggested. The hyperopic nomogram is also different for treatment of consecutive hyperopia following LASIK.

Because the right cornea is somewhat thin, the femtosecond laser might be a better choice than the microkeratome. The laser is capable of greater precision with regard to flap thickness. The microkeratome usually will create a thinner flap in a thinner cornea.

Given the patient's age, a discussion of monovision is warranted. If desired, determine the nondominant eye and either reduce the myopic correction or increase the hyperopic correction appropriately.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	IntraLase 9.0-mm flap diameter in case retreatment needed	9.5 mm	Preoperative $K < 45.00$ D
Plate size	IntraLase 110-µm flap depth, usually creates a flap not greater than 120 µm	180 µm	Hansatome flap in a thin cornea can be quite thin. Very thin flap after RK is a disadvantage
Ablation zone	6.0 mm	9.0 mm	Hyperopic protocol OS
Calculations with nomogram correction (enter into VISX)	-4.25 D × 9% = 0.38 $-4.50 + 0.38 = -4.12$ $-4.12 + 0.50 \times 175$	+3.00 + 0.75 × 40° See Table 7.2 for nomogram adjustment +3.375 × 2% = 0.07 +3.07 + 0.75 × 40°	+2% nomogram adjustment for a 66-year-old with consecutive hyperopia after RK
Ablation depth	4.25 D × 12 µm/D = 51 µm	3.445 D × 8 µm/D = 28 µm	Spherical equivalent × appropriate conversion
RSB	510 µm – 120 µm – 51 µm = 339 µm >250 µm	498 µm –180 µm –28 µm = 290 µm >250 µm	RSB OS likely >291 µm because flap likely to be thinner than 180 µm and hyperopic treatment is not deepest centrally

Take-Home Points

1. LASIK can safely be done following RK if there is no more than minimal irregular astigmatism, thin well-healed scars, and no large epithelial plugs.
2. The microkeratome should be used rather than the femtosecond laser, with the ring size based on the preoperative keratometry.
3. Should the flap separate, carefully replace the pieces after the excimer ablation has been completed and place a bandage contact lens on the eye.
4. The suggested nomogram adjustment for consecutive hyperopia following RK is considerably different than for treatment of primary hyperopia (see Table 7.2). A reduction rather than an addition to treatment may be required for patients under 50.

CASE 32

A 58-year-old woman was referred for management of painful recurrent corneal erosions, which had occurred in both eyes over a 2-year period. The pain would always begin in the early morning and last from a few hours to a few days. The episodes occurred at least once a week and she could never predict when an erosion would occur. Her mother had similar problems for years before she died of heart disease. She had tried tear supplements, hypertonic sodium chloride ointment, and drops, as well as a BSCL without relief of her symptoms. Epithelial debridement was tried in the left eye, but the symptoms recurred. Fortunately, her vision in spectacles remains excellent at distance and near. She is amenable to any suggestion that would allow her life to return to normal. She has heard about LASIK surgery from a friend and wonders if it would help her.

W	OD + 2.25 20/25 OS + 2.00 20/25	**Uncorrected Va** 20/200 20/200
M	OD + 2.25 + 1.00 × 25° 20/20– OS + 2.00 + 1.00 × 160° 20/20–	
C	OD + 2.25 + 1.00 × 30° 20/20– OS + 2.25 + 1.00 × 164° 20/20–	
K	OD 41.00 × 112°/41.75 × 22° OS 40.87 × 70°/41.50 × 160°	
Pachymetry OD 534 μm OS 536 μm	**Topography** Regular astigmatism OU	**Scotopic Pupils** OD 5.0 mm OS 5.0 mm

Additional Examination

The slit-lamp examination was significant for dots and fingerprints on the surface of the paracentral and mid-peripheral cornea OU. There was no evidence of corneal scarring or corneal neovascularization; and no staining with fluorescein. The anterior segment was otherwise completely normal. The IOP and fundus examinations were normal.

Discussion

This patient suffers from epithelial basement membrane dystrophy, which she likely inherited from her mother. Conventional treatments with lubricants, hypertonic NaCl, BSCL, and debridement have failed to control the patient's symptoms. Anterior stromal puncture is a treatment that has not been tried. In the absence of a frank erosion, it might be difficult to know exactly where to apply the punctures. The patients with this dystrophy often have diffuse involvement. This patient is a poor candidate for LASIK surgery because of the high risk of epithelial sloughing. The corneal hypoesthesia associated with LASIK might afford some pain relief, but cutting the corneal nerves to relieve corneal erosions symptoms is not a practical solution.

PRK is a practical solution, which would ultimately relieve symptoms, stabilize the cornea, and correct the hyperopic astigmatism with one procedure. Phototherapeutic keratectomy (PTK) has been described as a remedy for recurrent corneal erosion. The hyperopic ablation would treat all but an 0.8-mm central area within a 9.0-mm ablation zone. No nomogram adjustment is needed with hyperopic PRK. Her cornea has ample thickness and would not become abnormally steep after the treatment. Provided the patient understands the risk of surgery, PRK is an excellent therapeutic option for this patient.

Surgical Plan

	Right Eye	Left Eye	Comments
PRK OU			
Ablation zone	9.0 mm	9.0 mm	VISX STAR S4
Enter into VISX	+2.25 + 1.00 × 25°	+2.25 + 1.00 × 160°	No nomogram adjustment needed for hyperopic treatment
Ablation depth	+2.75 D × 8 μm/D = 22 μm	+2.75 D × 8 μm/D = 22 μm	Low risk of central haze

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Take-Home Points

1	LASIK surgery should be avoided in patients with epithelial basement membrane dystrophy.
2	PRK is an excellent option for treating the hyperopic patient suffering from recurrent corneal erosion, because the laser treatment of the surface will correct the refractive error; once the eye has healed, it will help prevent erosions from occurring postoperatively.
3	In some basement dystrophy cases, the surface is too irregular to get an accurate refraction. This can complicate performing PRK. PTK can reduce the risk of erosions, but may increase the degree of hyperopia.

CASE 33

A 49-year-old male wearing monovision contact lenses is interested in reducing dependence on glasses and contact lenses. He has worn soft contact lenses for 24 years and adapted to monovision easily. He is healthy and works as a clerk in a law firm.

W	OD – 6.75 + 0.25 × 81 OS – 6.00		
M	OD – 6.75 + 0.75 × 75 OS – 6.00		
C	OD – 6.75 + 1.00 × 75 OS – 5.75		
K	OD 44.8 × 80/43.6 × 170 OS 44.9 × 56/44.2 × 146		
Pachymetry	**Corneal Topography**	**Scotopic Pupils**	
OD 600 µm OS 598 µm	OD Regular astigmatism OS Power and elevation maps normal	OD 6.0 mm OS 6.0 mm	

Additional Examination

The dominant eye was OS. The monovision OD was – 450 + 1.00 × 75°. Mobility and slit lamp examinations were normal.

Treatment Plan[a] (see Chapter 6)

	OD	OS
Nomogram for Technolas	99% MR with 6.2 mm OZ	97% MR with 6.2 mm OZ
Laser treatment	–3.47 – 1.00 × 165	–5.82
Laser treatment ablation depth	86 µm	106 µm
Intraoperative measurements	110-µm flap 374-µm residual bed	115-µm flap 369-µm residual bed

The above represents Dr. Weisenthal's personal nomogram for use with the Technolas excimer laser.

Discussion

The patient is well adapted to monovision contact lenses, so this is a natural plan. However, if the patient is not over 45 or has not used monovision in the past, this option should be thoroughly

discussed. In most cases, a trial with monovision contact lenses is recommended prior to performing the laser treatment. A careful motility examination is important if monovision is being considered since blurred distance vision in one eye can potentially disrupt fusion. One might think that a patient with a tropia is ideally suited to monovision, but this is not the case if the patient cannot fixate with the deviated eye.

The optical zone diameter is chosen to exceed the size of the scotopic pupil. In the experience of this case author, a larger optical zone treatment tends to produce greater long-term stability and less nighttime side effects such as glare and haloes. The size of the treatment zone is limited by the thickness of the cornea since a larger optical zone requires more tissue removal. In general, slight regression of effect may occur over time so that a younger patient is treated more aggressively to prevent loss of distance vision, particularly since they can use accommodation to tolerate a slight overcorrection. In a patient over the age of 40 years, even a small overcorrection is not acceptable and the amount of laser treatment should be adjusted if there is a disparity between the manifest and cycloplegic refractions.

Three years postoperatively, this patient is 20/60 uncorrected OD with BSCVA 20/20 with a –2.00 D. In the left eye, the patient is 20/20 UCVA and BSCVA is –0.25 D and functioning well with the monovision.

Take-Home Points

1	Monovision correction is appropriate for patients of presbyopic age, particularly if they are already doing so in contact lenses.
2	If monovision is considered in a patient who has not experienced this type of correction, a trial in contact lenses is recommended.
3	A careful motility examination should be performed since monovision can potentially disrupt fusion.

CASE 34

A 26-year-old graduate student is interested in LASIK. She wears glasses full time and wishes to be less dependent on glasses. She enjoys scuba diving and snorkeling and has been unable to get a diving mask that adequately corrects her vision. She is in good health, has a negative past ocular history, and has a stable refraction.

W	OD – 3.00 + 4.00 × 94° 20/20– OS – 2.00 + 2.25 × 86° 20/30	**Uncorrected Va** OD CF dist; 12 pt near OS CF dist; 12 pt near
M	OD – 2.75 + 3.75 × 97° 20/20 OS – 2.75 + 3.00 × 85° 20/20	
C	OD – 2.50 + 3.25 × 95° 20/20+ OS – 3.00 + 3.50 × 85° 20/20	
K	OD 40.50 × 6°/43.75 × 96° OS 41.00 × 178°/43.00 × 88°	
Pachymetry OD 560 μm OS 559 μm	**Topography** OD + 3.5 D at 94°, regular astigmatism OS + 3.0 D at 89°, regular astigmatism	**Scotopic Pupils** OD 8.0 mm OS 8.0 mm

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Additional Examination

Excellent exposure with normal slit-lamp, IOP, and fundus examinations.

Discussion

This patient has mixed astigmatism in both eyes. This is present when the spherical portion of the refraction is less than the astigmatic portion and they are of opposite signs. The VISX laser is FDA-approved for treatment of mixed astigmatism, allowing a single laser treatment to correct the refractive error. Patients with higher levels of astigmatism generally have difficulty with unaided distance and near vision even prior to presbyopic age. The laser correction will benefit both distance and near visual function. If the patient does not correct to 20/20, refractive amblyopia may be present. However, it is also possible the refraction is inadequate. Wavefront technology can be helpful in this situation even if custom laser surgery is not being done. The WaveScan will generate a refraction that may be more accurate than was done with subjective refraction or retinoscopy. The manifest and cycloplegic refractions can be based on the wavefront-assisted manifest refraction (WAMR).

The mixed astigmatism profile requires a 9.0-mm treatment zone. This is ideal for this patient with 8.0-mm pupils. The patient should still be warned about the possibility of nighttime glare or haloes. A large flap will be needed to accommodate the large treatment zone.

Given the high degree of astigmatism, registration of the patient with the laser is critically important. The patient should be marked at the slit lamp at the 3 and 9 o'clock meridians and just prior to laser ablation, the form-fit pillow should be adjusted to align the marks with the reticle in the laser microscope. Simply moving the head may be inadequate to ensure that the patient's head will not slip back into the same unwanted position. Access to the iris registration feature will allow for excellent alignment of the laser treatment with the axis of refractive astigmatism. In the US, iris registration is available only with custom treatments. This patient's corrections fit within the parameters for mixed astigmatism custom treatment and this would be an excellent option, given the advantage of iris registration.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	9.5 mm	Need larger flap for mixed astigmatism
Plate size	160 or 180 µm	160 or 180 µm	Hansatome
Ablation zone	9.0 mm	9.0 mm	Standard ablation profile for mixed astigmatism
Spherical equivalent	Treat on the cycloplegic refraction	Treat on the cycloplegic refraction	Mixed astigmatism profile; VISX STAR S4
Enter into VISX	No calculations needed −2.50 + 3.25 × 095	No calculations needed −3.00 + 3.50 × 085	Custom-mixed astigmatism would be an excellent alternative
Ablation depth (from VISX computer)	560 µm − 160 µm − 21 µm = 379 µm >250 µm	559 µm − 160 µm − 27 µm = 372 µm >250	High astigmatism correction reduces the ablation depth in mixed astigmatism treatment

Take-Home Points

1. Treating astigmatism will improve reading function even in young people.
2. Do not assume the patient has refractive amblyopia unless a careful refraction has been done. Wavefront technology can help with refraction even if custom surgery is not being done.

3	No nomogram adjustment is required with the VISX mixed astigmatism profile.
4	Use a larger flap when treating a patient with mixed astigmatism.
5	The larger treatment zone of 9.0 mm is helpful for large-pupil patients, but it is important to discuss the risk of glare and haloes with the patient.
6	Do not forget to mark the eye at the slit lamp for registration of the patient with the laser.
7	Custom for mixed astigmatism would be an excellent option here. The surgeon can take advantage of the iris registration feature on the VISX laser if custom treatment is performed.

CASE 35

A 48-year-old Caucasian female was referred for a consultation. She had undergone LASIK approximately 9 years earlier. She complained of blurred vision and wanted to explore the possibility of retreatment. She was using reading glasses for reading and distance glasses for driving.

M	OD −1.75 + 0.75 × 65° 20/20 OS plano	**Uncorrected Va** OD 20/80–26 pt OS 20/20–12 pt
C	OD −2.00 + 0.75 × 45° 20/20 OS −0.25 + 0.50 × 70° 20/20	
Pachymetry	**Topography**	**Dominant Eye**
OD 516 µm OS 523 µm	OD No ectasia OS No ectasia	OD

Slit lamp examination showed a well-healed flap without striae or ingrowth OU.

Routine PRK was performed for refractive error of −1.75 + 0.75 × 65°. MMC 0.2 mg/cc was applied for 15 seconds according to the protocol described in Chapter 13. The immediate postoperative course was unremarkable.

Several months after the procedure, the patient began to report blurred vision. Her BCVA OD was 20/100 with significant central subepithelial fibrosis.

The decision was made to perform superficial keratectomy with MMC 0.2 mg/cc application for 2 minutes (See Videos 6, 9 & 21). Following the procedure, the patient regained 20/25 uncorrected visual acuity (UCVA) and BCVA of 20/20.

Discussion

There are several reasons why this patient might be bothered by the apparent regression in the right eye. First and foremost, this is her dominant eye. Patients generally have difficulty adapting to use of the nondominant eye for unaided distance vision. A myopic regression in the nondominant eye in a patient of presbyopic age can be a blessing for some, because it enables the patient to read without glasses. Further, the astigmatism correction reduces the effective near power, making the refractive error less desirable. Also undesirable for this patient is the oblique astigmatism, which blurs vision at every distance. This patient is clearly not benefitting from her refractive condition since she wears reading glasses full time.

In any case of regression, it is important to study the corneal topography and make certain no ectatic changes are present. A cycloplegic refraction is also important to make certain there is no significant difference between the cycloplegic and manifest refractions.

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The choice to correct the patient based on the manifest refraction is a good one considering the cycloplegic refraction is more myopic and there is a considerable shift in the astigmatism. Some clinicians prefer to initially try a flap lift even years after LASIK surgery thinking that if successful, the postoperative course will be easier for the patient. It is important to recognize that the edge of a microkeratome flap can be difficult to find years after surgery. A femtosecond laser flap may be easier to find due to scarring at the flap edge, but more difficult to lift due to a stronger adhesion of the flap edge. There is an increased risk of epithelial ingrowth and flap trauma in flap re-lifts years after the primary surgery. Over the last few years there has been a general trend toward using PRK on the flap. This eliminates the risks described above and has the advantage of not further ablating the RSB and weakening the cornea further. There are also the added risks of DLK and stromal haze. Many surgeons will use mitomycin applied at the time of surgery to reduce the risk of haze. Surgeons are split on whether or not to adjust the nomogram by reducing the myopic sphere in corrections that are usually low.

Haze prevention using MMC 0.2 mg/cc as described in detail in Chapter 13 should be entertained in any patient considered at high risk for developing post-PRK haze. These patients include (1) high myopia (> –6.00 D), (2) deep ablations (≥75 μm), (3) high astigmatism, (4) post-RK, (5) post-PKP, and (6) post-LASIK patients that will undergo subsequent PRK ablation. While MMC reduces the risk of developing haze, its use does not guarantee prevention as illustrated in this case. Haze may still occur and further intervention may be required.

Take-Home Points

1	Ametropia in the dominant eye, especially with oblique astigmatism, is a good reason to consider retreatment in a patient complaining of blurred vision.
2	While flaps can be lifted years after surgery, there is a general trend toward performing PRK on the flap, which avoids further thinning of the RSB, but increases the risk of stromal haze.
3	Consider using MMC 0.2 mg/cc at the time of surgery in any high-risk patient to reduce the chance of developing stromal haze.
4	Even if haze occurs postoperatively, good results can be obtained with superficial keratectomy and repeat MMC application. Care should be taken to avoid damaging the flap.

CASE 36

A 26-year-old man works in sales and requests LASIK surgery. He has not worn contact lenses for a year, because he cannot see as well with them. Without his glasses he cannot see distance or near. He is healthy and has no other significant past ocular history.

W	OD – 4.75 + 4.75 × 106° 20/30+ OS – 5.00 + 5.00 × 80° 20/25	**Uncorrected Va** OD 20/200 Near 18 pt OS 20/200 Near 8 pt
M	OD – 5.25 + 5.00 × 100° 20/20+ OS – 4.75 + 4.50 × 80° 20/15 –	
C	OD – 3.75 + 4.75 × 100° 20/15 OS – 4.00 + 4.50 × 85° 20/15 –	
K	OD 41.25 × 6°/44.87 × 96° OS 41.00 × 175°/45.00 × 82°	
Pachymetry OD 602 μm OS 597 μm	**Topography** Regular with-the-rule astigmatism OU	**Scotopic Pupils** OD 6.5 mm OS 6.5 mm

Additional Examination

There is a heavy brow, but lax lids and a wide fissure. The slit-lamp examination, IOP, and fundus examinations are normal.

Discussion

The refractive error in this case would be classified as mixed astigmatism, because the myopic sphere in the cycloplegic refraction is less than the cylindrical correction and has an opposite sign. This patient has surprisingly good visual acuity for an individual with this much astigmatism. Notice that the unaided near acuity is measured here and should be measured in any case of hyperopia and in patients with significant astigmatism. The perceived improvement in the pre-presbyopic patient is at near as well as in the distance.

The fact that this patient is comfortable in glasses with visual acuity in the 20/25 to 20/30 range is a favorable sign because his vision expectations would be less than someone who is accustomed to 20/15 visual acuity. It is imperative to educate this patient that at the upper levels of astigmatism correction 20/30 acuity is a more realistic expectation. The likelihood of retreatment is greater in this patient and this should also be discussed preoperatively. In addition, with conventional LASIK, night vision issues may arise because the astigmatism treatment area is smaller than the pupil diameter in the dark. The treatment zone in the VISX mixed astigmatism profile is 9.0 mm, which should adequately cover the pupil. The flap will need to be large enough to accommodate this large treatment zone.

The mixed astigmatism profile for CustomVue LASIK with the VISX STAR S4 laser can treat up to 5 D of astigmatism, but was not available at the time this patient was treated.

When treating large degrees of astigmatism, careful preoperative marking is essential to avoid the effect of cyclotorsion on astigmatism correction. Iris registration software available with the custom treatment would help to lessen alignment inaccuracies.

Some surgeons will reduce the spherical power of the correction by 0.2 D for each diopter of astigmatic correction. The logic behind this is that for each diopter of flattening in the steep meridian, there is 0.2 D of steepening in the flat meridian. Therefore, it is necessary to back off from the full spherical correction. Many surgeons have not found it necessary to make this adjustment.

For VISX laser treatment of mixed astigmatism, no nomogram adjustment to the cycloplegic refraction is needed. Multistage treatments are unnecessary. The patient is treated using the mixed astigmatism profile on the cycloplegic refraction. Surgeons vary on how the axis of astigmatism is handled. Some will use the axis in the cycloplegic refraction, while others use the axis from the manifest refraction. Still others will split the difference between the two.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	9.5 mm	
Plate size	160 µm	160 µm	Hansatome
Ablation zone	Mixed astigmatism profile 9.0 mm No nomogram adjustment needed here	Mixed astigmatism profile 9.0 mm No nomogram adjustment needed here	Pupils size should not be a problem The axis of cylinder matches the manifest refraction; see text
Enter into VISX	−3.75 + 4.75 × 100°	−4.00 + 4.50 × 80°	Custom treatment is an excellent option
Ablation depth taken from laser computer; RSB well above 300 µm	32 µm	34 µm	Cylindrical correction reduces impact of the myopic correction on ablation depth

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At 1 year after surgery, this patient has unaided acuity of 20/15– and 4 pt OD and 20/20± and 4 pt OS with no symptoms of nighttime glare or haloes. This result exceeded the expectations of the patient and the surgeon.

Take-Home Points

1	Mixed astigmatism is present when the myopic sphere is less than the plus cylinder. This should be treated with a mixed astigmatism profile or custom ablation if possible.
2	Expectations should be lower in patients with high astigmatism. UCVA of 20/30 or better after retreatment is reasonable. Retreatment is more likely in these cases. Counsel younger patients that near vision may improve after surgery. Night vision may be more problematic.
3	Registration (aligning the patient marks made at the slit lamp with the laser microscope reticle) is crucial in patients with high astigmatism due to the potential negative effects of cyclotorsion. Iris registration software is available with custom treatment.
4	With current mixed astigmatism profiles, even patients with high astigmatism may achieve surprisingly good visual acuity after surgery.

CASE 37

A 38-year-old man is interested in LASIK surgery to correct his vision. He currently uses a contact lens OS when he drives, otherwise he prefers to go with no correction. He does not have a pair of glasses and has never liked wearing them. His contact lenses bother him. For as long as he can remember, his left eye has been extremely nearsighted. He denies ever having double vision even when his contact lens is in place OS. He has no family history of eye disease and is otherwise healthy. He has read a lot about LASIK and is familiar with the risks of surgery.

W	No contact lens OD With soft contact lens OS 20/30	**Uncorrected Va** OD 20/40+ OS CF 3′
M	OD – 1.25 + 1.50 × 4º 20/15 OS – 13.75 + 0.75 × 150º 20/20	
C	OD – 1.00 + 1.25 × 4º 20/15 – OS – 13.25 + 0.75 × 150º 20/20 – Vertex distance 12 mm	
K	OD 44.00 × 90º/44.00 × 180º OS 45.87 × 60º/46.50 × 150º	
Pachymetry OD 584 µm OS 585 µm	**Topography** Against-the-rule astigmatism OU; no cone OU	**Scotopic Pupils** OD 5.0 mm OS 5.0 mm

Additional Examination

The external examination shows lax lids and a wide palpebral fissure. No tropia or phoria was detected while the patient was wearing the contact lens. The slit-lamp examination, IOP, and dilated fundus examinations were completely normal.

Discussion

Marked anisometropia can usually be corrected with keratorefractive surgery. A careful motility examination with the patient wearing full contact lens correction is important to reduce the

risk of postoperative diplopia. In this case, a full correction with LASIK is not recommended. While the Bausch & Lomb laser is approved for up to −12.00 D and the Nidek and VISX lasers are approved for even higher degrees of correction, treatment at this level usually is less reliable. This is true even when there is ample thickness and curvature. The patient could have LASIK surgery if he could accept less than the full correction OS. He will soon enter presbyopic age, and a myopic OS would provide near vision.

Another, perhaps better option for this patient is to consider a phakic IOL for the left eye (See Video 11). This would correct the bulk of the nearsightedness. At the time of this writing, only the iris-supported Verisyse (AMO) also known as the Artisan lens (Ophtec) and the Visian ICL (STAAR) were available in the United States. A small residual refractive error, if it occurred, could be treated with a subsequent PRK or LASIK. Refer to Chapter 15, specifically the section on phakic IOLs and bioptics. A clear lens exchange could be considered, but the risk of retinal detachment over the long term may be unacceptably high.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	Phakic IOL	Hansatome OD
Plate size	160 µm	None	
Ablation zone	9.0 mm	None	VISX STAR S4 OD
	No nomogram adjustment needed for mixed astigmatism		
Enter into VISX	−1.00 + 1.25 × 4°		
Ablation depth	Available from laser since there is no nomogram adjustment	Not a concern with the phakic IOL	See Chapter 15 for a more complete discussion of phakic IOLs
RSB	The cornea is ample and the ablation depth is small. RSB will far exceed 250 µm		

Take-Home Points

1. If you fully correct a large degree of anisometropia, diplopia is a risk. Evaluate motility function with full contact lens correction to be sure the patient is asymptomatic.
2. Know the practical limits of your laser. These may be somewhat less than the approved limits.
3. Phakic IOLs and bioptics have the potential to expand the limits of refractive surgery.

CASE 38

A 25-year-old woman has worn RGP lenses for 11 years and glasses for several years before that to correct myopia. She wants to drive and play tennis without wearing her contacts. All her friends have had good results from LASIK and she wants laser vision correction, too. She is generally healthy. Her only regular medications are birth control pills and multivitamins. She tolerates the contact lenses for 14 to 16 hours daily and sees well with them. The lens power has not changed in the last 2 years. Her family history is remarkable for glaucoma and high myopia in an aunt.

She was asked to leave her contact lenses out for 3 days before the examination, but she didn't have any glasses to wear and so wore the contacts up to the time of her examination.

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W	Patient has no glasses	**Uncorrected Va** OD CF 3′ OS CF 3′
M	OD – 8.75 – 2.50 × 90° 20/20 OS – 8.50 – 2.00 × 90° 20/20	Note: minus cylinder form
C	OD – 8.25 – 2.50 × 95° 20/20 OS – 8.00 – 2.25 × 90° 20/20	
K	OD 45.00 × 180°/47.25 × 90° OS 44.75 × 180°/46.50 × 90°	

Pachymetry	**Topography**	**Scotopic Pupils**
OD 515 μm OS 517 μm	Mild inferior steepening OU, corresponds to keratometry and refractions; posterior elevations are normal OU	OD 6.2 mm OS 6.2 mm

Additional Examination

Microscopic examination reveals 1-2 mm superficial vascularization in both corneas consistent with her long-term contact lens wear. Corneal diameters are 11 mm horizontally. The rest of her examination is normal. The eyelid fissures appear adequate for the microkeratome suction ring.

Discussion

The data reveal three issues to consider while evaluating this patient for refractive surgery: Will there be adequate stromal tissue for a laser ablation to correct this amount of myopia and astigmatism? With spherical equivalents of –10.00 and –9.50, a conventional laser procedure can be estimated (12 μm/D) to remove 120 and 114 μm to provide a complete correction. If we use an average flap thickness of 150 μm for the surgery, it would leave 245 μm (515 μm – 150 μm – 120 μm) and 253 μm (517 μm – 150 μm – 114 μm), respectively. This would leave a stromal bed that many surgeons would consider too thin for safety. Alternatives would include making a thin flap with a femtosecond laser or performing a surface ablation with adjunctive MMC.

The corneal topography shows inferior steepening along with somewhat high K readings and slightly thin central pachymetry. Although the latter two measurements are not particularly remarkable, the combination of all three should suggest a critical evaluation for FFKC. Could these findings have resulted from contact lens wear?

Many surgeons feel that large scotopic pupil size may be associated with the postoperative development of objectionable night vision symptoms, although there is little scientific data to support this. That said, nighttime vision problems may be reduced by wavefront-directed custom surgery. This will significantly increase the amount of stromal tissue removed and would eliminate LASIK as an option. Even with surface ablation, this could potentially result in thinning that exceeds standard guidelines.

The issues with laser vision correction were discussed with the patient along with the alternative option of phakic lens implantation. She was instructed to return after 2 weeks wearing only glasses for follow-up measurements.

Follow-Up Examination

On return examination, the measurements now show:

	OD	OS
Manifest	–8.25 – 2.50 × 180° = 20/20	–8.00 – 2.00 × 180° = 20/20
Keratometry	45.00 × 90°/47.25 × 180°	44.75 × 90°/46.50 × 180°
Pachymetry	505 µm	500 µm
Scotopic pupil	6.0 mm	6.0 mm

Topography shows nearly complete resolution of the inferior steepening and no inferior thinning on pachymetry. Slit-lamp examination was unchanged.

Discussion

These data still indicate borderline stromal thickness for laser vision correction, though FFKC is not a likely concern with improvement of the topographic findings. The importance of wavefront customized treatment to provide quality vision limits this option to surface ablation, but with concerns about corneal thinning problems and the possible need for future enhancement without enough stroma, she is now interested in phakic lens implantation. Anterior chamber depth is adequate and there is no pathology to cause concern with this procedure, but her corneal cylinder will not be corrected by a spherical implant. Toric PIOLs are available outside of the United States for this correction. Spherical lens implantation can be safely followed by LASIK to correct the residual astigmatism. She chose to have a Verisyse implant combined with LRIs performed for each eye (See Video 10). Her procedures were performed 2 weeks apart with the incision for lens insertion at the temporal limbus and a 3-clock hour LRI centered superiorly at 12 o'clock. The suture compression of the temporal limbus for wound closure helped the effectiveness of the superior LRI. With sutures out, both eyes have UCVA of 20/25 with stable phakic lens implants and minimal residual cylinder. She does not note any night vision problems, although her pupil size is close to the optic size of her implants.

Take-Home Points

1. The differentiation of FFKC from contact lens–induced corneal warpage is important for both accurate surgical correction and safety.
2. Phakic IOL implantation is a good option to discuss with patients who have any suggestion of FFKC on their preoperative topography. They can safely produce equivalent or superior vision for patients with inadequate or borderline stromal thickness for laser vision correction.
3. Wound placement with suturing can enhance the effectiveness of LRIs to make smaller, more peripheral incisions that provide greater cylinder correction.

CASE 39

In 1993, a 48-year-old man had 16-incision RKs performed in both eyes to correct –7.00 D. A year later he had an additional eight incisions in each eye for –1.50 residual myopia. The optical zone for both procedures was 3 mm. His vision progressively declined during the next 6 years and then stabilized with RGPCLs as noted below. Daily refractive fluctuations have ceased, but he still has severe night vision symptoms with terrible glare. He now finds that he cannot tolerate the RGP lenses for more than a few hours and does not want to wear the very thick glasses needed at all other times for clear vision.

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W	OD + 6.00 D RGP 20/20 OS + 6.25 D RGP 20/20	**Uncorrected Va** 20/400 OU
M	OD + 6.50 – 1.00 × 50° 20/30 OS + 7.00 – 2.25 × 125° 20/25	Note: minus cylinder form
C	OD + 6.25 – 1.25 × 50° 20/30 OS + 7.25 – 2.25 × 125° 20/25	
K	OD 36.50 × 55°/37.75 × 145° OS 35.00 × 130°/37.50 × 40°	

Pachymetry	**Topography**	**Scotopic Pupils**
OD 580 μm OS 575 μm	Mild inferior steepening OU, corresponds to keratometry and refractions; posterior elevations are normal OU	OD 6.0 mm OS 6.0 mm

Additional Examination

On slit-lamp examination, the corneal incisions look to be well made and tightly sealed without epithelial inclusions. There is minimal vascularization peripherally with iron deposits between the incision lines. The chamber angle is wide open and the lens is clear. The rest of the examination is normal.

Discussion

Perhaps the best thing for this patient is not to have any more refractive surgery done because the many problems from his previous surgeries will limit his chances for any stable and improved uncorrected vision. He must understand that any refractive procedure will still leave him with the corneal scars from RK that produce glare. The fluctuation of refractive error may return after surgery and there may also be continued progression of his hyperopia. Suturing procedures, such as the lasso suturing technique, have been described to improve vision in progressive hyperopia after RK. Permanent suture placement is required in order to retain the, often inaccurate, refractive correction. Conductive keratoplasty (CK) was initially considered as a treatment for hyperopia after RK but has been shown to be ineffective and perhaps detrimental inducing incisions to gape. LASIK can be successful, but risks fragmentation of the flap with opening of the RK incisions. The increased pressure of the suction ring may also stretch the RK incisions and lead to unstable and inaccurate results.

Two procedures are worth consideration. Surface ablation can be performed with gentle removal of the epithelium so as to not open the RK incisions. MMC applied at the time of surgery should be used to prevent stromal scarring in these cases. Phakic lens implantation avoids the corneal problems completely by correcting the refraction without altering the corneal structure. Both procedures fall short at correcting the mild irregular astigmatism that is apparent from the difference in acuity between the refractive correction and the rigid contact lens correction. The refraction is beyond the FDA-approved single PRK treatment parameters allowed in the United States. Some surgeons would consider performing a maximal treatment followed by planned enhancement at 3 months to correct the residual refractive error.

Clear lens exchange is a better option because it provides the refractive correction without altering the currently stable corneal surface. Advanced methods for IOL calculation (e.g., IOL Master) will be needed to achieve an accurate refractive correction. The cylinder in the right eye may not need correction, but a toric lens implant for both eyes can give an excellent result. Neither procedure is likely to provide the improvement in acuity obtained with RGP lenses because of the irregular astigmatism component.

Surgical Plan

After considerable discussion of the various options, the patient chose to have clear lens exchange with the STAAR Toric lens implant. The 2.0 D astigmatic lens was used for the right eye because it gives 1.5 D of cylinder correction. The lens was implanted with the long axis at 145 degrees. The left eye was corrected with the 3.5 D STAAR Toric lens implant because it gives 2.25 D of correction. This lens was aligned at 40 degrees. Postoperatively, the patient had 20/30 uncorrected acuity without fluctuation. Reading glasses were prescribed.

Take-Home Points

1. Progressive hyperopic shifts after RK are becoming more common as time passes from the RK era. When stable, it is possible to obtain a good refractive correction.
2. Refractive procedures will not eliminate the glare from the RK incisions.
3. Surface ablation may be safer than LASIK by avoiding problems of flap segmentation and stretching of incisions caused by the suction ring.
4. Phakic IOL or clear lens exchange avoids manipulation of a stable cornea and provides a wide range of refractive correction. Accuracy with IOL power calculations requires advanced biometric techniques.
5. These previously myopic patients may be at increased risk of retinal detachment with clear lens exchange.

CASE 40

A 45-year-old business executive has never worn glasses and always had good vision until the last 2 years when he started using reading glasses and now finds that he needs them even when driving. He hates wearing glasses and wants laser vision correction to allow him to drive the car and read without glasses. He plays ice hockey without wearing his glasses, but needs them for golf. He has hypertension, which is controlled with a diuretic, and is otherwise in good health. He has never had a complete eye examination and is not aware of any eye problems in family members.

W	Uses + 2.00 readers for driving as well as reading	**Uncorrected Va** 20/60 OU
M	OD + 2.00 20/40 OS + 2.00 20/40	
C	OD + 4.75 20/20 OS + 4.50 20/20	
K	OD 45.50 × 180°/45.75 × 90° OS 45.50 × 180°/45.50 × 90°	
Pachymetry	**Topography**	**Scotopic Pupils**
OD 555 μm OS 547 μm	Mild inferior steepening OU; posterior elevations are normal OU	OD 5.2 mm OS 5.2 mm

Additional Examination

The eyelid fissures are adequate for the microkeratome suction ring. The corneal diameter is 10.3 mm for each eye. The eyes are orthotropic. The slit-lamp examination reveals clear corneas

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and normal anterior segments. The angles are open to the top half of the trabecular meshwork and the lenses are clear. There is no posterior segment pathology.

Discussion

This case demonstrates some typical findings for patients with uncorrected hyperopia. Most of these patients believe that they have excellent distance vision even though their acuity is poor. They know that they need glasses for reading and try to go without glasses for as many activities as possible. This patient just uses his +2.00 over-the-counter reading glasses to help drive at night and see road signs. Sports that do not require excellent acuity or near vision (e.g., ice hockey and football) are not a problem for such patients. These patients often are unhappy after correction of their refractive error unless the presbyopia is addressed as well.

The examination uncovers three issues that need to be considered in order to determine what procedure will best help this patient:

1. The cycloplegic refraction falls within the range of hyperopic LASIK, but the accuracy of laser correction tends to fall off with treatment above +4.00 D. To achieve a monovision near correction, he will need more than 6 D of correction and this exceeds the limit for most lasers.
2. The keratometry readings are somewhat steep for a hyperope and the amount of steepening needed to correct his refractive error and presbyopia will exceed the 50.00 D upper limit used by most surgeons.
3. The corneal diameter is rather small. Hyperopic LASIK requires a large-diameter treatment zone and, therefore, a large flap to accommodate the ablation. His corneal diameter may be too small and the flap may extend into the limbus with bleeding that might complicate the laser ablation. While a surface ablation can avoid this problem, care must be taken to avoid damage to the limbal stem cells with alcohol-assisted epithelial removal.

Treatment Plan

The patient was informed that laser vision correction would not provide the best results for his vision problems. When he had the full cycloplegic correction in a trial frame, he felt that the correction was too strong and he would be satisfied with just the laser correction in the amount of his current +2.00 reading glasses. Clear lens exchange with an accommodative or multifocal lens implant was discussed as the best option for his vision problems. While phakic lens implants are available outside of the United States to correct this amount of hyperopia, they will not correct presbyopia. CK is not powerful enough for this degree of correction. The patient elected to seek laser vision correction from two other providers, but was told again that this would not be appropriate for his needs. He returned and was given a progressive course of disposable contact lenses, increasing as tolerated until he achieved his full cycloplegic correction for distance and maintained his current reading glasses as needed. He insisted that the contact lenses were making his vision worse since he could not see clearly when he removed them, and he believed that he was seeing clearly before he started to wear them. After 6 weeks he was comfortable with his full cycloplegic correction and underwent clear lens exchange with ReSTOR lens implants in both eyes targeted for a final refraction of +0.50. Following surgery, he was 20/20 in both eyes at distance and J2 for reading.

Take-Home Points

1	The latent hyperope should be allowed to adapt into the cycloplegic correction to allow the full amount of hyperopia to be treated.
2	The corneal diameter must be considered when a large flap is required.

3	The preoperative corneal contour must be assessed to ensure that it will not become too steep (>50.00 D) after surgery.
4	Clear lens exchange with an accommodating or multifocal IOL is a viable option for correcting the hyperopic patient in the presbyopic age group.

Intraoperative Decision Making

Despite careful preoperative planning, unexpected challenges occasionally arise during LASIK surgery. The following series of cases focuses on the intraoperative decision-making required to handle these unexpected situations. To keep the indexes from becoming cluttered, a separate case index will cover the intraoperative and postoperative cases. This can be found following the table of contents. It is hoped this will enable the reader to better access the cases relevant to the clinical situation of interest.

CASE 41

A 54-year-old woman seeks LASIK surgery to be less dependent on her glasses. She has a 10-year history of type 2 diabetes. She has never worn contact lenses. Her current glasses are 5 years old.

W	OD + 0.50 + 1.75 × 89° 20/25– OS + 1.25 + 0.50 × 90° 20/20	**Uncorrected Va** OD 20/80 OS 20/100
M	OD + 1.50 + 1.25 × 85° 20/15 OS + 2.25 20/15	
C	OD + 1.50 + 1.25 × 85° 20/15 OS + 2.25 20/15	
K	OD 42.00 × 172°/44.50 × 82° OS 42.00 × 175°/43.50 × 85°	
Pachymetry OD 545 μm OS 545 μm	**Topography** Regular astigmatism OU	**Scotopic Pupils** OD 5 mm OS 5 mm

Additional Examination

There is excellent exposure. Ptosis of the right upper lid is noted. The eyes do not appear to be dry. The motility examination is normal. The corneal diameter is 11 mm in both eyes. The slit-lamp examination revealed vascular pannus 360 degrees in both eyes, extending 1.0 to 1.5 mm from the limbus. The lens is clear in each eye. The IOP is 15 mmHg bilaterally and there is no evidence of diabetic retinopathy.

Discussion

Several useful teaching points are illustrated in this case. The patient is a 54-year-old woman, increasing the risk of postoperative dry eye because of both age and gender. The appropriate evaluation for dry eye was discussed in Case 16. Epithelial erosion or slippage is more likely in

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people older than 50 years and more likely in diabetics. The low compression head on the Hansatome makes epithelial trauma less likely. The possible occurrence of these conditions should be discussed before surgery. Diabetes can also increase the risk of infection and the risk of retinal circulation problems associated with increased IOP. In general, if there is minimal retinopathy the risk of a retinovascular event is low. It is especially important in a diabetic to be certain the refraction is stable. A chronically elevated blood sugar can be associated with increased myopia. This could potentially lead to a postoperative overcorrection if the blood sugar is subsequently brought under control. While this patient has no cataract now, diabetics have an increased risk of cataract. The development of cataract postoperatively could compromise the LASIK outcome. Finally, diabetics are at increased risk of neurotrophic keratopathy, which will be worse after LASIK surgery.

Ptosis is noted on the preoperative examination. This should be pointed out before surgery so the patient will not assume the refractive surgery was the cause of the lid abnormality.

The crux of this case is the realization that a large flap will be needed to accommodate a 9-mm treatment zone. In a small cornea, the flap edge will be placed near the limbus. However, in this case corneal neovascularization is noted near the limbus. With keratometry readings of <45.00 D, a 9.5-mm Hansatome ring is needed to ensure an adequate diameter of the flap. Remember that in general, the flatter the cornea, the smaller the flap made with a mechanical microkeratome. Bleeding from limbal vessels is likely and should be anticipated. Light compression at the site of limbal bleeding for 1 to 2 minutes with a nonfragmenting cellulose sponge will usually stop the hemorrhage. Blood beneath the flap within the ablation zone will interfere with the laser effect. Accumulating blood should be swept off the stromal surface with a cellulose sponge after briefly interrupting the ablation. Prolonged periods with the flap lifted will cause desiccation of the stromal bed and increase the risk of overcorrection. Blood under the flap outside the treatment zone will have no effect on the ablation, but should be swept or irrigated away as the flap is repositioned. Blood under the flap is a risk factor for DLK.

Using the femtosecond laser to create the flap would be an excellent alternative in this situation. The size of the flap is easier to control with this technology. Bleeding from limbal vessels tends to be less of an issue because a smaller, but adequate-sized flap may avoid the vessels and because hemorrhage is less apt to occur with the laser edge cut.

Another option is PRK, which would require a 9.0-mm area of epithelial debridement prior to the ablation. PRK would eliminate the risk of an ischemic event due to the increased IOP related to flap creation. The PRK ablation might reduce the risk of recurrent erosion that can occur in diabetics following debridement.

Surgical Plan

	Right Eye	Left Eye	Comments
Ring size	9.5 mm	9.5 mm	Keratometry <45 D; 9.5-mm ring is the better choice OU; Femtosecond laser would be a preferable alternative
Plate size	160 or 180 µm	160 or 180 µm	Hansatome
Ablation zone	9.0 mm	9.0 mm	VISX STAR S4
Spherical equivalent	+2.13 D	+2.25 D	
Calculations with nomogram correction	+2.13 × 30% = 0.64	+2.25 × 30% = +0.68	
Enter into VISX	+1.50 + 0.64 = +2.14 +2.14 + 1.25 × 085	+2.25 + 0.68 = +2.93 +2.93	

Surgical Plan (Continued)			
	Right Eye	**Left Eye**	**Comments**
Ablation depth	2.77 D × 8 µm/D = 22 µm	2.93 D × 8 µm/D = 23 µm	Hyperopic ablation is not deepest centrally, so RSB is greater than this estimate
Residual stromal bed	545 µm – 160 µm – 22 µm = 357 µm	545 µm – 160 µm – 23 µm = 356 µm	>250 µm OU

Take-Home Points

1. Point out preexisting abnormalities preoperatively to avoid the patient's perception that LASIK surgery caused the problem.
2. Warn older patients about postoperative epithelial instability and dry eye.
3. Anticipate and plan for limbal vessel hemorrhage if the cornea is small and the flap is large. A smaller ring is a reasonable choice if the cornea is steep. If the cornea is too small for a microkeratome flap, consider a surface ablation procedure or a femtosecond laser flap.
4. Manage active bleeding during the case by applying light pressure at the limbus with a sponge for 1 to 2 minutes before lifting the flap. Interrupt the ablation as needed to swab blood out of the treatment zone; irrigate blood from beneath the flap to reduce the risk of DLK.

CASE 42

This 60-year-old hyperopic man with 1+ nuclear sclerotic cataracts and 20/20 best spectacle-corrected vision OU desired LASIK to be able to play golf and drive and see the dashboard of his car without glasses.

W	OD + 2.75 – 0.50 × 93° 20/20 OS + 3.00 – 0.50 × 82° 20/20	**Uncorrected Va** OD 20/400 OS 20/400
M	OD + 3.25 – 0.50 × 92° 20/20 OS + 3.25 – 0.50 × 83° 20/20	Note: minus cylinder
C	OD + 3.25 – 0.50 × 92° 20/20 OS + 3.25 – 0.50 × 83° 20/20	
K	OD 42.75 × 142°/43.25 × 52° OS 42.25 × 101°/42.50 × 110°	
Pachymetry OD 531 µm OS 535 µm	**Topography** OD spherical OS spherical	**Scotopic Pupils** OD 6.0 mm OS 6.0 mm

Original Surgical Plan			
	Right Eye	**Left Eye**	**Comments**
Ring size	–1	–1	Hyperopia
Microkeratome head	130 µm	130 µm	See Moria microkeratome discussion in Chapter 4
Ablation zone	9.0 mm	9.0 mm	VISX

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Original Surgical Plan (Continued)			
	Right Eye	**Left Eye**	**Comments**
Cycloplegic Rx	+3.25 – 0.50 × 092	+3.25 – 0.50 × 083	
Calculations with nomogram adjustment (enter into VISX)	No adjustment +3.25 – 0.50 × 092	No adjustment +3.25 – 0.50 × 083	Before we knew the need to overcorrect hyperopia
Flap thickness	160 µm	160 µm	Assumed
Ablation depth	22 µm	22 µm	Hyperopic treatment deepest in mid-periphery
Estimated RSB	531 µm – 160 µm – 22 µm = 349 µm (if Rx were central)	535 µm – 160 µm – 22 µm = 353 µm (if Rx were central)	Hyperopic ablation is not deepest centrally, so RSB is significantly greater

The case was aborted after the microkeratome created a truncated superiorly hinged flap OD. The truncated flap was repositioned in its stromal bed, a bandage contact lens was placed, and the laser ablation was canceled. Fortunately, the inferior edge of the flap was just above the superior edge of the pupil OD. The truncated flap healed and the patient was counseled about his options for refractive surgery including a repeat attempt at LASIK, PRK over the truncated flap, contact lenses, or living with his eyeglasses. One month later his visual acuity returned to baseline OD, with a mild change in refraction of +3.50 – 1.00 × 77° resulting in 20/20 visual acuity. Three months after the initial attempt, the patient elected to have LASIK performed OU using the same Moria CB microkeratome with a −1 suction ring. His LASIK went uneventfully, and he obtained 20/30 vision OU on the first postoperative day, and 20/20 OU 1-month postoperatively. A faint scar persists above the visual axis OD, near the superior hinge of the flap.

Patient Characteristic	**Right Eye**	**Left Eye**	**Comments**
Ring size	−1	−1	Hyperopia
Microkeratome head	130 µm	130 µm	Moria
Ablation zone	9.0 mm	9.0 mm	
Cycloplegic Rx	+3.50 – 1.00 × 92°	+3.25 – 0.50 × 83°	
Enter into VISX	No nomogram adjustment +3.50 – 1.00 × 92°	No nomogram adjustment +3.25 – 0.50 × 83°	Before we knew the need to overcorrect hyperopia
Flap thickness	160 µm	160 µm	Assumed
Ablation depth	20 µm	22 µm	Hyperopic Rx in mid-periphery
Estimated RSB	531 µm – 160 µm – 20 µm = 351 µm (if deepest ablation were central)	535 µm – 160 µm – 22 µm = 353 (if deepest ablation were central)	Hyperopic Rx in mid-periphery RSB >250 µm

Take-Home Points

1. Abort the laser ablation if there is a problem with creation of the flap, particularly when the flap cannot accommodate the LASIK ablation.
2. Wait at least 3 months before attempting to make a new flap. Some surgeons wait 6 months. The surgical options are to consider a repeat attempt at LASIK or PRK.

3	If the inferior edge of the original LASIK flap had been more inferior, one might have considered creating a slightly larger and thicker flap, in order to be sure that the microkeratome cut begins outside the original flap edge and proceeds beneath the original cut.
4	Given the superior location of the inferior edge of the truncated flap, we could use the same microkeratome settings we attempted to use initially.

CASE 43

A 61-year-old woman complained of persistent decreased vision 24 years after having undergone RK in each eye. She denied any fluctuation of vision, glare problems, or discomfort. She wore spectacles full time.

Examination showed a four-cut RK with an optical zone of 4.5 mm. The incisions were generally thin with no gaping or prominent epithelial plugs, although slightly irregular. Visual acuity with her current 4-year-old glasses was 20/40 OD and 20/30 OS. The spherical equivalent of her glasses prescription was +3.25 OD and +3.50 OS. Cycloplegic refraction resulted in visual acuity of 20/20 in each eye. Scotopic pupils were 4 mm.

	OD	OS
Post-RK cycloplegic refraction	+3.75 + 0.50 × 160°	+4.00 + 0.50 × 5°
Post-RK keratometry	37.50 × 38.25 @ 105°	38.00 × 38.00
Post-RK pachymetry	572 µm	574 µm
Post-RK BSCVA	20/20	20/20

The preoperative discussion with the patient emphasized that a realistic expectation for postoperative UCVA was 20/40. The patient was told she might continue to need spectacles for distance for some tasks, and that she might lose a line of vision and have a BSCVA of about 20/25. A +3.25 trial lens was placed over each eye in the cycloplegic state to simulate the expected postoperative results.

LASIK was performed in the usual manner using a Bausch & Lomb Hansatome with a 180-µm head. No nomogram adjustment was made. No MMC was used. In the left eye there was some instability at the inferior RK incision with slight splaying of the inferior segments. These were carefully repositioned, and a bandage contact lens was placed on the eye to be removed the next day. The patient developed 1-2+ haze OU postoperatively that gradually cleared. The patient was maintained on topical steroids four times a day for 3 months. Despite a persistent refractive error in the left eye, the UCVA remained good and patient was able to see reasonably well at near without spectacles for a significant number of tasks.

	OD	OS
Post-retreatment UCVA	20/25	20/30
Post-retreatment cycloplegic refraction	−0.50	−2.00 + 3.25 × 160°
Post-retreatment keratometry	40.50 sphere	39.75 × 42.00 @ 180°

Discussion

This case is an example of the ideal RK patient for retreatment. The absence of fluctuating vision suggests maintenance of adequate corneal stability. Peripheral treatment for hyperopia may cause progressive symptoms that may be more likely in patients with poor corneal stability. Patients

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should be warned that it is not possible to determine how much glare and night vision issues are coming from irregular astigmatism associated with the original incisions and how much from the refractive error induced by the original RK procedure. Even a surface retreatment may not reduce glare, and as in any refractive procedure, may result in increased problems. Nevertheless, patients who are hyperopic after prior RK surgery are usually gratified by a significant if not complete correction of their refractive error.

Take-Home Points

1	Careful evaluation of the corneal incisions in patients having had RK will dictate the decision regarding the type of hyperopic procedure to be done, surface ablation, LASIK, or lens implantation.
2	The surgeon should be prepared to deal with potential RK wound instability in the corneal flap.

CASE 44

A 45-year-old-man presented for LASIK consultation. This patient was quite apprehensive about the procedure and reported getting nervous whenever anyone got close to his eyes. As such, he has never been able to wear contact lenses.

W	OD – 5.00 – 1.00 × 90º 20/20 OS – 5.00 – 0.50 × 90º 20/20	**Uncorrected Va** OD 20/200 OS 20/200
M	OD – 5.00 – 1.25 × 90º 20/20 OS – 4.75 – 0.75 × 90º 20/20	Note: minus cylinder
C	OD – 5.00 – 1.25 × 90º 20/20 OS – 4.75 – 0.75 × 90º 20/20	
K	OD 43.00 × 90º/44.50º × 180º OS 42.75 × 90º/43.50 × 180º	
Pachymetry OD 550 μm OS 560 μm	**Topography** Regular astigmatism OU	**Scotopic Pupils** OD 6.5 mm OS 6.5 mm

After a complete history and evaluation it was determined that he would be a satisfactory candidate for surgery. He chose to have the IntraLase rather than microkeratome procedure, because he perceived it to be a safer alternative for creating the flap.

On the day of treatment, he was even more anxious than when examined in the office. He was given twice the normal amount of oral diazepam, 10 mg, 30 minutes preoperatively.

He particularly disliked the insertion of the speculum just prior to placing the suction ring on the eye, and a strong Bell's reflex was observed. He was encouraged to look straight ahead, suction was applied to the fixation ring, and the applanating lens was brought down on to the cornea. About halfway through the raster pattern ablation, suction was lost and the cone lost contact with the cornea (See Videos 14 & 15).

Discussion

Suction loss most likely occurred in this patient due to eyelid squeezing and eye movement during creation of the flap. Other possibilities include a faulty suction ring with a slow leak or the

formation of conjunctival chemosis. Suction loss with a microkeratome can result in an incomplete flap, free cap, or no cap at all with a large epithelial defect. When this occurs with a blade keratome, there is typically a time lag of 3 to 6 months before any excimer treatment can be considered, whether it be a repeat LASIK or PRK with adjunctive MMC to reduce the risk of haze. In contrast, loss of suction during the creation of a laser-made flap is an easier complication to handle.

If suction loss occurs during creation of the flap, the surgeon should first assess the status of the bulbar conjunctiva. If it is fairly chemotic and the likelihood of obtaining good suction is not favorable, the patient should return for treatment another day. If treating on another day, a new applanating cone should be used, and the flap depth should be set at least 20 µm deeper to avoid creating a wedge of corneal stroma by cutting in two planes of tissue.

If the conjunctiva is not chemotic, the surgeon preferably reapplies the same suction ring (or a new suction ring if the device is felt to be faulty) to the eye. The same applanating lens should be used with the same settings for flap thickness and diameter. The previously treated stromal bed will not be damaged by re-lasering immediately at the same stromal depth.

If suction was lost before the flap was completed and a complete flap can be made with a second pass, the dissection should be started in the area of the virgin pass to determine the appropriate dissection depth. If suction is lost during the initial creation of the side cut, the laser can be reprogrammed to make only the side cut. This flap diameter should be reset 0.2 mm smaller to avoid any wedges of stroma being created from the intersection of two side cuts. If suction is lost with 5 or fewer seconds to go during the side cut, only the epithelium remains and the flap edge can be cut with a Vannas scissors at the time the flap is lifted to perform the excimer treatment.

Take-Home Points

1	Suction loss, while rare with the IntraLase, can still occur.
2	Watch the entire treatment carefully in order to recognize a problem and quickly stop the femtosecond laser ablation, if necessary.
3	Retreatment with the IntraLase is possible immediately if suction can be re-obtained; otherwise, it is best to return on another day.

CASE 45

A 55-year-old man is interested in refractive surgery to decrease his dependence on distance correction. He doesn't wear contact lenses and has no history of ocular trauma or recurrent erosions. He understands he will need reading glasses after surgery.

W	OD – 5.00 + 1.00 × 90º 20/20 OS – 5.25 + 1.25 × 90º 20/20 3 years old	**Uncorrected Va** 20/400 OU
M	OD – 5.00 + 1.00 × 90º 20/20 OS – 5.25 + 1.25 × 90º 20/20	
C	OD – 5.00 + 1.00 × 90º 20/20 OS – 5.25 + 1.25 × 90º 20/20	
K	OD 43.50 × 180º/44.25 × 90º OS 43.50 × 180º/44.50 × 90º	
Pachymetry OD 540 µm OS 540 µm	**Topography** OD regular bow-tie OS regular bow-tie	**Scotopic Pupils** OD 6.5 mm OS 6.5 mm

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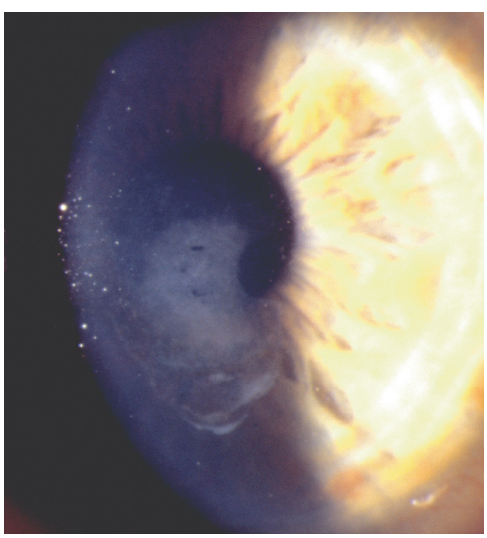
Additional Information

The anterior and posterior segment examinations were normal.

The patient underwent LASIK on the right eye first. After the microkeratome pass, there was an obvious 4 × 3 mm central corneal irregularity. How would you proceed?

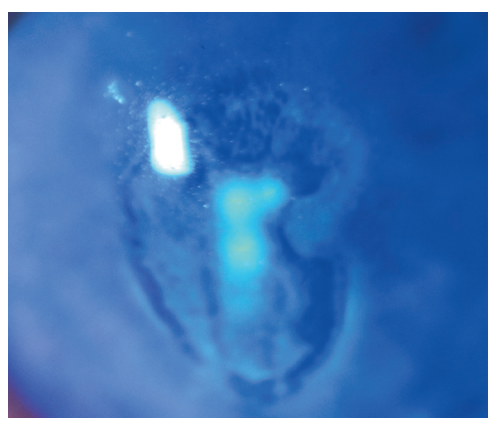
The surgeon used a dry cellulose sponge to try to determine whether it is simply epithelial loosening or whether the stromal aspect of the flap is also irregular. It was felt that the flap stroma was normal. The surgeon then gently lifted the flap, taking care not to traumatize the epithelium, and inspected the underside of the flap and the stromal bed for evidence of irregularity, such as a buttonhole. Once it was determined that the underside of the flap appeared regular and the size of the stromal bed was large enough to fit the planned laser ablation, the laser treatment was applied. The flap was floated into position and the interface irrigated. Once the flap rested in good position, the epithelium was very delicately moved with a moist cellulose sponge into as normal an anatomic configuration as possible. The flap was left to adhere for several minutes. A BSCL, Focus Night & Day, 8.6/–0.50, was placed on the eye. Due to the potential problems of a large area of epithelial loosening, such as delayed visual rehabilitation and increased risk of DLK and epithelial ingrowth, it was decided not to proceed with surgery on the fellow eye that day. The patient was placed on a fluoroquinolone and prednisolone 1% drops four times a day, and frequent preservative-free artificial tears.

The patient was seen the following day. The uncorrected and best-corrected visual acuity was 20/400 OD. Slit-lamp examination revealed that the BSCL was in good position. There was a central oval area of epithelial whitening measuring approximately 3 × 4 mm (Case 45, Figs. 1 and 2). There was minimal stromal inflammation, no stromal infiltrate, and the anterior chamber was deep and quiet. The patient was followed every 1 to 2 days for a week at which time the BSCL was removed. Over that time, the size of the whitened epithelium became smaller and smaller and eventually disappeared. The uncorrected vision reached 20/30 and with a correction of –1.00 + 0.50 × 90, the visual acuity improved to 20/20–2. Slit-lamp examination revealed mild microstriae and trace interface haze.



CASE 45, FIGURE 1

Epithelial slippage. (Courtesy of Christopher J. Rapuano, M.D.)



CASE 45, FIGURE 2

Same cornea as Case 45, Figure 1, with fluorescein instilled and cobalt blue illumination. (Courtesy of Christopher J. Rapuano, M.D.)

Discussion

Risk factors for epithelial loosening/defect include a history of recurrent erosions, anterior basement membrane dystrophy (ABMD), and increased age. Patients at higher risk for epithelial loosening/defect should be informed of this risk preoperatively. Some patients might select a surface ablation procedure instead of LASIK. Many surgeons consider ABMD as a contraindication to LASIK.

Prior to proceeding with LASIK in such patients, several precautions should be taken to decrease the risk of epithelial problems. Preoperative dry eye syndrome and blepharitis should be treated. A microkeratome with a lower risk of epithelial trauma (e.g., a Hansatome with a Zero Compression head or a femtosecond laser) should be selected when available. The eye should be anesthetized with the smallest effective dose of topical anesthetic, just prior to the procedure. The cornea should be well lubricated just before the microkeratome pass.

Once an area of loosening or defect is noted after the flap is created, it is critical to determine whether the flap stroma and the interface are normal. If so, the laser ablation can be performed. If not, the laser treatment should probably be deferred. If the epithelium is loose, the surgeon must decide whether to attempt to replace it in its original location or remove it and allow new epithelium to grow in. Generally, if the epithelium appears viable (i.e., not shredded), it is reasonable to attempt to replace it. Either way a BSCL is usually placed. With any epithelial irregularity, there is an increased risk of DLK and microstriae. If the epithelial irregularity involves the flap edge, there is also an increased risk of epithelial ingrowth. When properly managed, these eyes can do very well. Remember, when there is an untoward event in the first eye, it is often best not to proceed with surgery on the fellow eye on the same day. Proceed to Case 69 to find out what happened to this patient.

Surgical Plan

Patient Characteristic	Right Eye	Left Eye	Comments
Treat cycloplegic refraction in negative cylinder	−4.00 − 1.00 × 180°	−4.25 − 1.25 × 180°	
Ring size (Amadeus microkeratome)	9.0 or 9.5 mm	9.0 or 9.5 mm	A larger flap allows for adequate exposure if a hyperopic enhancement is required
Plate size	140 µm	140 µm	Amadeus microkeratome
Optical zone (VISX laser)	6.5 mm	6.5 mm	Larger treatment zone decreases risk of visual aberrations
Transition zone	8.0 mm	8.0 mm	A blend zone decreases risk of visual aberrations
Calculations (see Chapter 2 for alternative nomogram)	−4.00 D (−15%) = −3.40 D sphere	−4.00 D (−15%) = −3.40 D sphere	Subtract 15% since patient over age 40
Spherical treatment	−3.40 D	−3.40 D	
Cylinder treatment	−0.90 D × 180°	−1.17 D × 180°	Subtract 10% of cylinder
Approximate ablation depth	54 µm	54 µm	
RSB	540 µm − 140 µm − 54 µm = 346 µm >250 µm	540 µm − 140 µm − 54 µm = 346 µm >250 µm	

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Take-Home Points

1. Corneas need to be examined carefully preoperatively. If ABMD is present, think twice about proceeding with LASIK.
2. Loose epithelium should be replaced in its original location at the end of the procedure.
3. When there is an untoward event in the first eye, it is often best not to proceed with surgery on the fellow eye the same day, because there may be delayed visual rehabilitation with suboptimal final results, and there is a higher risk of a similar problem in the fellow eye.

CASE 46

A 26-year-old man with a stable refraction desires improved uncorrected vision. He has been out of his daily wear SCL for 2 weeks. He has no history of ocular trauma or recurrent erosions.

W	OD – 5.00 20/20 OS – 5.00 20/20 3 years old	**Uncorrected Va** 20/400 20/400
M	OD – 5.00 20/20 OS – 5.00 20/20	
C	OD – 5.00 20/20 OS – 5.00 20/20	
K	OD 40.00 × 180°/40.50 × 90° OS 40.50 × 180°/41.00 × 90°	
Pachymetry OD 550 μm OS 550 μm	**Topography** OD regular bow-tie OS regular bow-tie	**Scotopic Pupils** OD 6.5 mm OS 6.5 mm

Additional Examination

The anterior and posterior segment examinations are normal.

Surgical Plan

Patient Characteristic	Right Eye	Left Eye	Comments
Treat cycloplegic refraction	−5.00 D	−5.00 D	
Ring size (Amadeus microkeratome)	9.5 mm	9.5 mm	Flat *K*'s increase the risk of a free cap. Use a larger suction ring and larger hinge
Hinge size	0.9 mm	0.9 mm	
Plate size	160 μm	160 μm	Amadeus microkeratome
Optical zone VISX STAR S4	6.5 mm (6.0 with blend would also be acceptable)	6.5 mm (6.0 with blend would also be acceptable)	Larger treatment zone decreases risk of visual aberrations
Transition zone	8.0 mm	8.0 mm	A blend zone decreases risk of visual aberrations
Calculations	−5.00 (−10%) = −4.50 D sphere	−5.00 (−10%) = −4.50 D sphere	Subtract 10% as under age 30 years
Spherical treatment	−4.50 D	−4.50 D	

Surgical Plan (Continued)

Patient Characteristic	Right Eye	Left Eye	Comments
Approximate ablation depth	60 µm	60 µm	
RSB	550 µm – 160 µm –60 µm = 330 µm >250 µm	550 µm –160 µm –60 µm = 330 µm >250 µm	

Discussion

Due to the low keratometry readings indicating a flat cornea, the patient was warned he had a higher risk of a free cap with LASIK. The option of a surface ablation procedure was discussed, but the patient wanted to proceed with LASIK. What adjustments would you make in this case?

A large suction ring, 9.5 mm, and a large hinge width, 0.9 mm, were selected based on the nomogram provided by the microkeratome manufacturer. Additionally, a 160-µm rather than a 140-µm plate is selected, to give a little more thickness to the hinge. Heavy, asymmetric gentian violet marks are made on the right cornea, so they do not wash away during the procedure. Suction was obtained without difficulty. The pupil dilated, the tonometry was >65 mmHg, and the patient noted the light dim. The flap was created. As the blade retracts, the surgeon watched the ink marks on the flap to make sure the flap remained on the cornea and not in the microkeratome. The flap was slowly lifted and moved to the side, taking great care to place minimal stress on the hinge. The hinge was noted to be small, but intact. The ablation was performed without difficulty and the interface was irrigated and the flap replaced, aligning the ink marks. Again, minimal stress was placed on the hinge. The flap was allowed to adhere for 4 minutes, 1.5 minutes longer than average. Would you proceed with surgery on the left eye and, if so, would you make any changes to the treatment plan?

The decision was made to proceed with LASIK on the left. The microkeratome hinge width was adjusted to 1.0 mm for the left eye. Because the keratometry readings were slightly steeper on the left, along with a larger programmed hinge, the surgeon felt the risk of a free cap was small. Again, the cornea was marked, suction obtained, the microkeratome pass performed, and the blade retracted with the flap in place. However, as the flap was moved to the side, it was clearly a perfectly circular free cap. It was placed epithelial side down on the nasal conjunctiva. The stromal bed was inspected and felt to be uniform and large enough for the planned ablation, which was then performed without difficulty. The free cap was then replaced, right side up, on the stromal bed. Holding the edge gently with fine forceps, the interface was gently irrigated and then the free cap positioned, taking great care to line up the ink marks. The gutter is dried to make sure it was uniform for 360 degrees. The cap is allowed to adhere for 5 minutes after which a BSCL, Focus Night & Day 8.6/–0.50, is placed. He is placed on topical fluoroquinolone, prednisolone 1%, and preservative-free tears OU. The patient is told about the free cap and the danger of rubbing or touching his eye and to contact the surgeon immediately with any increase in pain or should the contact lens come out.

He was seen the following day. The flap on the right and the free cap on the left were in excellent position. He was seen 2 days later and 2 days after that at which time the BSCL was carefully removed without difficulty. The patient ended up happy with very good uncorrected vision. He was told that a future LASIK enhancement would be more difficult due to the free cap and, if necessary, a surface ablation might be a better option.

Flat corneas increase the risk of smaller flaps and free caps with mechanical microkeratomes. Adjustments for flat corneas include larger suction rings and larger hinge widths. However, these adjustments are not always successful. A free cap is less likely when a femtosecond laser is used to

make the flap, provided care is taken to dissect the flap after it has been created. The femtosecond laser flap is not dependent on corneal curvature.

In retrospect, what else could have been done to prevent the small hinge on the right and the free cap on the left? Certainly, a surface ablation procedure could have been performed. With LASIK, an even thicker flap, for example, a 180-µm flap could have been used. For the second eye, when there is a small hinge on the first, a new microkeratome blade might result in a thicker flap with a slightly more substantial hinge. Once the free cap occurred, another option would have been to place one to four interrupted 10-0 nylon sutures to secure the cap for a few days or weeks.

Once a free cap is noted, it must be located and protected. It may remain in the microkeratome and be damaged or discarded by the technician. Once it is safely stored (typically epithelial side down on a moist surface such as conjunctiva or a wet 4 × 4 gauze pad), the stromal bed needs to be inspected for uniformity and size to determine whether the laser ablation can be done. The cap then needs to be replaced in its original position using the ink marks and checking the gutter. If a free cap is small, the marks may not reach the edge of the cap. Extra care must be taken to align the flap properly in this challenging situation. Managed properly, eyes with free caps can end up with excellent visual results. In fact, prior to the advent of the flap hinge, LASIK procedures were performed with intentional free caps.

Take-Home Points

1	Pay attention to the corneal curvature during the preoperative evaluation to appropriately inform the patient of the surgical risks.
2	Adjust the microkeratome settings to decrease the chance of suboptimal flaps.
3	Mark the cornea to aid in proper replacement of the flap or free cap.
4	When removing the microkeratome from the eye, make sure the flap is on the cornea.

CASE 47

A 45-year-old woman with a stable refraction of −6.00 D, normal anterior and posterior segment examinations, normal topography, pachymetry, and pupil size undergoes LASIK. Asymmetric gentian violet marks are made temporally and superiorly. A Chiron (now Bausch & Lomb) Automated Corneal Shaper (ACS) microkeratome is used to make the LASIK flap. The technician alerts the surgeon that suction is achieved according to the machine. The patient tells the surgeon that the light has dimmed. The Barraquer tonometer does not demonstrate a consistently small circle. How would you proceed?

Because the tonometer did not confirm proper suction, the surgeon should have released the suction ring, checked the microkeratome, and reattempted to achieve adequate suction. Instead, the surgeon proceeds with creation of the flap. After the pass is made and the microkeratome is removed from the eye, the corneal surface appears irregular. The surgeon makes sure the technician does not clean the microkeratome until he checks the cornea and makes certain there are no missing pieces of cornea. The surgeon then carefully examines the cornea to figure out whether the flap epithelium and/or stroma are abnormal. It is clear that a shredded flap stroma is present. The temporal edge of the flap is relatively normal appearing, although the flap in that area is definitely thinner than usual. Approximately one-third of the way across the cornea, the flap becomes very irregular and becomes a completely free cap with jagged edges about two-thirds of the way across the cornea. How would you proceed?

The best option at this point is to attempt to replace all the pieces of cornea into their original orientation. This maneuver can be achieved with fine forceps and dry and moist cellulose sponges. If any pieces are missing, the microkeratome needs to be inspected again, searching for any lost tissue. Once the epithelium and stroma are pieced back together, and allowed to adhere for several minutes, a BSCL is placed, fluoroquinolone and prednisolone 1% drops are instilled,

and the eyelid speculum carefully removed. The patient is examined at the slit lamp immediately and again 30 minutes later. The patient is placed on a topical fluoroquinolone and prednisolone 1% drops four times daily and seen the following morning.

The patient's BCVA is 20/25 with approximately the same refraction as preoperatively. The BSCL is removed on postoperative day 4; the epithelial surface is intact and the stroma quite smooth. Over the next several months, the BCVA returns to 20/20. Treatment options, including repeat LASIK with a microkeratome or femtosecond laser and transepithelial PRK with or without MMC, are discussed with the patient. The patient elects not to proceed with refractive surgery and to continue with contact lens wear.

Discussion

One of the worst intraoperative complications during LASIK is a shredded flap. It is unlikely to occur (1) if the machine registers good suction, (2) the patient says the light has dimmed, and (3) the IOP measures >65 mmHg. Most surgeons use a Barraquer tonometer or pneumotonometer to check the pressure. If these three conditions are not met, it is often best to stop. Release suction and recheck the machinery and try again. Occasionally "pseudosuction" is achieved, meaning that the suction ports are occluded with conjunctiva, so the machine senses adequate suction, but the IOP is not adequately elevated. Suction may be adequate as the microkeratome pass is started, but can be lost during creation of the flap (often related to patient movement or squeezing), which can shred or amputate a flap. Future treatment options include repeat LASIK with a microkeratome or laser and transepithelial PRK with or without MMC.

Take-Home Points

1. Use multiple methods to make sure the IOP is adequate to safely create the flap.
2. Whatever the cause, if the stromal component of the flap is not perfect, the pieces should be replaced in their original position (as best as possible), a BSCL placed, and no laser treatment applied.
3. When there is an untoward event in the first eye, it often best not to proceed with surgery on the fellow eye the same day.

Postoperative Decision Making

Many of the cases presented in this section cover postoperative management issues such as enhancement, dry eye, striae, epithelial ingrowth, buttonhole, flap displacement, DLK, and infection. While there are some simple cases, many of the cases are fairly complex. The indexes for these cases are combined with the intraoperative decision-making cases. The cases are arranged according to issue as much as is practical. The format may vary depending on the nature of the case and the author.

CASE 48

A 56-year-old man with myopic astigmatism had bilateral LASIK. A central corneal abrasion occurred on the right cornea intraoperatively and was managed with a BSCL overnight. On postoperative day 1, the contact was removed and the UCVA was 20/100 in the right eye and 20/25 in the left. At 1 week, the UCVA was 20/80 in the right eye and 20/20 in the left eye. The flap was in good position and there were no striae or punctate keratopathy. At 1 month, the UCVA and the BSCVA in the right eye were both 20/60. Keratometry of the right eye showed mild distortion of the rings. The patient was unhappy with his vision and complained of starbursting and haloes at night. Two months postoperatively, the UCVA in the right eye was 20/50

and BSCVA was 20/20 with a manifest refraction of –0.75 and a cycloplegic correction of –1.25 + 0.50 × 105. Keratometry was regular. At 3 months, the cycloplegic refraction of the right eye was unchanged and BSCVA was 20/20. The flap was lifted and the patient was retreated (See Video 4) for the cycloplegic refraction without nomogram adjustment. One week following retreatment, the UCVA in the right eye was 20/20.

Cycloplegic refraction OD prior to original surgery	–5.50 + 0.50 × 110°
Keratometry prior to original surgery	44.25/44.75 @ 110° (regular mires)
Pachymetry prior to original surgery	634 µm
Postoperative UCVA OD at 1 mo	20/60
Postoperative BSCVA OD at 1 mo	20/60
Postoperative keratometry OD at 1 mo	41.25/42.50 @ 105°
Postoperative UCVA OD at 2 mo	20/50
Postoperative BSCVA OD at 2 mo	20/20
Postoperative manifest refraction OD at 2 mo	–0.75
Postoperative cycloplegic refraction OD at 2 mo	–1.25 + 0.50 × 105°
Postoperative keratometry OD at 2 mo	41.25/42.00 @ 105° (regular mires)
Postoperative cycloplegic refraction at 3 mo	–1.25 + 0.50 × 105°
UCVA after retreatment	20/20

Discussion

This patient had an undercorrection that was causing decreased vision and troublesome night vision disturbances. The stabilization of acuity after treatment was prolonged by irregular astigmatism caused by an intraoperative abrasion. The eventual retreatment was routine (see section on surgical techniques for retreatment, Chapter 10). In the presence of striae, epithelial ingrowth, or surface irregularity, the complication must be treated to eliminate its contribution to the visual symptoms. In this case, retreatment was postponed until a stable refraction with good acuity was demonstrated as well as stabilization or absence of the confounding complication.

Take-Home Points

1. When there is an untoward event during or after surgery, such as the surface abrasion with residual surface irregularity that occurred in this case, postpone refractive retreatment until the abnormality is rectified.
2. The cycloplegic refraction and manifest refraction may be significantly different despite 20/20 vision with each. Most surgeons base retreatment on the cycloplegic refraction.
3. Do not retreat until stability has been established by two refractions at least 1 month apart.
4. Treating a residual refractive error is the first step in caring for a patient with night vision complaints.

CASE 49

A 36-year-old contact lens–intolerant baseball player requested refractive surgery. He complained of mild star-bursting and haloes at night while wearing his spectacles. His preoperative UCVA was 20/30 OU. He did not wear spectacles to play ball.

	Right Eye	Left Eye
Original UCVA	20/30	20/30
Original cycloplegic refraction	−1.25 + 1.00 × 5°	−1.00 + 0.75 × 180°
Original keratometry	44.75 × 45.25 @ 30°	45.50 × 46.00 @ 95°
Original pachymetry	649 µm	650 µm

The patient was treated with conventional LASIK because custom LASIK was not available at the time of his original surgery. Despite postoperative visual acuity of 20/20 in each eye, he continued to complain of blurred vision in his right eye. Repeated manifest and cycloplegic refractions showed varying refractive errors from plano to minimal myopia, but correction in the office with trial lenses in any combination failed to improve his vision subjectively.

	Right Eye	Left Eye
Posttreatment UCVA	20/20–	20/20
Posttreatment cycloplegic refraction	Plano to −0.50 (variable)	Plano

Approximately 9 months after the initial treatment, custom treatment was FDA approved. The patient's right eye was measured with the VISX WaveScan and showed large amounts of coma and trefoil. A PreVue lens was cut using the VISX laser based on the intended CustomVue retreatment. He immediately noticed a significant improvement using the lens and LASIK retreatment was performed using a CustomVue retreatment card. Postoperatively, the patient's visual acuity was 20/15 with resolution of his subjective symptoms.

Discussion

This case illustrates the value of custom retreatment in some patients with minimal objective refractive error and significant subjective complaints. Using the PreVue lens in this situation alleviated both physician and patient anxiety about the potential benefit of custom retreatment. By allowing the patient to participate in the decision-making process regarding retreatment, the chances of significant postoperative patient dissatisfaction was reduced.

Take-Home Points

1. Custom retreatment may be considered in patients who have subjective complaints out of proportion to the measured refractive error. This is true regardless of whether the patient had custom LASIK initially.
2. The PreVue lens allows the patient and physician to gain some knowledge about the potential benefit of retreatment.
3. This technique is also of potential value in patients with good daytime visual acuity who complain solely of night vision issues.

CASE 50

A 45-year-old man underwent conventional LASIK for high myopia. The original treatment was −10.50 + 0.75 × 80° OU. His BSCVA was 20/20 OU and he had sufficient corneal thickness (OD = 585, OS = 589) to allow 105-µm treatment with a multizone (sphere 5.5 mm and ellipse 6.0 × 5.7 mm) and a blend out to 8.0 mm. The corneal contour (OD 45.50 × 46.00 @ 80° and OS 45.00 × 45.75 @ 80°) was steep enough to accommodate the large myopic correction without excessive flattening. The Hansatome with a 160-µm head and 9.5-mm ring was used. The flap

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thicknesses were measured intraoperatively at 102 µm OD and 111 µm OS. The ablations were well centered and uncomplicated. However, 6 months after the original treatment, the patient was undercorrected, experiencing some problems with glare and haloes at night, and decided to have a CustomVue enhancement.

W	OD – 2.00 sph OS – 1.00 sph	**Uncorrected Va** 20/100 20/50
M	OD – 2.50 sph 20/20 OS – 1.25 + 0.50 × 150° 20/20	
C	OD – 2.50 sph 20/20 OS – 1.25 + 0.50 × 148° 20/20	
WR	OD – 2.65 + 0.11 × 39° RMS 3.67 HOA 13.5% OS – 1.29 + 0.49 × 152° RMS 3.23 HOA 24.6%	
K	OD 40.00 × 60°/40.12 × 150° OS 39.25 × 60°/40.00 × 150°	
Pachymetry OD – 522 µm OS – 531 µm	**Topography** Well-centered ablations OU without ectasia	**Scotopic Pupils** OD 5.8 mm OS 5.7 mm

Discussion

Because the manifest and WaveScan refractions were well matched, no physician adjustment was required. The residual pachymetric values of 522 µm OD and 531 µm OS were sufficient to allow elliptical treatments of 29 µm OD and 47 µm OS with an 8.5-mm ablation zone. The flaps were marked at the slit lamp and lifted. The surgery was uncomplicated and resulted in successful, well-centered ablations.

One month postoperatively, the patient presented with minimal residual refractive error OD and OS plano; and UCVA 20/25 OD and UCVA 20/20 OS.

Often patients with good visual acuity still complain of blurred vision or monocular diplopia. When a situation like this arises and the patient is asking for an enhancement, the surgeon needs to be very careful in analyzing the clinical situation. The cause for the complaints first needs to be determined. If a treatment table can be generated by the WaveScan, it must be carefully compared with the refraction. Even a very low WaveScan treatment can reduce patient symptoms and improve visual outcome. It is best to listen to the patient's complaints, carefully analyze the clinical information, and only treat if there is adequate tissue and the patient has realistic expectations.

Take-Home Points

1	CustomVue treatment as an enhancing procedure can be very effective.
2	Make sure that the refraction is stable prior to enhancement and that there is adequate tissue in the stromal bed.
3	The amount of tissue removed in an enhancing procedure can sometimes be much larger than expected.
4	Anytime there is a significant discrepancy between the manifest and WaveScan refraction, it is best to err on the side of the manifest refraction and not perform the CustomVue treatment.

CASE 51

After 3 months, the patient in Case 23 had stabilized. The corneal surface was smooth and the minimal corneal haze had faded. The patient's uncorrected Va was 20/15 OD and 20/50 OS. The refractive error was plano OD and +1.50 + 0.50 × 155° OS. Therefore, the patient was overcorrected and hyperopic OS. Because the postoperative refractions were stable and the residual corneal thickness was adequate, a repeat treatment OS was planned.

W	OD none OS none	**Uncorrected Va** 20/15 20/50–
M	OD Plano OS + 1.00 + 0.50 × 155°	
C	OD Plano 20/20 OS + 1.50 + 0.50 × 155° 20/20	
K	OD not tested OS 41.00 × 132°/40.50 × 42°	
Pachymetry OD not tested OS 380 µm	**Topography** Normal central flattening S/P PRK OS	**Scotopic Pupils** OD 6.5 mm OS 6.5 mm

Discussion

Because the 46-year-old patient was unhappy with her hyperopic refractive error OS, a retreatment was performed.

Surgical Plan: First Retreatment

	Left Eye	Comments
Do not perform further laser if the cornea is too thin. Make sure postoperative refractive error is stable		
Ring size	None—PRK	Too thin for LASIK
Plate size	None—PRK	
Ablation zone	6.5 mm with 8.0-mm blend	Pupil = 6.5 mm
Spherical equivalent	+1.75 D	
Conventional surface treatment based on manifest and cycloplegic refractions. Treatment is entered in minus cylinder form	+1.50 + 0.50 D × 155° +2.00 – 0.50 × 65°	There is no nomogram adjustment with PRK
Ablation depth	32 µm	The Alcon software calculates the ablation depth
RSB	380 µm – 32 µm = 348 µm	Must be >250 µm

The patient's original PRK was performed in February 2002; the enhancement charted above was performed in July 2002. By June 2004, the patient's uncorrected Va was 20/20 OD and 20/30 OS (see second data chart below). There was a refractive error of –0.50 OD and –1.00 OS. The patient complained of poor night vision and poor contrast sensitivity OS. Wavefront testing

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revealed an RMS of 0.76 µm OS with high horizontal coma, spherical aberration, trefoil, and tetrafoil OS.

W	OD none OS none	**Uncorrected Va** 20/20 20/30
M	OD – 0.50 20/20 OS – 1.00 20/25	
C	OD Plano 20/20 OS – 1.00 20/25	
K	OD Not tested OS 40.90 × 132/40.50 × 042	
Pachymetry OD not tested OS 345 µm	**Topography** Expected central flattening and depression OS	**Scotopic Pupils** OD 6.5 mm OS 6.5 mm

It was decided to enhance the left eye with a wavefront-guided custom PRK in March 2005.

Second Discussion

Alcon wavefront testing was performed twice in the left eye with consistent results. An Alcon wavefront-guided custom PRK was performed in March 2005 because of poor visual acuity from residual myopic refractive error and pronounced HOAs. Corneal thickness was determined and found to be adequate at 345 µm. The refractive error and corneal healing were stable from the retreatment almost 3 years previously. Four months after the wavefront-guided custom PRK OS, the patient is extremely happy with 20/20 uncorrected Va OS, a plano refraction OS, and a reduction of the HOAs with a RMS of 0.32 µm.

Surgical Plan: Second Retreatment

	Right Eye	Left Eye	Comments
	Test the patient vision with the wavefront-derived refraction in phoropter before committing her to treatment		
Ring size	None—PRK	None—PRK	Too thin for LASIK
Plate size	None—PRK	None—PRK	
Ablation zone		6.5 mm with blend	Standard for custom ablation
Spherical equivalent		–1.00 D	
CustomCornea treatment based on Alcon wavefront measurements	No treatment performed OD	–0.50 – 0.55 D × 175°	There is no nomogram adjustment with PRK. An offset of +0.25 D was programmed to reduce the spherical treatment
Ablation depth		30 µm	The Alcon software calculates the ablation depth
RSB		345 µm – 30 µm = 315 µm	>250 µm

Take-Home Points

1. A patient can be retreated more than once if the refractive error, corneal topography, slit-lamp examination of the cornea, and wavefront maps are stable. Pachymetry must be adequate.
2. Some patients will have a minimal refractive error but clinically significant visual complaints secondary to HOAs.
3. An offset can be added to the Alcon CustomCornea software to reduce the spherical correction and therefore reduce the chance of overcorrection.

CASE 52

A 41-year-old man presents for a LASIK follow-up evaluation. He complains of blur OD for the past 6 months. His past ocular history is significant for LASIK 3 years earlier, but no history of prior ocular trauma, infection, or prior surgery. He takes no systemic or ocular medications, and has no known drug allergies. He is OD dominant.

	OD	OS
Pre-LASIK manifest refraction	–9.00 + 1.50 × 90°	–8.75 + 1.00 × 90°
Pre-LASIK pachymetry	520 µm	518 µm
Hansatome 160-µm plate	Measured flap: 120 µm	Measured flap: 100 µm
Bausch & Lomb laser, optical zone 6.0 mm	Ablation depth: 153 µm	Ablation depth: 157 µm
Calculation RSB	247 µm	261 µm
Post-LASIK UCVA	20/60	20/25+
Post-LASIK manifest refraction	–1.50 + 0.50 × 90° (20/20)	–0.75 + 0.50 × 90° (20/20)
Post-LASIK cycloplegic refraction	–1.50 + 0.50 × 90° (20/20)	–0.75 + 0.50 × 90° (20/20)
Post-LASIK keratometry	38.50 × 90°/38.00 × 180°	37.50 × 90°/36.50 × 180°
Topography	Symmetric central flattening	Symmetric central flattening
Scotopic pupil size	6.5 mm	6.5 mm
Expected ablation	27 µm	

Additional Examination

The slit-lamp examination reveals normal corneal structure without evidence of guttata or KC. The lenses are clear, and the IOP is 13 OU. Dilated funduscopic examination is unremarkable. Orbscan evaluation reveals posterior elevation of 41 µm in the right eye and 43 µm in the left eye. The anterior elevation, keratometry, and pachymetry maps of the Orbscan are normal.

Discussion

This patient has had a successful LASIK result, but is troubled by regression. Unfortunately, the RSB in the right eye is below the widely accepted cutoff of 250 µm; therefore, further thinning of the stromal bed is not recommended. A recent refraction was not available, so serial refractions and topography were performed until the refraction was proven stable, that is, no change in refraction for at least 1 month. Once the regression has stabilized, the patient may be eligible for a PRK enhancement in the LASIK flap. In this manner, the refractive error can be corrected and further thinning of the stromal bed is avoided.

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Some reports have indicated that surface ablation of a prior LASIK flap can lead to significant corneal haze, while others have performed the procedure without difficulty. In our experience, PRK with MMC has been successful in correcting the residual ametropia, without further thinning of the stromal bed, and the adjunctive use of MMC has been helpful in preventing corneal haze.

The technique is as follows (See Video 9): Either ethanol (20%) or PTK may be used to remove the epithelium. Care should be taken in ethanol-assisted debridement to stroke the epithelium away from the hinge downward (in the case of a superiorly hinged flap) so as to minimize trauma to the flap. PRK is then performed with the appropriate nomogram adjustments for MMC use (see Chapter 13). MMC is used exactly as in the protocol for haze prophylaxis. This technique may afford the refractive surgeon another alternative for enhancement in cases where the residual corneal stromal bed may be too thin to perform additional LASIK safely.

Take-Home Points

1. Avoid reducing the RSB thickness to <250 µm.
2. If further laser treatment is required due to regression, surface ablation of the flap may be a better alternative.
3. MMC prophylaxis may be required in order to prevent significant flap haze.
4. Use the MMC nomogram adjustment for the retreatment.

CASE 53

A 34-year-old man with myopia had primary PRK performed in both eyes because of thin corneas. Over a 3-month period the corneal surface stabilized; however, symptomatic regression of the refractive effect was noted. By 4 months the refraction was stable. There was no evidence of haze in either eye. The patient requested retreatment. The pre- and postoperative data are summarized in the following table.

	OD	OS
Original refractive error (cycloplegic)	−6.00 D	−5.75 D
Preoperative pachymetry	499 µm	493 µm
Postoperative UCVA at 1 mo	20/25	20/25
Postoperative manifest refraction at 1 mo	+0.50	+0.50
Postoperative UCVA at 2 mo	20/25	20/25
Postoperative UCVA at 3 mo	20/40–	20/40
Postoperative BSCVA at 3 mo	20/20	20/20
Postoperative cycloplegic refraction at 3 mo	−1.00 + 0.25 × 75°	−0.75 + 0.50 × 60°
Postoperative BSCVA and cycloplegic refraction at 4 mo	Unchanged	Unchanged
Pachymetry prior to retreatment	430 µm	430 µm
UCVA 3 mo after retreatment	20/20	20/20
Pachymetry 3 mo after retreatment	420 µm	428 µm

Discussion

This patient had a normal course following PRK, specifically, an initial hyperopic response due to thin epithelium with associated neurotrophic changes. As the epithelial layers proliferated and returned to normal thickness, the induced hyperopia diminished. In this patient, the final myopic refraction should be considered an undercorrection rather than regression. The magnitude of the residual refractive error was small and had little impact on the residual corneal thickness. Because of this small residual correction and the absence of haze after the original treatment, MMC was not used.

Take-Home Points

1. Because patients having PRK typically require a longer period of healing to achieve maximal visual acuity, it is important to wait a longer period of time and to confirm stability prior to retreatment.
2. Any haze or keratitis associated with the primary treatment must be treated or allowed to clear prior to retreatment.

CASE 54

A 44-year-old man had LASIK in both eyes. Three months after the procedure he continued to complain of difficulty with intermittent blurry vision, and persistent haloes and star-bursting phenomenon at night. The LASIK flaps were without striae, keratitis, epithelial ingrowth, or fluorescein staining. Topography confirmed well-centered ablations OU. Essential data are shown in the table below. LRIs were performed in each eye using paired 30-degree arcs in the right eye, and paired 45-degree arcs in the left eye. See Chapters 10 and 15, respectively, on retreatment and alternatives to LASIK for more information on the LRI technique. (See Video 10) that demonstrates LRI technique.

	Right Eye	Left Eye
Original cycloplegic refraction	–9.50 + 1.25 × 105°	–9.75 + 1.50 × 70°
Original keratometry	44.25 × 45.25 @ 60°	44.25 × 46.00 @ 70°
Original pachymetry	629 µm	619 µm
Scotopic pupil	6.5 mm	6.5 mm
UCVA before LRI	20/25–	20/40
Cycloplegic refraction before LRI	–0.25 + 0.75 × 30° 20/20	–1.25 + 1.00 × 40° 20/20
Keratometry before LRI	39.25 × 40.00 @ 30°	38.75 × 39.25 @ 45°
Pachymetry before LRI	498 µm central 670 µm peripheral	485 µm central 672 µm peripheral
UCVA after LRI	20/20–	20/20–

Discussion

The patient had a residual refractive error in each eye, with oblique astigmatism as the primary abnormality. The spherical equivalent in each eye was about +0.25. Patients with residual "with-the-rule" or "against-the-rule" astigmatism have fewer subjective complaints than patients with oblique astigmatism. Because our general environment is oriented primarily vertically and horizontally, for most patients with astigmatism, at least one of these orientations is in relatively good focus, and patients are able to interpret what they are seeing accurately. Patients with oblique astigmatism have a blur for both vertically and horizontally oriented borders and, therefore, have more subjective complaints.

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Take-Home Points

1	The elimination of oblique astigmatism frequently results in a subjective improvement out of proportion to any modest improvement in visual acuity.
2	LRIs are an easy and safe way to reduce or eliminate residual astigmatism in patients with a spherical equivalent close to zero.

CASE 55

This 45-year-old man was originally treated with conventional LASIK for mixed astigmatism. His preoperative refraction was OD −1.00 + 4.00 × 120° 20/20 and OS −0.75 + 4.25 × 88° 20/20. Six months postoperatively the patient had an UCVA of 20/20 OU, but was lost to follow up until 4 years later. He then presented with complaints of decreased vision and was found to have residual refractive error OD.

W	No correction	**Uncorrected Va** 20/30 – 2 20/20
M	OD + 0.25 + 1.50 × 100° 20/20 OS Plano	
C	OD + 0.50 + 1.00 × 95° 20/20 OS + 0.25	
WR	OD + 1.32 + 0.85 × 95° RMS 2.09 19.9% HOA	
K	OD 43.12 × 175°/44.00 × 85°	
Pachymetry OD 550 μm OS 550 μm	**Topography** No cone	**Scotopic Pupils** OD 6.5 mm OS 7.0 mm

Discussion

Following a complete examination, enhancement of the right eye using CustomVue was recommended. The difference between manifest and WaveScan refraction prompted an adjustment of −0.75 D toward an intended postoperative goal of plano. The standard 6.0-mm optical zone and 9.0-mm ablation zone were set. The patient was originally treated with the Hansatome (160-μm head and 9.5-mm ring). The maximum retreatment depth calculated by the CustomVue software was 23 μm. The patient would still be left with an RSB of at least 367 μm postoperatively. The flap was marked at the slit lamp and lifted with the patient under the laser (See Video 4 demonstrating flap lift for retreatment). Flaps can still be lifted even several years postoperatively. After several years, flaps will occasionally demonstrate a prominent edge or a fibrotic appearance. These flaps can be a little more difficult to lift and care must be taken to carefully break the edge adhesions with a blunt fine-tipped spatula. The surgeon needs to be aware of where the original hinge location was in order not to tear it. In this case, treatment proceeded in an uncomplicated fashion.

At 1-week postoperatively, the patient had a plano refraction and a UCVA of 20/20–2. He was quite satisfied.

Take-Home Points

1	Custom enhancements can be performed after prior conventional LASIK.
2	The surgeon should be careful to make sure that the correlation between the subjective refraction and WaveScan refraction is close.
3	If a significant deviation exists between the two, then it might be best not to perform a WaveScan enhancement and to instead stick with a conventional treatment.
4	Adequate RSB thickness is extremely important.
5	Even years after LASIK surgery it may be possible to lift the flap.

CASE 56

A 44-year-old woman had LASIK performed 6 years previously to correct myopic astigmatism, and until 2 years ago she was happy with her uncorrected vision. At that time she began to notice the increasing need for reading glasses; and now she finds that she cannot dial her cell phone or even read her watch without them. Review of her previous surgery indicates that her preoperative correction was −5.00 D OD and −5.50 D OS. Her flaps were created with an 8.5-mm microkeratome ring. She is OS dominant.

	OD	OS
Uncorrected near vision	J8	J8
Near correction	+2.00 add J2	+1.00 add J4
Manifest refraction	+0.50 20/20	Plano 20/20
Cycloplegic refraction	+1.00 20/20	+0.75 20/20
Keratometry	39.50 × 39.50 @ 90°	39.00 × 39.50 @ 90°
Pachymetry	480 µm	477 µm
Scotopic pupil	6.4 mm	6.5 mm

The flap margins are difficult to see but are 7.0 mm in diameter with a nasal hinge in each eye. The rest of the anterior and posterior segment examination is normal.

Discussion

Presbyopia may become an increasingly common complaint as previously well-corrected LASIK patients get older. It presents earlier in myopic patients who were overcorrected. Even though prepared for this eventuality by counseling and informed consents, when the reality hits, patients express dissatisfaction and seek some remedy. There are three reasonable surgical options to present. LASIK enhancement can be performed to produce monovision with near correction in the nondominant eye. A contact lens trial will help define the amount of correction that gives comfortable monovision. The nondominant eye is generally felt to be the best choice for monovision near correction, but there are some people who are more comfortable the other way.

Near vision conductive keratoplasty (NVCK) has been used to correct presbyopia in previously unoperated eyes. It can be used to induce myopia in eyes after LASIK, but there are significant differences in the effect produced by the surgery in these eyes. There is an exaggerated response to the CK such that minimal treatment can produce a dramatic refractive correction. Thus only one ring of eight applications is typically applied and it can be performed with a 9.0-mm optical zone and still provide a robust correction. Because this probably depends on how much thinning the previous LASIK created, it is difficult to get a precise refractive correction in these cases. When NVCK is performed on post-LASIK eyes, the refractive effect is more like monovision with

contact lens wear. These patients do not typically get back good distance vision in the operated eye and tend to rely on one eye for distance and the other for near vision rather than the blended effect produced by CK surgery in natural presbyopes.

The last option is clear lens exchange with an accommodative or multifocal implant. This can produce excellent distance and near vision and eliminates any future concerns of cataract development. This choice requires intraocular surgery for both eyes. With these lens implants, the precise refractive outcome is crucial to success, and it may be difficult to calculate the precise implant power in some patients after LASIK.

Surgical Plan

The patient decided to have NVCK surgery and wore a +2.50 corrective contact lens for a week in her nondominant right eye to be sure that she would tolerate the correction. After a week, she felt that a stronger correction was needed and this lens power was increased to +3.00. She tolerated this well and had an 8-spot Light Touch CK performed at an 8.5-mm diameter. All the spots were outside of her flap and the flap remained secure. She had a 1-week correction of −2.75 − 0.50 × 65° that gradually regressed to a 6-week refraction of −2.00 − 0.50 × 50° for an UCNV of J2.

Take-Home Points

1. True monovision may not be comfortable for some patients, and a contact lens trial will help determine the eye and the appropriate lens power. Do not just assume that the nondominant eye is the best eye for reading correction.
2. Consider clear lens exchange with an accommodative or multifocal IOL for people who cannot tolerate monovision. Use sophisticated techniques to determine the proper lens power (see Chapter 14) because an accurate refractive result is critical to success with these lenses.
3. CK after laser vision correction produces true monovision rather than blended vision. Prepare patients for the fact that their uncorrected distance vision will not come back in the treated eye.
4. CK after laser vision correction produces a more dramatic refractive change than in eyes that have not had prior surgery. A minimal treatment can produce an exaggerated effect.

CASE 57

This 77-year-old woman had long-standing Fuchs corneal dystrophy and had previously undergone cataract extraction with posterior chamber IOLs in both eyes. She subsequently developed pseudophakic bullous keratopathy and underwent a penetrating keratoplasty (PK) OD. She was left with significant post-keratoplasty astigmatism OD after all the sutures had been removed, measuring 7 D by keratometry and 8 D on refraction. Her best spectacle–corrected vision was 20/200. Although an RGP contact lens trial improved her vision to 20/25 OD, she could not manipulate the contact lens.

Myopic LASIK was performed OD in an effort to improve her best spectacle–corrected vision and restore binocular vision.

Surgical Plan

	Right Eye	Comments
Ring size	+2	
Microkeratome head	130 µm	Moria usually cuts a 160-µm flap
Ablation zone	6.5 mm	

Surgical Plan (Continued)		
Cycloplegic Rx	−1.50 − 8.00 × 73°	
Calculations with nomogram correction (VISX)	95% factor for −1.23 − 4.00 × 73°	VISX could only treat 4 D of astigmatism
Flap thickness	160 µm	Assumed
Ablation depth (from tables)	68 µm	Deliberate under correction
RSB	586 µm −160 µm −68 µm = 358 µm	Estimated >250 µm

The VISX laser was only approved to treat astigmatism of ≤4.0 D. We deliberately attempted to keep her mildly myopic, knowing that she would need an enhancement to further reduce her astigmatism. Four-and-half months later, her preoperative refraction of −1.50 − 8.00 × 75° had improved to −2.25 − 5.00 × 90° correcting her to 20/40, but the anisometropia still contributed to discomfort wearing this eyeglass prescription. Her keratometry measured 46.0 × 52.6 @ 177°. A pair of corneal relaxing incisions was placed along the horizontal meridian to try to reduce the post-keratoplasty astigmatism further. Four months after the relaxing incisions, her refraction improved to −6.00 − 2.00 × 100 giving 20/30 vision, and her keratometry readings were 47.00 D × 48.75 D @ 27°.

We had successfully reduced the astigmatism, but increased the spherical myopia because of the coupling effect, and, therefore, we needed further manipulations to reduce the anisometropia. A repeat LASIK finally succeeded in reducing her refractive error to a level of 20/30 uncorrected. Finally, 4½ years after her PK, we had achieved excellent uncorrected vision OD and comfortable binocular vision.

Retreatment Plan After Relaxing Incisions

	Right Eye	Comments
Ring size	+2	
Microkeratome head	130 µm	Moria cuts a 160-µm flap
Ablation zone	6.5 mm	
Cycloplegic Rx	−6.00 − 2.00 × 100	
Calculations with nomogram correction (VISX)	90% factor for −5.40 − 2.00 × 100	
Flap thickness	160 µm	Assumed
Ablation depth	89 µm	Pachymetry 558 µm prior to this LASIK
RSB	309 µm	

This case illustrates the difficulty of trying to treat large amounts of astigmatism with LASIK. LASIK will often not eliminate more than 4 D of astigmatism. Corneal relaxing incisions with or without compression sutures are more reliable at reducing high degrees of post-keratoplasty astigmatism than LASIK. One must always take into account the coupling effect of corneal surgery. Based on spherical equivalents, every 2 D of astigmatism reduced by tissue sparing corneal surgery (such as relaxing incisions or radial keratometry) will result in 1 to 2 D of increased steepening in the flat meridian. In retrospect, the relaxing incisions could probably have been performed before the LASIK. Note, however, that LASIK performed in the presence

of deep keratotomy incisions increases the risk of wound rupture from increased IOP during flap creation.

LASIK flaps should generally be made larger than the graft diameter to reduce the chance of disrupting the keratoplasty wound. Some surgeons do not perform the excimer treatment immediately after the flap is cut, because significant changes in refractive error can result from simply creating a flap. The laser is later applied as a retreatment. In this case, a second LASIK flap was cut at the same depth as the first. This increased the likelihood of an irregular stromal bed. If possible, a second flap should be cut at a deeper level to avoid partially cutting into the first flap. Perhaps better alternatives to a second flap cut would be relifting the first flap or performing PRK with adjunctive MMC to prevent haze.

Finally, pachymetry should be carefully considered as an indicator of the health of the graft endothelium. If the cornea is somewhat thick, the endothelium may no longer be robust and flap adherence following LASIK may be an issue.

Take-Home Points

1	LASIK is an excellent procedure for correcting postoperative refractive error following intraocular surgery such as cataract surgery and PK.
2	The potential advantages of LASIK include the ability to relift the flap and perform enhancements if the desired refractive results are not obtained. The potential disadvantages of LASIK over a PK include the risk of rupturing the PK wound from the elevated IOP during attachment of the suction ring, a risk of rejection of the corneal transplant, and a less reliable refractive response compared to pristine corneas.
3	Corneal relaxing incisions with or without augmentation sutures are more reliable than LASIK for reducing high degrees of post-keratoplasty astigmatism.

CASE 58

A 62-year-old man who underwent bilateral myopic LASIK 8 years previously complains of slowly progressive decreased vision starting about 1 year ago. He says his uncorrected distance vision was very good after his LASIK, although he did need reading glasses. During the past year he felt he was somewhat less dependent on his reading glasses.

Manifest refraction reveals mild myopia but does not improve his vision to a satisfactory level. Slit-lamp examination demonstrates a clear cornea with well-healed LASIK flaps and nasal hinges. The rest of the anterior and posterior segment examinations are unremarkable except for moderate nuclear sclerotic cataracts OU.

W +2.75 readers J3 OU		**Uncorrected Va** OD 20/50 OS 20/50
M OD – 1.00 + 0.50 × 90º 20/40 OS – 1.00 + 0.50 × 90º 20/40		
C OD – 1.00 + 0.50 × 90º 20/40 OS – 1.00 + 0.50 × 90º 20/40		
K OD 39.5 × 180º/40.50 × 90º OS 39.5 × 180º/40.50 × 90º		
Pachymetry OD 480 µm OS 480 µm	**Topography** Central symmetrical flattening OU	**Scotopic Pupils** OD 5.5 mm OS 5.5 mm

The patient is unhappy with both his uncorrected and best-corrected visual function, and wants to discuss cataract surgery. What are the important issues with cataract surgery after LASIK? See Chapter 14 for a detailed discussion of this topic.

Discussion

The most important issue is that IOL calculations are not as accurate after keratorefractive surgery. To make this problem worse, these patients generally expect to see well without correction following cataract surgery.

It is challenging to determine the actual corneal power after keratorefractive surgery. Multiple factors contribute to this difficulty. Small optical zones, especially after RK, lead to inaccurate keratometry measurements since keratometers and most corneal topography machines measure the corneal curvature from data points several millimeters away from the center of the cornea. In addition, the anterior and posterior corneal curvatures do not resemble each other, especially after excimer laser surgery, which can lead to inaccurate results. Because the measured keratometry and simulated K readings are higher than the real central corneal power, the pseudophakic refractive result will be hyperopic. The converse is true for eyes after refractive surgery for hyperopia. Therefore, more accurate assessment of the corneal power must be obtained.

A variety of techniques are available for improving the accuracy of IOL calculations after keratorefractive surgery. One of the most reliable is the "clinical history method." This method can only be used if the preoperative keratometry and the pre- and postoperative refractive measurements are known. The preoperative keratometry is adjusted by the refractive effect of the surgery (adjusted to the corneal plane). For example, if the preoperative average keratometry reading is 45.00 D and the preoperative refraction was −5.00 D (vertex distance 12 mm) and the postoperative refractive was plano, the change in keratometry reading would be $-5/(1 - (0.012x - 5)) = 4.7$, so the new keratometry reading would be $45 - 4.7 = 40.3$ D.

Other methods depend on how much preoperative information is available. If only the pre- and postoperative refractions are known, another method involves adding 20% of the change in refraction to the current keratometry reading. For example, if the preoperative refraction was −5.50 D and the stable postoperative refraction (prior to any myopic shift from cataract) was −0.5 D, then the change in refraction was −5.00 D; and 20% of −5 D is −1. The current measured keratometry reading is 40 D so the "new" keratometry reading would be $40 - 1 = 39$ D.

When no preoperative information is available, the "hard contact lens method" can be used, but the visual acuity must be adequate for this method to work. A hard contact lens of known base curve and power is placed on the eye. The eye is then refracted. The new refraction is compared to the refraction without the contact lens. The difference is subtracted from the curvature of the contact lens.

The modern third-generation theoretical optical formulas (e.g., Holladay 2, Hoffer Q, SRK/T, Haigis) are generally thought to be more accurate after keratorefractive surgery than the empirical regression formulas (e.g., SRK I, SRK II). Several methods should be used and the results compared. Usually the lowest keratometry reading and the highest IOL power generated are used.

None of these methods is perfect. These patients need to be told prior to cataract surgery that the refractive outcome may not be plano and further surgery—for example, IOL exchange, piggyback IOL, or even refractive surgery—may be needed to get the refraction closer to plano.

Take-Home Points

1. IOL calculations after keratorefractive surgery are not as accurate as prior to corneal surgery.
2. The more preoperative information you have, the better your chances are of accurately calculating the IOL power for cataract surgery.
3. Patients need to be told that they may need corrective lenses or additional surgery in order to achieve their best vision after cataract surgery.

CASE 59

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A 50-year-old myopic woman seeks a refractive surgery consultation for her −3.50 D correction. One of the reasons she is interested in LASIK is that she is becoming increasingly contact lens intolerant. She understands that she will need reading glasses after surgery. The preoperative evaluation is unremarkable. There is no punctate fluorescein staining on the cornea or conjunctiva of either eye. The Schirmer's test after topical anesthesia measured 7 mm of wetting OU. How would you proceed?

After appropriate informed consent, stressing the fact that her eyes would feel drier for weeks to months after surgery and most likely return to baseline after 3 to 6 months, she underwent uncomplicated LASIK OU. Postoperatively, she was treated with a topical fluoroquinolone, prednisolone 1%, and preservative-free tears each four times daily. On the day after surgery her UCVA was 20/50, and 20/30 with −0.75 D sphere OU. She had significant central and superior SPK. How would you proceed?

Numerous options were discussed with the patient including punctal occlusion, use of tears, gels and ointments, and cyclosporine drops. The patient opted for 90-day dissolvable collagen plugs and one was placed in the lower punctum OU. She was also started on topical cyclosporine 0.05% (Restasis) twice daily OU. Her preservative-free artificial tears were increased to every 2 hours while awake once the antibiotics and steroids were discontinued 5 days after surgery.

During the next several weeks her symptoms and punctate staining slowly improved. At 1 month postoperatively, her uncorrected vision had improved to 20/25, correcting to 20/20 with −0.25 D sphere OU. At 3 months postoperatively she had minimal dry eye symptoms, minimal inferior SPK, and her uncorrected vision improved to 20/20. She was still using the cyclosporine 0.05% twice daily, but had decreased the artificial tear use to two to three times a day.

Discussion

The incidence of tear deficiency increases with age, especially in women. Long-term contact lens use also probably increases dryness due to decreased corneal sensation and diminished blink rate. Consequently, as long-term contact lens users get older, they may have increasing contact lens intolerance and, hence, an increasing interest in refractive surgery.

During the consultation it is important to determine whether the patient has a significant dry eye condition, not to prevent refractive surgery, but rather to give appropriate informed consent and plan for optimal preoperative and postoperative management. Anterior and posterior blepharitis are both commonly associated with dry eyes, so the lids should also be carefully evaluated preoperatively and treated.

An important component of ocular surface health is corneal innervation. Many of the central nerves are severed during LASIK. Although corneal innervation tends to recover, it may take between 3 and 12 months. During this period, many patients experience increased symptoms of dry eye including reduced and/or fluctuating vision, foreign body sensation, and reflex tearing due to irritation. Fortunately, these symptoms improve with time in the majority of patients. The major trunks of nerves enter the cornea at the 3 and 9 o'clock meridians. Some surgeons feel that a nasal-hinged flap preserves more of the nerves than a superior-hinged flap. The hypoesthesia induced from bilateral surgery may decrease the blink rate. This in turn increases exposure and contributes to an evaporative dry eye. Sequential surgery waiting for the first eye to recover before the second eye is done may be a consideration. The ambient humidity should always be considered in dry eye patients. The season and the geographical region may have an impact on the outcome in these patients.

Numerous treatment options are available pre- and postoperatively to treat dry eyes including minimally preserved and preservative-free artificial tears, tear gels and ointments, cyclosporine 0.05% (Restasis), and temporary and permanent punctal plugs. When the doctor and patient are considering starting cyclosporine 0.05%, several issues need to be discussed. The patient should know that it may take several weeks to have an effect, the drops may burn temporarily, and it

is an expensive medication without a prescription insurance plan. Blepharitis should be treated with warm compresses, eyelid hygiene, and antibiotic ointment.

Take-Home Points

1. The patient should be evaluated by history and examination for evidence of dry eye. If present, the condition should be discussed with the patient and treated preoperatively.
2. Dry eye symptoms after LASIK are common, generally respond to treatment, and usually return to the preoperative state by 3 to 6 months postoperatively.

CASE 60

A 52-year-old woman presents for LASIK consultation. After evaluation she is found to be a candidate for surgery. She has realistic expectations and understands the risks. She does not want monovision treatment. A contact lens trial was offered, but she declined.

W	OD – 4.00 20/20 OS – 4.50 20/20	**Uncorrected Va** OD 20/400 OS 20/400
M	OD – 4.25 + 0.25 × 180° 20/20 OS – 4.50 20/20	
C	OD – 4.25 + 0.25 × 180° 20/20 OS – 4.50 20/20	
K	OD 43.75 × 90°/44.00 × 180° OS 44.00 × 180°/44.00 × 90°	
Pachymetry OD 550 μm OS 550 μm	**Topography** Spherical OU	**Scotopic Pupils** OD 5.5 mm OS 5.5 mm

Additional Information

The patient elects to undergo the procedure using the femtosecond laser to create the flap. A drop of brimonidine HCl 0.15% (Alphagan) is instilled 30 minutes prior to treatment in order to blanch the conjunctiva, making it easier to obtain suction with the suction ring. A drop of ketorolac tromethamine 0.5% (Acular) is used immediately postoperatively to help keep the eye comfortable. On examination the next morning, the flap of the right eye is noted to have slipped and the UCVA OD is 20/200 compared to 20/20 OS, where the flap is noted to be in good position.

The flap is refloated immediately once the displacement is noted. The patient is taken back to the laser suite and the eye carefully prepped and draped. A topical anesthetic and antibiotic is placed on the eye and the flap is completely retracted. The underlying bed is carefully observed for any encroachment of epithelium. If noted, the epithelium is wiped away from the bed. A drop of topical antibiotic is placed on the bed as well as a topical steroid before the flap is floated back into place with sterile BSS. An ironing-like motion may be required to smooth out any wrinkles that may have formed. The flap is left to dry in place for 10 minutes while the surface of the flap is moistened with BSS. A bandage contact lens is placed on the eye overnight and the patient given instructions to frequently lubricate the eye and not to touch it.

Discussion

Despite the presence of a steeper side-cut angle in a laser-prepared flap (laser 70 degrees versus microkeratome 20 degrees), flap displacement can still occur after femtosecond laser flap. Flap

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slippage tends to occur more commonly in postmenopausal women. Such patients have a higher incidence of keratitis sicca, and it is thought that the movement of the eyelid over a dry cornea surface can pull the flap out of position. Therefore, added care to avoid direct trauma to the flap is warranted, as is added lubrication in the form of artificial teardrops or gels to reduce the likelihood of displacement. Hinge location can also play a role, because superior flaps are less likely to slip than nasal flaps. Topical brimonidine can also play a role in flap slippage and should be avoided perioperatively. Finally, adjusting the side-cut angle to 70 degrees will make slippage of the flap less likely.

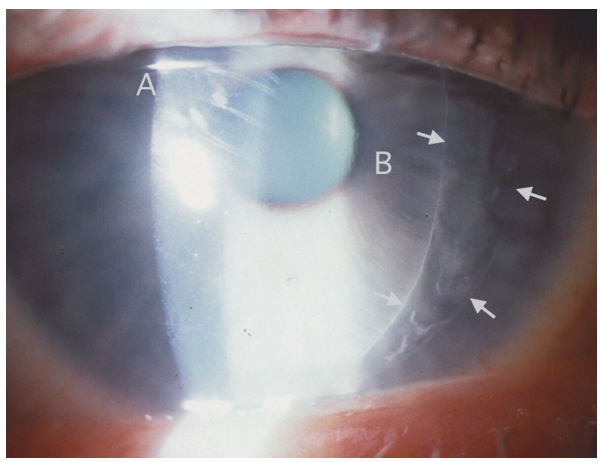
Take-Home Points

1	Flap displacement is possible with the IntraLase, but perhaps less likely than with a microkeratome.
2	A superior hinge, 70-degree side-cut angle, frequent postoperative lubrication, and avoiding brimonidine (Alphagan) perioperatively may reduce the incidence of this complication.
3	A displaced flap should be repositioned as soon as possible once it is recognized.
4	Brush back epithelium that has grown onto the stromal bed to reduce the risk of epithelial ingrowth.

CASE 61

A 38-year-old police detective underwent uneventful LASIK treatment (Case 4) achieving a postoperative UCVA of 20/20 in both eyes. Three months after surgery, while helping a friend move furniture, a wooden dowel rod struck him in the right eye. He presents in the office the next day complaining of pain and blurred vision OD.

Visual acuity without correction:	OD 20/400– OS 20/20
External examination OD:	1+ lid edema and erythema, 1+ conjunctival injection
Pupils:	Briskly reactive without APD
Slit-lamp examination:	See Case 61, Fig. 1



CASE 61, FIGURE 1

Partial flap displacement/macrofolds. *Arrows* on the right indicate margin of the flap bed. *Arrows* on the left delineate the displaced flap edge. *A* indicates Descemet's folds due to stromal edema. *B* indicates macrofolds related to the displaced flap. (Courtesy of Robert S. Feder, M.D.)

Discussion

This patient's symptoms of pain and decreased vision are consistent with the finding of a flap displacement OD that occurred as a result of the blunt injury. It is worth noting that this occurred 3 months postoperatively and is a reminder of the fragility of the flap even months after surgery. The findings of macrofolds in the flap and the presence of a gap between the flap edge and the peripheral cornea are typical. This flap should be repositioned as soon as possible. Most affected patients will seek attention soon after the injury, so the macrofolds will be relatively easy to smooth out. Unless the area of flap slip is small, it is generally preferable to unseal the remainder of the flap edge and reflect the whole flap rather than working only on the part that has been displaced.

After a flap displacement, corneal epithelium will begin to grow over the gap. The epithelium appears as a smooth sheet and is relatively easy to differentiate from the rougher appearing stromal bed. It is very important to recognize the presence of this epithelium and clear it from the stromal bed in order to reduce the chance of epithelial ingrowth.

The epithelium is often irregular at the flap edge and a bandage contact lens should be placed on the eye. Depending on the extent of the injury, a traumatic iritis may be present. The patient should be treated with topical prednisolone 1% and a topical fluoroquinolone each four times daily. The patient should be watched closely for signs of DLK, iritis, and infection, as well as epithelial ingrowth.

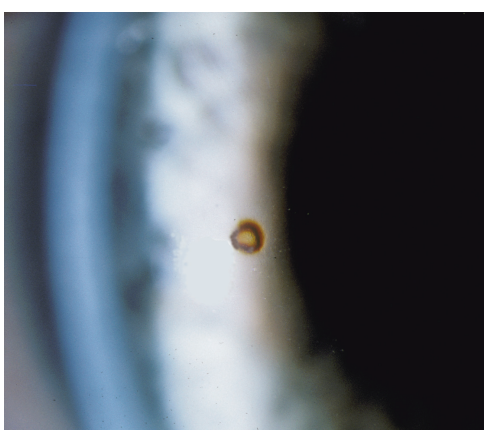
The patient in this case recovered 20/20 unaided acuity.

Take-Home Points

1. Traumatic flap displacement can occur long after LASIK surgery.
2. The flap should be repositioned as soon as possible.
3. Macrofolds should smooth out as the flap is repositioned.
4. Reduce the risk of ingrowth by recognizing and removing overgrown epithelium from the flap bed before the flap is laid down.

CASE 62

A 38-year-old police detective (see Cases 4 and 61) had uncomplicated LASIK surgery to correct myopia with astigmatism. Three months postoperatively he suffered a traumatic flap displacement OD. The flap was repositioned and he had recovered 20/20 unaided acuity. Two months later he presented with the onset of irritation and blurred vision OD. The visual acuity without correction was 20/25 OD and 20/15– OS. No external inflammation was seen. On slit lamp examination the appearance OD is seen in Case 62, Fig. 1. The flaps OU were without striae or epithelial ingrowth



CASE 62, FIGURE 1

Rust ring on a LASIK flap. (Courtesy of Robert S. Feder, M.D.)

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Discussion

This patient appears to have a rust ring in the LASIK flap. The consequence of aggressive removal would be a buttonhole in the flap, which conceivably could lead to epithelial ingrowth. Creating an epithelial defect in a LASIK flap could result in DLK and the epithelium may be slow to heal due to the neurotrophic nature of a LASIK flap. The consequence of leaving the rust ring would be chronic irritation and possibly the risk of infection. The decision was made to judiciously remove the retained foreign material. This was accomplished using a 25G needle after topical anesthetic was instilled. The epithelium was slow to heal despite the use of a BSCL. No DLK or epithelial ingrowth occurred, but a small scar developed at the site. The unaided visual acuity OD was 20/25–, which improved to 20/20+ with a −0.50 D sphere.

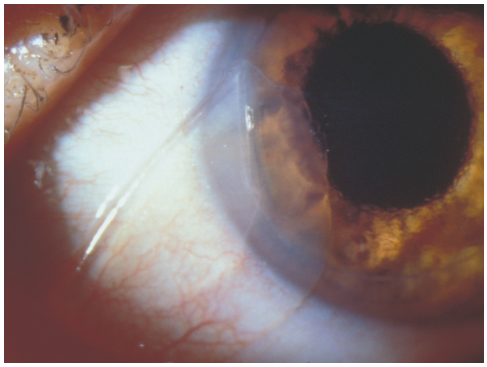
Take-Home Points

1. The possible consequences of corneal foreign body removal in a LASIK flap are persistent epithelial defect, DLK, buttonhole with or without epithelial ingrowth, and infection.
2. Epithelial healing may be slower in a neurotrophic LASIK flap.

CASE 63

A 58-year-old woman had undergone uncomplicated LASIK OU 3 years prior to correct −4.00 D OU. She was doing well with very good uncorrected distance vision in both eyes. She used reading glasses for near tasks. While gardening one morning (without glasses), she was poked in the left eye by a tree branch. She developed immediate pain and decreased vision in that eye. She went immediately to the Emergency Department where an ophthalmologist was called in to treat her.

In this case, the flap was dehisced, just attached at its hinge (Case 63, Fig. 1). The decision was made to replace it in the minor surgery suite using an operating microscope. After informed consent was obtained, the eye was prepped and draped, topical antibiotic and anesthetic were placed, and an eyelid speculum inserted. A blade (e.g., Alcon 67 or Beaver #15) was used to remove all debris and cells from the underside of the flap and from the stromal bed. Epithelium that had migrated onto the stromal bed was pushed peripherally. Once this was completed, the flap was replaced and the interface irrigated. There was a crease in the flap, where it had been folded prior to presentation at the hospital. The flap was stretched in an attempt to flatten the crease with a cyclodialysis spatula and dry and moist cellulose sponges. While the stretching helped the fold somewhat, it also damaged the flap epithelium slightly. The gutters were examined and felt to be even. A BSCL (Focus Night & Day 8.6/−0.50) was placed on the eye and the patient placed on a topical fluoroquinolone, prednisolone 1%, and preservative-free tears. The patient was seen daily and the BSCL was removed on the third postoperative day. The flap remained in excellent position with no significant striae and the uncorrected vision returned to baseline.



CASE 63, FIGURE 1

Flap displacement. (Courtesy of Christopher J. Rapuano, M.D.)

Discussion

What are the important issues to address in cases of trauma after LASIK? First, the extent of ocular injury needs to be evaluated, making sure there is no ruptured globe, ocular foreign body, hyphema, and so forth. Second, check on the status of the LASIK flap, making sure it is intact and in good position. Third, if the LASIK flap is not in perfect position, decide how to best correct its position.

Trauma to a LASIK flap, even years postoperatively, can cause a partial or total flap dehiscence. In such cases, the flap needs to be replaced in its original location. Both the bed and underside of the flap need to be cleaned of epithelium and debris. It is critical to debride the stromal bed of all epithelium, which begins to cover the periphery quickly after such an injury. Surface corneal epithelial cells migrate onto the stromal bed within an hour or two after such an injury. If these cells are not removed, epithelial ingrowth will occur. In fact, many surgeons will remove the epithelium 0.5 to 1.0 mm away from the flap edge to help prevent epithelial growth under the flap. After the flap is repositioned, the flap interface should be irrigated. Flap folds are common and typically resolve over a few days after the flap is repositioned. If the flap does not adhere well during the repositioning procedure, perhaps due to excessive hydration, four to eight interrupted sutures or a running suture can be placed to hold the flap in good position until it is secure. These patients should be followed closely because they are at higher risk for DLK, infection, and epithelial ingrowth. However, with proper emergent management and follow-up care, these patients can do very well.

Take-Home Points

1. LASIK patients need to be examined at a slit lamp after ocular trauma to make sure the flap was not disturbed.
2. When replacing a dehisced LASIK flap, make certain all epithelium is removed from the undersurface of the flap and the stromal bed.

CASE 64

A 60-year-old man with a BCVA of 20/20 OU underwent uncomplicated LASIK for correction of −4.00 D. Postoperatively, his uncorrected distance vision over the first several weeks was approximately 20/25 OD and 20/40 OS. He had noted a significant decrease in the quality of his vision OS compared to OD ever since surgery. One month postoperatively, the manifest refraction OD was −0.50 (20/20) and OS was −1.25 + 1.00 × 125° (20/30–2). How do you proceed?

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The slit-lamp examination OD revealed a nicely healed LASIK flap with a superior hinge. The flap appeared to be in excellent position with a few "cracked mud microstriae" centrally. There was no noticeable "negative staining." Slit-lamp examination OS also revealed a well-healed LASIK flap with a superior hinge. The flap appeared to be in excellent position with moderate "microstriae" centrally; there were several vertically oriented "microstriae" centrally. There was mild "negative staining" of the vertically oriented lines.

A complete examination including dilation was normal and unchanged from before surgery. Computerized corneal topography with an EyeSys unit revealed symmetrical central flattening OU. A hard contact lens over-refraction improved the vision OS to 20/20–. How do you proceed?

The patient was unhappy with the poor quality of his vision OS and was not interested in wearing an RGPCL. The surgeon discussed several options with the patient including (1) giving the cornea more time to smooth out, (2) attempting a flap lift and stretch procedure, (3) attempting a flap lift and heating procedure, and (4) attempting a flap lift and suture procedure. Because there is a low likelihood that the cornea will smooth out enough to significantly improve his vision, they agreed to try a flap lift and stretch procedure.

The flap lift and stretch procedure was performed (See Video 18) with an operating microscope with topical anesthesia, similar to removal of epithelial ingrowth. The flap edge was marked, and then the flap was lifted completely and replaced after irrigation of the interface. A cyclodialysis spatula and dry and moist cellulose sponges were used to stretch the striae, in this case horizontally. The flap can also be stretched while reflected back. The ink marks were realigned. A BSCL may be used. This patient underwent this procedure, but unfortunately his vision did not improve. How would you proceed?

It was decided to attempt a flap lift and suture procedure. This is performed in the same manner as a flap lift and stretch, except after the flap is laid down and aligned, the flap is sutured with multiple interrupted 10-0 nylon sutures, oriented to stretch out the "striae." The knots are buried peripherally. Once the sutures were placed, the "striae" were still quite visible. Consequently, a central epithelial defect was created with a semi-sharp blade (e.g., Tooke knife), being careful not to get near the flap margin. Once the central epithelium was removed, the "striae" almost completely disappeared. A BSCL (e.g., Focus Night & Day 8.6/–0.50) was inserted. This patient was placed on a topical fluoroquinolone and prednisolone 1% four times daily and followed closely. The BSCL was removed 5 days later, at which time the epithelial defect had healed. One suture loosened at 2 weeks and was removed. The remaining sutures were removed 6 weeks postoperatively. The uncorrected vision improved to 20/25 correcting to 20/20 with a –0.50 D refraction. The central vertical "striae" improved significantly but did not completely disappear; however, the patient felt his quality of vision was much improved.

Discussion

Mild, "cracked mud" pattern microstriae are seen frequently after LASIK, especially after larger corrections. They generally are not thought to affect vision. That said, a patient with striae and quality of vision complaints should be consider for flap lift and stretching even if the visual acuity is 20/20. Frank folds, often emanating from the flap hinge, are due to a misaligned flap and affect vision and topography. There is a gray area in between where they are not frank folds and yet seem to be affecting vision. Clues that these "striae" are clinically significant include "negative staining," topographic irregularity, and improved vision with an RGPCL. Microstriae are usually not treated. Frank folds require flap lift and stretch as soon as possible. Clinically significant striae should be treated sooner rather than later, because the irregularity seems to "cement in" the longer it persists. Treatment options include flap lift and stretch, flap lift and heat, excimer laser PTK, and flap suturing. Central epithelial debridement is felt to be helpful in some cases. It is believed that the epithelium somehow holds the striae in place and these attachments must be broken to get the striae to resolve. After these cases, especially if the epithelium is removed, patients must be followed closely for signs of DLK.

Take-Home Points

1. Obvious folds from flap misalignment require lifting and realignment of the flap in a better position as soon as possible.
2. Less prominent striae can still cause visual disturbances, which can improve with a variety of treatments.
3. Isolated striae that appear outside the visual axis need not be addressed unless they are visually significant. Changes in the nondominant eye are often less problematic than those occurring in the dominant eye.

CASE 65

A 49-year-old man complained of decreased vision in his right eye 8 years after having undergone LASIK. The original records were unavailable. The UCVA in the right eye was 20/100–. The cycloplegic refraction was −1.75 + 2.00 × 10°. Slit-lamp examination of the original flap showed a flap diameter of only 7.4 mm, with no obvious hinge noted. In addition, there was an oblique linear truncation of the flap from 3 to 5 o'clock with an effective diameter of 6 mm in the oblique axis. There were a few microstriae and a central irregularity of tear film. Because of the overall truncation of the flap, the potential for the original flap to have been free, and the surface irregularity, a surface retreatment was suggested. PRK was performed and a Merocel corneal protector soaked in MMC 0.02% was placed on the treatment bed for 1 minute followed by copious irrigation. Five days after the procedure, the contact lens was removed. Examination showed UCVA of 20/400 with +1 haze. The patient was maintained on topical steroids and lubrication. One month after the procedure, the UCVA was 20/60 and BSCVA was 20/25. Two months after the retreatment, the UCVA was 20/30– with minimal haze correctable to 20/20–. At 5 months the UCVA was 20/30 with faint haze and BCVA of 20/25+ with a cycloplegic refraction of −1.00 + 1.00 × 95°. LRI was performed and, at 10 months, UCVA was 20/25– with a residual refractive error of −0.25 D.

Cycloplegic refractive error OD before initial treatment	−7.00
Original keratometry	Not available
Original pachymetry	Not available
Cycloplegic refraction OD prior to retreatment	−1.75 + 2.00 × 10°
Pachymetry OD prior to retreatment	495 µm
Keratometry OD prior to retreatment	38.12 × 110°/39.25 × 20° (irregular)
Postoperative UCVA OD at 1 mo	20/60
Postoperative cycloplegic refraction OD at 1 mo	−1.75 + 1.75 × 80°
Postoperative UCVA OD at 2 mo	20/30–
Postoperative cycloplegic refraction OD at 5 mo	−1.00 + 1.00 × 95°
Postoperative UCVA OD at 10 mo following LRI	20/25

Discussion

This case demonstrates the effectiveness of surface retreatment after LASIK and the need for patience following retreatment in this circumstance. The patient must accept the need for patience before embarking on any course of visual rehabilitation. Although many surgeons use MMC in this circumstance, there are numerous reports of patients doing equally well after retreatment without the use of the medication.

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Take-Home Points

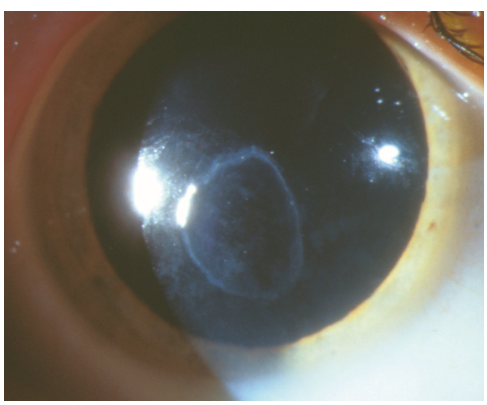
1	Complicated keratorefractive cases require extended periods of observation before the final results become evident.
2	Visual rehabilitation after complicated LASIK may require multiple or different procedures performed sequentially, each after the refractive error has stabilized.
3	Surface retreatment is usually a better alternative than re-cutting when working with poor-quality flaps and no information about the original LASIK surgery.

CASE 66

This 49-year-old woman had myopic astigmatism and small palpebral fissures. The ophthalmologist who performed her LASIK commented on the difficulty seating the microkeratome on her left eye due to the small interpalpebral fissures and intraoperative blepharospasm. The surgeon inadvertently created a free cap OS and he proceeded with the refractive ablation because he felt there was an adequate stromal bed.

The patient was referred 5 months postoperatively for evaluation and management of undercorrected myopia OS. The initial examination revealed a small free cap (Case 66, Fig. 1). Her UCVA was 20/60, and the residual refractive error was −1.00 − 0.75 × 30° OS correcting to 20/20.

W	OD – 0.25 20/20 OS – 1.75 – 1.25 × 38° 20/20	**Uncorrected Va** OD 20/25 OS 20/70
M	OD – 0.25 20/20 OS – 1.75 – 1.25 × 40° 20/20	
C	OD plano 20/20 OS – 1.50 – 1.50 × 40° 20/20	
K	OD 41.25 × 178°/41.75 × 88° OS 41.00 × 42°/42.75 × 132°	
Pachymetry OD 510 μm OS 502 μm	**Topography** Central flattening OD Regular astigmatism OS	**Scotopic Pupils** OD 5.5 mm OS 6.0 mm



CASE 66, FIGURE 1

Illustration of a small free cap from a different patient. BSCVA will depend on the degree of surface irregularity and stromal opacity near the visual axis. BSCVA in this patient would not be 20/20. (Courtesy of Christopher J. Rapuano, M.D.)

Given the potential instability of a free cap, for example, the risk of a recurrent free cap with any attempt at relifting and the small potential ablation zone, we elected to perform an excimer laser PRK to enhance her refractive result. To minimize the risk of dislodging the free cap, we elected to perform a "no touch" technique consisting of a laser epithelial removal, followed by the refractive keratectomy.

	Left Eye	Comments
Ablation zone	6.5 mm with 8.0-mm blend	
Cycloplegic Rx	−1.50 − 1.50 × 40°	
Calculations with nomogram correction (VISX)	10% reduction for MMC −1.35 − 1.50 × 40°	Reduce risk of post-PRK haze
Flap thickness	N/A	
Ablation depth (from tables)	40 µm	
Residual stromal bed	502 µm − 40 µm = 462 µm	

There is a significant risk of post-PRK haze in a post-LASIK eye. We applied prophylactic MMC 0.2 mg/cc on a Merocel circular sponge for 2 minutes after the laser ablation, and irrigated the cornea with 30 mL of chilled BSS. We reduced the cycloplegic refraction by 10% before entering the desired treatment into the laser, because the MMC inhibits the normal healing response. Her postoperative visual acuity was 20/25 uncorrected.

Take-Home Points

1. This case illustrates the risk of a free cap in a LASIK case, especially one in which there are problems getting the suction ring seated properly. Risk factors include a small interpalpebral fissure and poor patient cooperation.
2. Because of the potential instability of the free cap, LASIK enhancement is often best accomplished using surface PRK.
3. The prophylactic use of MMC is often desirable to reduce the risk of postoperative corneal haze in these cases.

CASE 67

A 20-year-old woman presents for a refractive surgery consultation. Her past ocular history is significant for attempted LASIK 6 weeks earlier, complicated by a buttonhole flap in the right eye. She is inquiring about visual rehabilitation for her right eye.

W	OD − 4.50 + 0.50 × 90° 20/25 OS − 4.75 + 0.75 × 90° 20/30	**Uncorrected Va** 20/400 20/400
M	OD − 3.00 20/20 OS − 2.50 20/20	
C	OD − 2.75 + 0.25 × 95° 20/20 OS − 2.25 + 0.50 × 85° 20/20	
K	OD: 44.75 × 90°/44.75 × 180° OS: 44.75 × 90°/45.12 × 180°	
Pachymetry OD 554 µm OS 557 µm	**Keratome** ACS 180-µm flap 8.5-mm ring	**Dominant Eye** OD

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Additional Information

After identification of the buttonhole flap, the flap was repositioned carefully without application of the excimer laser. A bandage contact lens was placed, and the postoperative course was closely monitored for development of epithelial ingrowth or scarring. The patient's refraction and topographic examination were stable at 6 weeks, with BSCVA equivalent to preoperative levels. On slit-lamp examination, the corneal flap was well-healed with a faint central buttonhole scar present (Case 67, Fig. 1).

Discussion

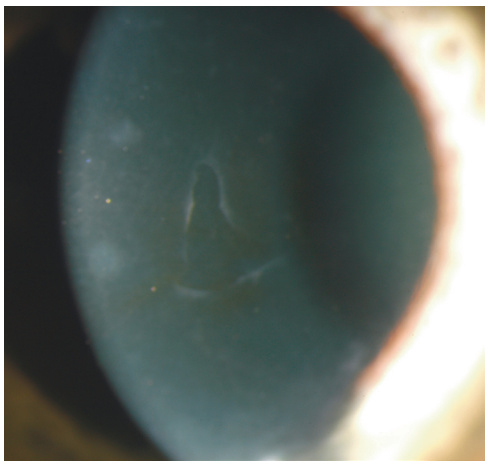
In this patient who has already sustained a buttonhole flap, attempting to create another flap with a mechanical microkeratome is risky for several reasons. If the proximate cause of the first buttonhole flap is unknown, there is a higher likelihood that a second buttonhole may occur. Indeed, this patient's cornea was not excessively steep, and the surgeon was experienced in using the ACS microkeratome. In addition, the use of a mechanical microkeratome for the second surgery may also create a flap that intersects with the first, possibly resulting in irregular astigmatism. The femtosecond laser may be beneficial in re-cutting buttonholed flaps. However, another option is transepithelial PTK/PRK with adjunctive MMC. It has been reported that surface ablation over LASIK flaps, especially buttonholed flaps, may put the patient at increased risk for significant corneal haze. The use of MMC may prevent this. (See Video 20)

This patient requested laser vision correction without the use of a microkeratome. The VISX STAR S4 was used to remove the epithelium with a 6.5-mm diameter and 50-µm depth PTK setting. PRK treatment, reduced due to the use of MMC, with a 6.0-mm optical zone and an ablation depth of 33 µm, was then applied. A 6-mm-diameter corneal light shield that had been soaked in MMC 0.02% was then placed on the stromal bed and left in position for 2 minutes. Following removal of the shield, the cornea was irrigated with 30 mL of BSS. A Soflens 66 bandage contact lens was then applied to the right eye. Standard PRK without MMC was then performed on the left eye.

Postoperatively, the patient had an uneventful course. Both corneas were well healed without any evidence of scarring or haze in either eye. At 16 weeks postoperatively, both corneas remained clear and the UCVA was 20/20 in both eyes. Manifest refraction was –0.25 D OD and plano OS.

Take-Home Points

1	Know your microkeratome and the typical flap thickness produced for each plate.
2	To minimize the potential for buttonholes, avoid LASIK with mechanical microkeratomes in steep corneas with an average keratometry value of >48 D.
3	If a buttonhole is created, do not apply the excimer laser treatment. Replace the flap carefully and place a bandage contact lens.
4	Re-cutting another flap should be avoided. Consider surface ablation with MMC prophylaxis.



CASE 67, FIGURE 1

Buttonhole flap. (Courtesy of Christopher J. Rapuano, M.D.)

CASE 68

A 56-year-old man had undergone LASIK surgery 3 years previously. Retreatment was performed twice OD and once OS. The original treatment data were unavailable. He was now being followed by his general ophthalmologist, who noted a white opacity in the superficial stroma OS that had not been seen previously. The patient was pain free, but he had noted a gradual decrease in vision OU since the surgery. The ophthalmologist suspected infectious keratitis and began treatment with frequent topical moxifloxacin. The opacity remained unchanged after 3 days of therapy. He now suspected fungal keratitis and sent him for consultation.

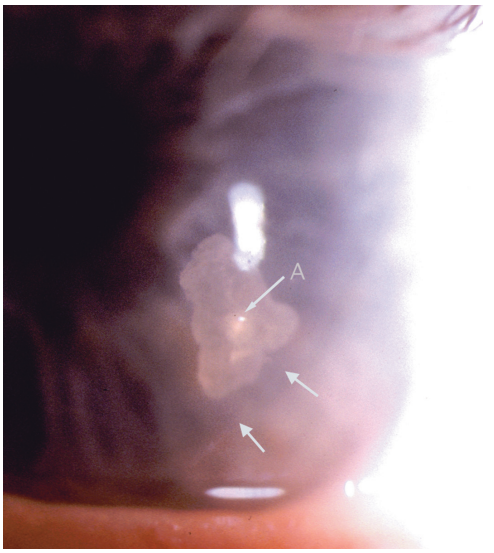
M OD – 1.50 + 1.50 × 123° 20 / 25– OS – 0.75 + 1.25 × 70° 20/20–	**Uncorrected Va** 20/50 20/30–
K OD 40.75 × 30°/42.25 × 120° Slightly irregular mires OU OS 40.50 × 160°/41.75 × 70°	
External Examination Lids without edema or erythema; no discharge; bulbar conjunctiva white and quiet	
Slit-Lamp Examination An 8.0-mm nasal hinged flap was present OU. There was scattered debris in the interface OU. A dense, white opacity was noted at the inferotemporal flap interface OS (Case 68, Fig. 1). There was no surrounding keratitis. There was a pinpoint area in the center of this lesion that appeared to be possible flap necrosis. The area showed negative staining. There was no vascularization or stromal edema. The anterior segment was otherwise normal in each eye.	
Pachymetry OD 502 μm OS 510 μm	**IOP and Fundus** Normal OU **Dominant Eye** OD

Given the lack of inflammation, it seemed clear that this opacity did not represent infectious keratitis, bacterial or fungal. The dense, white opacity had the appearance of epithelial ingrowth with possible early flap necrosis (Case 68, Fig. 1). The lesion was not particularly large; however, the small central necrotic area was worrisome. The risk of further necrosis was explained to the patient and he agreed to a flap lift OS for removal of this material. He was not interested in further laser surgery and was content to wear glasses.

The patient was taken to the laser suite where, after instillation of topical anesthetic and appropriate prep and drape, the flap was partially lifted (See Video 17 of removal of epithelial ingrowth). A smooth patch of epithelium was adherent to the stromal bed. There was also some material on the underside of the flap. All of the epithelium was gently removed. The interface was irrigated, but the flap was not sutured. A BSCL was placed. It could not be determined intraoperatively if the flap was intact; however, postoperatively a small buttonhole could be seen in the area that had appeared necrotic (Case 68, Fig. 2). After 8 months of follow-up, the epithelial ingrowth has not recurred and the vision is stable.

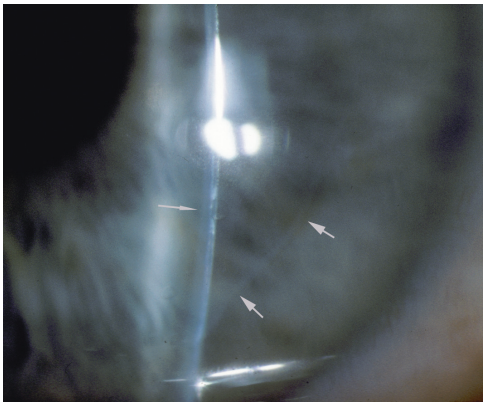
Discussion

The risk of epithelial ingrowth is increased with multiple flap lifts for retreatment or in patients who have had a flap slip postoperatively. The adherence of the corneal epithelium is reduced in patients over the age of 50, in diabetics, and in patients with basement membrane dystrophy.



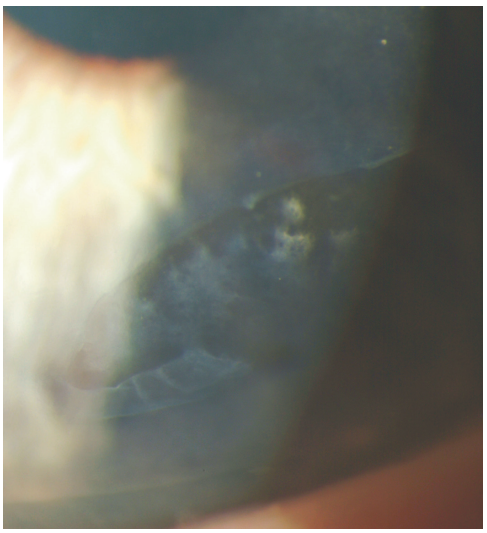
CASE 68, FIGURE 1

"A" arrow points to an area of suspected flap necrosis within a patch of dense epithelial ingrowth. Heavier arrow delineates the flap edge. (Courtesy of Robert S. Feder, M.D.)



CASE 68, FIGURE 2

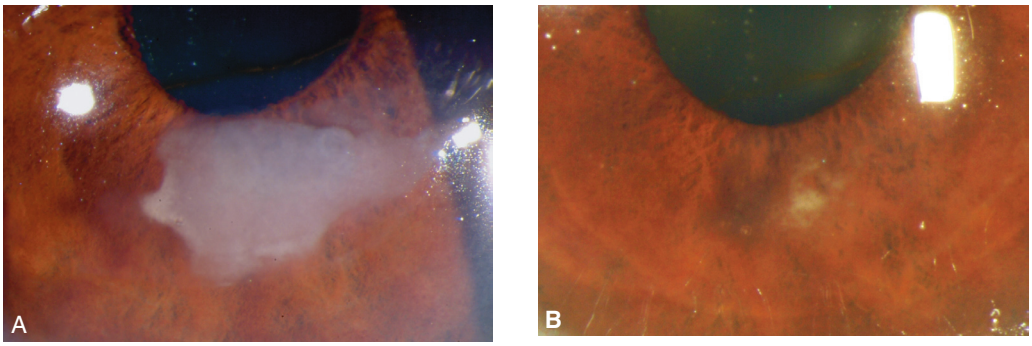
Fine arrow indicates buttonhole caused by flap necrosis confirmed after flap lift and ingrowth removed. *Heavier arrows* delineate the flap edge. (Courtesy of Robert S. Feder, M.D.)



CASE 68, FIGURE 3

Peripheral flap necrosis caused by epithelial ingrowth. (Courtesy of Robert S. Feder, M.D.)

Irrigating the interface after the flap is replaced can remove epithelial cells that have been trapped. This patient had moderate debris in the interface, suggesting inadequate irrigation. Ingrowth can present contiguous with the flap edge or as an isolated lesion not connected with the flap edge. It can affect vision by causing irregular astigmatism or by blocking the visual axis. A dense patch of epithelium can prevent nutrients from reaching the overlying flap and therefore can result in necrosis at the flap edge or within the flap (Case 68, Fig. 3). Occasionally, even a dense lesion can resolve spontaneously (Case 68, Figs. 4A and B); therefore, a compliant patient can be watched carefully if the lesion is relatively small and out of the visual axis. The indications for treatment are ingrowth extending ≥2 mm from the flap edge, an opalescent patch that may threaten flap necrosis, or decreased vision due to opacity or irregular astigmatism.



CASE 68, FIGURE 4

A: Dense epithelial ingrowth with no overlying flap necrosis. **B:** Same cornea 3 months later shows nearly complete resolution of ingrowth without treatment. (Courtesy of Robert S. Feder, M.D.)

Take-Home Points

1. The risk of epithelial ingrowth is greater after flap displacement or retreatments, if epithelium is poorly adherent, or if the interface is not properly irrigated.
2. Ingrowth can affect vision by invading the visual axis or by inducing irregular astigmatism.
3. The indications for removal are extension ≥2 mm from the flap edge, increasing density of the lesion with threatened flap necrosis, or decreased vision.

CASE 69

The 55-year-old man from Case 45 returned 3 months after LASIK OD, which was complicated by a large area of central epithelial loosening that was treated and resolved. He noted some ocular irritation and decline in his vision on the right.

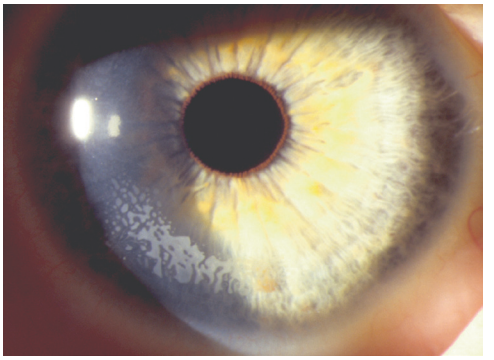
M OD – 1.50 + 0.75 × 90° (20/30)		**Uncorrected Va:** OD 20/50
C OD – 1.25 + 0.75 × 90° (20/30)		
K OD 39.50 D × 180°/40.00 D × 90°		
Pachymetry 586 μm	**Topography** OD asymmetric ATR astigmatism	**Scotopic Pupil** OD 3.5 mm

Additional Examination

Slit-lamp examination revealed a well-healed epithelium OD with some mild peripheral ABMD changes and a completely normal OS. There was an area of epithelial ingrowth inferiorly OD, from 5 to 8 o'clock reaching approximately 2 to 3 mm centrally from the flap edge. There was mild elevation of the flap and corresponding topographic flattening producing irregular astigmatism. Mild punctate fluorescein staining of the epithelium was present over the area of epithelial ingrowth. There was no stromal inflammation or vascularization and the anterior chamber was deep and quiet (Case 69, Fig. 1). How would you proceed?

Discussion

A patient with epithelial ingrowth can usually be followed unless the condition is affecting vision or the health of the flap. Generally, small amounts of epithelial ingrowth, for example, <2 mm



CASE 69, FIGURE 1

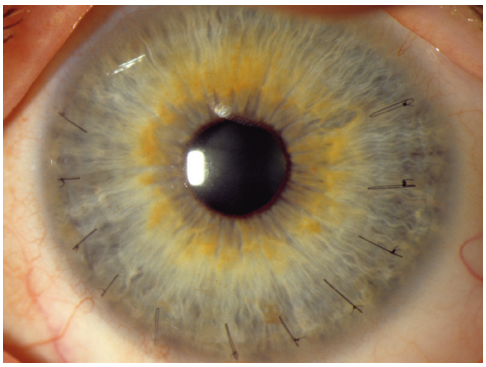
Epithelial ingrowth beneath LASIK flap inferiorly. (Courtesy of Christopher J. Rapuano, M.D.)

from the flap margin, do not cause trouble. When epithelial ingrowth extends >2 mm toward the center of the cornea, it may begin to cause decreased vision from irregular astigmatism. Also large or dense areas of epithelial ingrowth can prevent proper nutrients from getting to the overlying flap and can lead to superficial punctate staining, epithelial defect, and even flap melting. In cases of decreased vision and a "sick" flap, as in this patient, the epithelial ingrowth should be removed. Patients need to understand the benefits and risks of this procedure, including recurrent epithelial ingrowth, decreased vision, infection, DLK, and the potential need for additional surgery.

Removal is typically performed with topical anesthesia, using an operating microscope. The area may be outlined lightly with a marking pen to be able to identify exactly where it is under the operating microscope. Ink marks can also be made at the flap edge to aid in repositioning at the end of the procedure. The flap edge is opened with an instrument such as a Sinskey hook. Depending on the size and location of the epithelial ingrowth, a small area or the entire flap can be lifted with an instrument such as a cyclodialysis spatula. The stromal bed and the underside of the flap need to be scraped carefully but effectively with a sharp blade (e.g., an Alcon #67 blade or Beaver #15 blade) or semi-sharp knife (e.g., Tooke knife). While care does need to be taken not to damage the flap or stromal bed while scraping, no residual epithelium should remain. The epithelium often comes off as a sheet of tissue. The epithelium peripheral to the edge of the flap may also be removed or pushed back from the flap margin for about 1 mm to prevent recurrent ingrowth. Once all the interface epithelium has been removed, the flap is replaced, the interface irrigated, and the flap allowed to adhere for several minutes. A BSCL may be placed for several days. The patient should be treated with topical antibiotics and steroids.

This patient underwent an uncomplicated flap lift and scrape procedure. The patient received topical fluoroquinolone and prednisolone 1% qid for 7 days and frequent preservative-free tears for a month. The BSCL was removed after 5 days. The uncorrected vision improved to 20/30 and with a $-1.00 + 0.50 \times 90°$, the visual acuity was 20/25+2 and the patient was happy.

Recurrent epithelial ingrowth can be treated in an identical manner if the surgeon believes this procedure is more likely to be successful a second time. Additional treatment options include flap suturing and placement of fibrin glue. Flap suturing involves the exact same initial procedure as the flap lift and scrape (See Video 17 on epithelial ingrowth). Once the flap interface is cleared of epithelium and the interface irrigated, either interrupted sutures or a running 10-0 nylon suture is placed to secure the flap edge to the stroma. If fluorescein staining is noted at the flap edge preoperatively, this may indicate the origin of epithelial ingrowth. This site should be marked and a suture should be placed at this site to secure the flap at this location. Typically 7 to 14 interrupted sutures are placed if the entire flap is lifted (in all areas except the hinge), or fewer if just part of the flap is lifted. The knots are buried peripherally so as not to disrupt the flap when the sutures are removed. The sutures are usually kept in place for 4 to 6 weeks (Case 69, Fig. 2). Fibrin glue, for example, Tisseel (Baxter), can also be used to secure the flap edge in attempt to prevent recurrent epithelial ingrowth. It is placed on the flap edge once the flap interface is cleared of epithelium, irrigated, and repositioned. The glue dissolves over days to weeks.



CASE 69, FIGURE 2

Following a flap lift and removal of epithelium, the flap is sutured to reduce the risk of recurrence. (Courtesy of Christopher J. Rapuano, M.D.)

Take-Home Points

1	Small degrees of epithelial ingrowth at the edge of the flap are common and do not require removal.
2	Larger degrees of epithelial ingrowth (e.g., >2-mm central growth) tend to cause problems such as irregular astigmatism and decreased vision and even damage to the health of the flap, and they require treatment.
3	When epithelial ingrowth is removed, both the underside of the flap and the stromal bed need to be scraped.
4	Recurrent epithelial ingrowth can be managed by suturing the flap or using fibrin glue to seal the flap edge after the offending epithelium has been removed.

CASE 70

A 45-year-old man with a refraction of –8.50 D OU and thin corneas measuring 487 µm OD and 472 µm OS desired LASIK. Computation of his RSB showed results of 217 µm OD and 202 µm OS. Although there are no controlled studies to confirm the safe level of RSB, we believe that ≥250 µm is a more desirable threshold. Therefore, we elected not to perform LASIK and instead recommended PRK.

Given the high degree of myopia, and the 115 µm of estimated stromal ablation, we elected to treat the ablated corneas with prophylactic MMC 0.02% on a Merocel sponge (corneal protector) for 2 minutes, and then rinse thoroughly with 30 mL of chilled BSS per eye. His UCVA improved to 20/20 OU at 2 months postoperatively.

Nine months following the PRK, he developed late-onset corneal haze in an arcuate pattern OD, associated with a decrease in visual acuity to 20/30. He was treated with a corneal scraping and repeated application of MMC 0.02% on a Merocel corneal protector for 2 minutes. This was followed by a rinse with 30 mL of chilled BSS. Six weeks later, his uncorrected vision improved to 20/25 and his cornea was clear.

Four months after this treatment, the corneal haze recurred. This time he was treated with prednisolone acetate 1% drops (Pred Forte) every 2 hours while awake, and vitamin C 1,000 mg orally each day, which was then tapered gradually over 4 months. The corneal haze has not recurred.

Take-Home Points

1	PRK is an excellent alternative for corneas that are too thin for LASIK.
2	Late-onset corneal haze may occur after PRK, even in a patient who was treated with prophylactic MMC to try and prevent such an occurrence. This case demonstrates the benefit of topical steroids to treat corneal haze, rather than a repeat application of MMC.
3	Vitamin C, a potent antioxidant, may be of benefit in preventing post-PRK corneal haze.

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CASE 71

A 48-year-old woman undergoes uncomplicated LASIK for −3.50 D myopia in both eyes using a mechanical microkeratome. On the first postoperative day, her uncorrected vision was 20/25 OU and other than mild subconjunctival hemorrhages OU, the examination was unremarkable. She was told to continue her antibiotic and steroid drops four times daily and to return in 1 week. However, on postoperative day 3 she noted more photophobia and was told to come in and be examined. On the basis of this information, what would you be thinking about prior to examining her?

On examination, her UCVA was 20/30 OD and 20/25 OS. The slit-lamp examination OS was stable, but there was mild inflammation at the level of the flap interface in the mid-periphery and centrally OD. The cornea has a granular appearance with a slight undulating pattern. There is no epithelial defect, cellular clumping, focal infiltration, or anterior chamber reaction; the iris details were clearly visible. The diagnosis of DLK was made and the patient was treated with topical prednisolone acetate 1% every 2 hours while awake and was seen the following day. The examination was unchanged, but the patient felt slightly worse. The prednisolone was increased to every hour while awake. The patient was seen daily and slowly improved over the next week, and the steroid drops were slowly tapered and stopped over 3 weeks. The inflammation resolved over several weeks and the uncorrected vision improved and was equal to the left eye.

Discussion

The two biggest concerns prior to seeing this patient are infection and sterile inflammation (DLK). DLK is a sterile inflammatory reaction that typically occurs within a few days after LASIK. The exact etiology is often unknown. It most commonly occurs in a sporadic fashion but occasionally occurs in epidemics, often due to bacterial toxins resulting from contaminated sterilization equipment. It is associated with epithelial defects, both at the time of LASIK and months or years later (so-called late-onset DLK). A sterile inflammatory reaction that looks identical to DLK can also occur with other corneal surface problems such as recurrent corneal erosions and herpes simplex virus dendritic keratitis. There may be an increased incidence of DLK with use of a BSCL, although it is difficult to separate the lens as a cause from the reason the lens is being used. The differential diagnosis of both classic DLK and especially late-onset DLK also must include infection. If there is a high index of suspicion for infection, the flap needs to be lifted and the stromal bed and underside of the flap scraped for smears and cultures.

DLK is graded from 1 through 4 depending on location and severity (see Figs. 11.5–11.10 in Chapter 11). Milder forms of DLK involving only the periphery are treated with moderate-dose topical prednisolone 1% and follow-up within 2 days. More severe forms are treated with hourly steroids or even oral prednisone and patient follow-up in 1 day. For more severe forms, such as when there is a dense accumulation of white blood cells in the interface centrally, the flap may need to be lifted and the interface debris removed. A low threshold for flap lift is advisable since the inflammation can ultimately spoil the refractive result and improvement after a lift and scrape can be dramatic. Scrapings can be sent for smears and cultures since the specimen is easily accessible. Ideally, the severe form is prevented by appropriate treatment and follow-up. The main danger of DLK is that the severe inflammation causes tissue loss and scarring. The tissue loss can lead to localized central thinning and flattening, causing irregular astigmatism and poor vision. Scarring can also reduce vision.

Take-Home Points

1. Patients need to be examined carefully on the first postoperative day for signs of DLK and, if present, they should be treated with an increased frequency of topical steroids and followed closely.
2. Late-onset DLK can occur from ocular surface problems such as corneal abrasions, recurrent erosions, and HSV dendritic keratitis, but it can also be a sign of indolent flap interface infection, such as with atypical mycobacteria or fungus.

CASE 72

This 28-year-old man presents to the clinic expressing an interest in refractive surgery. He enjoys windsurfing and downhill skiing, which he cannot do in his glasses. He has not been able to wear contact lenses, because it is difficult for him to insert the lenses.

W	OD – 2.00 20/20 OS – 2.00 20/20	**Uncorrected Va** OD 20/100 OS 20/100
M	OD – 2.25 – 0.25 × 90° 20/20 OS – 2.00 – 0.25 × 90° 20/20	
C	OD – 2.25 – 0.25 × 90° 20/20 OS – 2.00 – 0.25 × 90° 20/20	
K	OD 42.00 × 90°/42.25 × 180° OS 42.00 × 90°/42.00 × 180°	
Pachymetry OD 600 μm OS 600 μm	**Topography** No evidence of keratoconus OU	**Scotopic Pupils** OD 6.0 mm OS 6.0 mm

Additional Examination

After being given the choice between traditional blade LASIK and creating the flap with the femtosecond laser, he chose the laser. At the laser center, the settings on the IntraLase were as follows:

Flap thickness: 100 μm	Raster energy: 3.5 mJ
Flap diameter: 8.7 mm	Side-cut energy: 5.0 mJ

The case was performed uneventfully. On the first postoperative visit, the patient reported hazy vision and mild foreign body sensation. The visual acuity was 20/30 in each eye. Diffuse white cell infiltration was noted in the interface throughout the entire flap. There was no clumping of inflammatory material, no thinning of the flap, and the iris details were easily seen.

The patient was started on prednisolone 1% every hour while awake and once at night. A topical antibiotic was also used four times a day. Over the next week, the inflammation subsided and the patient's UCVA improved to 20/20 in each eye.

Discussion

In this case, an important factor can be identified that may have triggered the DLK. The laser settings for the raster energy and side-cut energy were too high. More appropriate settings would be in the range of 2.6 mJ for the raster energy and 3.5 mJ for the side-cut energy. Each femtosecond laser is unique and is typically adjusted by a field engineer to optimize the settings, but it is still the surgeon's responsibility to double check the settings prior to use. The energy settings should gradually be decreased if DLK is noted postoperatively in more than one patient. If after reducing the energy the surgeon notices that there is moderate resistance to lifting the bed, the raster energy can be increased in 0.1-mJ steps until the lift is easier. The same process can be used if the surgeon notices that the side cut is incomplete. Raising the energy setting in small steps will reduce the incidence of epithelial tags but increases the chance of focal inflammation.

The use of topical steroids preoperatively, for example, prednisolone acetate three times a day for 3 days preoperatively, can help reduce the incidence of postoperative inflammation.

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Take-Home Points

1	There may be an increased risk of DLK occurring with the femtosecond laser.
2	This risk can be lessened by optimizing the energy settings on the laser and also by using preoperative topical steroids.
3	Adjustments in laser energy up or down should be done in small increments.

CASE 73

The same patient as in Case 71 develops mild to moderate DLK OD, which is treated with topical prednisolone acetate 1%. However, in contrast to Case 71, the patient does not respond as expected to the topical steroid treatment. After 1 week of prednisolone 1% every hour while awake, the vision remains 20/30 without correction and the interface inflammation has not changed. The regimen is continued and the patient is seen every 3 to 7 days over the next few weeks. Six weeks postoperatively, the uncorrected and best-corrected vision is 20/40 and diffuse interface inflammation remains. How do you proceed?

The patient is referred to a cornea specialist. On slit-lamp examination, there is diffuse cellular infiltration at the level of the LASIK interface OD. There is no epithelial defect, no distinct infiltrate, and no anterior chamber reaction. There is no fluid cleft in the interface. By Goldmann applanation centrally, TonoPen centrally and peripherally, the IOP OD is 47 mmHg. The diagnosis of pressure-induced stromal keratitis (PISK) is made. The steroid drops are rapidly tapered and several glaucoma medications are started. The patient is followed closely and over the next week the IOP returns to the mid teens and the interface inflammation decreases significantly. Over the next 3 weeks, the inflammation OD resolves completely and the glaucoma medications are all eventually discontinued. Optic nerve analysis and automated visual field testing reveal mild damage compared to the fellow eye.

Discussion

Elevated IOP after LASIK can cause a clinical appearance identical to DLK. Since DLK is typically treated with topical steroids and some patients are steroid responders, the IOP may become elevated in some patients. This can be responsible for the persistent interface inflammation. Many doctors are reluctant to check IOP after LASIK for fear of dislodging the flap. Routine pressure checks should begin 1 week postoperatively. Surgeons vary in their routine for frequency of IOP measurement after surgery. Certainly, any keratorefractive patient on topical steroids for longer than 1 to 2 weeks should have their IOP checked every visit.

Significantly elevated IOP can cause a fluid cleft in the LASIK flap interface (See Figs. 3.3 and 3.5, page 44). This fluid cleft, which can be seen on anterior segment OCT, can cause the applanation IOP measurement to be falsely very low, in the 4 to 5 mmHg range. In these cases, the applanation needs to be performed peripherally or a peripheral TonoPen or pneumotonometer measurement needs to be done.

Take-Home Points

1	Make sure to check the IOP in eyes on topical steroids and in eyes with suspected DLK.
2	Elevated IOP can cause a DLK-like picture.
3	If the IOP is very low, for example, 4 to 5 mmHg, look carefully for a fluid cleft behind the flap and recheck the IOP peripherally.

CASE 74

A 38-year-old woman underwent bilateral LASIK with the VISX STAR S4 and the Hansatome to correct high myopia (> −9.00 D OU). Refer to Case 2. The surgery was entirely uncomplicated. She was using prednisolone 1% and a topical fluoroquinolone four times daily in both eyes. On

postoperative day 1, her UCVA was 20/25+ in each eye. The external eye was white and quiet. Anterior stromal infiltrates were noted in both eyes. The infiltrate OD was near the inferior flap edge, but not in the interface (Case 74, Fig. 1). In the OS, the infiltrate was smaller and near the temporal aspect of the hinge. The anterior chamber was without cell or flare. What is the differential diagnosis? What is an appropriate plan?

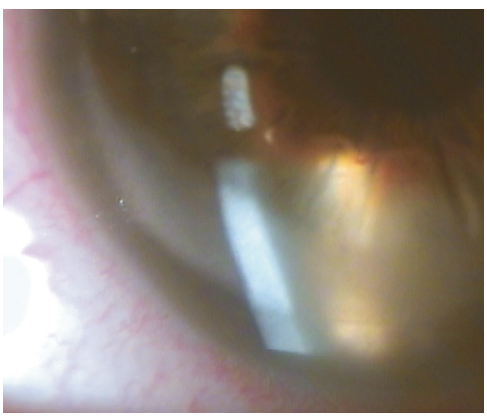
The topical steroid was increased to every hour. The patient returned the next day with increased irritation and watering in the OD. The unaided acuity was 20/25– OD and 20/15 OS. The infiltrate in the OD had increased in density, making the view of iris detail difficult. The area of inflammation extended 1.5 mm circumferentially and 1.0 mm centrally beneath the flap. A small epithelial defect was noted. There was no anterior chamber reaction. Mild peripheral flap inflammation was noted in the OS extending 1 mm from the flap edge superotemporally. What action should be taken at this point?

The flap OD was partially lifted and irrigated. The bed was gently scraped and the undersurface of the flap scraped. Topical fluoroquinolone was placed in the interface. A bandage contact lens was placed on the right eye. Oral prednisone 40 mg was added. The next day the patient felt 40% improved. The visual acuity OD was 20/40–. There was no discharge. The epithelial defect OD was nearly healed. There was a DLK-like picture extending from 10 to 2 o'clock inferiorly and about 2 mm centrally (Case 74, Fig. 2). The DLK OS looked better superiorly, but a new infiltrate was present inferotemporally. With worsening DLK OD despite adding oral prednisone and a new infiltrate OS, what action should be taken?

The decision was made to relift the flap for culture and scraping. Scrapings were plated on blood, chocolate, and Sabouraud's agar, along with Löwenstein -Jensen slant and a second agar for atypical mycobacteria. The interface was swabbed with a lightly moistened Merocel sponge. Oral prednisone was boosted to 80 mg/day and oral doxycycline 100 mg was added to reduce the risk of keratolysis.

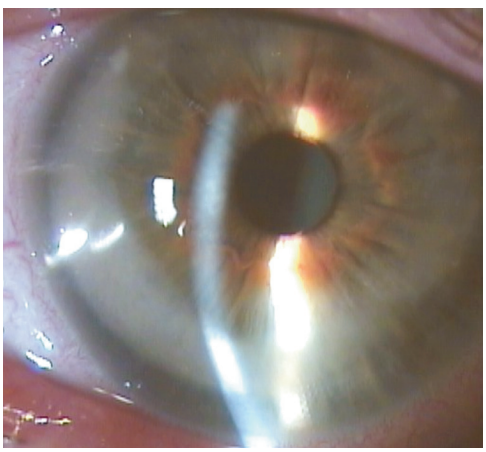
On day 3 the visual acuity was 20/100 OD and 20/20+ OS. The infiltrate OD was receding. The cultures were negative. The infiltrate OS was slowly increasing. By 6 days after LASIK surgery, the infiltrates were being replaced with stromal haze. There was 20% thinning of the stroma inferiorly with no epithelial defect. There was no anterior chamber reaction. By 2 weeks post-LASIK, the prednisone had been reduced to 40 mg and the doxycycline 50 mg twice daily. Topical steroid was reduced to four times daily.

The visual acuity was 20/20 OD with –2.50 D and 20/20– OS with –0.75 D. The prednisone was tapered off during the next week.



CASE 74, FIGURE 1

Initial presentation diagnosed as DLK. (Courtesy of Robert S. Feder, M.D.)



CASE 74, FIGURE 2

Progression of DLK-like inflammation despite treatment. (Courtesy of Robert S. Feder, M.D.)

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After 7 months the central corneal was clear in both eyes but haze and thinning was noted in the periphery of the flap OD > OS. The visual acuity was OD 20/15 with −3.25 D and OS 20/15− with −1.25 + 0.50 × 120° on cycloplegic refraction. Did the patient have regression or was the change in refraction due to the inflammation and subsequent scarring? What action should be taken now to improve her visual acuity? What are the options and what are the consequences of each option?

Discussion

This case illustrates the management of postoperative inflammation after LASIK. The cause of inflammation after surgery is often not found. No risk factors, such as lid margin disease, epithelial defect, or improper sterilization techniques, were identified at the start of the inflammation that occurred in this case. She did have a scar in the OS noted preoperatively (see Case 2) without a corresponding history or record of erosion, ulceration, or keratitis. Inflammation after LASIK often gets worse before improving despite frequent topical prednisolone and oral prednisone. The surgeon managing this case had a low threshold for relifting the flap for both culture and the removal of inflammatory material in the interface. The risk of relifting the flap is relatively low; however, the risk of continued inflammation—that is, corneal thinning and scarring—is significant. In this case the inflammation was contained in the periphery preserving the BCVA; however, thinning did occur in the periphery OD. This may have contributed to the large regression that occurred in that eye. Should retreatment be considered?

Because of the peripheral thinning, relifting the flap, especially in the OD, would be hazardous. PRK over the flap could be done provided there is sufficient RSB. Haze is more likely to occur when ablating a LASIK flap and a recurrence of inflammation could occur. Adjunctive MMC could be considered to reduce the risk of haze, but its long-term effects in this setting have not been well studied. Intacs could also be inserted to correct low myopia, but the risk of unexpected inflammation would be higher in this patient.

Because of the high preoperative myopia, the patient is able to appreciate the significant improvement in visual function despite the regression. Glasses and/or contact lenses are always an option that should be presented as a nonsurgical approach to dealing with regression.

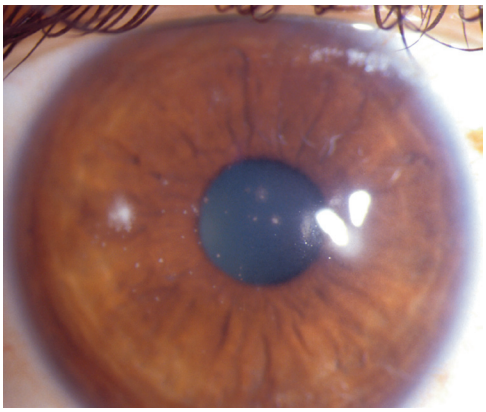
Take-Home Points

1	The etiology of postoperative inflammation is often not found, but infectious keratitis should always be considered.
2	Close observation with aggressive use of topical and oral steroids early on is important to prevent significant central progression with associated thinning and scarring.
3	A low threshold for lifting the flap for removal of inflammatory debris and possible culture is advised.

CASE 75

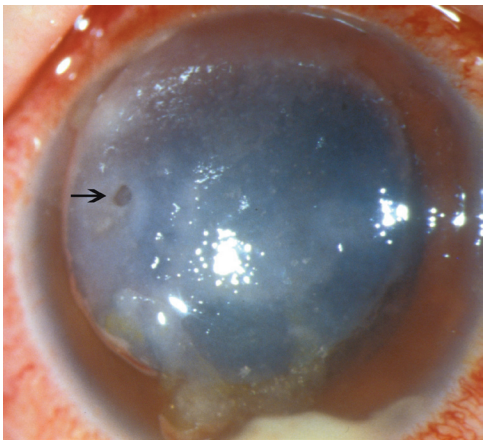
A 35-year-old woman undergoes hyperopic LASIK in order to correct a refractive error of +2.50 D in both eyes. The surgery is uncomplicated. Her initial postoperative course is unremarkable. Approximately 2 weeks after surgery the patient notes some mild light sensitivity in the right eye. On slit-lamp examination at that time the surgeon notes multiple tiny white "dots" scattered in the flap interface OD (Case 75, Fig. 1). The left cornea is clear. There is no epithelial defect, no interface or stromal inflammation, and no anterior chamber reaction. How would you proceed?

The surgeon feels these "dots" are likely reactions to interface debris and decides to reexamine the patient in 1 week. Over the next week, the patient's symptoms are unchanged. On examination, the "dots" are slightly larger than 1-week prior, but no other findings are noted. How would you proceed?



CASE 75, FIGURE 1

Multiple fine infiltrates within the flap interface. (Courtesy of Christopher J. Rapuano, M.D.)



CASE 75, FIGURE 2

Flap edema and infiltration with a focal area of necrosis (*arrow*). (Courtesy of Christopher J. Rapuano, M.D.)

The surgeon places the patient on ofloxacin 0.3% every 2 hours while awake. Fourth-generation fluoroquinolones were not available at the time. The "dots" become small infiltrates at the level of the flap interface over the next week and symptoms gradually worsen. How would you proceed?

The surgeon decides to lift the flap and scrape the stromal bed for smears and cultures. Slides are sent for Gram, Giemsa, Calcofluor white, and Ziehl-Nielsen acid-fast stains. Culture media are chocolate, blood, Sabouraud's agar, and a Löwenstein-Jensen slant. Topical fortified amikacin (50 mg/mL) and vancomycin (25 mg/mL) are placed on the stromal bed. The flap is replaced and the patient started on hourly amikacin and vancomycin around the clock, 5 minutes apart. The smears are negative. The cultures are negative initially. The infiltrates worsen significantly during the following 2 weeks. The patient develops increased pain, redness, light sensitivity, and decreased vision. On examination, the flap is diffusely infiltrated and edematous (Case 75, Fig. 2). There is a full-thickness hole in the flap in an area of epithelial erosion. There is a large hypopyon. The surgeon decides it is best to remove the flap to debulk the infection and allow better penetration of antibiotic. This procedure is performed with the operating microscope by lifting the flap and amputating the superior hinge with Vannas scissors. The flap is bisected and half is sent for histopathology and half is sent for culture. The stromal bed is again scraped for smears and cultures and to debulk the infection and inflammatory debris. At this time the original culture is determined to be atypical mycobacteria. The second stromal bed culture confirms this finding. The patient is continued on the amikacin and topical clarithromycin (10 mg/mL) is used in place of the vancomycin. The infection resolves during the next several weeks and the antibiotics are slowly tapered. The eye heals with significant central corneal scarring and a best-corrected vision of 20/400.

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Discussion

Many different pathogens have been reported to cause post-LASIK infection. Most infections early after LASIK are due to gram-positive organisms, especially staphylococcus and streptococcus. Most infections with onset after the first few weeks are due to atypical mycobacteria and less commonly to fungi. Small, white inflammatory reactions to debris in the flap interface can occur and need to be distinguished from infections. Typically, a foreign body can be identified in the center of a sterile inflammatory reaction. Additionally, there is no surrounding edema or anterior chamber reaction and they cause no symptoms. If unsure, they can be followed closely to make sure they resolve.

When an infectious infiltrate is suspected after LASIK, scrapings for smears and cultures should be performed. If the infiltrate is superficial (often associated with an epithelial defect), surface scrapings can be done with no need to lift the flap. If the infiltrate is in the interface, the flap needs to be lifted and the interface scraped (See Video 19). Multiple smears and cultures should be obtained, as described earlier. Intensive broad-spectrum antibiotics should be started in order to cover gram-positive bacteria, gram-negative bacteria, and atypical mycobacteria, until specific culture and sensitivity results are available. Currently, other medications are available for the treatment of atypical mycobacteria infections including a topical fourth-generation fluoroquinolone (gatifloxacin 0.5%, moxifloxacin 0.5%, or besifloxacin) and oral clarithromycin 500 mg bid. When a flap is severely infiltrated and/or necrotic, it is hurting more than helping, and removing it often helps the infection resolve. While infections after LASIK can be devastating, prompt attention and management can result in acceptable outcomes.

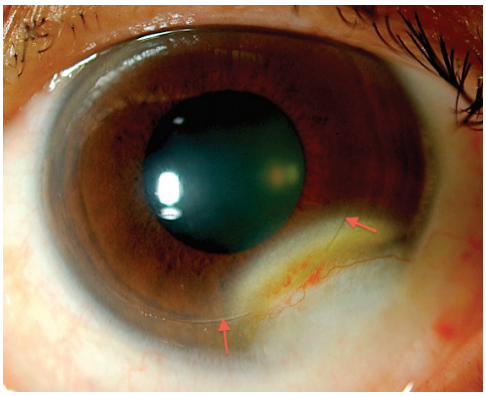
Take-Home Points

1	White "dots" in the flap interface are typically small bits of foreign material with a small sterile surrounding inflammatory reaction; however, they need to be differentiated from infectious infiltrates by history, examination, and close follow-up.
2	Suspicious infiltrates in the interface should be scraped for smears and cultures once the flap is lifted.
3	Aggressive antibiotic treatment and close follow-up is required when infection is suspected.

CASE 76

A 57-year-old lady with left limbal dermoid presented for LASIK consultation with the aim of reducing spectacle dependence for distance vision.

W	OD +3.00 + 0.25 × 180° (20/25) OS +3.00 + 0.25 × 177° (20/25) + 2.50 (J5) OU	**Uncorrected Va** OD CF 5′ OS CF 4′
M	OD +3.25 DS (20/20) OS +3.50 DS (20/20)	
C	OD +3.25 DS (20/20) OS +3.50 DS (20/25)	
K	OD 44.50 × 178/45.00 × 88° OS 43.50 × 150/44.25 × 60°	
Pachymetry OD 538 µm OS 535 µm	**Topography** OD Normal OS Missing information over 3 clock hours outside 5-mm zone inferotemporally	**Scotopic Pupils** OD 5.9 mm OS 6.2 mm



CASE 76, FIGURE 1

Limbal dermoid first day after LASIK. ***Arrows*** **indicate flap edge.** (Courtesy of Wee-Jin Heng, M.D.)

Additional Examination

The external examination revealed a white-to-white corneal diameter of 11.5 mm in the left eye. The fleshy portion of the limbal dermoid measured 1.8 mm from the limbus, while the lipid deposit was 3.3 mm from the limbus (Case 76, Fig. 1). There were no other significant ocular findings. The lens and IOP were normal.

Discussion

The key problem in this case is the presence of an ocular surface protrusion involving part of the cornea. The use of a microkeratome in this situation may be problematic as there is a higher chance of suction loss leading to irregular flap creation. Using the femtosecond laser for flap creation may reduce this risk as the downward force of the applanation plate helps to keep the suction ring in place. Moreover, in the event of a suction loss with the femtosecond laser, the laser could be stopped immediately while under direct visualization and the LASIK procedure could be aborted completely. The eye would still be relatively normal as the partial flap would not have been physically cut or lifted. On the other hand, the option of repeating the flap cutting using the same patient interface and flap parameters would still be possible.

The next problem is in deciding the size and location of the flap with the aim of avoiding the limbal dermoid both because of the potential for bleeding and the possibility that the laser may not be able to create a complete resection through the dermoid. In hyperopic LASIK, a larger corneal flap is generally preferred as most of the ablation is in the mid-periphery. As the fleshy portion of the dermoid is 1.8 mm away from the limbus, a flap that is centered on his cornea would have a radius of (11.5 mm/2) − 1.8 mm = 3.95 mm, in order to avoid the dermoid. The maximum flap diameter possible would therefore be 3.95 mm × 2 = 7.9 mm. A flap diameter of 8.5 mm was therefore chosen with an intentional 0.5 mm decentration superonasally to avoid cutting the fleshy portion of the dermoid. The femtosecond laser would be preferred for flap creation because it would allow more predictable flap diameter and flap placement. In this case, the flap margin would still fall within the lipid deposit region at the head of the dermoid but this would not pose a problem for femtosecond laser resection. The optical zone chosen was 6.0 mm and for a +3.50 D ablation, the treatment zone was 9.7 mm on the Technolas 217p excimer laser.

Surgical Plan

	OD	OS	Comments
Treatment	IntraLase + PlanoScan	IntraLase + PlanoScan	IntraLase iFS, Technolas 217p
Flap parameters	Thickness 110 µm, diameter 8.7 mm	Thickness 110 µm, diameter 8.5 mm	

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Surgical Plan (Continued)

	OD	OS	Comments
Attempted correction	+3.25 DS	+3.50 DS	
Optical zone	6.2 mm	6.0 mm	
Ablation depth	69 µm	71 µm	
RSB	538 – 110 – 69 µm = 359 µm	535 – 110 – 71 µm = 354 µm	

Take-Home Points

1. Recognize the potential problems posed by the presence of ocular surface growths (e.g., dermoids, pterygia, etc.).
2. If possible, remove them first and allow the refractive error to stabilize before proceeding with LASIK.
3. To avoid flap-related complications, consider PRK or employ the femtosecond laser for flap creation.
4. The femtosecond laser can be used to create a flap of precise diameter, depth and placement. It is invaluable in this setting.

CASE 77

A 35-year-old electrician was interested in reducing dependence on distance glasses. He has never worn contact lenses and has worn glasses since age 6. He does not make a move without his glasses on and has always felt self-conscious about the need to wear his spectacles. That said, he wouldn't care if he still had to wear them part time. He was diagnosed with type 2 diabetes 3 years ago, has never used insulin, and has no history of eye disease.

M

OD – 10.00 + 1.50 × 20° 20/20
OS – 10.50 + 2.00 × 160° 20/20
VD 8 mm OU

Uncorrected Va
CF 2′ J1 @ 4″ OU

C

OD – 10.00 + 1.50 × 30° 20/20
OS – 10.25 + 1.50 × 165° 20/20–
VD 8 mm OU

K

OD 42.00/42.50 × 20°
OS 42.00/43.00 × 160°

Pachymetry	Topography	Scotopic Pupils
OD 535 µm	No evidence of ectasia OU	OD 6.5 mm
OS 540 µm		OS 6.3 mm

Additional Examination

The dominant eye was OD. External and motility examinations were normal. The slit-lamp examination showed a peripheral cortical spoke in the left eye. The fundus examination was completely unremarkable.

Discussion

This case raises several important issues. The patient was recently diagnosed with diabetes. Four important risks come to mind when considering LASIK on a diabetic: retinal ischemia, corneal erosion with possible epithelial ingrowth or DLK, corneal neuropathy, and cataract. In this case the patient had no retinopathy, so retinal ischemia was unlikely; and with early stage disease, corneal erosion and preexisting neuropathy are less likely. PRK eliminates the risk of retinal ischemia due to elevated IOP during flap creation, but the epithelial defect may set the patient up for a slow healing surface. Cortical cataracts are common in diabetics and can be associated with glare and reduced acuity when they progress centrally. A peripheral spoke is unlikely to be a problem particularly if old records indicate a lack of progression. It is not uncommon for nuclear cataracts to develop in high myopes. Very nearsighted patients should be prepared for this possibility. In this patient's right eye, two-thirds of the refractive astigmatism is lenticular. One can tell by comparing the keratometry values to the refraction. If cataract surgery was required after LASIK surgery, there could be an astigmatic surprise because the refractive surgery is based on refraction and not the corneal astigmatism.

Is this patient a candidate for LASIK? One must determine if the cornea is steep enough and thick enough. The average keratometry readings are 42.25 D OD and 42.50 D OS, and the spherical equivalents are –9.25 OD and –9.50 OS. Remember that a conservative conversion factor used in myopic LASIK for predicting the change in post-keratorefractive corneal curvature is 0.8 (many surgeons use 0.7), which in this case would yield 7.4 D OD (9.25 × 0.8) and 7.5 D OS (9.50 × 0.8). The predicted postoperative corneal curvature would be 34.85 D OD (42.25 D – 7.4 D) and 35.00 D OS (42.50 – 7.5). These predicted postoperative corneal curvature values are at the lower limit of the acceptable range. Treatment of a large regression or undercorrection might result in unacceptable corneal flattening. The patient would need to be informed about this possible limitation to retreatment during the preoperative discussion.

Corneal thickness measured 535 µm OD and 540 µm. Using a 6.0-mm ablation zone rather than 6.5 mm on the VISX laser would conserve 3 µm/D (15 µm/D – 12 µm/D). A blend zone to 8.0 mm would add an additional 8 µm. The calculated ablation depth would be 111 + 8 µm or 119 µm OD and 114 + 8 µm or 122 µm OS. A 110-µm flap created with the femtosecond laser would leave a RSB of 306 µm OD (535 µm – 229 µm) and 308 µm OS (540 µm – 232 µm).

Treatment

	OD	OS
IntraLase flap	110 µm	110 µm
Conventional LASIK VISX	6.0-mm treatment zone and 8.0-mm blend zone	6.0-mm treatment zone and 8.0-mm blend zone
Ablation depth	119 µm	122 µm
Residual stromal depth	306 µm	308 µm

Take-Home Points

1. LASIK can be safely performed in early diabetic patients; however, risk of retinal or optic nerve ischemia, epithelial erosion, corneal neuropathic disease, and cataract development can be associated with advanced disease.
2. High myopes and diabetics may develop nuclear cataracts at a younger age. Make a note of lenticular astigmatism. Discuss implications of cataract management with the patient preoperatively.
3. In a high myope with a flatter cornea it is wise to calculate a predicted postsurgical central corneal steepness. It is preferable for the postoperative average keratometry to be ≥35 D.

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CASE 78

A 20 year-old male who wears soft contact lenses is interested in LASIK surgery.

W	OD −2.75 20/20 OS −3.25 + 0.50 × 157 20/20
M	OD −2.25 + 0.25 × 20 OS −2.75 + 0.50 × 153
C	OD −2.00 OS −2.75 + 0.50 × 53
K	OD 43.9 × 66/43.0 × 156 OS 44.0 × 127/42.8 × 37

Pachymetry	Endothelial Cell Count	Scotopic Pupils
OD 649 µm OS 635 µm	OD 3,000 cell/mm^2 OS 3,024 cell/mm^2	7.0 mm OU

Additional Examination

The dominant eye was OD.

Discussion

The presence of a thick cornea raises a concern about endothelial cell dysfunction, a contraindication for LASIK surgery. Specular microscopy enables the surgeon to confirm that the endothelial cell appearance and cell count are normal. A stable thickness measured by pachymetry in the early morning, when a dysfunctional endothelium would be maximally stressed, also indicates the endothelium is healthy. Finally, a negative family history of endothelial dystrophy or dysfunction is helpful.

The large scotopic pupils may be a risk factor for the development of nighttime glare and haloes after LASIK surgery, although the objective evidence for this is lacking. This should be reviewed with the patient during the presurgical consultation.

Treatment

	OD	OS
Technolas laser	7.0-mm OZ with a blend zone to 10 mm	7.0-mm OZ with a blend zone to 10 mm
Laser treatment	MR (sphere) × 102% Weisenthal nomogram (refer to Table 6.1) −2.29 − 0.25 × 110	MR (sphere) × 100% Weisenthal nomogram (refer to Table 6.1) −2.25 − 0.50 × 63
Laser ablation	63 µm	68 µm
Moria CB microkeratome	+1 ring/110 µm blade	+1 ring/110 µm blade
Flap thickness	106 µm	115 µm
Residual stromal bed	440 µm	437 µm

Eighteen months postoperatively, the visual acuity is 20/15 without correction. The patient does not complain of glare or haloes around lights and repeat specular microscopy shows an endothelial cell count of 3,000 cells/mm^2 in both eyes.

Take-Home Points

1. In patients with large scotopic pupils, it is important to discuss the potential of glare and haloes around lights after surgery and to use an appropriately sized optical zone. There is some controversy about the significance of pupil size and many surgeons use the largest treatment zone that anatomical constraints allow.

2	A patient with preoperative pachymetry ≥600 µm should be investigated with specular microscopy noting appearance and cell count, morning pachymetry noting significant increase in thickness, and slit-lamp examination looking for signs of endothelial dystrophy. Endothelial dysfunction is a contraindication to LASIK surgery.
3	The Moria CB microkeratome may create a thicker flap due to the increased corneal thickness preoperatively, and thus a thinner 110 blade may be more appropriate for the head. In addition, a somewhat rapid pass may prevent creating an excessively thick flap. Intraoperative pachymetry should routinely be measured to monitor flap thickness and the available stromal bed.

CASE 79

A 41 year-old construction worker expresses interest in keratorefractive surgery to relieve symptoms of "tired eyes" that seems to come on when he is reading. He sees well in the distance, but notes that the vision seems to go in and out particularly when he is tired or has had a few drinks after work. He usually does not wear glasses, but recently noted an easier time reading with a friend's reading glasses. He was once told he had a lazy eye. His general health is good, but he has had some intermittent frontal headaches over the past year.

M	OD + 1.50 20/20 J1 OS + 2.25 20/20+/– J2–	**Uncorrected Va** OD 20/20–2 J3 OS 20/40– J5
C	OD + 2.00 20/20 OS + 3.00 20/25+/–	
K	OD 46.00/46.25 × 110° OS 45.50/46.00 × 75°	
Pachymetry OD 503 µm OS 509 µm	**Topography** No ectatic disease OU	**Motility** SC 15 PD LET; 15 PD LET′ CC Flick LET

Additional Examination

The dominant eye was OD.

Discussion

This presbyopic patient's symptoms are most likely related to latent hyperopia. He appears to be slightly amblyopic OS with an accommodative left esotropia. An effort should be made to slowly adapt this patient to the full cycloplegic correction if possible. This will help assure long-term refractive stability after surgery. The corneas are thin, but the hyperopic correction will not require as deep an ablation as a myopic correction would. The VISX laser ablates a maximum of 8 µm/D of hyperopic spherical equivalent.

In this case, postoperative corneal steepness is a greater concern than the RSB thickness. The conversion factor for diopters of hyperopic refractive error to diopters of corneal power is 1 D of keratometric power/D of correction. The postoperative central steepness should not exceed 49.50 D. In this case, if the full cycloplegic refraction were selected for the treatment, the average postsurgical keratometric value would be 48.12 D OD and 48.75 D OS.

Custom treatment can be advantageous for hyperopic treatment if it results in excellent centration on the visual axis. If excimer treatment with LASIK or PRK results in the complete hyperopic correction, this patient would be expected to experience excellent stable visual acuity at distance and near with relief from both eyestrain and headache. The accommodative esotropia

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would also be expected to resolve. In summary, this case is more about relief of symptoms than about improvement of uncorrected acuity.

Take-Home Points

1	Refractive surgery in some cases can be used more to relieve symptoms of eyestrain, headache, and esotropia than to improve uncorrected acuity.
2	It is best to allow the patient to adapt to the full hyperopic correction before performing excimer ablation in order to increase the chance of long-term refractive stability.
3	Compute the predicted postoperative keratometry by adding the spherical equivalent to the average preoperative keratometry. The value should not exceed 49.50 D.

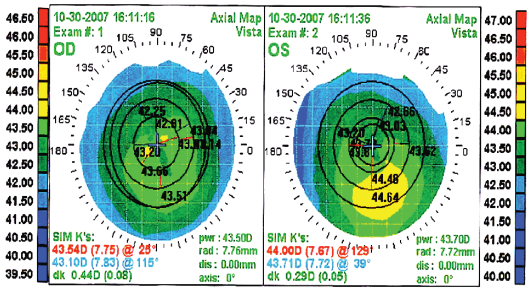
CASE 80

A 24-year-old woman presented for LASIK consultation. Her refraction remained unchanged for 2 years. She has been wearing soft contact lenses for 4 years. She has not worn lenses for a week before the examination. There was no family history of KC.

W	OD $-3.50+0.50\times20°$ 20/20– OS $-3.25+0.50\times140°$ 20/20–	**Uncorrected Va** 20/400 20/400
M	OD $-3.50+0.75\times15°$ 20/15– OS $-3.25+0.5\times145°$ 20/15–	
C	OD $-3.50+0.75\times15°$ 20/15– OS $-3.25+0.5\times140°$ 20/15–	
K	OD $44.00\times105°/45.00\times15°$ OS 44.00/44.00	
Pachymetry OD 513 µm OS 506 µm	**Topography** OD Against-the-rule astigmatism with inferior steepening OS Inferior steepening (Case 80, Fig. 1)	**Scotopic Pupils** OD 6.0 mm OS 6.0 mm

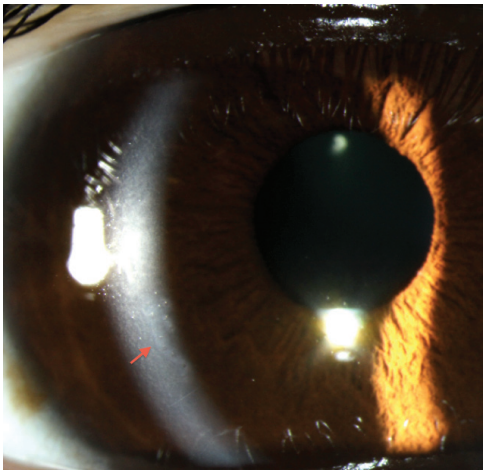
Additional Examination

The slit-lamp examination revealed endothelial vesicles in the inferior temporal cornea in OD (Case 80, Fig. 2), characteristic of posterior polymorphous dystrophy (PPMD) trait. The cornea in OS was normal. The anterior chamber was deep and quiet. The lens was clear. The IOP and



CASE 80, FIGURE 1

Corneal topography (Vista, Eyesys Vision, Houston, TX): asymmetric pattern with an inferior steepening suggesting FFKC. (Courtesy of Arie L. Marcovich, M.D.)



CASE 80, FIGURE 2

Slit-lamp photograph of OD: multiple endothelial vesicles characteristic of PPMD trait are seen in the inferior temporal cornea (*arrow*). (Courtesy of Arie L. Marcovich, M.D.)

fundus examination were normal. Specular microscopy revealed a normal looking endothelium with a density of 2,041 cells/mm^2 in OD and 2,440 cells/mm^2.

Discussion

The inferior steepening may be incorrectly attributed to contact lens warpage. However, the presence of PPMD signs in the cornea of OD may disclose a genetic linkage to KC. Although PPMD and KC involve separate layers of the cornea and differ histopathologically, both have been associated in several reports.[1,2] Mutations in the VSX1 (visual system homeobox 1) gene have been found in Canadian patients affected by either KC or PPMD.[3] An Italian study found mutations in the same gene in 7 of 80 unrelated patients (8.7%) affected by KC.[4] Therefore, in a patient with PPMD and a normal topography, a decision to perform surface ablation may be more justified to lessen the risk of ectasia. This may also be justified if there is any question regarding endothelial function. In the presence of an asymmetric topography suggestive of FFKC, particularly in a young patient, surgery may be ill-advised. Our patient was advised not to undergo keratorefractive surgery. She was examined again 4 years later, and neither the refraction nor the topography had changed.

Take-Home Points

1. Inferior steepening on a power map particularly in a young patient should raise a red flag about the possibility of KC and the risk of post-LASIK ectasia.
2. An association between PPMD and KC has been described and a genetic link is possible.
3. Patients with extensive endothelial dystrophic changes (PPMD, Fuchs' dystrophy) may have reduced endothelial function, which might impact postoperative flap adherence. Corneas that are significantly thicker in the early morning may have endothelial dysfunction.

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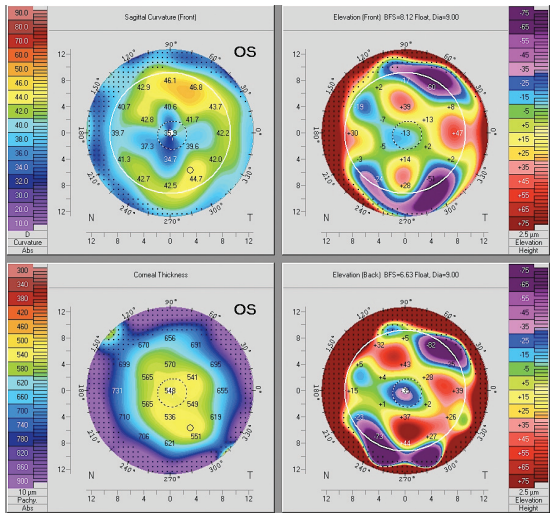
CASE 81

A 52-year-old woman who worked at the city aquarium was interested in refractive surgery. She had RK 10 years previously to correct myopia OU and now had blurred vision in both eyes. Her job required her to spend hours in scuba gear in the tropical fish tank feeding the fish and lecturing the patrons with a special underwater microphone. She was having difficulty seeing the fish and doing her job. Not surprisingly her passion was scuba diving and she couldn't see well even with a prescription mask. Custom-made contact lenses were uncomfortable and difficult to tolerate.

	OD	OS
Dominant eye		X
Vsc	20/60 J5	20/80 J8
M	+2.50 20/20–	+2.00 + 2.00 × 175° 20/25+2
C	+2.75 20/25+	+2.25 + 2.00 × 175° 20/25+2
K	38.00/39.00 × 165°	35.75/ 38.25 × 178°
Scotopic pupil	5.5 mm	5.7 mm
Pachymetry	543 µm	545 µm
Topography (Case 81, Fig. 1)	Typical post RK pattern	See below

Additional Examination

Slit-lamp examination showed eight-cut RK OU. The scars were thin and no significant epithelial plugs were seen. There was no neovascularization. The anterior chamber was deep and quiet and no cataract was seen. The IOP and fundus examination were normal.



CASE 81, FIGURE 1

Pentacam corneal topography of the left eye shows central flattening with peripheral areas of steepening. There are also focal areas of elevation in the periphery both anteriorly and posteriorly. The corneal thickness is normal. These are typical topographic findings of a post-RK patient. (Courtesy of Robert S. Feder, M.D.)

Discussion

Radial keratotomy has been largely abandoned because the procedure failed to provide postoperative refractive stability. A significant percentage of patients would develop progressive effect and become hyperopic years later. This is just such a patient. Fortunately this can be corrected with

the excimer laser using either PRK or LASIK. The full cycloplegic refraction should be corrected because the progressive RK effect may continue to move the patient in the direction of hyperopia. If LASIK is the chosen technique, one should avoid a flap-making procedure that requires significant dissection at the interface, that is, an older generation femtosecond laser. This could result in RK wound disruption. Even with a mechanical microkeratome it is possible to see "pizza pie slices." These pieces must be replaced carefully and a bandage contact lens gently inserted. The risk of epithelial ingrowth is significant in this situation. Alternatively PRK can be used, which avoids RK wound disruption. The surgeon should not be surprised by the appearance of the RK incisions once the epithelium has been removed. Epithelial debridement should be performed parallel rather than perpendicular to the incisions to avoid disruption. Some surgeons prefer to apply MMC 0.2 mg/cc for 12 to 30 seconds using a pupil protector following the excimer ablation in order to prevent postoperative haze. The mitomycin should be copiously irrigated from the cornea before placing the BSCL. A final option is clear lens exchange; however, given that myopia predated the RK, there is greater risk of retinal detachment in addition to the other risks of intraocular surgery. Corneal astigmatism OS could be corrected with a toric IOL. An LRI after RK may be less predictable.

Treatment

Hyperopic Custom PRK OU was performed with the VISX laser based on the cycloplegic refraction (See Video 8). Epithelial debridement performed with 20% alcohol. Mitomycin 0.2 mg/cc applied for 20 seconds with a pupil protector. Copious irrigation followed with a bandage contact lens insertion. Postoperatively the patient was myopic, which gradually regressed toward emmetropia over a 6-month period. At 1 year, the unaided acuity was 20/20-2 OD and 20/25+ OS. She could do her job with ease and could again enjoy diving.

Take-Home Points

1. Radial keratotomy can result in progressive effect and a hyperopic correction.
2. Hyperopia following RK can be successfully corrected with PRK and LASIK.
3. Care should be taken not to disrupt the RK incisions.
4. Some surgeons prefer to use MMC to prevent post-PRK haze.

CASE 82

A 60-year-old male who underwent bilateral sequential cataract surgery 7 months previously presented to explore the option of keratorefractive surgery to improve his unaided distance visual acuity in both eyes. The cataract surgery was uneventful; however, he was left with a residual astigmatism that decreased his UCVA for distance. He works at the Chicago Board of Trade, which requires him to read the trading boards and accurately see the prices of commodities.

W No glasses OU		**Uncorrected Va** OD 20/40 OS 20/30 –2
M OD –0.25 + 1.75 × 180° OS –0.50 + 1.00 × 18°		
C OD –0.50 + 1.75 × 180° OS –0.25 + 1.00 × 180°		
K OD 43.25 × 44.25 @ 90° OS 44.00 × 44.25 @ 180°		
Pachymetry OD 592 µm OS 600 µm	**Topography** Minimal amounts of regular astigmatism OU	**Scotopic Pupils** 5.5 mm OU

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Additional Examination

The refractive cylinder exceeded the keratometric and topographic cylinder OU. The eyelids and tear film were normal on external examination. The slit lamp evaluation show clear corneas and deep quiet anterior chambers. The posterior chamber lens implants were well-positioned OU. The right posterior capsule was clear, the left showed a minimal opacity. The fundus examination was normal OU.

Discussion

Some surgeons avoid performing LASIK with a mechanical microkeratome after cataract surgery because of the high pressure necessary with the mechanical microkeratome. However, the femtosecond laser requires less applanation pressure, therefore, femtosecond laser LASIK surgery is relatively safe. PRK or surface ablation is another acceptable option. This patient has a significant astigmatic refractive error that is much greater on refraction than on topography. Because he is pseudophakic, the lenticular component of his astigmatism should remain stable. As always the amount of cylinder to correct should be based on his refraction, not his topography. Because of his age, care should be taken to rule out dry eyes and other ocular disease. An older patient may require slightly less treatment because of the natural collagen cross-linking that occurs with age.

Surgical Plan
Ziemer femto LDV flap diameter: OD 9.0 mm OS 9.0 mm
Flap thickness: OD 110 µm OS 110 µm
Ablation depth (Allegretto): OD 28 µm OS 15 µm
Ablation zone (Allegretto): 6.5-mm optical zone with a 1.20-mm transition zone and a total ablation area of 8.9 mm OU
Original planned treatment: OD −0.50 + 1.75 × 175° OS −0.50 + 1.00 × 180°
DataLink adjusted treatment: OD −0.30 + 1.75 × 180° OS −0.30 + 1.00 × 180°
Measured RSB: OD 454 µm OS 474 µm

Take-Home Points

1	LASIK with the femtosecond laser or surface ablation are safe techniques that can be used to correct residual refractive error after cataract surgery.
2	After cataract surgery, astigmatism treatment parameters should be guided by manifest and cycloplegic refraction, not topography.
3	An older eye may react slightly differently than the usual younger refractive surgery patient. Care must be taken to look for dry eye and rule out other age-related eye disease.

CASE 83

A 23-year-old man was interested in LASIK surgery. His friends have all had refractive surgery and he was familiar with the risks and was ready to proceed. His general health was excellent. He was a second year law student looking forward to being less dependent on his glasses. He never wore contact lenses because of eye allergies and admitted to rubbing the eyes at times.

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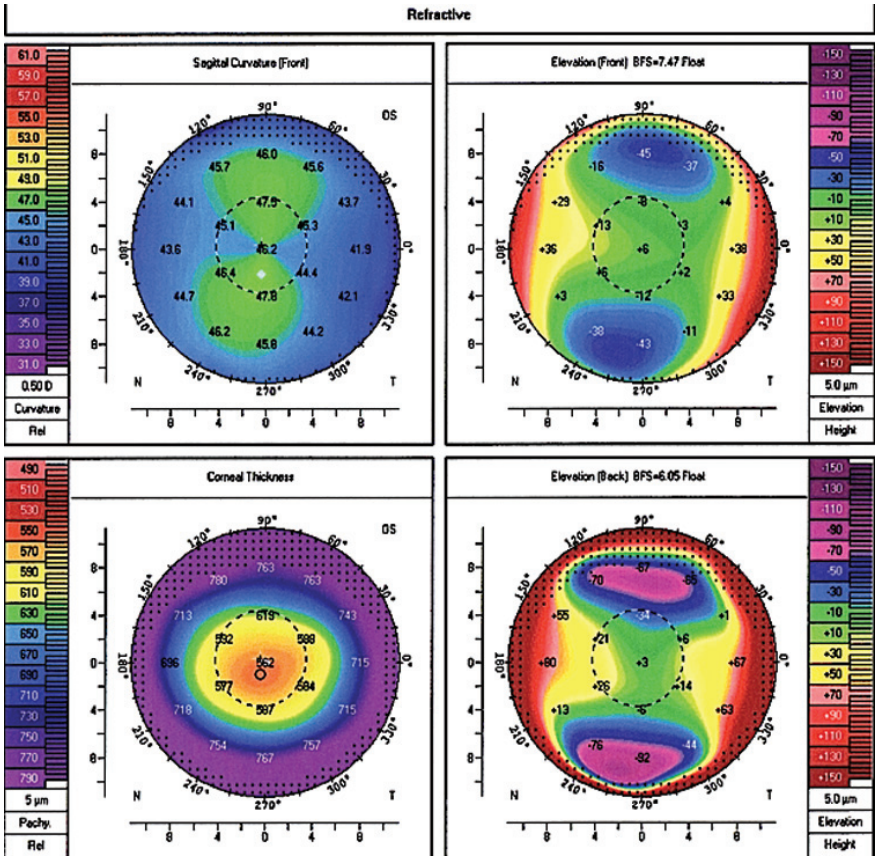
M	OD −8.25 + 2.00 × 85° OS −9.25 + 3.00 × 90°	**Uncorrected Va** CF 3' OU
C	OD −8.00 + 2.00 × 85° OS −8.75 + 3.00 × 90°	**Best corrected Va** OD 20/15 OS 20/20+/–
K	OD 45.25 × 47.50 @ 85° OS 43.75 × 46.75 @ 90°	
Pachymetry OD 560 µm OS 554 µm	**Topography** Case 83, Figs. 1 and 2	**Scotopic Pupil** 7.2 mm 7.0 mm

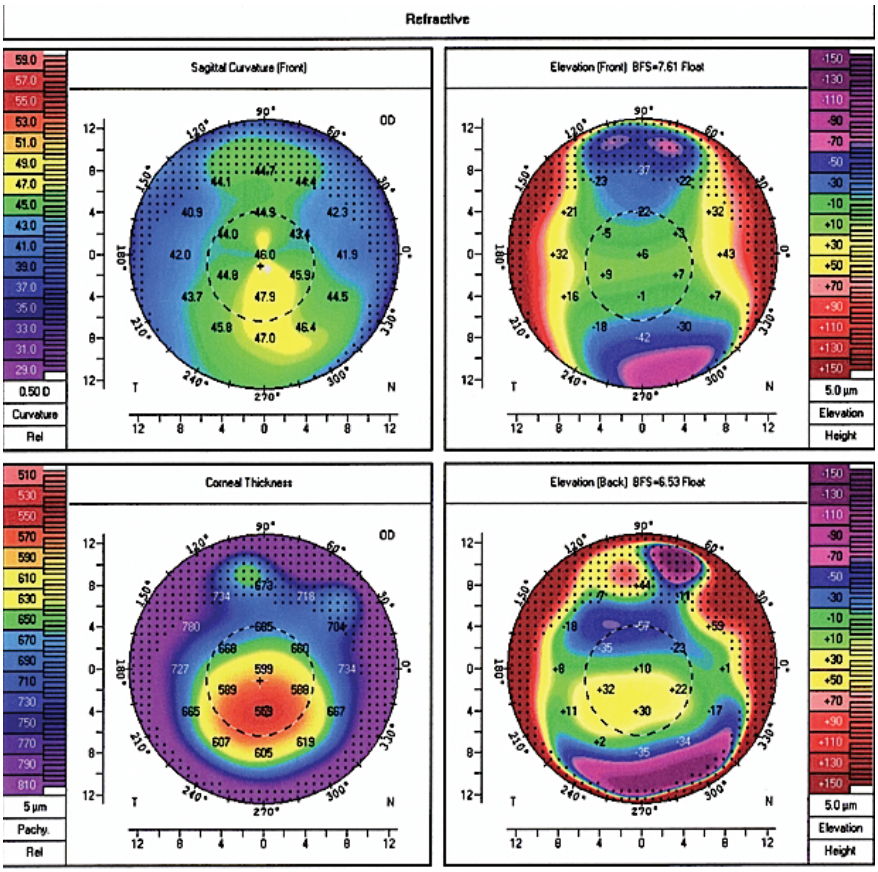
Additional Examination

The slit-lamp examination were unremarkable.



CASE 83, FIGURE 1

Corneal topography OD reveals "with-the-rule" astigmatism. The power map upper left shows a symmetrical dumbbell without skewed axes. The elevation maps upper right and lower right show no abnormal islands of elevation, and the pachymetry map lower left shows the thinnest portion of the cornea to be well centered. (Courtesy of Robert S. Feder, M.D.)



CASE 83, FIGURE 2

Corneal topography OS reveals inferior steepening with a very asymmetric dumbbell shape in the power map (*upper left*). The anterior elevation map (*upper right*) is normal; however, the posterior elevation map (*lower right*) shows an island of elevation inferiorly that is at least 32 µm above a best-fit sphere. The pachymetry map (*lower left*) shows the point of maximum thinning coincident with the point of maximum posterior elevation. There is significant asymmetry between the thickness at the inferior pupil (*dashed circle*) and the thickness at the superior pupil border. (Courtesy of Robert S. Feder, M.D.)

Discussion

In this case, there is adequate corneal thickness and adequate corneal steepness to perform LASIK surgery. The problem here is the corneal topography in the left eye, which suggests FFKC. While the patient is not a contact lens wearer, he does admit to eye rubbing and has a history of allergic eye disease. These are both commonly associated with KC. Notice that the best-corrected acuity in the left eye is not quite as crisp as the right. This patient is rather young and KC can progress until around age 40, therefore, even if left alone his condition may progress. In my opinion, this patient is not a candidate for LASIK in either eye because of the topography in the left eye. Would PRK be an option? I would avoid keratorefractive surgery in this case, but there might be some surgeons who would attempt it, perhaps with collagen cross-linking (see Chapter 12). Even if the cornea is of adequate thickness, there may be an inherent quality to his cornea that might result in ectasia after PRK. This degree of myopia would necessitate MMC be applied to prevent postoperative haze. Phakic IOL might be a better option than excimer laser ablation for this patient, however, a plan for astigmatism management would be necessary. Clear lens extraction with insertion of a toric IOL could correct distance vision, but would leave this law student chained to glasses for near unless monovision was performed and would increase his risk of retinal detachment.

Take-Home Points

1	Even when corneal thickness and steepness are adequate for a large correction such as this, an abnormal topography should cause one to reject a perspective candidate.
2	Consider risk factors for KC such as allergic eye disease and eye rubbing.
3	A young patient with FFKC may progress over time. Consider observing a patient with subtle signs of ectasia on topography.

CASE 84

A 44-year-old woman was interested in LASIK to reduce dependence on glasses and contact lenses. She worked as an interior designer and enjoyed hiking and kayaking. She was healthy and had no history of trauma or strabismus.

W	OD + 3.00 20/20– OS + 3.50 + 0.75 × 20° 20/20	**Uncorrected Va** 20/400 OU
M	OD + 3.00 + 0.50 × 170° 20/20 OS + 4.00 + 1.00 × 17° 20/20	
C	OD + 3.75 + 0.50 × 10° 20/20 OS + 4.50 + 1.00 × 20° 20/20	
K	OD 43.25/43.87 × 70° OS 43.37/43.50 × 180°	
Pachymetry OD 558 µm OS 552 µm	**Topography** Normal OU	**Scotopic Pupils** OD 6.7 mm OS 6.3 mm

Additional Examination

The patient was OD dominant, the slit lamp examination was normal, and the IOP was 14 mm Hg OU. Hyperopic LASIK was discussed and the following treatment was performed.

Treatment

	OD	OS
IntraLase flap diameter	8.9 mm	9.1
IntraLase flap depth	110 µm	110 µm
VISX CustomVue	+3.29 + 0.49 × 8°	+4.32 + 1.08 × 12°
Maximum ablation depth	41 µm	53 µm

Thirteen months later, the patient presented with a 2-month history of headaches and eyestrain.

Examination

	OD	OS
Uncorrected acuity	20/20+ J6	20/20– J3
Manifest refraction	+1.00 + 0.25 × 75° 20/20	–0.25 + 1.50 × 110° 20/20
Cycloplegic refraction	+1.50 + 0.25 × 75° 20/20	+0.25 + 1.50 × 110° 20/20
Slit-lamp examination	Flap without striae or ingrowth	Flap without striae or ingrowth

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Discussion

Regression after hyperopic excimer ablation is not uncommon. Treatment of the full cycloplegic refraction can lessen the chance of undercorrection or perceived regression as the pre-presbyopic patient ages. The patient should be given adequate time preoperatively to adapt to the cycloplegic correction. In this case retreatment was recommended because of the symptoms of headache and eyestrain rather than because of reduced unaided distance acuity. The added benefit of retreatment here is the expected improvement in the unaided near acuity. The cycloplegic refraction is an essential part of the evaluation in this case. The retreatment should ideally be for the full cycloplegic refractive error to reduce the chance of undercorrection and improve the likelihood of long-term refractive stability. It will also help support uncorrected near vision. The astigmatism in the left eye cannot be corrected with LRI because the patient is hyperopic and while LRI can correct the astigmatism, it would worsen the hyperopia.

Turn to Case 89 to find out what happened to this patient.

Take-Home Points

1. Latent refractive error should be suspected in post-LASIK patients with symptoms of headache and eyestrain even when unaided acuity is good.
2. Cycloplegic refraction is an important part of the evaluation.
3. Treating the full cycloplegic correction can increase the likelihood of refractive stability.

CASE 85

A 25-year-old woman presented for refractive surgery. She wanted to reduce her dependence on glasses and contact lenses. Her health was excellent. After an explanation of the risks and benefits of surgery, she explained that she did not expect perfection and would be satisfied if she only wore glasses for driving.

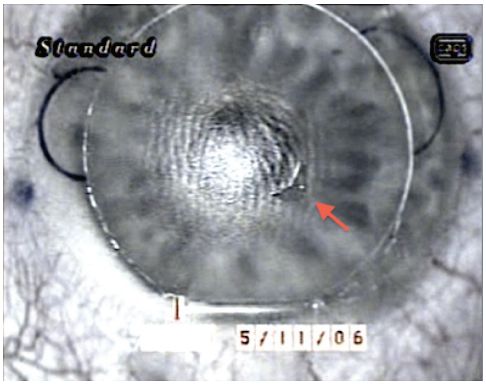
	OD	OS
Vsc	20/400	20/400
M = C	−3.00 20/20	−3.00 20/20
Pachymetry	580 µm	580 µm
Topography	Normal	Normal

Discussion

Buttonholes rarely occur when the femtosecond laser is used to create the flap. It is more likely to occur when significant debris is on the interface. Presumably, the debris can indent the cornea causing a more superficial ablation to occur in a focal area. A tiny area would likely be of little consequence, but a larger area might result in an irregular excimer ablation. Whenever a buttonhole is suspected, the flap should be inspected to be certain it is not full thickness. Replacing the flap and aborting the excimer treatment is always a safe option. Haze is more likely when ablating a flap and many surgeons will choose to reduce this risk with MMC.

Treatment

After a thorough discussion of keratorefractive procedures, the patient opted for LASIK surgery. The IntraLase was used to create a 110 µm flap OD. A similar flap was attempted OS; however, there was a bean-shaped spot of debris on the interface glass of the docking cone noted while the femtosecond laser ablation was being performed. While the raster pattern progressed, a dark area was noted in



CASE 85, FIGURE 1

Femtosecond laser flap with a stromal bed irregularity (arrow) due to a partial thickness buttonhole. (Courtesy of Robert S. Feder, M.D.)

the area of debris. The side cut was completed. The flap was lifted without difficulty; however, a bean-shaped smooth area of elevation was noted on the stromal bed (see Case 85, Fig. 1). The flap was carefully inspected but no hole was seen. It was presumed that the buttonhole was partial thickness and the smooth area was likely to be a small area of Bowman's layer rather than epithelium. Given the irregularity of the stromal bed, the decision was made to replace the flap and abort the excimer laser ablation. Three months later, PRK with a 20-second mitomycin 0.2 mg/cc application was performed. The sphere was reduced by 10% to reduce the chance of overcorrection.

Take-Home Points

1. The interface lens on the IntraLase cone should be cleaned with compressed air prior to docking to reduce the risk of an abnormal stromal bed.
2. Buttonholes rarely occur with the femtosecond laser.
3. Excimer ablation should be aborted if the stromal bed within the center of the treatment zone is irregular.

CASE 86

A 61-year-old female presented with decreased vision and glare bilaterally, having undergone uncomplicated myopic LASIK surgery in January 2005.

Current Examination	OD	OS
UCVA	20/200	20/200
BSCVA	20/50	20/50
Manifest refraction	+1.50 + 0.75 × 160°	+1.50 + 0.75 × 42°
Slit-lamp examination	3+ cortical cataract	3+ cortical cataract

The right eye was dominant and the remainder of the ocular examination was normal.

The following pre-LASIK patient data was available:

Pre-LASIK Examination	OD	OS
Manifest refraction	−2.25 + 0.25 × 160° (SE −2.12)	−3.00
Keratometry	44.94/45.42 (45.18)	44.94/45.30 (45.12)
Excimer laser treatment	−1.86 − 0.25 × 70°	−2.73
UCVA 4 mo post LASIK	20/20	20/20
Manifest refraction 4 mo post	plano	plano

16

After a discussion of the risks, including the challenges involved in IOL power selection due to previous refractive surgery and the possible need for refractive enhancement, the patient opted to proceed with cataract surgery. The patient wanted to minimize the need for glasses postoperatively and so the discussion also included risks and benefits of multifocal versus accommodative lenses. Given the patient's favorable past experience with monovision, modified monovision using monofocal implants targeting emmetropia in the dominant eye and −1.50 in the nondominant eye was chosen.

Discussion

There are many methods used to calculate the IOL power after previous keratorefractive surgery (see Chapter 14). The clinical history method is a common method often used when one has access to patient data from the previous refractive surgery. In the clinical history method, the difference in pre- and post-LASIK (or PRK) spherical equivalent (at the corneal plane) is subtracted from the average pre-LASIK keratometry value. The corneal plane measurements are determined by compensating for vertex distance. This becomes important when high myopia has been treated. Take care that the post-LASIK spherical equivalent is chosen prior to cataract development to avoid a value corrupted by lens-induced myopia. The modified keratometry value is then used for biometric IOL calculation. Using measured post-LASIK keratometry values for biometry is incorrect and will result in the selection of an underpowered IOL and an unhappy patient.

In this case, the average preop *K* was 45.12 D OS and the difference in pre- and post-LASIK spherical equivalent is 3.00 D. The effective keratometry value would be 42.12 D. The desired postop refraction is −1.50, which requires an IOL power of 24.5 D using the SRK/T and Holladay 1 formulas. It is essential to check the results with several methods to provide the most accurate IOL power. This is discussed more fully in Chapter 14. In general, it is best to err on the myopic side in order to avoid a hyperopic surprise.

Take-Home Points

1	Time spent explaining the challenges and opportunities that surround IOL selection after keratorefractive surgery is time well spent. Make the patient a partner in the decision-making process.
2	If the patient has a desire for monovision, do the near eye first; it provides a greater latitude for inaccuracy.
3	In determining change in refractive power for IOL calculation, choose an examination in which the refractive power has stabilized and avoid examinations in which lens-induced myopia might be present.
4	Always calculate the lens power using different methods and formulas keeping in mind a common sense approach to the impact of the refractive surgery on the IOL power. Look for and follow the trends among formulaic results. The ASCRS website for IOL calculation post-keratorefractive surgery is a valuable asset (http://iolcalc.org/).

CASE 87

A 24-year-old woman presented for refractive surgery in 2001; the medical history was unremarkable.

Preoperative examination (for illustration purposes only the findings of the right eye are presented)

Examination right eye:

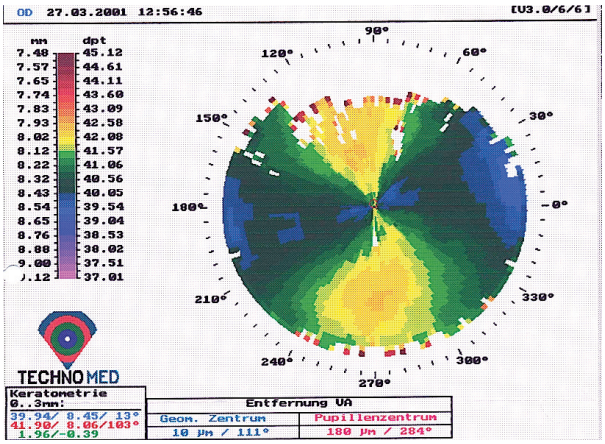
UCVA: 20/200 (0.1)

BCVA: 20/20 (1.0)

Manifest and cycloplegic refraction: −5.00 +1.25 × 140°

Pachymetry: 550 µm

Topography: regular astigmatism (Case 87, Fig. 1)



CASE 87, FIGURE 1

Preoperative corneal power map OD shows 2 D of regular astigmatism at 103°. (Courtesy of Frederik Raiskup, M.D., Gregor Wollensak, M.D., and Eberhardt Spoerl, PhD.)

Initial procedure 2001: Lasik OD

Hansatome ring: 9.5 mm

Plate: 160 µm

Hinge: 6.1 mm

Optical zone: 6.5 mm

Ablation per pulse: 0.194 µm

Procedure completed successfully

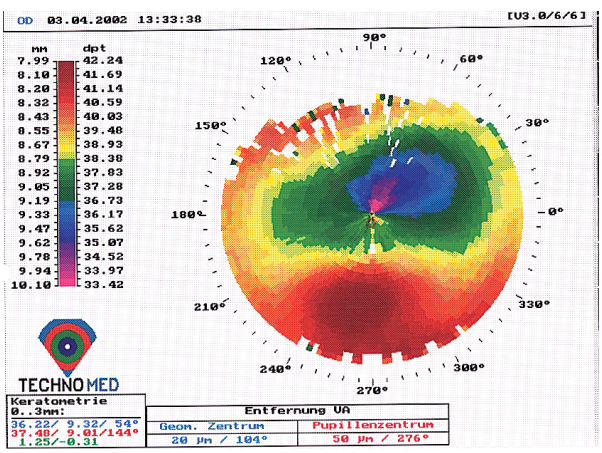
2 months after LASIK OD

UCVA OD: 20/30 (0.7)

BCVA OD: 20/25 (0.9)

Cycloplegic refraction OD: −1.75 +1.25 × 140

Topography OD: postoperative ectasia (Case 87, Fig. 2)



CASE 87, FIGURE 2

Two months post-LASIK OD; power map shows 1.36 D of astigmatism with central flattening and inferior steepening. (Courtesy of Frederik Raiskup, et al.)

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10 months after LASIK OD

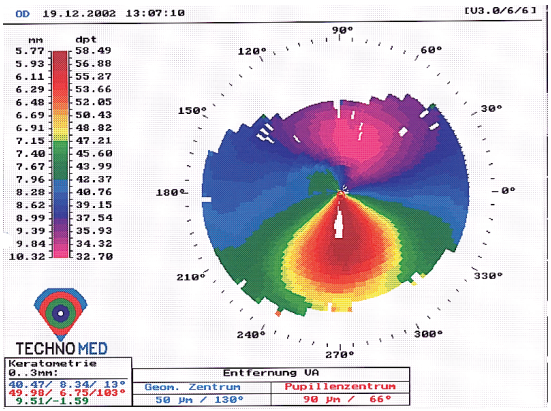
UCVA OD: 20/40 (0.5)

BCVA OD: 20/20-3 (0.9)

Cycloplegic refraction OD: −2.00 + 2.50 × 160°

Topography OD: rapid progression of postoperative ectasia (Case 87, Fig. 3)

Patient considered for collagen cross-linking.



CASE 87, FIGURE 3

Ten months following LASIK OD; power map shows marked inferior steepening with superior flattening. (Courtesy of Frederik Raiskup, et al.)

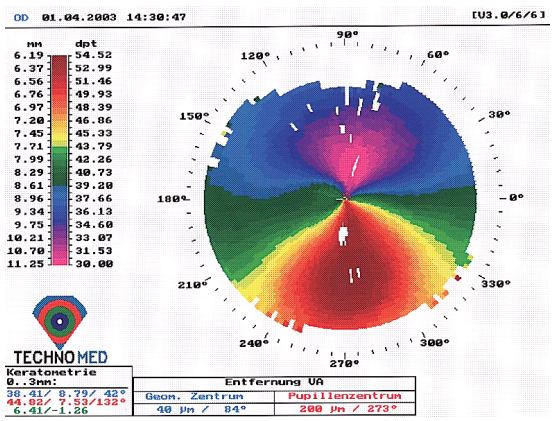
4 months following collagen cross-linking (CXL)

UCVA OD: 20/30 (0.6)

BCVA OD: 20/25 (0.8)

Manifest refraction OD: −1.00 + 1.50 × 155°

Topography OD: regression of K_{max} at the apex of the cone (Case 87, Fig. 4)



CASE 87, FIGURE 4

Four months after collagen cross-linking OD there is regression of the K_{max} at the cone apex. (Courtesy of Frederik Raiskup, et al.)

See Case 88 for discussion CXL and take-home points.

CASE 88

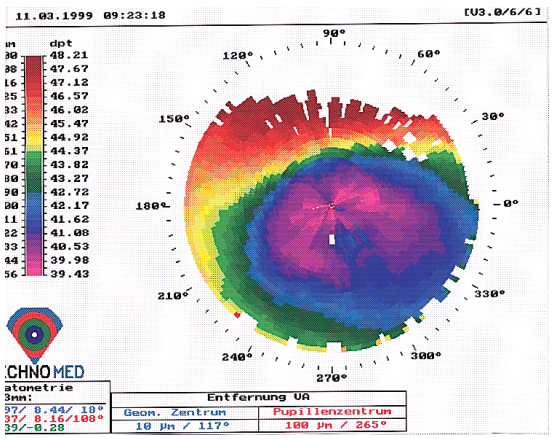
A 29-year-old woman with atopic dermatitis, asthma, and multiple allergies presented with severe giant papillary conjunctivitis for cryotherapy of the tarsal conjunctiva OU. She had undergone bilateral LASIK 3 years previously. For illustration purposes the examination data is presented for the left eye only.

3 years post-LASIK

UCVA OS 20/50 (0.4)

BCVA OS 20/30 (0.6)

Topography OS showed corneal irregularities (Case 88, Fig. 1).



CASE 88, FIGURE 1

Corneal power map OS shows central flattening with superior steepening. (Courtesy of Frederik Raiskup, et al.)

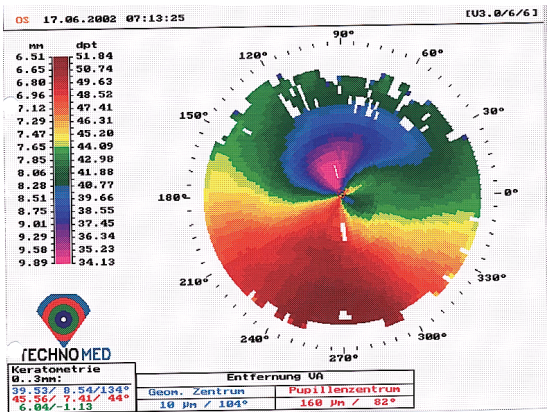
The conjunctival inflammation regressed after the cryotherapy procedure, but the patient remained dependent on topical and systemic steroid and antihistamine therapy. Three years later the same patient presented with deterioration of vision OS. She was contact lens intolerant due to conjunctival disease.

6 years post-LASIK OS

UCVA: 20/200

BCVA: no improvement

Corneal topography: shows marked irregularity with inferior steepening and superior flattening (Case 88, Fig. 2).



CASE 88, FIGURE 2

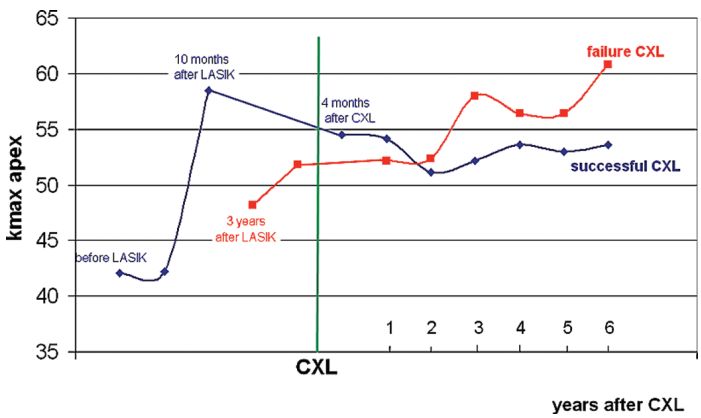
Six years following LASIK OS, there is continued progression of inferior steepening due to ectasia. (Courtesy of Frederik Raiskup, et al.)

Because of prominent corneal ectasia OS CXL was performed in an attempt to stabilize the corneal contour, however ectasia continued to progress.

Discussion

Cases 87 and 88 are two illustrations of CXL for post LASIK corneal ectasia. Case 88, Figure 3 shows a plot of the maximum keratometric reading (Kmax) from corneal topography for both cases before and after CXL. Clearly CXL is not successful in all cases as illustrated here. In case 88 the patient's 2 pregnancies, severe steroid-dependent atopic dermatitis, bronchial asthma, and papillary conjunctivitis may also have contributed to unstable corneal biomechanics[1] which resulted in progression of ectasia despite collagen cross-linking.

Preoperative ectasia risk assessment and post LASIK ectasia are discussed in Chapters 1, 2, and 11. PRK and thin flap LASIK using the femtosecond laser may reduce this risk. CXL is a reasonably safe procedure that has the potential to stabilize the ectatic cornea after keratorefractive surgery provided the cornea is not too thin (See Chapter 12). Prophylactic cross-linking treatment right after LASIK using accelerated cross-linking with a shorter irradiation time and a higher than standard dose may be the future technology in LASIK patients who have significant ectasia risk factors.



CASE 88, FIGURE 3

K_{max} apex before and after corneal collagen cross-linking in Case 87 (*blue*) and Case 88 (*red*).

Take-Home Points

1. Stabilization of post-LASIK ectasia can be achieved using CXL, however patient expectations must be realistic. CXL will not always be successful and will not restore the uncorrected acuity to the pre-ectasia level.
2. Careful evaluation of risk factors preoperatively can help reduce the risk of post LASIK ectasia. This condition is more challenging to treat than to prevent.

Reference

1. Spoerl E, Zubaty V, Terai N, Pillunat LE, Raiskup F. Influence of high-dose cortisol on the biomechanics of incubated porcine corneal strips. *J Refract Surg*. 2009;25:S794–S798.

CASE 89

A 45-year-old woman presented with a 2-month history of headaches and eyestrain 13 months after LASIK surgery (see Case 84).

M	OD +1.00 + 0.25 × 75° OS–0.25 + 1.50 × 110°	**Uncorrected Va** OD 20/20+ J6 OS 20/20– J3
C	OD +1.50 + 0.25 × 75°– OS +0.25 + 1.50 × 110°	
Slit-lamp examination	OD Flap without striae or ingrowth OS Flap without striae or ingrowth	

The risks and benefits of retreatment were explained to the patient and retreatment by means of flap lift and excimer ablation of the full cycloplegic refraction was planned.

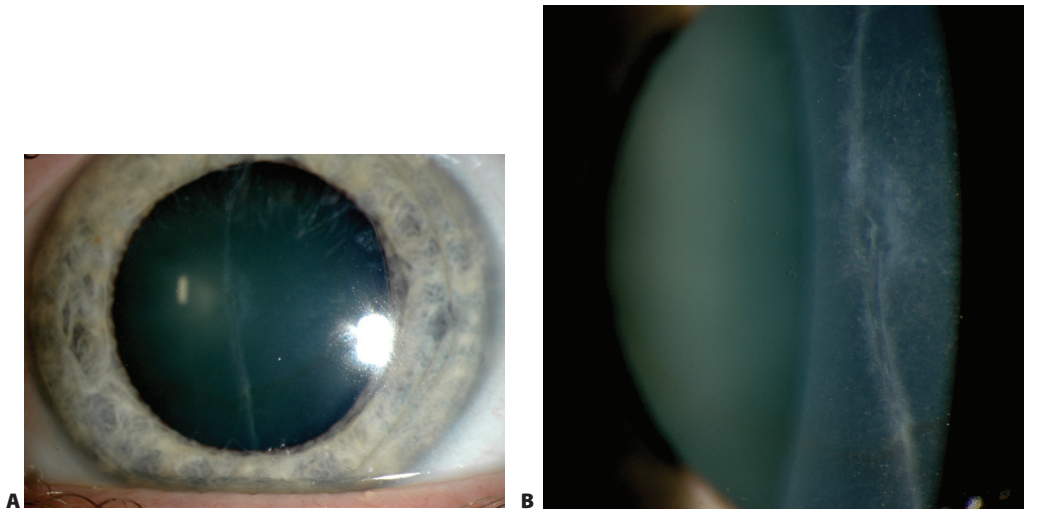
The OD was treated uneventfully, but during the flap dissection OS, the lamellar dissector inadvertently pierced the mid-portion of the flap near the hinge. The surgeon was unaware of this, and as the dissection was carried inferiorly, the flap was bisected roughly in half with the hinge still attached (See Video 16).

The flap portion that had been lifted was replaced and the excimer ablation OS was aborted. A bandage contact lens was place-d and the patient was treated with topical steroid and fluoroquinolone four times daily for 1 week, at which time the lens was removed.

Epithelial ingrowth was initially noted centrally, but over time spontaneous involution occurred. The right eye healed without event. The patient complained of blurred vision and glare OS. The decision was made to wait for refractive stability to occur before intervening.

Eight months post retreatment, the refraction was stable.

M	OD –0.25 + 0.50 × 175° 20/15– OS –1.00 + 1.00 × 60° 20/50	**Uncorrected Va** OD 20/20 OS 20/60
C	OD Plano + 0.50 × 175° 20/15– OS +1.50 + 1.25 × 60° 20/40	
Slit-lamp examination	OD No flap striae or ingrowth. OS See Case 89, Figs. 1A and B	



CASE 89, FIGURE 1

A: Well-healed vertical scar through the center of the LASIK flap. **B:** High magnification slit view of a well-healed flap laceration prior to PRK. (Courtesy of Michael Rosenberg, M.D.)

PRK was performed OS 10 months after the flap laceration. The full cycloplegic correction was treated, after which MMC 0.2 mg/cc was applied for 30 seconds.

One year following PRK, the patient was symptom-free, the unaided acuity OS was 20/30, and the manifest refraction was −0.75 with BCVA 20/25+. The scar was significantly fainter.

Take-Home Points

1	The ability to easily retreat by flap relift is a great advantage of LASIK, but care should be taken in lifting a flap to avoid damage.
2	In the rare case of flap tear or laceration, replace the fragments and insert a bandage contact lens. Do not retreat until the corneal contour is stable, and consider using MMC to reduce the chance of post-PRK haze.
3	Proper management of a LASIK complication can, in most cases, increase the chances of an improved vision outcome.

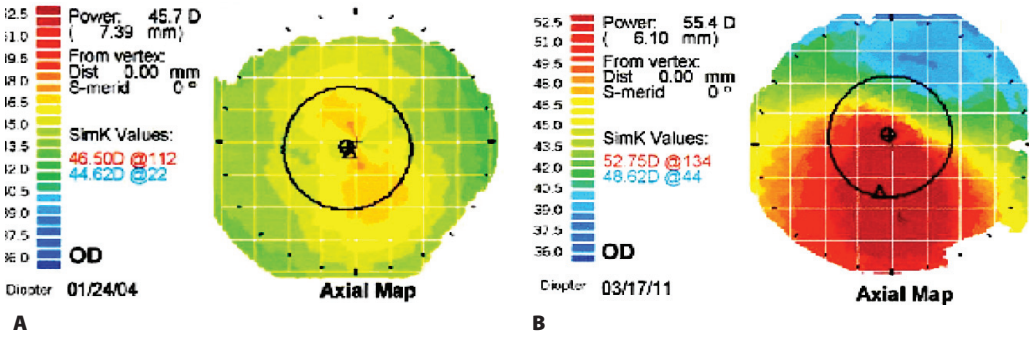
CASE 90

A 48-year-old woman was referred for a progressive decrease in visual acuity in her OD after refractive surgery. She had uncomplicated LASIK treatment for myopia in 2004 to correct −4.75 D in her OD and −3.75 D in OS eye. The patient had no family history of keratoconus and denied eye rubbing. Her LASIK flap was made with a microkeratome and the attempted flap thickness was 130 µm.

Additional Information

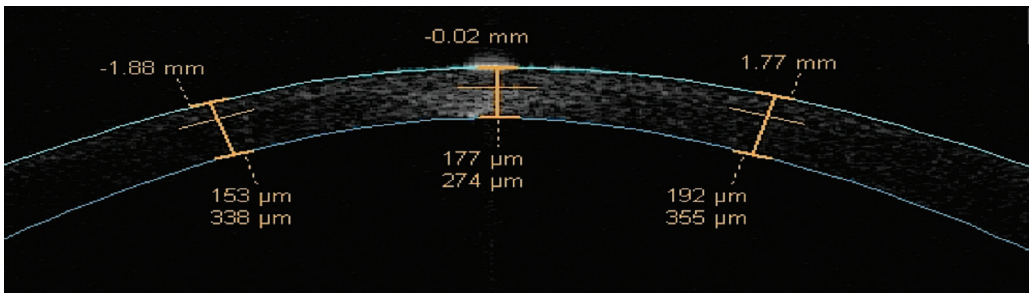
Analysis of ectasia risk factors suggested the low risk. Normal topography (Case 90, Fig.1A); estimated RSB >300 µm; age >30 years; central corneal thickness >510 µm; correction for low myopia.

In 2011 her refraction was −12.00 + 9.00 × 130° and BCVA was 20/50−1. Corneal topography demonstrated a pattern consistent with ectasia in the right eye, that is, prominent inferior steepening (Case 90, Fig. 1B). Central corneal ultrasonic pachymetry was 463 µm in the right eye and 536 µm in the left eye. Optical coherence tomography (OCT) revealed a postoperative flap thickness of 177 µm, resulting in a residual corneal stromal bed (RSB) of 274 µm in the right eye (Case 90, Fig. 2).



CASE 90, FIGURE 1

A: Preoperative power map OD (2004) shows regular astigmatism. B: Postoperative power map OD shows marked inferior steepening with superior flattening consistent with post-LASIK ectasia. (Courtesy of Alexandre Marcon, M.D., Marcony R. Santhiago, M.D. and Marcelo Netto, M.D.)



CASE 90, FIGURE 2

Post-LASIK OCT shows LASIK flap 177 µm, much thicker than intended. (Courtesy of Alexandre Marcon, M.D., Marcony R. Santhiago, M.D. and Marcelo Netto, M.D.)

Timeline	Manifest Refraction OD	BCVA OD
2004 preop	−4.75 D	20/20
2004 1 mo postop	−1.00 + 0.50 × 155°	20/20
2007	−4.00 + 2.00 × 55°	20/30
2011	−12.00 D + 9.00 × 130°	20/50
Preoperative Pachymetry 568 µm OD 570 µm OS	**Preoperative Topography** Regular with-the-rule astigmatism	**No history of keratoconus**

Discussion

The importance of this case is that post LASIK ectasia rarely can occur in the absence of apparent risk factors.[1–4] In this case, we highlight the role of thick flaps as a cause of corneal ectasia after LASIK in otherwise normal eyes.

It has been well documented that microkeratomes may create thicker-than-expected flaps, and since the anterior lamellar flap is thought to not contribute significantly to postoperative corneal tensile strength, we hypothesize that the flap cut was sufficiently deep to weaken the cornea, making it susceptible to ectasia.[5] Previous studies have demonstrated that cohesive tensile strength is inversely correlated with the depth of treatment in the stroma, and that the anterior

40% of the corneal stroma has significantly greater cohesive tensile strength than the posterior 60% of the corneal stroma. Thus, it could be that the depth of a LASIK flap cut relative to total corneal thickness is a better predictor of ectasia risk than absolute flap thickness.[6,7]

The posterior cornea described in this case was further weakened by removal of stroma by the excimer laser ablation. The excimer laser ablation reduces not only the quantity of the remaining load-bearing corneal tissue but also the quality of the residual load-bearing corneal tissue (measured as reduced cohesive tensile strength), especially when the laser ablation extends beneath the anterior 40% of corneal stroma. The OCT analysis (Case 90, Fig. 3) revealed a flap thickness of 177 µm and an actual RSB of 274 µm (48% of the original central corneal thickness). The original central corneal thickness before surgery was 568 µm. Flap thickness + tissue ablation = 52% of the anterior stroma, which is more than 40% of the original central corneal thickness.[6,7]

The estimate of flap thickness can be a major source of imprecision in RSB prediction. The probability of leaving an RSB significantly thinner than expected is largely a function of the standard deviation of flap thickness and the bias of actual versus intended flap thickness.[8,9] Flaps created by femtosecond lasers have been shown to be more accurate and precise, and make LASIK a more predictable surgery compared to LASIK performed with microkeratomes.[10]

Take-Home Points

1	Corneal topography remains a most trusted tool to use in the screening of a keratorefractive surgery candidate.
2	In cases of post-LASIK ectasia, OCT can be helpful to measure the actual flap thickness.
3	There may be other, as yet unidentified, risk factors for ectasia. A possible cause may include inherent preoperative corneal biomechanical characteristics that lead to varying responses to LASIK flap creation. Different eyes may have different potential for ectasia dependent on these unique intrinsic biomechanical thresholds.

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4. Binder PS. Analysis of ectasia after laser in situ keratomileusis: risk factors. *J Cataract Refract Surg*. 2007;33:1530–1538.
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10. Von Jagow B, Kohnen T. Corneal architecture of femtosecond laser and microkeratome flaps imaged by anterior segment optical coherence tomography. *J Cataract Refract Surg*. 2009;35:35–41.

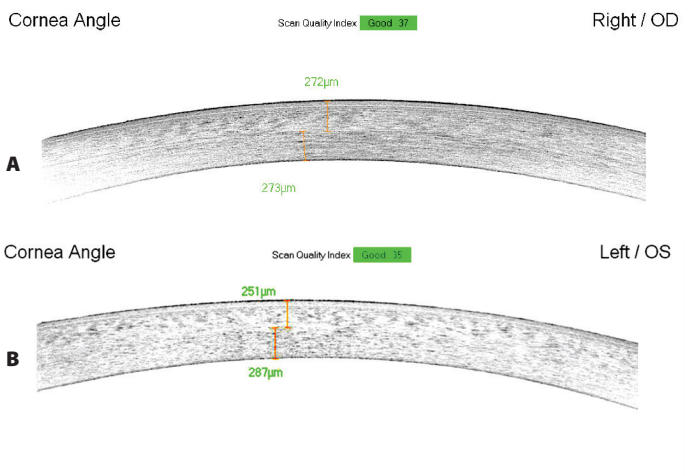
CASE 91

A 43-year-old woman complains of decreased vision at distance and near, not fully corrected with her glasses. She has a past ocular history of LASIK surgery OU in 2003.

Pre-LASIK Examination	OD	OS
Manifest refraction	−3.00 + 0.75 × 130° 20/20	−2.75 + 0.75 × 55° 20/20
Cycloplegic refraction (CR)	−2.75 + 0.75 × 129°	−2.50 + 0.50 × 55°
Keratometry	44.37 D/45.62 D × 114°	45.12 D/46.12 D × 72°
Pachymetry	532 µm	542 µm
Scotopic pupil	5.5 mm	5.0 mm
Corneal topography	Normal	Normal

LASIK Treatment	OD	OS
Moria CB microkeratome	2+ suction ring; 160 µm	2+ suction ring; 160 µm
VISX laser based on CR	6.0 zone; Ablation depth 28 µm	6.0 zone; Ablation depth 27 µm
Intraoperative pachymetry	Unavailable	Unavailable
6 wk postop acuity sc	20/25	20/25
3 yr postop sc	20/60	20/50
Cycloplegic refraction	−3.75 + 3.00 × 164° 20/20	−1.75 + 1.50 × 15° 20/20
7yr post op sc	Counting Fingers	Counting Fingers
7yr Manifest refraction	−4.50 + 4.00 × 10° 20/25	−8.50 + 3.75 × 172° 20/30

In this patient with no known risk factors for an unpredictable response to LASIK surgery, what factors could be contributing to the suboptimal results and what steps can be taken to treat the patient at this point? (see Case 91, Fig. 1A and 1B)



CASE 91, FIGURE 1

A: OCT OD shows a flap thickness of 272 µm and remaining corneal bed of 273 µm. B: OCT OS shows the flap to be 251 µm with RSB of 287 µm. (Courtesy of Robert W. Weisenthal, M.D.)

The options for the patient at this point include contact lens fitting to correct the corneal irregularity and refractive error, collagen cross-linking to attempt to stabilize the progressive ectasia perhaps in combination with Intacs to provide flattening of the cornea and center the inferiorly displaced cone, and as a last resort, deep anterior lamellar keratoplasty or PK.

Take-Home Points

1	Flap thickness with the Moria CB microkeratome can vary significantly depending on the speed of the pass, e.g. slow pass results in a thicker flap.
2	This case highlights the value in obtaining intraoperative pachymetry measurements, enabling you to modify your treatment plan if you find that the flap is abnormally thick.
3	Corneal ectasia is uncommon but should be in the differential diagnosis of patients who present with myopic regression. Corneal topography and OCT preoperatively are essential tools prior to considering enhancement surgery.
4	Fortunately there are now options for patients with ectasia to stabilize the process and hopefully improve the vision.

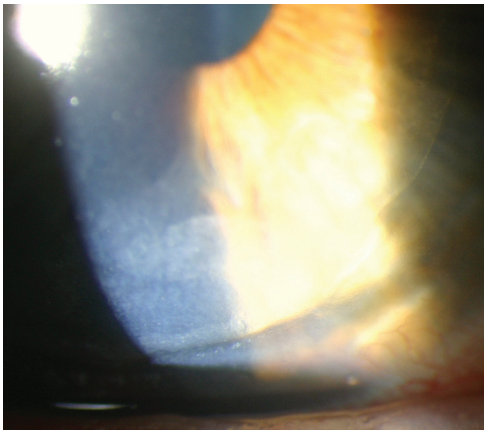
CASE 92

A 59-year-old male s/p LASIK surgery with a mechanical microkeratome 5 years prior presents with decreased vision OD. The risks and benefits of enhancement surgery OD were explained. Further, it was mentioned that if it were possible to lift the flap then the hyperopic enhancement would be performed on the bed, otherwise a surface ablation would be performed.

	OD	OS
BCVA	20/50	20/20
Manifest refraction	+0.25 + 1.50 × 165°	Plano + 0.50 × 17°
Cycloplegic refraction	+0.75 + 1.00 × 170°	Plano + 0.75 × 17°
Slit-lamp examination	Flap without striae or ingrowth	Flap without striae or ingrowth

The surgery went very well with a straightforward flap lift and laser treatment performed without complication. A bandage lens was left in place for 24 hours.

On the first postoperative day the patient felt comfortable. The UCVA was 20/60 OD. There was stippling of the corneal epithelium and significant edema presumed secondary to contact lens induced hypoxia. The bandage lens was removed.



CASE 92, FIGURE 1

Epithelial ingrowth beneath the LASIK flap with flap erosion. (Courtesy of Robert W. Weisenthal, M.D.)

CASE 92, FIGURE 2

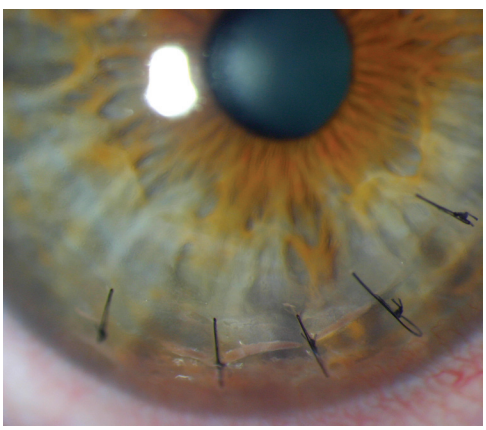
OCT reveals anterior flap displacement with a hyper-reflective area beneath the flap corresponding to the area of epithelial ingrowth. (Courtesy of Robert W. Weisenthal, M.D.)

Four days postoperatively the UCVA had improved to 20/30 OD with persistent surface irregularity inferiorly. Five days later the visual acuity was 20/60 and epithelial ingrowth was noted inferiorly from 4 to 8 o'clock extending 2.5 mm under the edge of the flap (Case 92, Fig. 1).

An OCT demonstrated a flap shift as well as a hyper-reflective area beneath the flap corresponding to the area of epithelial ingrowth (Case 92, Fig. 2). Corneal topography showed 4.17 D of induced astigmatism.

Due to the extent of the epithelial ingrowth and the impact on the refractive error, the patient was informed that it was necessary to relift the flap, remove the epithelial ingrowth, and treat the flap edge with tissue glue or suture to secure the position and seal the flap edge.

Three days following the procedure the visual acuity was 20/20 without correction with the sutures in place (Case 92, Fig. 3) (See Video 17).



CASE 92, FIGURE 3

Epithelium removed from beneath the flap and the edge sutured to reduce the risk of recurrence. (Courtesy of Robert W. Weisenthal, M.D.)

Take-Home Points

1	When contemplating LASIK enhancement one must consider the risk of epithelial ingrowth, which leads to flap erosion, induced astigmatism, and reduced vision. Surface PRK may have been a safer option, especially since the initial procedure was performed years ago.
2	The majority of cases of epithelial ingrowth can be managed without surgery. If the ingrowth extends ≤1 mm beneath the flap edge, is stable in radial or circumferential dimension, is not inducing refractive error, and is not associated with significant flap erosion, the patient can safely be monitored.
3	Rapidly progressive ingrowth with or without flap melting or induced significant refractive effect should be promptly treated surgically.
4	Epithelial tissue appears smooth and glistening on the stromal surface and can easily be removed. Both the bed and the flap should be checked for evidence of epithelium. Use of alcohol or other chemical agents are rarely needed.
5	Suturing or gluing the flap edge may reduce the chance of recurrent ingrowth.

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CASE 93

A 28-year-old soccer player presented for LASIK in both his eyes. He was a successful soft contact lens wearer, but desired freedom from contact lenses and glasses to pursue his career in sports.

W	OD	−4.25 − 0.75 × 180° 20/20−
	OS	−4.00 − 0.50 × 180° 20/30+
M	OD	−4.25 − 1.25 × 180° 20/15
	OS	−3.75 − 1.75 × 180° 20/15
C	OD	−4.00 − 1.25 × 180° 20/20
	OS	−3.75 − 1.50 × 180° 20/20
K	OD	43.8 × 88/42.6 × 178°
	OS	44.1 × 85/42.4 × 175°
Pachymetry	OD 510 µm	OS 517 µm

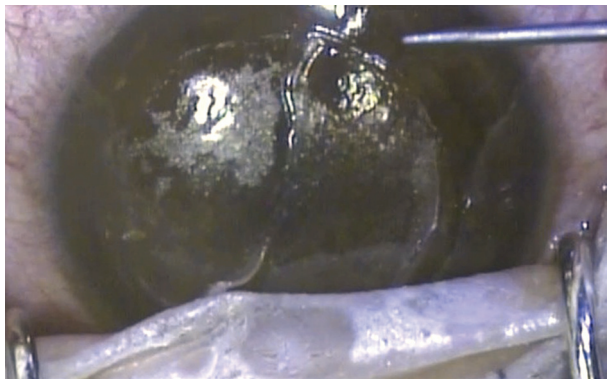
Additional Information

LASIK surgery was performed using the Visumax femtosecond laser and the Technolas 217Z excimer laser. Flap creation was uneventful; however, a mishap occurred during the flap lift OD with a sharp-tipped Seibel flap lifter. The patient was asked to look up while the flap lifter was in the interface near the hinge. He did so quite forcefully and this resulted in a linear full thickness flap tear from the hinge down to the inferior flap edge (Case 93, Fig. 1).

The two torn halves of the flap were lifted independently and laser ablation was performed. The two halves of the flap were then meticulously repositioned to minimize striae and guttering between them. A bandage contact lens was applied. LASIK OS was performed uneventfully. The patient did have flap striae postoperatively but maintained a visual acuity of 20/25 at his 3-month postoperative visit. He had a linear scar across the visual axis with a few nests of epithelial ingrowth at the flap edge (Case 93, Fig. 2).

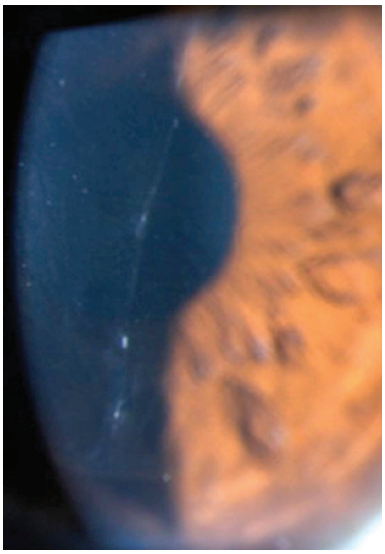
Discussion

Lifting of a femtosecond flap can be done using various techniques. However, using a single underpass technique with a sharp-edged instrument like a Seibel flap lifter is associated with the risk of a torn flap. This is more likely to happen if the flap is adherent, if the patient tends to move



CASE 93, FIGURE 1

Still picture from intraoperative video shows a linear vertical tear in the LASIK flap, which occurred during flap dissection. (Courtesy of Pravin K. Vaddavalli.)



CASE 93, FIGURE 2

Slit-lamp photograph of the right eye 3 months postoperatively, showing a linear vertical scar through the flap. (Courtesy of Pravin K. Vaddavalli.)

suddenly, and if the tip of the flap lifter is within the interface. In the event of a flap tear, there is increased risk of epithelial ingrowth, inflammation, and irregular astigmatism. While one can proceed to ablation of the stromal bed, an alternative approach would be to wait until the flap has healed and the refraction has stabilized, performing surface ablation with MMC to reduce the risk of haze (See Video 16).

Take-Home Points

1. The flap must always be lifted with care.
2. Avoid the use of sharp flap elevators.
3. Instruct patients not to move while the instrument is under the flap.
4. The surgeon can proceed with excimer ablation or perform surface ablation at a later date.

CASE 94

A 54-year-old female had PRK without MMC in 1997 to correct −4.00 D OD and −4.75 D OS, with a good visual outcome by 3 months after surgery (see Case 94, Table 1). In January 2009, she presented with decreased visual acuity OD. The patient reported having sustained trauma to the right eye with a tree branch 2 months earlier. The BCVA was 20/100 and the slit-lamp examination revealed localized grade 3 corneal haze (Case 94, Fig. 1) overlying the pupil.

Case 94, Table 1 Clinical Summary

Right Eye	UCVA	BCVA	Spherical Equivalent	Haze
Preoperative	20/400	20/20	−4.00 D	0
3 mo after PRK	20/25	20/20	−0.50 D	0
12 yr after PRK	20/100	20/100	−1.75 D	3+ localized
1 yr after	20/30	20/20	−0.50 D	Central 0
PTK with MMC				Peripheral trace

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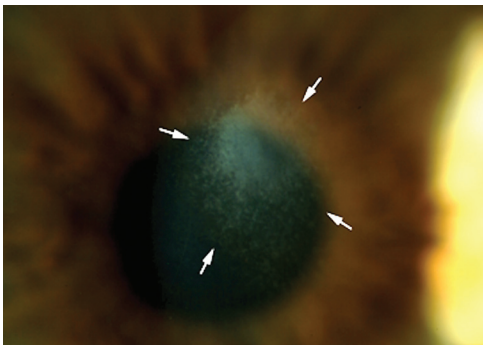

CASE 94, FIGURE 1

Area of stromal haze (*arrows*) initially responsive to topical steroid, but ultimately required PTK with MMC application to clear the cornea and improve visual acuity. (Courtesy of Alexandre Marcon, M.D., Marcony R. Santhiago, M.D. and Marcelo Netto, M.D.)

Clinical Evaluation and Management

The onset of haze initially responded to prednisolone acetate 1% four times daily for 2 weeks, followed by fluorometholone acetate 0.1% four times daily for 2 weeks, tapered to twice a day over 1 month, with decreased haze and improved vision. After the initial improvement with the corticosteroid therapy, topical cyclosporine A was initiated twice a day for several months. The patient reported further mild improvement in the vision in her right eye, but grade 3 localized haze recurred after a few months and was unresponsive to corticosteroids. Ultimately, PTK was performed in the right eye with MMC 0.2 mg/cc applied on a sponge after the ablation for 1 minute.

One year after PTK, UCVA in the right eye was 20/30 and BCVA with $-0.75 + 0.50 \times 130°$ was 20/20. Slit-lamp examination showed the cornea overlying the pupil was clear.

Discussion

The development of late corneal haze after trauma in our case indicates that myofibroblasts can be generated years following the original PRK surgery. It is possible the localized persistent haze could have occurred in the eye after trauma even if PRK had not been performed previously, but this is exceedingly rare in our experience. We hypothesize that the epithelial trauma and injury in the anterior basement membrane triggered the release and penetration into the stroma of mediators such TGFβ and PDGF that stimulated myofibroblast generation and produced an isolated area of subepithelial haze due to the opacity of the myofibroblasts themselves and large amounts of disorganized extracellular matrix materials they produce (See Video 21).[1,2]

During corneal surgery or after trauma or infection, the natural conformation of the extracellular matrix is altered along with changes in corneal cell density and phenotype, resulting in the production of disorganized extracellular matrix components and causing some degree of loss of corneal transparency, often referred to as haze when associated with refractive surgical procedures.[3–10] The complex corneal healing process is initiated immediately after epithelial injury through the release of multiple cytokines and growth factors, from the injured corneal epithelium, activated stromal cells, invading inflammatory cells, and tear film filled with components from the lacrimal glands and conjunctiva. The penetration of these epithelium-derived mediators and growth factors into the stroma only occurs at significant levels if the basement membrane is damaged. The cytokines bind their respective receptors on keratocytes and bone marrow–derived cells, and trigger a variety of biologic responses.[1,2] The resulting cascade leads to important changes in the stroma, including keratocyte apoptosis and necrosis, keratocyte activation, keratocyte proliferation, production of chemokines, and sometimes generation of myofibroblasts.[3]

Take-Home Points

1	Corneal haze can still occur years after PRK if triggered by trauma.
2	Epithelial trauma and injury in the anterior basement membrane trigger the release and penetration into the stroma of mediators that stimulate myofibroblast generation and can produce an isolated area of subepithelial haze similar to what occurs with PRK.
3	PTK with MMC 0.2 mg/cc is an effective treatment.

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CASE 95

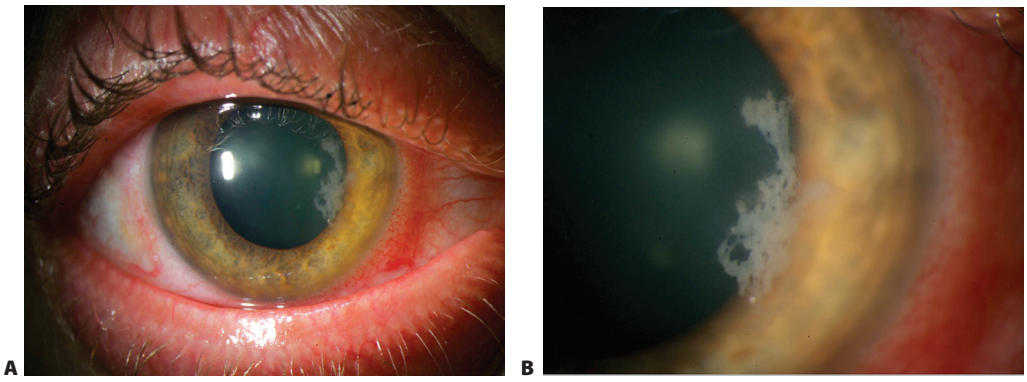
A 46-year-old healthy woman had a 6-week history of pain and tearing OD. She had undergone bilateral LASIK 9 years previously with subsequent enhancement procedures OU. She wore soft contact lenses for residual refractive error, but denied overnight lens wear. She reported swimming in a pool a few days prior to onset of her symptoms. She had been treated with levofloxacin 0.5% and topical corticosteroids. The working diagnosis was recurrent corneal erosion.

	OD	OS
BCVA	20/40	20/20
External examination	1+ injection	White and quiet
Slit lamp: Cornea	Epithelial ingrowth nasal flap edge with pinpoint epithelial defect and few anterior stromal cells No DLK, KP, or melt	Flap without ingrowth or striae
Anterior chamber	Deep and quiet	Deep and quiet
Lens	Clear	Clear
Fundus	Normal	Normal

Steroids improved her symptoms, but when taken off steroids, her symptoms returned and worsened. Repeat examination OD showed 1-2+ cells in the anterior chamber (Case 95, Figs. 1A and B).

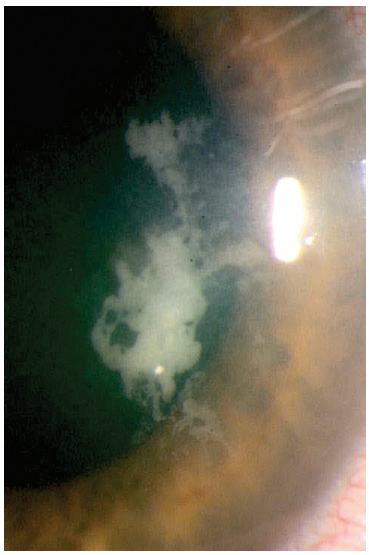
Examination of the affected area showed a well-defined infiltrate with an overlying 2 × 2 mm epithelial defect (Case 95, Fig. 2).

There was no evidence of DLK or surrounding keratitis. At this time, a presumptive diagnosis of infectious keratitis was made. Given the risk of keratolysis and worsening infection, the flap was lifted, the epithelial ingrowth was removed, and the interface was scraped for Gram's stain and culture. The interface was irrigated with moxifloxacin 0.5%, fortified ceftazidime (50 mg/mL), and fortified tobramycin (15 mg/mL). A bandage contact lens was placed, and the patient was



CASE 95, FIGURE 1

A: Diffuse slit-lamp photograph of the right eye shows grayish material in the interface suggesting epithelial ingrowth. **B:** Higher magnification of epithelial ingrowth in the interface. (Courtesy of Surendra Basti, M.D.)



CASE 95, FIGURE 2

Epithelial ingrowth with infiltrate in the flap interface. (Courtesy of Surendra Basti, M.D.)

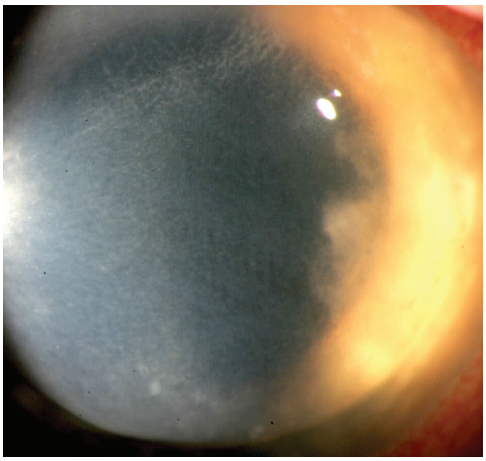
instructed to use the fortified antibiotics every 2 hours, moxifloxacin every 3 hours, and homatropine 5% twice daily (See Video 19).

Cultures revealed growth of *Achromobacter xylosoxidans*. Her pain had improved significantly, but her vision had significantly decreased. Examination revealed BCVA 20/400 OD. The corneal epithelium was intact, overlying a resolving infiltrate, grade 2 DLK, and 2+ stromal edema (Case 95, Fig. 3).

Systemic prednisone 80 mg/day was added and tapered over 1 month. Over the next 10 weeks, her BCVA improved to 20/50, and the inflammation and edema subsided. The infiltrate fully resolved (Case 95, Fig. 4). While she continued to have some minor light sensitivity due to her corneal scar, she has largely been asymptomatic for a year.

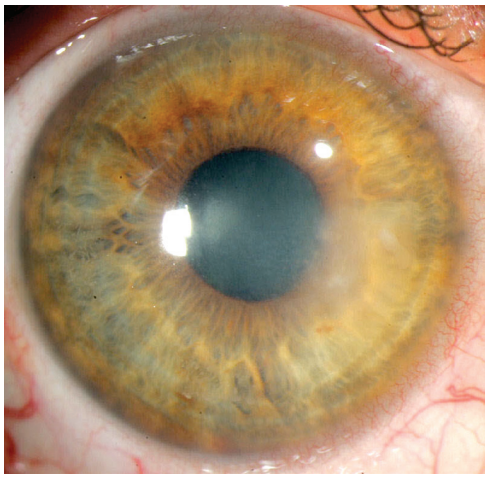
Discussion

A. xylosoxidans is an aerobic, non-fermenting gram-negative bacterium with microbiological similarities to *Pseudomonas* species.It can be distinguished by its peritrichous flagella, that is, flagella around the entire organism, not just at the poles, that potentially could allow for increased



CASE 95, FIGURE 3

After flap lift procedure, the patient developed DLK with stromal edema. (Courtesy of Surendra Basti, M.D.)



CASE 95, FIGURE 4

After several months, the inflammation resolved and the symptoms did not recur. (Courtesy of Surendra Basti, M.D.)

mobility to overcome host defense mechanisms. It has been reported that this bacterium has a propensity to cause systemic infections in immunocompromised hosts.

Contact lens use, topical steroid treatment, and epithelial ingrowth may have been factors increasing the risk of this infection. Treatment of infectious keratitis in the flap interface cannot be managed with topical therapy alone. The flap should be lifted and the interface gently scraped for culture and sensitivity as well as to remove epithelial ingrowth. Most LASIK surgeons irrigate the interface with antibiotics. Appropriate topical antibiotics are then continued after the flap-lift procedure. The development of DLK can complicate the management of infectious keratitis post LASIK and should be treated aggressively once the management of the infection is well underway.

Take-Home Points

1. Epithelial ingrowth may cloud the clinical picture of infectious keratitis after LASIK.
2. Lower your threshold for flap lift, interface scraping, and culture in the setting of epithelial ingrowth with intermittent or chronic pain.
3. Consider infectious keratitis in the setting of pain with little inflammation and in the presence of atypical appearing epithelial ingrowth.
4. Epithelial ingrowth, contact lens use, and chronic steroid use may all increase the risk of late post-LASIK infectious keratitis.

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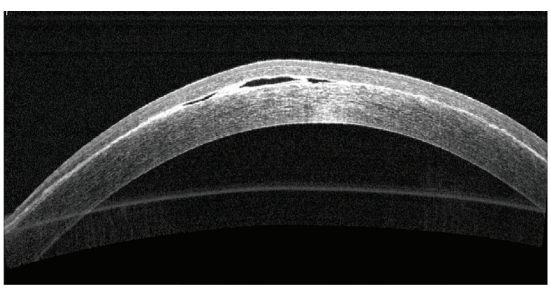
CASE 96

A 37-year-old lady presented with a history of poor visual acuity in her left eye following LASIK in both eyes 5 months previously. She was referred with a diagnosis of persistent post-LASIK interface haze OS despite flap re-lift and interface washout twice before. She was using prednisolone 1% three times daily for presumed DLK.

W	None	UCVA OD 20/25 OS 20/400
M	OD -0.75 + 0.75 × 90° OS No retinoscopy reflex	BCVA OD 20/20 OS 20/400
C	OD -0.50 + 0.50 × 180° OS No retinoscopy reflex	

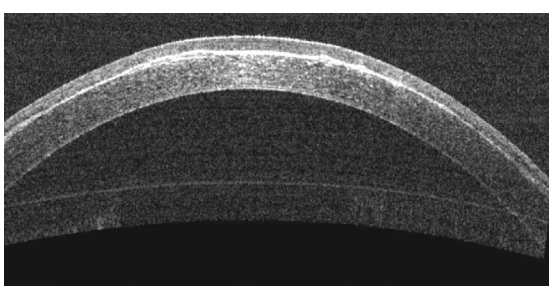
Additional Examination

The right cornea was essentially normal with appropriate flap edge scarring seen. The left cornea showed dense interface haze, more centrally, with a clear space between the flap and stromal bed. IOP measurement with the Goldman applanation tonometer revealed pressures of 14 and 18 mmHg respectively. Fundus evaluation showed a medium-sized disc with a cup-to-disc ratio of 0.6 OD and 0.8 OS. Anterior segment OCT (Case 96, Fig. 1) showed a clear space between the flap and the stromal bed. Repeat IOP measurements with a TonoPen over the peripheral cornea revealed an IOP of 16 mmHg OD and 32 mmHg OS. Repeat OCT (Case 96, Fig. 2) showed resolution of the fluid once the IOP had been controlled; however, glaucomatous changes on the visual field OS (Case 96, Fig. 3) were not reversible.



CASE 96, FIGURE 1

Horizontal line scan on the Optovue OCT of the left cornea of the patient showing interface fluid accumulation seen as a clear space in the interface. (Courtesy of Pravin K. Vaddavalli, M.D.)

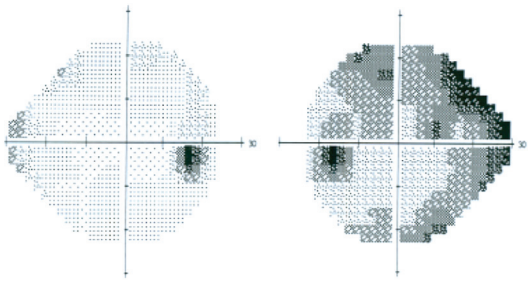


CASE 96, FIGURE 2

OCT reveals resolution of the interface fluid once the IOP has been controlled. (Courtesy of Pravin K. Vaddavalli, M.D.)

Discussion

This is a case of interface fluid syndrome in a steroid responder, where raised IOP leads to a fluid cleft in the interface between the flap and stroma. This interface fluid leads to erroneously low



CASE 96, FIGURE 3

A: (*Left*) HVF 24-2 OD full; **B:** (*Right*) HVF 24-2 OS superior arcuate with inferior nasal step defect. (Courtesy of Pravin K. Vaddavalli, M.D.)

IOP measurements with an applanation tonometer used in the center of the cornea. This patient was initially diagnosed as DLK following LASIK and was treated with intensive steroids and interface wash, which further exacerbated the condition. It is important to look for a fluid cleft on slit-lamp examination. Anterior segment OCT can be of great diagnostic benefit. When this condition is suspected, it is imperative to measure IOP using a TonoPen, away from the corneal center.

Take-Home Points

1	Interface fluid accumulation can occur with elevated IOP.
2	This condition can artifactually reduce IOP.
3	Check IOP from the periphery for a more accurate reading.
4	Anterior segment OCT can be helpful.

CASE 97

A 30-year-old man presented for LASIK consultation with the aim of eliminating the use of contact lenses as he had developed allergies to contact lens wear.

W	OD –8.25 + 2.00 × 110° 20/20– OS –8.50 + 1.25 × 70° 20/20	**Uncorrected Va** OD CF 3′ OS CF 3′
M	OD –8.00 + 1.50 × 110° 20/20 OS –8.75 + 1.50 × 75° 20/20	
C	OD –7.25 + 1.50 × 115° 20/20 OS –7.75 + 1.50 × 75° 20/20	
K	OD 46.00 × 13°/48.12 × 103° OS 46.37 × 170°/48.87 × 80°	
Pachymetry OD 539 µm OS 523 µm	**Topography** OD Normal OS Normal	**Scotopic Pupils** OD 5.6 mm OS 5.4 mm

Additional Examination

The white-to-white corneal diameter measured using Orbscan II (Bausch & Lomb, Rochester, NY) corneal topography was 10.9 mm OD and 11.0 mm OS. Slit-lamp examination of the anterior segment was otherwise normal. The IOP and retina examinations were also normal.

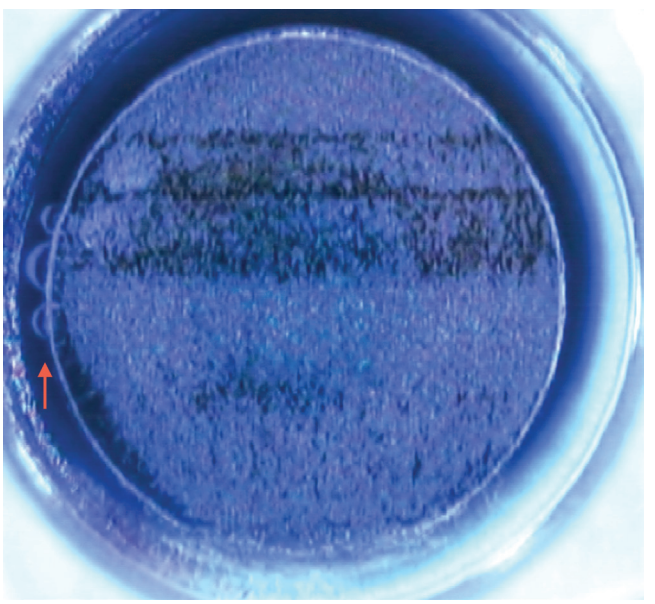
Surgical Plan			
	OD	OS	Comments
Treatment	IntraLase + tissue-saving	IntraLase + tissue-saving	IntraLase iFS, Technolas 217p
Flap parameters	Thickness 110 µm, diameter 8.5 mm, 120° inverted bevel edge	Thickness 110 µm, diameter 8.5 mm, 120° inverted bevel edge	AC bubbles encountered in right eye
Attempted correction (with nomogram correction)	−7.48 − 1.50 × 20°	−8.33 − 1.50 × 165°	Laser ablation for both eyes postponed to the next day
Optical zone	6.5 mm	6.5 mm	
Ablation depth	137 µm	150 µm	
RSB	539 − 110 − 137 µm = 292 µm	523 −110 − 71 µm = 263 µm	

Discussion

In view of the relatively steeper keratometry, the femtosecond laser would be preferred over a mechanical microkeratome for creation of the LASIK flap to avoid the risk of a flap buttonhole.

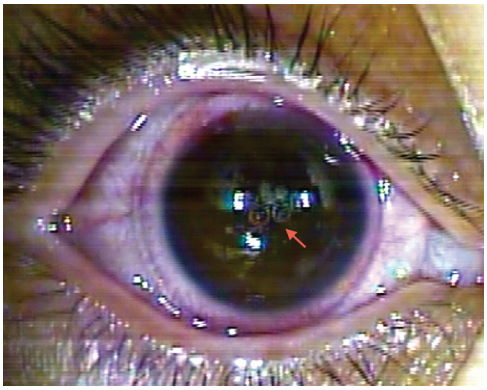
The formation of anterior chamber bubbles during femtosecond laser flap creation is caused by gas tracking from the stromal resection plane through Schlemm's canal. Due to the smaller corneal diameter and the use of an inverted bevel-edged flap in this case, the flap margins were closer to the limbus than usual. Suction ring decentration can also contribute to flap decentration, which can result in the presence of intracameral air. These are possible reasons for the extension of gas bubbles into the anterior chamber (Case 97, Fig. 1) (See Video 12).

If the anterior chamber bubble is tiny and occupies an insignificant area of the pupil, a trial of pupil registration and tracking can be performed before attempting excimer laser ablation. Occasionally, tracking of the pupil center can be achieved before laser ablation but once laser ablation commences, vibrations from the impact of laser pulses on the cornea may cause the bubble to move around and can affect pupil tracking during the ablation. In the presence of larger anterior chamber bubbles, tracking of the pupil center may not be possible, especially when the bubbles



CASE 97, FIGURE 1

Anterior chamber bubble formation (*arrow*) during femtosecond laser flap creation. (Courtesy of Wee-Jin Heng, M.D.)



CASE 97, FIGURE 2

Anterior chamber bubbles will affect tracking of the pupil center and prevent proper centration of the excimer laser ablation. (Courtesy of Wee-Jin Heng, M.D.)

cover a major portion of the pupil (Case 97, Fig. 2). In such cases, even if the eye-tracker somehow manages to register the "pupil center," this may be inaccurate and result in X-Y misalignment and a decentered ablation. The surgeon should avoid the temptation of proceeding with the ablation in an attempt not to disappoint the patient. The safest approach is to wait for the air bubbles to dissolve before proceeding with the laser ablation, although this may mean waiting for hours or even a full day.

Take-Home Points

1	Recognize the risk factors for anterior chamber bubble formation associated with the femtosecond laser, that is, small corneal diameter, inverted beveled-edge flaps, and possibly higher femtosecond laser energy settings.
2	Recognize the risk of decentered ablation due to erroneous pupil tracking in the presence of anterior chamber bubbles.
3	Consider a safer waiting period for the bubbles to dissipate before attempting laser ablation.

CASE 98A

A 66-year-old woman was unhappy 2 years following uncomplicated cataract surgery OD, because her vision without glasses was less than expected. She had hoped for excellent unaided distance vision.

M	OD +1.00 + 0.50 × 15° 20/15 OS +0.75 + 0.75 × 50° 20/40	**Uncorrected Va** OD 20/40 24 pt OS 20/60 12 pt
C	OD +1.25 + 0.25 × 40° 20/15 OS +1.00 + 0.75 × 40° 20/40	
K	OD 43.87 × 43.87 OS not measured	
Pachymetry OD 560 µm OS 554 µm	**Topography** OD Normal power and elevation maps OS Normal power and elevation maps	**Scotopic pupils** OD 5.5 mm

Additional Examination

Punctal stenosis RLL > RUL was noted. The corneal diameter was 10.5 mm OU. On slit lamp examination the cornea was clear OU. A well placed posterior chamber IOL was seen OD and a 2+ nuclear cataract with cortical opacities was noted OS.

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Discussion

Managing expectations is a constant challenge in cataract surgery as well as refractive surgery. The refractive surgeon can provide the unhappy cataract surgery patient with the option postoperatively to correct unexpected ametropia with LASIK or PRK. The hyperopic outcome after IOL insertion is often the most disturbing to the patient because both distance and near vision are affected. Oblique astigmatism can be equally disturbing, but is more easily foreseen when the corneal contour is properly evaluated preoperatively. In the case of myopic astigmatism with a spherical equivalent between plano and − 0.50 D, the LRI is an additional refractive remedy. Refractive surgery touch up is often included in the price of cataract surgery with a premium IOL, where expectations may be even higher.

Emmetropia after a refractive surprise can reliably be achieved with keratorefractive surgery in most cases because the ametropic corrections are generally quite low and pachymetry and contour are generally in the acceptable range. This allows lens exchange or piggyback IOL insertion to be avoided.

It is important to be certain the refractive error has become stable. IOL selection after prior refractive surgery is less easily predicted and patients should be properly prepared preoperatively. For a more complete discussion, see Chapter 14.

Treatment

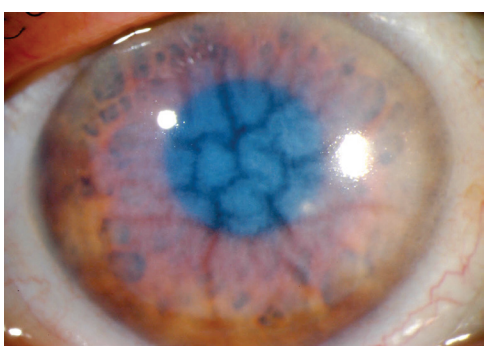
Risks and benefits of custom PRK OD was discussed with the patient.

VISX CustomVue with WaveScan treatment of +1.27 + 0.25 × 38 with a 9-mm treatment zone was selected. Epithelium was removed with 20% alcohol applied for 20 seconds; and after the ablation, cold saline was applied for 60 seconds and a bandage contact lens with base curve 8.7 mm and diameter 14.0 mm was applied. Surgery was tolerated well.

Postoperatively there was marked stromal edema confined to the ablation zone. The edema was most prominent in the posterior cornea with both stromal folds and thickening (see Case 98A Fig. 1 and 2). The management and ultimate outcome will be revealed in part B of this case.

Take-Home Points

1	The hyperopic surprise is most disturbing to the patient if emmetropia was expected because both distance and near vision are suboptimal.
2	It is important to wait until the refractive error has become stable before considering a keratorefractive remedy.
3	PRK and LASIK are reliable remedies with predictable outcomes, particularly in cases of low degrees of refractive error; however, a thorough keratorefractive evaluation should be performed.
4	Patients should be adequately informed about the potential risks of refractive surgery and the outcomes should never be oversold.



CASE 98A, FIGURE 1

Marked stromal edema within the area of ablation noted 1-day post-PRK for correction of hyperopia. (Courtesy of Robert S. Feder, M.D.)

CASE 98A, FIGURE 2

Slit view of corneal edema noted especially posteriorly on the day after PRK OD. (Courtesy of Robert S. Feder, M.D.)

CASE 98B

A 66-year-old woman had uncomplicated PRK OD for correction of a hyperopic surprise after cataract surgery. On the first day after refractive surgery, she was noted to have extensive corneal edema, as shown in Case 98A, Figures 1 and 2.

Examination

The visual acuity with bandage lens in place was 20/100. The edema was present within the entire ablation zone and appeared to be primarily in the posterior half of the cornea. There was no evidence of discharge or conjunctival injection and neither keratitis nor anterior chamber cell was seen. The contact lens appeared to move and center well.

Discussion

The first thought in the presence of greater than expected corneal edema is a tight contact lens. The fit must be checked and lens exchanged for one with a flatter base curve if needed. Another possibility is toxic keratopathy which can occur in PRK, although is more likely to occur after LASIK surgery (see Chapter 11). The edema in that case would have been more anterior and would have resulted in corneal scarring and contour flattening. This patient had a small cornea, which means the absolute endothelial cell count would be expected to be lower than the average patient and prior cataract surgery may have lowered the cell count even more. Therefore the endothelial pump overall may have been less robust. The presence of punctal stenosis likely reduced tear drainage. Ultimately we suspected that the patient's reduced endothelial pump could not easily clear the stromal edema brought on by a large epithelial defect, irrigation and increased tearing.

Treatment

The patient was treated with topical prednisolone 1% bid and topical fluoroquinolone qid and was watched carefully.

The epithelial defect healed over a 5-day period and the corneal edema completely resolved. The IOP remained normal throughout the postoperative period. One month postoperative, the cornea had slight punctate stain inferiorly and slight haze superiorly and the acuity was 20/20–. By 3 months post-PRK, the cornea was completely clear, and the visual acuity was a crisp 20/20. She presented 4 months postoperatively with a progressive posterior subcapsular cataract in the left eye

and visual acuity of 20/100. She opted for cataract extraction with insertion of a Crystalens. The Crystalens was chosen because the patient wished to have reduced dependence on glasses. She was not willing to accept the unique risks inherent with a multifocal IOL. Further, she wanted her distance function to be similar to the fellow eye. Four months after surgery her visual acuity was 20/15 OD and 20/20 OS distance, 20/20 intermediate OS, and 20/30 near OS. The patient was extremely pleased with her ultimate outcome, using glasses only for the most detailed near activities.

Take-Home Points

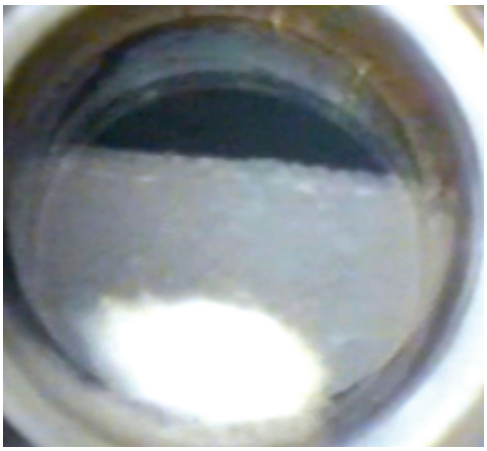
1	The differential diagnosis of post-PRK corneal edema includes a tight bandage lens, toxic keratopathy, infectious keratitis, large epithelial defect with copious irrigation, and reduced endothelial pump function.
2	A patient with uncharacteristic findings should be closely observed.
3	The best outcomes occur when expectations are exceeded. Good communication with the patient is essential. The time spent preoperatively explaining risks and benefits is a worthwhile investment. Finally, make it your policy to undersell and over deliver.

CASE 99

A 52-year-old man with moderate myopia in both eyes was interested in reducing his dependence on glasses and contact lenses. He had a history of sleep apnea with floppy eyelids and slight conjunctival edema. His refractive error was −6.25 + 1.25 × 83° OD and −6.75 +1.50 × 94° OS with BCVA of 20/20 OU. The examination including corneal topography was normal. After discussion with the patient, it was decided to perform LASIK using the IntraLase in both eyes.

Suction in the right eye was somewhat difficult to obtain because of the floppy lid condition with redundancy of the conjunctiva. Suction was ultimately obtained, and the right eye was brought under the femtosecond laser. During docking, suction was lost and then re-obtained on two separate occasions, but finally was maintained. Approximately halfway through the creation of the flap, a suction break occurred again (Case 99, Fig. 1). Further attempts at achieving suction were unsuccessful, despite changing to a new suction ring.

PRK was performed 1 month later in both eyes without complication, and at the 6 month follow-up, uncorrected vision was 20/25 OD and 20/20 OS. No flap haze occurred.



CASE 99, FIGURE 1

Suction loss occurred before the flap had been completed. Note the incomplete raster pattern. (Courtesy of David Hardten, M.D.)

Discussion

There are many advantages of femtosecond flap creation, including a much-reduced risk of buttonhole and free or shredded cap. Suction breaks can occur, though, especially in patients with edematous or redundant conjunctiva or patients who squeeze the eyes vigorously. If a suction

break does occur, typically there is no break in the epithelium. If suction can be reestablished with the same cone, a good quality flap can be obtained at the same setting or at later setting. If a suction break occurs during creation of the side cut, then a side-cut only program with a slightly smaller diameter can be used to make the side cut. A new cone should not be used to create the flap, because there may be variability of the flap depth when different cones are used, resulting in a second lamellar plane with the potential for tissue loss in the interface. Animal studies have shown flap irregularities even if the opaque bubble layer is still present.

In patients with a larger nasal bridge, the nose pushing on the cone of the laser increases the risk of suction loss. Turning the head to the side slightly can reduce this pressure, leading to a more complete applanation.

If suction cannot be successfully obtained on repeated attempts, most patients do fine with surface laser ablation, which can be performed at the same setting or at a later date. In this case, because of the redundant conjunctiva, LASIK was not attempted on the second eye. PRK was performed OU at a later date without complication (See Videos 14 & 15).

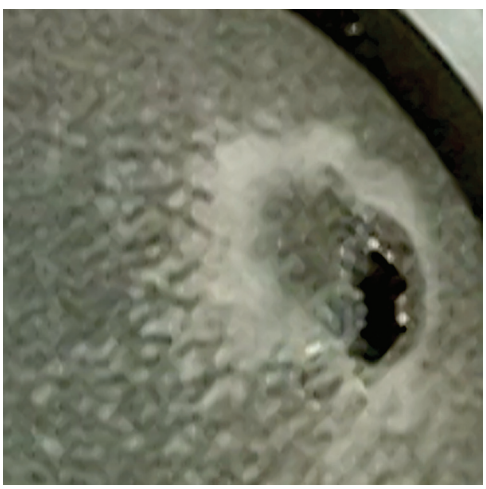
CASE 100

A 43-year-old man with mild myopia in both eyes was interested in reducing his dependence on glasses and contact lenses. He has worked in a hardware store for years, and yet denied any specific eye trauma. He understood and accepted the necessity for reading glasses after surgery.

W	OD −3.00 + 0.50 × 85° 20/20 OS −2.75 + 0.75 × 92° 20/20	**Uncorrected Va** 20/400 OU
C	OD −2.75 + 0.50 × 85° 20/20 OS −2.50 + 0.75 × 92° 20/20	
K	OD 44.50 × 45.00 @ 90° OS 44.25 × 45.00 @ 90°	
Pachymetry OD: 528 µm OS: 530 µm	**Topography** Regular astigmatism OU	**Scotopic Pupils** 5.7 mm OU

Additional Examination

External examination was unremarkable OU. The slit lamp examination should a couple of faint old foreign body scars in each cornea, but was otherwise unremarkable. The IOP was 14 mmHg OU and the fundus was normal OU.



CASE 100, FIGURE 1

Vertical gas breakthrough has resulted in a flap buttonhole. (Courtesy of David Hardten, M.D.)

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Discussion

There are many advantages of femtosecond flap creation, including a more consistent flap thickness, improved safety, and more even hydration of the underlying stromal bed. However, when the flap thickness achieved is 100 to 120 µm, there is only 50 to 70 µm of stroma beneath the epithelium. In patients with superficial corneal scars that are nearly as deep as the flap interface, vertical gas breakthrough can occur. This occurs when gas formed within the lamellar plane escapes through the area of stromal scar, which has been filled in by the epithelium. The gas can then collect under the applanation lens, pushing the corneal stroma away from the laser-cornea interface. This potentially results in a larger area of uncut tissue. Provided this tissue is not lifted, there will typically be a faint scar in this area. This cornea will be amenable to treatment with PRK without complication. If the flap is lifted, then a buttonhole will be present in this area, and there is the potential for irregular scarring and epithelial ingrowth. Recutting with the femtosecond laser has been advocated, but because of prior experience with high complication rates recutting with mechanical keratomes, we prefer surface laser ablation.[1] Some authors have advocated recutting with a mechanical keratome in this situation.[2] It is possible for gas to collect beneath the epithelium without breaking through. In this situation, if the flap is carefully dissected a buttonhole can be avoided.

Because of the potential for vertical gas breakthrough, a careful preoperative slit-lamp examination to rule out corneal scarring is important. These scars can be from old foreign bodies, contact lens–related sterile or infectious keratitis, or viral scars. Planning primary PRK in this situation can prevent the occurrence of this nuisance complication.

Treatment

The plan was to use IntraLase femtosecond laser for flap creation and VISX excimer laser for stromal ablation. Creation of the flap OD was uneventful. Toward the end of flap creation OS, vertical gas breakthrough occurred at the site of a prior corneal scar (Case 100, Fig. 1). The flap was not lifted, and 3 months later the patient underwent uneventful PRK with a good result. LASIK was completed in the right eye. Visual acuity was 20/20 in the distance in each eye at 3 months postoperatively, with no other complications.

Take-Home Points

1	Vertical gas breakthrough is a potential risk of femtosecond laser ablation in the presence of a stromal scar, which can lead to flap buttonhole.
2	Careful slit-lamp examination looking for stromal scars is important.
3	Surface ablation without flap lift is a reasonable alternative when vertical gas breakthrough occurs.

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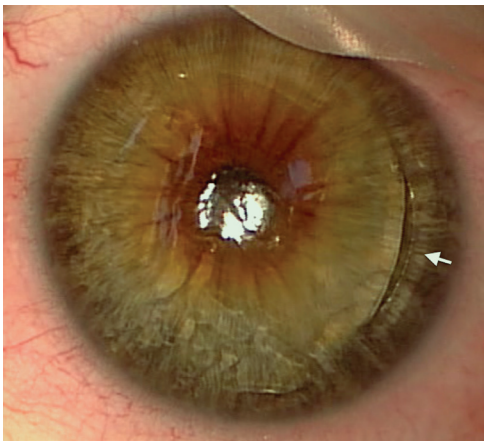
2. Chang JS, Lau S. Intraoperative flap re-cut after vertical gas breakthrough during femtosecond laser keratectomy. *J Cataract Refract Surg*. 2010;36:173–177.

CASE 101

A 26-year-old woman presented after being hit in the left eye on a table corner. She had had LASIK OU 7 years earlier. The preoperative refraction was −10.00 − 1.50 × 10° in the right eye and −10.50 − 1.75 × 175° in the left eye with a BCVA of 20/20 in both eyes. Preoperative



CASE 101, FIGURE 1

Operating microscope photography of the left eye before reposition of the traumatically displaced LASIK flap. (Courtesy of Ori Mahler, M.D.)

ultrasound pachymetry measurements were 580 µm in the right eye and 583 µm in the left eye. The LASIK flaps were created with a superior hinge using the Bausch and Lomb Hansatome keratome with a 160-µm head.

Postoperative UCVA was 20/20 in both eyes.

After the trauma the UCVA was 20/20 in both eyes. Slit-lamp examination of the right eye was normal, but the left eye (Case 101, Fig. 1) revealed displacement of the temporal edge of the flap.

On the day of presentation, the patient's flap was surgically lifted in the area of displacement. The epithelium on the lifted edge and opposite the peripheral edge was scraped, and the stromal surfaces of the flap and bed were scraped to remove debris and epithelial cells. The flap was repositioned and smoothed with a dry triangular sponge, and a bandage contact lens was placed. The patient was started on ofloxacin (Oflox, Allergan, Ireland) drops and dexamethasone phosphate 0.1% (Sterodex, Fischer, Israel) drops four times a day. Two weeks postoperatively, the bandage contact lens was removed and the UCVA was 20/20 in the left eye. There was no evidence of epithelial defect, DLK, or epithelial ingrowth. The antibiotic and steroid drops were discontinued. There were no folds. A slight edge irregularity remained.

Discussion

Several reports have described cases of late-onset traumatic LASIK flap dislocation, up to 14 years postoperatively.[1–3] Appropriate surgical treatment has good results and should be performed as soon as possible. Slit-lamp surgical repair has been advocated in cooperative patients.[4] However, whenever possible, flap reposition should be performed under the operating microscope. Delay in diagnosis and treatment may result in complications such as permanent flap macrostriae, DLK, and epithelial ingrowth beneath the flap.[3,4] To minimize the risk of epithelial ingrowth, scraping of the epithelium from the stromal bed and the stromal surfaces of the flap edges should be done. Leaving the epithelium over the flap edge may impede flap flattening. The epithelium may fixate folds, especially in long-standing cases. After stretching the flap edge, striae may be still present. They usually disappear the next day. If there is a limited peripheral flap dislocation, only the dislocated sector should be lifted and repositioned to avoid unnecessary manipulation. A bandage contact lens should be placed and may be left in place for 1 to 2 weeks to assure proper epithelial healing, reducing the risk of ingrowth.

Take-Home Points

1. Even years after LASIK surgery, the lamellar flap adhesion is weak and susceptible to traumatic displacement.
2. Prompt diagnosis and surgical treatment usually restores anatomical integrity and visual acuity.

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3	Delay in flap reposition may result in permanent flap striae and epithelial ingrowth. Irregular astigmatism and visual impairment may persist.
4	Scraping of the stromal surface of the flap and the stromal bed should be performed in order to minimize the risk of epithelial ingrowth.
5	Placement of a bandage contact lens and use of antibiotic and steroid treatment for 1 to 2 weeks can reduce the risk of infection and DLK.
6	Close follow-up is advised to detect significant epithelial ingrowth that may occur despite all the precautions described above.

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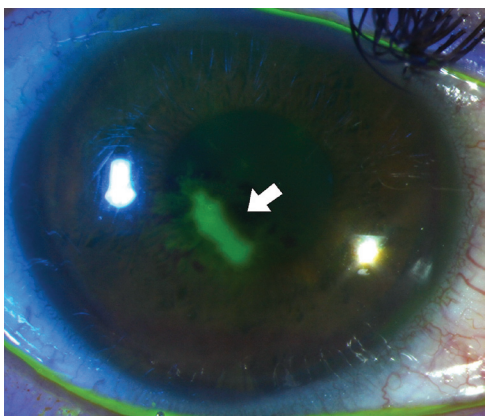
CASE 102

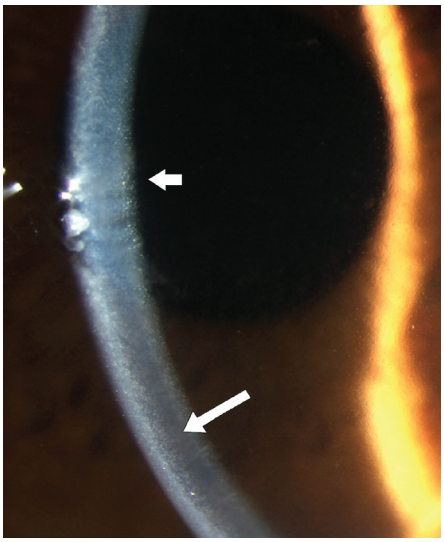
A 31-year-old man was referred 2 days after traumatic corneal erosion in his right eye that occurred while playing basketball. He underwent LASIK vision correction in both eyes 9 years earlier. After the trauma, he was treated with ofloxacin (Oflox, Allergan, Ireland) drops qid. After an initial subjective improvement, he developed severe photophobia with blurring of vision and eye redness.

The corrected distance visual acuity (CDVA) in the affected eye was 20/70 with normal IOP. Slit-lamp examination showed diffuse conjunctival injection with a paracentral corneal epithelial defect 0.5 mm × 1.7 mm (Case 102, Fig. 1). Cellular infiltration was present in the stroma and at the peripheral edge of the flap, as well as a granular appearance of the endothelium (Case 102, Fig. 2). Cells were visible in the anterior chamber. DLK was diagnosed. Topical prednisolone acetate 1% (Pred forte, Allergan, Ireland) eye drops every 2 hours were added to the initial therapy. The next day, the patient's pain and discomfort improved and the epithelial defect had completely healed. The stromal cellular infiltration diminished and there were still traces of anterior chamber cells. The ofloxacin drops were stopped. After 1 week, CDVA was 20/25. The corneal lamellar and anterior chamber inflammation had completely resolved. The steroid drops were tapered over the following 2 weeks.



CASE 102, FIGURE 1

Slit-lamp examination showed diffuse conjunctival injection with a paracentral corneal epithelial defect 0.5 mm × 1.7 mm. (Courtesy of Arie L. Marcovich, M.D.)



CASE 102, FIGURE 2

Cellular infiltration in the stroma (*long arrow*) and a granular appearance of the endothelium (*short arrow*) with overlying epithelial irregularity. (Courtesy of Arie L. Marcovich, M.D.)

Discussion

This case shows that even 9 years after LASIK surgery, a traumatic corneal epithelial defect can induce DLK. DLK is a rare inflammatory complication of LASIK surgery of unknown origin that typically starts in the early postoperative period. Treatment consists of topical and systemic steroids. In severe cases, washing the space under the corneal flap with saline is recommended. Despite intensive treatment, some cases do not improve and may lose visual acuity due to interface scarring and melting of the LASIK flap. Factors reported to trigger DLK are infections, endotoxins, eyelid secretions, talc from gloves, and debris from absorbent sponges, among others.[9] The presence of an epithelial defect in the flap is strongly associated with the development of DLK, increasing the incidence from 2% to 56%.[10,11] Epithelial defects lead to keratocyte damage with activation of inflammatory cells.[12] A late-onset DLK, induced by a corneal epithelial defect, was reported 8 years after LASIK. In that case, the DLK had developed after epithelial closure in the area of the preexisting defect with anterior chamber inflammation.[13]

In our case, the corneal stroma was infiltrated diffusely with endothelial involvement and anterior chamber cellular reaction. Cellular infiltration of the edge of the flap was present. Intensive topical steroid therapy was successful in the management of the inflammation and restoration of visual acuity.

Take-Home Points

1. Corneal epithelial defect can induce DLK many years after LASIK surgery.
2. Treatment of corneal erosions after LASIK should include topical steroids to minimize risk of DLK.
3. Patients that develop corneal epithelial defect after LASIK have to be followed up closely for the early detection and treatment of DLK.

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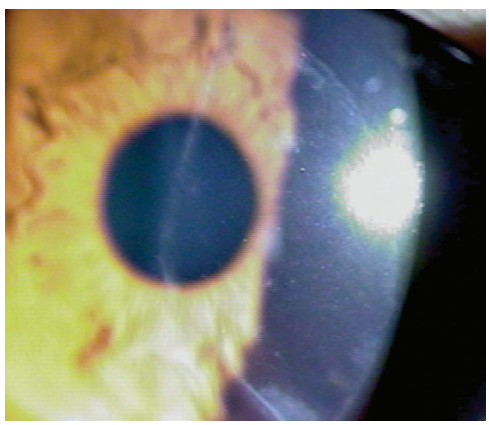
CASE 103

A 27-year-old male who underwent LASIK about 1 month previously presented to Apgujung Yonsei Eye Center for a second opinion. LASIK on the right eye was well performed. However, during the creation of the flap OS, suction was lost, and the flap was amputated at the center of the pupil. The surgeon repositioned the amputated flap and aborted the excimer procedure.

Although the BCVA was 20/25, the patient was complaining of blurred vision due to irregularity of the corneal anterior surface. There was epithelial ingrowth both at the 1 and 5 o'clock positions (see Case 103, fig. 1). This patient showed improvement in his visual acuity with time and his BCVA OS reached 20/20 after 2 years, but the quality of the vision was still problematic for the patient. Keratorefractive surgery OS with a surface ablation using PTK and PRK with intraoperative MMC applied for 2 minutes was performed (Case 103, Table 1).

The UCVA of this patient at 6 months post-enhancement follow-up was 20/20 (see Case 103 Fig. 2). More importantly, the patient was satisfied with the quality of his vision due to absence of irregular astigmatism.

M	OS −4.25 + 1.00 × 75° 20/25		
C	OS −4.00 + 0.75 × 75° 20/25		
K	OS OS 41.25 × 171°/43.25 × 81° mild irregularity		
Pachymetry OS 503 µm		**Topography** OS Horizontal asymmetry with flattening temporally	**Scotopic Pupils** OS 6.2 mm

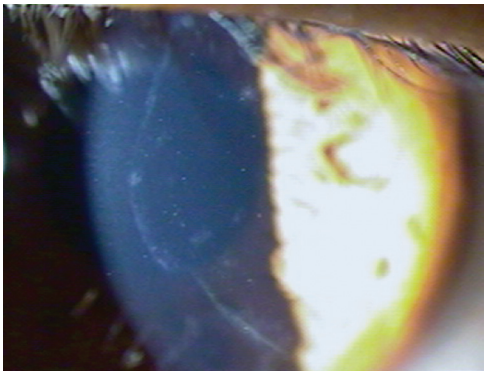


CASE 103, FIGURE 1

Slit-lamp photography showing an amputated and repositioned flap bisecting the pupil. (Courtesy of Dongho Lee, M.D., Ph.D.)

CASE 103, TABLE 1 Summary of Surgical Procedures Left Eye

PTK	7 mm 50 µm Nidek EC 5000	Consider hyperopic shift
PRK	−4.50 + 0.75 × 90° 20/20	Adjust nomogram for hyperopic shift due to PTK
MMC 0.2 mg/cc	Applied for 2 min	



CASE 103, FIGURE 2

Slit-lamp photography after the treatment with PTK and PRK with MMC application. (Courtesy of Dongho Lee, MD., PhD)

Discussion

Corneal flap amputations may occur with mechanical microkeratomes during LASIK procedure. It can vary from a large free cap with amputation near the hinge to a small flap amputation that bissects the pupil, as in this case. The latter is one of the most severe complications during LASIK flap creation. Flap amputations can be associated with epithelial ingrowth under the flap and can cause severe irregularity of the corneal surface and decrease in visual acuity. Patients usually complain of poor vision due to irregular astigmatism. To manage such a case, a great deal of patience is required for both patients and doctors because given sufficient time, the vision may improve and become stable. There are several options for this patient. The flap can be recut with a microkeratome or with the femtosecond laser. One may consider a surface ablation. When you perform a surface ablation, you should be careful not to separate the previous flap edges. PTK is a good option in this case, and MMC must be used to prevent corneal haze.

Take-Home Points

1. Wait long enough for the patient to reach BCVA.
2. Use PTK for the epithelial removal.
3. Use MMC 0.2 mg/cc for 2 minutes.

CASE 104

A 23-year-old man, who has been working at a dairy, presents for LASIK consultation for good vision without glasses. He never wore contact lenses.

W	OD −2.00 OS −2.00	**Uncorrected Va** 20/200 OU
M	OD −2.25 + 0.50 × 30° OS −2.00	
C	OD −2.25 + 0.50 × 30° OS −2.00	
K	OD 45.50 × 30°/46.25 × 120° OS 45.50 × 6°/46.00 × 96°	
Pachymetry OD 540 µm OS 542 µm	**Topography** OD Regular, round OS Regular round	**Scotopic Pupils** OD 5.3 mm OS 5.6 mm

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Additional Examination

The external examination reveals good exposure with a corneal diameter of 11.5 mm. The slit-lamp examination shows a normal anterior segment. The IOP and fundus examinations are normal.

Discussion

This patient is a good candidate, very motivated for refractive surgery. He opted for LASIK OU; however, a microkeratome problem occurred OD. During the backward pass the microkeratome jammed. Suction was released and the microkeratome was removed gently. The flap was carefully checked with an irrigation cannula. It was round and complete. Luckily, the stromal bed was smooth, and the flap edges did not have any nicks. Therefore, the right eye was treated as planned, and the situation was explained to the patient asking how he would like to proceed with the left eye. LASEK or PRK could be performed if he insisted on having the left eye surgery that day, or LASIK could be performed later. He decided to have LASIK OS later and meanwhile wanted to have an extended wear soft contact lens for the left eye. He was fit a 30-day silicone hydrogel.

Three weeks later he called in describing pain and redness OS. He was seen by the local ophthalmologist with a diagnosis of keratitis and was started on hourly topical fluoroquinolones. He was seen by us a week later with a superior marginal infiltrate of about 1.5 × 1.5 mm. The rest of the cornea was clear with a quiet anterior chamber. The lesion resolved over the next 10 days and the patient was eager for LASIK OS. He was convinced to wait, and LASIK was performed 4 months later since the scar from the infiltrate was superficial and would not be in the path of the microkeratome.

Surgical Plan

	Right Eye	Left Eye (4 mo Later)	
Patient opts for LASIK OU	Moria M2-90 head/ring 2/stop 7.5	Moria M2-90 head/ring 2/stop 7.5	
Ablation zone	6.5-mm blend	6.5-mm blend	Zeiss Mel 80
Correction entered	−2.25 + 0.50 × 30°	−2.00	Discuss postponing or LASEK OS
Ablation depth	53 µm	53 µm	
RSB	367 µm	369 µm	

Take-Home Points

1. If the microkeratome jams on the reverse pass, release suction. Slowly and carefully disengage the device from the eye.
2. If there is a problem with the microkeratome on the first eye that cannot be explained or corrected, do not use the device on the second eye until evaluation and repair has been done.
3. If the flap is adequate, one can proceed with excimer treatment; however, consider the implications if only one eye gets treated.

CASE 105

A 29-year-old-female presented for LASIK surgery. She had had a consultation and evaluation in which the risks and benefits had been explained. She was considered a good candidate for bilateral simultaneous LASIK.

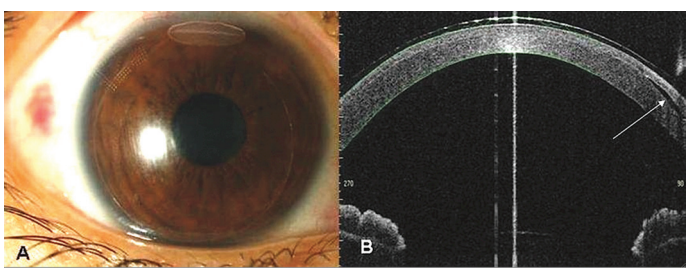
Preoperative Evaluation

M	OD −3.25 20/15 OS −3.50 20/15
C	OD −3.00 20/20 OS −3.50 20/20

Pachymetry	Topography	Scotopic Pupils
OD 540 µm OS 536 µm	No ectasia OU	6.4 mm OU

IntraLase iFS150 (AMO Inc., Irvine, CA) was used to create a 9.0-mm-diameter superior-hinged flap bilaterally with desired flap thickness of 110 µm. Femtosecond laser settings used were 0.75-mJ bed energy, 1.1-mJ side-cut energy, and 115 degree side-cut angle. The pocket setting was enabled. A 200-µm pocket start width and 210-µm pocket start depth with both pocket tangent and radian spot separation of 4-µm were used. A line and spot separation of 6-µm were employed for the laser pass.

At the beginning of flap creation in the right eye, the patient moved suddenly. The surgeon noted vertical movement of the suction ring on the video monitor. Since there was no suction loss or disturbance in flap centration, the flap cut was continued and completed. This was followed by cutting of LASIK flap in the left eye using the same laser parameters. A 9-mm flap diameter was achieved bilaterally. During subsequent lifting of the flap in the right eye, the surgeon could not open the pocket completely. However, since the treatment zone was 6.5 mm and the flap diameter was 9.0 mm, surgery was continued, and the rest of the procedure was completed uneventfully. Stromal ablation was performed with the WaveLight Allegretto laser (WaveLight Inc, Sterling, VA). The stromal bed was irrigated with BSS after the excimer laser ablation to remove any debris and the flap was repositioned. LASIK surgery was uneventful in the left eye. Slit-lamp examination 30 minutes after LASIK showed a flap pocket in the superior quadrant close to the flap hinge (Case 105, Fig. 1A).



CASE 105, FIGURE 1

A: Slit-lamp photograph after surgery showing fluid-filled pocket close to the hinge of the femtosecond LASIK flap. **B:** ASOCT showing a clear space between the flap and the underlying corneal stromal bed close to the flap hinge (*arrow*).

An anterior segment OCT (ASOCT, Casia SS-1000, Tomey, Japan) was performed to delineate the extent of the pocket. ASOCT scan showed a clear space located superiorly close to the flap hinge between the flap and the underlying stromal bed corresponding to the clinical appearance. There were no air bubbles in the space (Case 105, Fig. 1B). The overlying epithelium was intact. A bandage contact lens was inserted in the right eye. The patient was discharged and advised to use levofloxacin 0.5%, prednisolone 1%, and hypromellose eye drops four times a day.

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On the first postoperative day, unaided visual acuity was 20/20 OU. Slit-lamp examination revealed well-centered flaps and quiet anterior chambers bilaterally. Right eye examination showed complete resolution of the gas from the interface. ASOCT showed a uniform LASIK flap with a clear flap-stromal interface. Follow-up examinations at the end of 1 week and 1 month were unremarkable with a final UCVA 20/20 OU.

Discussion

One of the foremost concerns in this scenario would be to rule out any major intraoperative problems related to flap creation. It is important to look for any signs of loss of suction, which can usually be visualized by the sudden appearance of gas bubbles under the glass interface. In the present case, once it was ensured that the flap creation was running smooth, the procedure was completed. Although the flap lift was uneventful, the flap pocket could not be dissected. This occurred due to disruption of laser application during flap creation following sudden movement of the patient's eye. There was a discontinuity of the laser pass very close to the flap hinge. Consequently, a thin strip of corneal interface between the flap pocket and the hinge was untreated. Nevertheless, laser ablation was continued after reduction of the diameter of the treatment zone to 6.5 mm. The patient was discharged with a bandage contact lens in order to avoid any flap displacement. Spontaneous resolution of the interface gas was seen on the first postoperative day, and a good visual outcome was achieved.

Take-Home Points

1. This is an unusual complication encountered during femtosecond flap creation. Careful observation of intraoperative events is important in order to decide on further course of action.
2. ASOCT is a useful adjunct in management of flap-related issues. Because it is a noncontact imaging modality, it can safely be used for diagnosis and follow-up after keratorefractive surgery.

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SECTION VIII

International Perspectives in Refractive Surgery

chapter 17

International Perspectives

In our busy professional lives we rarely have an opportunity to consider how the work we do is being performed throughout the world. One might expect there to be significant differences and similarities in how we practice. How do the climate, the economy, government regulation and population demographics, customs and characteristics impact clinical practice in different countries? In a quest to gain a deeper understanding about refractive surgery as performed throughout the world this chapter will take the reader on a virtual voyage of exploration to China, Singapore, South Korea, Brazil, Germany, Turkey, and Israel. A set of questions was submitted to several of our international contributors. This survey included queries about the evolution of refractive surgery in the individual country, unique patient management pearls, equipment preferences, and business models. Through their responses it is hoped you will come to appreciate and gain insight from the similarities and differences in the practice of refractive surgery. We begin our virtual journey in Hong Kong.

CHINA (HONG KONG)

VISHAL JHANJI

Hong Kong has prospered under the "one country, two systems" policy since its handover to the Chinese government in 1997.[1] An excellent infrastructure, including a sound banking system, a strong legal system, and ample foreign exchange reserves, enable Hong Kong to quickly respond to changing circumstances. With this dynamic background, ophthalmology here has managed to keep pace with the international advances.[1] In fact, it is one of the top choices for medical graduates in Hong Kong.

Laser vision correction or refractive surgery is a very popular and commonly performed surgical procedure in Hong Kong. This may

be attributed to the high prevalence of myopia in the Chinese population[2] as well as high life expectancy. Although nearly all the private as well as University-based ophthalmology clinics in the city provide refractive surgery services to about 7 million people in the city, this facility is not available in the public sector. Based in a private clinic affiliated to a University, we have an in-house refractive surgery suite for performing common refractive procedures such as LASIK and surface ablation. Although microkeratome-assisted LASIK was successfully being performed earlier, a femtosecond LASIK machine (iFS 150 kHz, AMO Inc.) was acquired about 2 years ago. There is a general trend toward performing more LASIK as compared to surface ablation or other refractive surgeries, without compromising on the safety of the patients. The major reason behind this choice is that the patients want to resume work as soon as possible after the surgery. We also encounter a considerable proportion of high myopia (>6 diopters [D]). These patients seek to be rid of spectacles and/or contact lenses in the quickest possible manner. Much like other countries, major reasons for denying surgery in Hong Kong are inadequate corneal thickness and suspicious corneal topography.[3] We also have our own share of preoperative issues such as contact lens–induced dry eyes, lid margin disease, and retinal degenerations requiring prophylactic treatment before LASIK.

Another important issue for refractive surgeons in Hong Kong is the peculiar anatomy of Chinese eyes. It has been shown that there are considerable differences in Chinese eyes compared to their Caucasian counterparts.[4] We frequently come across patients who have very small palpebral apertures and a wide nasal bridge (Fig. 17.1). Since iFS femtosecond machine is available only with a "one-size" suction ring, it is challenging at times to insert the ring into the patient's eye during flap creation. Having cancelled a few surgeries due to inability to fit the suction ring in these eyes, we now routinely measure the horizontal and vertical palpebral aperture in all the patients. These patients are informed preoperatively that the surgery might have to be aborted in case the suction ring cannot be inserted into the eye intraoperatively. These patients are offered microkeratome-assisted LASIK or surface ablation in such scenarios.

Another feature in ocular anatomy that is relevant to refractive surgery is small corneal diameter. In most of the cases, LASIK flap diameters are set at a lower value (typically 8.8 mm compared to 9.0 mm in Caucasian eyes). In many cases, the LASIK flap edge is close to the corneal limbus. Consequently, we encounter cases with intraoperative anterior chamber gas bubbles (Fig. 17.2). Likewise, we inform the patients about this potential complication during preoperative counseling.

Postoperative management and treatment protocol of refractive surgery patients match the international standards followed elsewhere. We do, however, encounter many steroid responders. This may be related to the degree of myopia as well as the prevalence of glaucoma in the Chinese[5] people. These cases are detected well in advance and are managed appropriately.

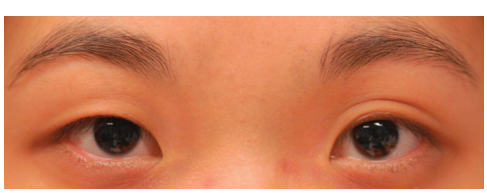

FIGURE 17.1

Chinese eyes often have small palpebral apertures with small corneal diameters.

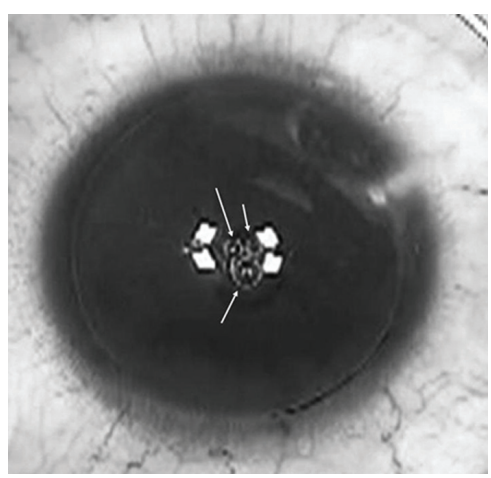

FIGURE 17.2

Bubbles (*arrows*) entered the anterior chamber during femtosecond laser flap creation in a patient with a small cornea.

One more aspect that deserves mention is the popularity of femtosecond technology amongst the general population in Hong Kong. Since the time of acquiring femtosecond machine, the number of surgeries performed using a microkeratome at our center is <1%. This is in spite of the fact that all patients are offered both microkeratome as well as femtosecond surgery at the time of preoperative counseling. It is also interesting that although microkeratome LASIK is more economical compared to femtosecond LASIK everywhere in the city, nearly all patients prefer to receive femtosecond or "all laser surgery." Upon inquiring the reason for choosing femtosecond over microkeratome, common responses include "peer pressure," "new technology," and "available online information." It is only fair that people find femtosecond LASIK to be a more advanced and safer technology compared to other options. However, this behavior also reflects the paying capacity of an average patient in Hong Kong in the absence of any reimbursement by insurance agencies. To my knowledge, the cost of refractive surgery varies in Hong Kong from about US $1,500 to $4,000. Regardless, most of the refractive surgery centers are busy and flourishing. This further creates a lot of competition among different centers. It is not uncommon to see "discount slogans" all over the place offering concession on LASIK surgery.

Refractive surgery in Hong Kong is experiencing exciting developments parallel to the expansions in the field of laser vision correction surgeries. Most of the research is being conducted in University-based clinics, which continue to lure more patients by reducing the total cost of surgery. Yet I have come to believe that potential refractive surgery candidates in Hong Kong have confidence in receiving treatment in teaching hospitals such as ours, irrespective of the cost of the procedure. As mentioned earlier, longer life expectancy in Hong Kong is an additional blessing. We are treating more patients who are >50 years old and want to enjoy life free of spectacle or contact lenses. We hope to see refractive surgery becoming increasingly safer and accessible to all patients in Hong Kong.

Acknowledgments: I wish to thank all the doctors and staff in the University Eye Clinic of the Chinese University of Hong Kong, Hong Kong.

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SOUTH KOREA

DONGHO LEE and HAK SUNG CHUNG

LASIK was first introduced to South Korea in the early 1990s. Since then, refractive surgery has been growing over the years in Korea. There are 3,600 ophthalmologists in Korea, and almost three-fourths of them are active in clinical practice. Three hundred thirty-six of them are actively performing refractive surgeries and are members of the Korean Society of Cataract and Refractive Surgery (KSCRS).

The prevalence of myopia in South Korea is very high, and is reported to be 54%.[1] Most of the myopes in Korea have a strong desire for refractive surgeries, and many of them have already undergone refractive surgeries.

Based on a survey conducted by the KSCRS in 2007,[2] LASIK was the most popular surgery among PRK, LASIK, and LASEK, although its popularity significantly decreased

from 78% in 1999 to 48% in 2007. LASEK, Epi-LASIK, and PRK were 36%, 10%, and 6%, respectively. In 2001, I (Dr. Lee) was the first in Korea to start using prophylactic intraoperative mitomycin-C during PRK, and reported a large case series of 1,000 patients with my colleagues.[3] PRK with mitomycin-C has increased in popularity, and some Korean refractive surgeons prefer PRK with mitomycin-C to LASIK in their practice. For myopes with >8 D, phakic intraocular lens (IOL) implantation was preferred. Ever since the wavefront analyzer was introduced, the number of wavefront analyzer users has increased from 17% in 2002 to 65% in 2007 in Korea. When asked whether wavefront ablation improved vision, 62% of KSCRS members answered yes. Thirty percent of KSCRS members perform presbyopia surgery with multifocal laser procedure, and 70% of them are satisfied with the results. Multifocal corneal surgeries using excimer lasers were introduced in Korea in 2004, and now most of the laser companies provide presbyopia-correction programs. In my own study, presented at Korean and European ophthalmology meetings, multifocal corneal excimer laser surgery showed safe and effective correction of presbyopia for up to 90% of patients.

VISX laser system was the most commonly used by KSCRS members (about 32%), followed by Technolas (20%) and Zeiss Meditec MEL-80 (17%). For LASIK flap creation, 34% of surgeons used Hansatome, 22% used IntraLase, and 18% used Moria M2 microkeratome. Femtosecond laser users are increasing, and 73% of doctors responded that it would further increase in the future.

Most of the refractive surgeons in Korea own their laser surgery system in their private clinics. Only a few laser surgery centers, if any, share a laser system with other surgeons. Thanks to less strict governmental regulation compared to FDA, Korean refractive surgeons are performing refractive surgery with new technologies, including multifocal laser surgery and a variety of phakic IOL implantation techniques.

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SINGAPORE

WEE-JIN HENG

High myopia is very common in Asia, and one of the problems is insufficient corneal thickness for LASIK. Postoperative glare and haloes may be more apparent and prolonged due to higher power treatments or the need to shrink the treatment zone. In Singapore, air force pilots and navy divers are allowed to undergo PRK, but are not permitted to have LASIK.

We have found that keys to improved outcomes include a multidirectional eye tracker with active tracking in at least three dimensions (x, y, and cyclo), more frequent fluence checking between the eyes, duochrome testing for refractive tolerance, drying of the flap edge and conjunctival fornices before flap lift, and waiting for resolution of femtosecond laser–induced OBL before proceeding with excimer laser ablation.

There was a dip in the volume of refractive surgery after 2009, but the volume has remained quite stable since then. While the typical patient is in the economically productive age group—between 20 and 40 years old—the number of patients above 40 or who are pseudophakic is on the rise. LASIK is still the overwhelming favorite refractive procedure with both patients and surgeons. Health insurance only covers refractive surgery for spectacle- or contact lens–intolerant individuals who have anisometropia with spherical

equivalent of 3 D or more. The average cost is US $1,150 per eye with a range of $770 to $2,000 per eye.

In Singapore, the phakic IOL is still viewed as an alternative only when patients are deemed not suitable for LASIK. However, it offers a possible solution to very high myopes in whom full correction was previously impossible. An increasing number of patients are now seeking presbyopia treatment.

There are nine excimer lasers in Singapore serving a population of 5 million. The most popular excimer lasers are Technolas, WaveLight, Mel 80, SCHWIND AMARIS, and iLASIK. Amadeus, Zyoptix XP, and Moria are the most commonly used microkeratomes, but there has been a big move toward bladeless LASIK. More than 90% of LASIK cases are performed with femtosecond lasers today. IntraLase, Ziemer LDV, and VisuMax are the most widely used femtosecond lasers. The mechanical microkeratome will likely be relegated to being a backup instrument or will be used when cost is really an issue for the patient.

BRAZIL

ALEXANDRE MARCON, MARCONY R. SANTHIAGO, and MARCELO V. NETTO

Young patients represent the majority of Brazilian refractive surgery candidates. The patient's hobbies must always be considered when deciding the appropriate surgical technique. In young active patients, there is a slight trend in favor of surface ablation procedures. Surface ablation has the advantage of safety in case of accidents following contact sports and outdoor activities, as well as of biomechanical stability, since the posterior stroma is less affected than with LASIK. On the other hand, ultraviolet light related to strong sun exposure must always be considered a potential source of postoperative corneal haze. The use of intraoperative haze inhibitors, such as mitomycin-C, is strongly recommended in tropical countries. In addition, general care, for example, vitamin C, extended use of steroid drops, and sunglasses during the first weeks of surgery is recommended.

The strength of emergent economies, such as Brazil and China, tends to favor the refractive surgery market. An increasing number of patients now have access to refractive procedures. The younger population has become more affluent and is willing to invest in their health. Increased job opportunities and stability in the economy facilitate and stimulate the interest in elective surgical procedures. Payment facilities and special deals are also pumping up the refractive surgery market. As a consequence, many facilities are also investing in newer technologies to attract these potential clients.

In general terms, the volume of refractive surgery is stable. In the past, a high surgical volume was sustained by insurance coverage. Health insurance covers refractive surgery for patients with hyperopia up to 6 D and myopia over 5 D. Insurance companies pay around US $350 per eye. Private surgery costs around US $1,000 per eye. Nowadays, fewer surgeons are accepting insurance coverage for refractive procedures, since the reimbursement has not been adjusted. As a result, the number of private procedures is increasing significantly. Many refractive surgeons are operating less, but earning more money due to the trend toward increased surgery on private patients.

While there is currently a trend favoring PRK over LASIK, the introduction of the femtosecond laser surgery may have a positive impact on the volume of LASIK surgery over the next few years. Phakic IOL insertion is a much more expensive procedure that is not covered by insurance. In the past decade, the number of phakic IOL surgeries performed has been very limited. Due to the increase in economic stability, an increase in the number of these special procedures is expected. Many patients interested in this technology simply did not have the surgery performed due to financial constraints. These patients are still interested in alternatives for refractive

correction and possibly will have an opportunity in the near future.

Refractive surgery is primarily performed in major cities, but the number of surgeons and the number of modern centers in rural communities is increasing. An equal volume of refractive surgery is performed in hospitals and surgicenters. High volume practices usually have their own surgical center, while small offices tend to operate in local hospitals. Competition is increasing over time and marketing methods are tending to mirror the US trends. Very aggressive marketing methods are not allowed in Brazil. Local medical bureau offices control the ethics of marketing methods and try to punish aggressive competitors.

The most popular excimer lasers, in order, are Nidek, Chiron (Bausch & Lomb), Allegretto (Alcon), and SCHWIND. The most popular microkeratomes are Hansatome, Moria, and Nidek. The femtosecond laser is currently used by 30% of refractive surgeons in Brazil. Femtosecond laser is currently replacing the mechanical microkeratome, but it will probably take a few decades before the microkeratome technology is completely replaced. The Brazilian community is investing not only in newer ophthalmic devices and facilities but also in scientific information. The number of participants in international meetings worldwide is progressively increasing, as is the number of young specialists participating in fellowship programs and international postdoctoral programs.

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GERMANY

GERNOT I.W. DUNCKER

In Germany, with a population of 81.7 million, there are about 300 clinics and practices offering refractive laser surgery. There are around 600 LASIK surgeons in the country. The estimated number of LASIK procedures performed in a year ranges from 70,000 to about 125,000, and increases by around 3% per year.

It is typical for several surgeons to use the same excimer laser. There are 175 excimer lasers and around 80 femtosecond lasers in the country. The most commonly used excimer lasers in descending order are Alcon (50), VISX (45), Technolas (30), SCHWIND (30), Zeiss (20), and Nidek (1). The femtosecond lasers in descending order are IntraLase (45), Ziemer (12), VisuMax Zeiss (10), Alcon (10), and FemTec (5). The most popular microkeratomes in descending order are the Hansatome XP, Amadeus, Moria, and Pendular. In Germany, 70% of the LASIK procedures are still performed with the microkeratome, while only 30% are done with the femtosecond laser.

In my opinion, there will continue to be a high percentage of microkeratome users in Germany. The reasons for that are mainly the costs of an additional laser. Also significant are the greater cutting variability of microkeratomes, especially regarding the hinge positioning, shorter suction time with less risk at inducing ischemic optic neuropathies, less maintenance costs, better conditions for retreatment procedures, and a comparable cutting quality between microkeratomes and femtosecond lasers.

According to the agreement of an academy-based commission of refractive surgery, LASIK

surgery in Germany is restricted to myopic corrections up to −8 D, astigmatism of 5 D, and hyperopia of 3 D. Beyond these limits, higher standards are necessary for informed consent. The German Association for Technical Inspection (TÜV) requires a high standard of quality for the performance of LASIK surgery, which includes the refractive results from LASIK operations. The refractive surgeon must perform 250 LASIK surgeries, and 90% of the myopic patients must be within ±0.5 D of emmetropia postoperatively in order for the surgeon to get a certificate.

Contemporary surgeons are much more sensitized to avoiding surgery on pathological, weak, and thin corneas. Routinely, ectatic corneas are ruled out using the Pentacam device. In such patients, UVA collagen cross-linking is performed followed either by PRK or by implantation of a toric ICL.

In Germany, map-dot-fingerprint dystrophy is quite common. In such patients, surface ablation is preferred. LASIK surgery is not indicated in patients suffering from forme fruste keratoconus, symptomatic cataract, glaucoma with visual field defects, or patients with exudative macular degeneration. Usually, LASIK is not performed before the age of 18. The minimum corneal thickness for femtosecond laser surgery is 480 µm, and for microkeratome procedures it is 500 µm. For sportsmen like boxers or wrestlers, who are at high risk of ocular trauma, surface ablation or ICL surgery instead of LASIK is recommended.

High astigmatism, >5 D, may be difficult for surgeons to accurately correct. In such cases, we first do femtosecond laser arcuate incisions in the steep meridian to lower the amount of astigmatism, for example, 60 degree at 80% of corneal thickness, followed by LASIK surgery 3 months later.

The major demographic group seeking refractive laser correction is the age group between 25 and 35 years, mainly middle-class people. German patients usually visit laser facilities within the country, whereas immigrants, for example Turkish people, prefer going to Turkey or to Turkish laser centers in Germany that may offer the procedure at a lower cost.

LASIK is still the number one refractive laser procedure in Germany. Surface ablation, PRK, and epi-LASIK constitute only 20% of the procedures. Very few laser centers restrict themselves to surface ablation procedures alone.

Lens implant surgery has dramatically changed my refractive practice in two ways. Eyes that are not suitable for LASIK surgery can now be easily operated on by implanting phakic IOLs. In addition, about 10% of patients who have undergone refractive IOL exchange are now good candidates for additional LASIK correction aimed at improving the refractive result. In my practice, the number of LASIK procedures is as high as the number of phakic IOLs, mainly toric ICLs. IOL surgery has markedly improved our refractive armamentarium.

There are few refractive surgery units in rural communities. However, some do very well, offering an excellent service to patients. They are able to attract people even from major cities via the internet and recommendations by word of mouth.

The majority of patients pay the whole procedure either upon receiving a bill after surgery or by paying cash on the day of surgery. There are leasing models, called Medipay, to facilitate payment. The cost of LASIK surgery usually ranges between $1,140 and $2,280 per eye. There are some chains in the market offering LASIK for much lower prices, in the range of $603 (Optical Express) to $869 (City Lasik). There are some private insurance companies willing to cover the cost of refractive surgery. Some of them require a statement attesting to the need for refractive surgery, in other words, that the patient is intolerant to contacts or glasses. Obligatory insurance is strictly against refractive surgery and does not cover any such costs.

The majority of surgeries are performed in so-called LASIK centers that are shared by several surgeons or run by a chain. There are also some University-based hospitals offering LASIK surgery.

The marketplace is increasingly competitive, especially in major German cities. In the

Munich area, for instance, there are 15 different lasers and laser centers competing with one other. The main marketing tool is the internet and website presentation. Other methods are radio, cinema, and advertisement on trains, buses, and trolleys.

TURKEY

ZEYNEP OZBEK

The population of Turkey in 2010 was 74,724,269.[1] Ankara, the capital, is located in the heart of Anatolia and has a population of 4,890,893, while the most famous and most crowded city is Istanbul, with 13,624,240 residents. One could easily call Ankara the Washington, D.C. and Istanbul the New York of Turkey.

The history of refractive surgery in Turkey goes back to the 1990s, starting primarily with radial keratotomy. Laser refractive surgery started soon after in 1992.[2]

In those days, almost all of the refractive surgery was performed in Istanbul at a couple of private hospitals by Sinan Goker, M.D., Bozkurt Sener, M.D., and Emrullah Tasindi, M.D. Dr. Goker and Dr. Sener started doing PRK with Technolas Keracor 110 in 1992, while Dr. Tasindi started with Aesculap Meditec Mel 60.[2–5] Technolas lacked normative data at the time and they based their calibration on the results of the patients done by Dr. Sener and Dr. Goker.[3] Dr. Tasindi also started treating astigmatism with the mask method.[5] The first excimer laser at a government hospital was a Summit purchased by Istanbul University Ophthalmology and Corneal Transplantation Center.[3,6] Unfortunately, it did not have much potential since they could not form a motivated team with experienced service technicians and nurses.[2,3]

In January 1993, Professor Stephen Tokel, who was the consultant for VISX at that time, was invited to Turkey to share his experience for the first VISX 20/20 surgery in Istanbul.[2]

The first LASIK surgery was performed in 1995 by Dr. Goker and Dr. Sener.[7] The first LASIK at a government hospital was performed by Bahçeciog˘lu et al.[6] By the end of 1996, Dunya Hospital started a chain of eye centers where laser refractive surgery literally exploded.[2] Technolas was also being used. Around the same time, Dr. Kaskaloglu started with Technolas at his private eye center in Izmir.[8] In Ankara, laser refractive surgery started in 1998, later than in Istanbul and Izmir, and the second university hospital that purchased a Mel 60 was Gazi University.

Today there are over 150 excimer lasers in Turkey. The most frequently used lasers in descending order are VISX: 35, WaveLight Allegretto: 27, Carl Zeiss Meditec: 25, SCHWIND: 26, Nidek: 23, and Zyoptix: 17.

University hospitals that have excimer lasers are as follows: Hacettepe University and Gazi University (Zeiss Mel 70); Cerrahpasa University (SCHWIND AMARIS); Capa University (VISX); Samsun Ondokuz Mayıs University (VISX S4); and Erciyes University (Nidek). Some of these lasers are inactive due to staffing problems.

Moria is the most commonly preferred microkeratome. However, centers that are using the Nidek excimer laser tend to use the Nidek MK 2000 microkeratome. There are 60 Moria microkeratomes, 30 of which are actively used. There are thirty 150-kHZ femtosecond lasers in the country. There are two FemTecs on which Dr. Goker and Dr. Tasindi perform Intracor surgery. There is one VisuMax (Carl Zeiss Meditec), which incorporates both femtosecond and excimer lasers in one body.

The patient population is mostly young (<40 years). Meibomitis and blepharitis are very common and a challenge for the refractive surgeon to manage. Turkey is mostly sunny and warm in summer, and our people are not very keen on wearing sunglasses. In addition, smoking is very common; therefore, postoperative haze is a serious problem.

Excimer laser refractive surgery is in decline since physicians have become more conservative and prices are low. LASIK is more frequently performed compared to surface treatment because of the shorter follow-up required. IOL surgery did not have much of an impact on laser refractive surgery because most of the IOLs are not readily available. Insurance does not cover most of the premium IOLs and is expensive.

Laser refractive surgery is covered by insurance only if there is bilateral myopia > −5 D with at least 3 D of anisometropia, or bilateral hyperopia > +3 D with at least 3 D of anisometropia, or if one eye is emmetropic while the other has 4 D of refractive error.[9] Otherwise the patient must pay all the expenses. Early on, one could have LASIK at a cost of around $1,000 per eye in the U.S. currency. Several years ago, the prices dropped as low as $300 per eye because of competition in the market. There were even advertisements during prime-time television soap operas. However, with the introduction of femtosecond laser flaps, the prices rose again. Still the cost is much lower than that in the United States and Europe, and that is why some European people have a cheap vacation in Turkey with a "refractive package"!

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ISRAEL

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There are several refractive surgery centers in Israel. While most of them are private, two are attached to hospitals. The Israeli Society of Refractive Surgeons holds several annual meetings with case presentations and professional discussions. The estimated number of refractive procedures is 10,000 eyes per year in a population of 7 million people. Approximately half of them are LASIK and half are surface ablations. Wavefront-guided treatment is considered advantageous. The cost of a refractive procedure varies between US $800 and 2,300 per eye. There are no government restrictions on performing or advertising refractive surgery.

Army recruits wishing to serve in units that require good uncorrected visual acuity undergo refractive surgery usually at the ages of 17 to 20, at their own cost. Although the Israeli army's official policy is to discourage refractive surgery before recruitment due to the candidates' young age, the number of youngsters who undergo refractive surgery has been increasing over the years. A study found that significantly more recruits who had surgery were assigned to combat units compared to recruits who wore corrective eye wear, and their dropout rate was significantly lower.[1] Pilots were reported to continue flying combat jets after having LASIK.[2]

PRK was first performed in Israel in 1991, and LASIK surgery was initiated in 1997. The microkeratomes in use today are the Bausch & Lomb Hansatome and the Moria M-2. In 2003, the femtosecond laser IntraLase was

introduced for flap creation in both surgical facilities of one center. Nowadays, there are four IntraLase devices (iFS, AMO) and one Z-LASIK (Ziemer). The excimer lasers that are currently used are VISX, Bausch & Lomb, Nidek, SCHWIND, and Allegretto wave.

Most surgeons do not treat more than −10 D by surface ablation. Some prefer LASEK, while others perform PRK, but most surgeons apply mitomycin-C during surface ablation. In recent years, due to the risk of ectasia, there has been a tendency toward surface ablation. LASIK is the preferred procedure for hyperopia.[3] Currently, most surgeons prefer to limit hyperopia treatment to +5 D.

A common reason for the rejection of a candidate for refractive surgery is the identification of keratoconus on topography. Keratoconus is relatively prevalent in Israel. According to a recent study, topographic findings consistent with keratoconus were detected in 2% of students in a college in Jerusalem.[4] This prevalence figure is significantly greater than that reported in US studies, of between 1/1,000 and 1/2,000.[5]

A suspicious asymmetric topography may cause the surgeon to prefer surface ablation to LASIK.

Presbyopia treatment is currently performed in the nondominant eye only, while the dominant eye is targeted for distance. This practice emerged in order to overcome the slow recovery of distance vision that sometimes occurred when both eyes were treated with a multifocal treatment.[6] The number of refractive procedures has been relatively stable in recent years, and patients come from all strata of society.

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Conclusion

And so it seems that from the Far East to the Middle East and parts in between, there is a market for high-quality keratorefractive surgery. There are unique patient challenges that necessitate good judgment and technique, including small corneal diameter and small palpebral fissure in China, the effect of tropical sun on stromal haze in Brazil, meibomianitis and blepharitis in Turkey, and keratoconus in Israel. The degree to which government control and insurance impact the refractive surgery market varies from country to country. In general, refractive surgery continues to grow in volume, and there is significant competition worldwide. The equipment currently in use is similar between countries. In most countries, the femtosecond laser is replacing the mechanical microkeratome. The use of phakic IOLs and multifocal ablations seems to vary from country to country and perhaps with the specific clinician, as seen in Germany. One idea remains clear: there is much we can learn from each other when it comes to the best practice of refractive surgery.

SECTION IX

Self-Assessment (Online only)

The following 70 multiple-choice questions are designed to help the reader assess the acquired knowledge of LASIK surgery. Each question is followed by four short answers. Only one answer is correct. The answers and a short discussion are found in the Answers section. Refer to the text for further study if a given topic is not well understood.

Questions

1. Which of the following statements about LASIK surgery is true?
   - **a.** The need to leave a minimum of 250 µm of the stroma untouched has been proven.
   - **b.** LASIK is always safer than photorefractive keratectomy (PRK) because Bowman layer is not destroyed.
   - **c.** LASEK is the same as LASIK, only deeper.
   - **d.** Entering the cycloplegic refraction into the VISX STAR S4 laser computer in a higher myope and performing LASIK may result in an overcorrection.
2. A 56-year-old patient is interested in refractive surgery. She is myopic and on initial screening was found to have a central corneal thickness of 635 µm. Which is the next step in the further evaluation of this patient?
   - **a.** Perform corneal topography to evaluate corneal elevation.
   - **b.** Perform specular microscopy.
   - **c.** Obtain a diurnal curve.
   - **d.** Refuse to treat this patient because the corneas are too thick.
3. You are performing LASIK with a blade microkeratome on the second eye of a patient who is a high myope. You realize that you have lost suction and the flap is incomplete. What is the best choice on how to proceed?
   - **a.** Place the flap back into position, abort the surgery, and recut a new flap after 6 months.
   - **b.** Use a deeper plate to create a new thicker flap, then continue with the laser.
   - **c.** Continue with the excimer laser ablation to finish the surgical plan.
   - **d.** Convert to photorefractive keratectomy (PRK) since the flap is mostly epithelium.

4. The corneal flap on the fellow eye will be thicker than it would otherwise be if:
   a. the microkeratome blade is reused.
   b. the cornea is thin.
   c. the translation of a manual microkeratome head is faster.
   d. the plate thickness is increased.
5. Which of the following statements about residual stromal bed (RSB) is true?
   a. Leaving an RSB of at least 250 µm guarantees that post-LASIK ectasia will not occur.
   b. RSB can be accurately determined prior to surgery.
   c. Nomogram-adjusted ablation depth calculations should be used to determine RSB.
   d. Ectasia can occur even when the RSB is well above 250 µm.
6. The advantages of the low-vacuum setting on the Moria CB and M2 microkeratomes include:
   a. Allows for cutting a thinner flap.
   b. Affords greater protection to the optic nerve when cutting the LASIK flap.
   c. Allows the surgeon to maintain control of the eye during laser ablation.
   d. Less likely to cause postoperative dry eye syndrome.
7. The advantages of a manual microkeratome include:
   a. Ability to vary the translation speed to create thinner or thicker flaps.
   b. Creates a smoother stromal bed.
   c. Less chance for LASIK flap complications.
   d. More reliable and reproducible flap thickness.
8. Which of the following statements regarding microkeratomes is true?
   a. Thicker corneas result in thinner flaps.
   b. Thinner corneas result in thinner flaps.
   c. Flatter corneas result in larger flaps for the same ring size.
   d. Steeper corneas result in smaller flaps for the same ring size.
9. Which of the following is not an advantage of the femtosecond laser over a blade microkeratome for flap creation?
   a. The entire process of flap creation is much faster with the laser
   b. The femtosecond laser provides more control over flap diameter
   c. The laser can create a good quality flap even in steep or flat corneas
   d. Peripheral neovascularization is less of a problem with the laser
10. Which of the following statements is true about the adjustment to the correction that is entered into the VISX laser?
   a. When calculating the correction for entry into the laser, the nomogram adjustment is applied to the sphere portion of the refraction
   b. The nomogram adjustment is dependent on both the age of the patient and the spherical equivalent
   c. The nomogram adjustment will depend on whether the cornea is steep or flat
   d. The nomogram adjusted correction for the VISX laser should be used to calculate the ablation depth
11. Which of the following statements is true regarding single-piece microkeratomes?
   a. A single-piece microkeratome frequently results in a decreased overall time for intraocular pressure (IOP) elevation during flap creation.
   b. A single-piece microkeratome can only be used for the creation of a nasal hinge.
   c. A single-piece microkeratome increases the risk of entrapping eyelashes or eyelid tissue when the LASIK flap is created.
   d. A single-piece microkeratome requires a higher IOP than a two- or three-piece microkeratome.
12. When the LASIK flap is created on the first eye and a small epithelial defect is noted, which of the following is the most appropriate course of action?
   a. The LASIK surgery should be terminated and the second eye canceled.
   b. A bandage contact lens should be placed on the eye after the LASIK flap

is repositioned and prednisolone acetate drops should be initiated.

c. No accommodations or changes in techniques are necessary when a small epithelial defect is noted on the flap.

d. Photorefractive keratectomy (PRK) should be performed on the second eye.

13. The recommended concentration of mitomycin-C (MMC) for refractive surgery prophylaxis is:

a. 0.2%

b. 0.02%

c. 0.02 mg/mL

d. 2 mg/mL

14. Buttonhole flaps are more likely to occur in patients with:

a. flat corneas

b. steep corneas

c. myopia

d. hyperopia

15. The Orbscan topography device:

a. uses Scheimpflug photography to measure the corneal contour.

b. is not helpful in identifying early keratoconus suspects.

c. cannot provide elevation data.

d. can provide a pachymetry map of the cornea.

16. The Zyoptix (Bausch & Lomb) system:

a. can be used in patients with hyperopia.

b. can be used to treat mixed astigmatism.

c. is the system of choice for a patient with −8 D of myopia.

d. can accurately correct refractive error < −7 D of myopia and −3 D of astigmatism, with a maximum spherical equivalent of −7.5 D.

17. In the United States, the Bausch & Lomb Technolas 217 laser:

a. utilizes an active eye tracker.

b. has a customizable optical zone size with a customizable blend zone.

c. has a cyclotorsional tracker.

d. cannot treat hyperopia.

18. Mitomycin-C (MMC) is:

a. an anti-inflammatory agent.

b. derived from bacteria.

c. an inhibitor of DNA synthesis.

d. an antifungal agent.

19. Photorefractive keratectomy (PRK) haze is:

a. more common in low myopic ablations.

b. never seen with LASEK.

c. unpredictable, but more common in deeper ablations.

d. not possible with modern excimer lasers.

20. Diffuse lamellar keratitis (DLK) associated with the IntraLase can best be avoided by:

a. use of topical steroids preoperatively.

b. use of nonsteroidal eye drops preoperatively.

c. assurance of the proper laser settings.

d. use of doxycycline preoperatively.

21. Which of the following patients would be best suited to undergo LASIK with the IntraLase rather than a blade microkeratome?

a. A 55-year-old woman with a myopic refraction of −2.00 D.

b. A 32-year-old −12.00 D myope with preoperative keratometry values of 41.00 D.

c. A 22-year-old −2.00 D male.

d. A 35-year-old woman with Schirmer values of 0 and conjunctival staining.

22. Explanations for the inability to obtain adequate suction for IntraLase flap creation include all of the following, except:

a. small palpebral fissure.

b. boggy conjunctiva.

c. use of Brimonidine preoperatively.

d. faulty suction ring.

23. The femtosecond laser creates a lamellar flap via the process of:

a. thermal breakdown

b. plasma creation

c. carbon–nitrogen bond release

d. photodisruption

24. The IntraLase can be used for all of the following procedures, except:

a. Photorefractive keratectomy (PRK).

b. intrastromal ring segment (Intacs) insertion.

c. penetrating keratoplasty.

d. deep lamellar endothelial keratoplasty (DLEK).

25. A 42-year-old patient comes in for evaluation for refractive surgery. She wears toric soft contact lenses, which she discontinued 3 days ago. Her manifest refraction

(MR) shows 0.5 D of cylinder and her topography shows 1.25 D of cylinder. How do you plan her surgery?

a. Treatment plan based on the MR.
b. Treatment plan based on the topography.
c. Ask the patient to stay out of her contact lenses for another week and then treat based on her repeat MR.
d. Have the patient stay out of her contact lenses until the MR and topography are stable, repeatable, and consistent, no matter how long it takes.

26. A 26-year-old myope desires laser keratorefractive surgery:

Central corneal thickness = 595 µm OU

Scotopic pupil size = 6.0 mm OU

Manifest Refraction (MR) = −10.00 + 1.50 × 90 OU

Cycloplegic Refraction (CR) = −9.50 + 1.50 × 90 both eyes

Keratometry = 42.00 D at 90° by 40.00 D at 180° OU

Pachymetry = 605 µm OU

Preoperative topography and elevation maps are normal OU

Is this patient a good candidate for LASIK?

a. No, because the CR differs too much from the MR.
b. No, because the average corneal power postoperatively will be too flat.
c. No, because of the risk of ectasia in this high myope.
d. No, because the amount of astigmatism on keratometry is greater than the amount of astigmatism on refraction.

27. A −3.00 D myope is determined to be a good candidate for LASIK. After the microkeratome pass, major sloughing of the corneal epithelium is noticed. The best course of action is to:

a. replace the flap and the epithelium as best as possible and not perform the laser.
b. replace the flap and then perform photorefractive keratectomy (PRK) after debriding the epithelium.
c. perform the laser ablation as planned, reposition the flap, replace the epithelium as well as possible, and then apply a bandage contact lens.
d. amputate the flap and treat the bed with laser.

28. Which of the following is not a sign that adequate suction is being obtained with a mechanical microkeratome?

a. The patient reports dimming of vision.
b. Conjunctival vessels have blanched.
c. The Barraquer tonometer or pneumotonometer reads an intraocular pressure (IOP) >65 mmHg.
d. Pupil dilates and remains so.

29. Which statement regarding free caps is true?

a. They are thought to be less common in corneas with keratometry readings <40 D.
b. Excimer laser treatment to the stromal bed is contraindicated in the presence of a free cap.
c. Corneal ink marks make it difficult to manage a free cap.
d. A free cap can be lost or damaged as the microkeratome unit is removed from the eye and either prepared for the fellow eye or cleaned.

30. Which of the following is not considered a risk factor for epithelial loosening or an epithelial defect during LASIK?

a. Anterior basement membrane dystrophy.
b. Age over 50 years.
c. High astigmatism.
d. Epithelial shift or defect in the fellow eye.

31. Proper management of epithelial loosening or defect during LASIK includes all of the following, except:

a. the flap needs to be carefully examined to make certain the flap stroma is intact and the stromal bed examined to make sure it is uniform.
b. great care should be taken to replace the epithelium back in its original location.
c. if an epithelial defect occurs, the laser treatment should not be performed.
d. postoperatively, a bandage soft contact lens is often useful in management.

32. Risk factors for ectasia after LASIK include all of the following, except:
    a. central cornea that is thinner than the inferior periphery.
    b. asymmetric inferior steepening on corneal topography.
    c. keratometry readings >47 D.
    d. residual stromal bed <250 µm.
33. Proper management of diffuse lamellar keratitis (DLK) includes all the following, except:
    a. mild DLK (mild peripheral cellular infiltration) is treated with an increase in topical steroids and close follow-up.
    b. moderate DLK (moderate peripheral and central cellular infiltration with an undulating pattern) is treated with an injection of steroid beneath the flap done at the slit lamp.
    c. severe DLK (dense, undulating central and peripheral cellular infiltration, associated with decreased vision and photophobia) with a possible infiltrate should be treated with flap lift, scrapings to remove inflammatory material, and for smears and cultures, interface antibiotics and steroids, postoperative steroids and antibiotics, and close follow-up.
    d. oral steroids may be helpful in severe DLK.
34. Appropriate treatment options for epithelial ingrowth include all of the following, except:
    a. follow mild epithelial ingrowth not affecting vision.
    b. lift the flap, remove epithelium from the stromal bed.
    c. lift the flap, remove all of the interface epithelium, and suture the flap.
    d. lift the flap, remove all of the interface epithelium, and apply fibrin glue to the flap margin.
35. Regarding intraocular pressure (IOP) and LASIK, all of the following are true, except:
    a. the IOP should not be measured for at least 1 month after LASIK due to the risk of flap dislodgement.
    b. the measured applanation IOP is probably less than the true IOP after LASIK for myopia.
    c. the central applanation IOP measurement can be falsely low (e.g., 3 to 5 mmHg) if there is a fluid cleft between the stromal bed and the LASIK flap.
    d. elevated IOP after LASIK can appear identical to diffuse lamellar keratitis (DLK) at the slit lamp.
36. Proper management of ocular surface diseases such as dry eyes and blepharitis in a LASIK patient includes all of the following, except:
    a. patients with significant dry eye symptoms or epithelial punctate fluorescein staining should undergo further evaluation (e.g., with Schirmer test, tear break-up time) prior to LASIK.
    b. patients with dry eye signs and symptoms should be treated to decrease the signs and symptoms prior to final evaluation for LASIK.
    c. topical cyclosporine drops are often helpful pre- and postoperatively for dry eye signs and symptoms.
    d. dry eye symptoms are worse after LASIK for 3 to 6 months, but always return to baseline by 12 months.
37. Which of the following statements about glare, haloes, and night vision symptoms after LASIK is not true?
    a. Risk factors for glare, haloes, and night vision symptoms after LASIK are often considered to include high myopia, high astigmatism, and large pupils.
    b. Pupil size in normal and dim illumination should be measured prior to LASIK.
    c. Topical Brimonidine and low-dose pilocarpine are helpful in reducing glare, haloes, and night vision symptoms in some patients.
    d. Patients with dim pupil diameters >7 mm should not undergo LASIK.
38. A 46-year-old woman had bilateral LASIK for myopia 1 month ago. The preoperative refraction in the dominant OD was −8.00 + 1.00 × 90° and −8.50 + 1.00 × 90° OS. Postoperative visual acuity was 20/20 OD with an initial cycloplegic

refraction of −0.25, and 20/40 OS with a cycloplegic refraction of −1.50 + 1.25 × 35°. The patient is unhappy, complaining of difficulty seeing at distance and near when she covers her right eye. The most appropriate treatment would be:

a. retreatment using laser following a flap relift.
b. Limbal relaxing incision (LRI).
c. custom retreatment.
d. offer glasses.

39. The patient from Question 38 returns 6 weeks later. The cycloplegic refraction is stable. The most appropriate retreatment would be:

a. retreatment using the laser following a flap relift.
b. Limbal relaxing incision (LRI).
c. custom retreatment.
d. nothing.

40. A 30-year-old man had LASIK OD to correct a preoperative cycloplegic refraction of −1.25 + 1.75 × 160°. His preoperative best-corrected visual acuity (BCVA) was 20/20. Postoperatively, his visual acuity was 20/25–. There were no microstriae, the flap was well centered, and there was no debris. Over the next 3 months, manifest and cycloplegic refraction varied by small amounts, but visual acuity could be corrected only to 20/25. Wavefront measurements showed a minimal spherical aberration, modest amounts of coma, and trefoil. Refraction over a gas-permeable contact lens improved the vision only slightly. The patient was adamant about doing something. The most appropriate retreatment would be:

a. surface retreatment using custom treatment.
b. surface retreatment with mitomycin.
c. conventional laser retreatment.
d. LASIK custom retreatment, if improvement with PreVue lens.

41. LASIK surgery is being planned OD for a patient with myopic astigmatism using conventional excimer laser treatment on the VISX STAR S4 platform. The cycloplegic and manifest refractions are similar at −4.00 + 2.00 × 60° and are stable. The patient has a 7.0-mm pupil in dark illumination and corneal pachymetry of 558 µm. The examination is otherwise normal. A reasonable estimate of the ablation depth is:

a. 53 µm.
b. 35 µm.
c. 60 µm.
d. The ablation depth cannot be estimated until the nomogram adjustment is determined.

42. Which of the following can the surgeon change when designing a CustomVue treatment?

a. Axis of astigmatism
b. Magnitude of astigmatism
c. ±1.0 D sphere
d. ±10% nomogram adjustment

43. Which of the following is true?

a. The root-mean-square (RMS) value determines whether or not a patient is a candidate for CustomVue.
b. The percent preoperative higher order aberration (HOA) determines whether or not a patient is a candidate for CustomVue.
c. The RMS value is an overall assessment of the HOAs.
d. Mixed astigmatism cannot be treated with the VISX CustomVue platform.

44. Which of the following statements is false?

a. Hyperopic treatments should result in a postoperative keratometry value of <49 D.
b. The lower limit keratometry value in a myopic treatment is 32 D.
c. Iris registration will passively track the cyclorotation of the eye during a CustomVue treatment.
d. The ablation zone can be enlarged out to 9.0 mm with CustomVue.

45. Which of the following statements best describes a patient who is not a good candidate for a CustomVue procedure?

a. The patient has an average keratometry reading of 40.5 D OU.
b. The patient has a high percentage of vertical coma and spherical aberration on the preoperative WaveScan screening.

c. The patient is hyperopic and the cycloplegic refraction and WaveScan refraction correlate and indicate at least 1.5 D of latent hyperopia.
d. The scotopic pupil measures 8.5 mm.

46. A 52-year-old patient presents for LASIK consultation. His refraction is +5.00 D in both eyes with a best-corrected visual acuity (BCVA) of 20/20 in each eye. The anterior segment appears normal. Provided he understands the risks of surgery and the rest of the examination is normal, the potential surgical options include all of the following, except:
a. hexagonal keratotomy
b. phakic IOL
c. clear lens exchange
d. photorefractive keratectomy (PRK)

47. Bioptics is a term that refers to:
a. a specialized multifocal implant.
b. a piggyback lens implant system in which one implant is placed in the ciliary sulcus and one is placed in the capsular bag.
c. the use of a long-lasting collagen contact lens after cataract surgery.
d. LASIK surgery performed some time after a phakic IOL has been implanted in order to refine the visual outcome.

48. Which of the following statements about Intacs is true?
a. Another name for Intacs is the "living contact lens."
b. Intacs can be used to treat ectasia after LASIK or photorefractive keratectomy (PRK).
c. Intacs can be used to treat progressive effect after radial keratotomy.
d. Intacs are inserted at the limbus.

49. Conductive keratoplasty is a procedure performed with a(n):
a. holmium-YAG laser
b. argon laser
c. femtosecond laser
d. radiofrequency probe

50. The effect of the toric IOL is:
a. short-lived.
b. dependent on accurate placement in the axis of the (+) cylinder in the refraction.
c. dependent on accurate placement in the axis of the (+) cylinder on keratometry.
d. dependent on accurate placement 90° away from the axis of the (+) cylinder in the refraction.

51. When using the Hansatome keratome with the 160 head,
a. the flap is typically within 10 µm of 160 µm.
b. the flap is typically thinner than 160 µm.
c. the flap is typically thicker than 160 µm.
d. the flap is thicker in the middle than it is in the periphery.

52. When using the Moria M2 keratome with the 130 µm head,
a. the flap is typically within 10 µm of 130 µm head.
b. the flap is typically thicker than 130 µm.
c. the flap is typically thinner than 130 µm.
d. the flap is thicker in the middle than it is in the periphery.

53. The primary reason intraocular lens calculations are less accurate in eyes that have had previous keratorefractive surgery is:
a. Current keratometers, topographers, and tomographers do not accurately measure the central corneal power.
b. The axial length measurements are not as accurate.
c. Central epithelial hypertrophy (after myopic treatments) and thinning (after hyperopic treatments) adversely affect the accuracy of corneal curvature measurements.
d. Superficial punctate keratopathy interferes with the accuracy of corneal curvature measurements.

54. A 61-year-old man presents 10 years after uncomplicated LASIK with −3 D of myopia complaining of a slow decrease in his uncorrected distance vision over the past year. He has no reading vision complaints. He is most likely to have:
a. corneal ectasia causing irregular myopic astigmatism.
b. progressive worsening of his punctate keratopathy due to dry eyes.
c. development of a nuclear sclerotic cataract causing a myopic shift.
d. an early epiretinal membrane.

55. Regarding intraocular lens calculations after keratorefractive surgery:
    a. The clinical history method just requires stable postoperative manifest refraction and current manifest refraction and the current keratometry readings.
    b. The hard contact lens method is the most accurate, but requires preoperative keratometry and manifest refraction data.
    c. The IOL power calculations are more accurate after LASIK than after photorefractive keratectomy (PRK).
    d. The online IOL Calculator allows the surgeon to input all available data, and the program will calculate IOL powers based on a variety of methods, from which the surgeon can select.
56. Which statement about corneal collagen cross-linking treatment of post-LASIK ectasia is correct?
    a. The main effect is a high temperature.
    b. The main effect is photochemical.
    c. The main effect is the thickening of Bowman layer.
    d. The main effect is an increase in keratocyte density.
57. Which of the following is the minimum acceptable stromal thickness to avoid a cytotoxic risk to the endothelium from collagen cross linking?
    a. 250 µm
    b. 350 µm
    c. 400 µm
    d. 450 µm
58. Which of the following are not typical risk factors for the development of post-LASIK ectasia?
    a. High myopia (>8 D)
    b. A thin residual stromal bed (RSB)
    c. Preexisting forme fruste keratoconus
    d. A thin LASIK flap
59. Optical coherence tomography (OCT) imaging is helpful in the screening of patients prior to refractive surgery because it can perform all the following functions, except:
    a. detect areas of corneal steepening.
    b. detect areas of corneal stromal thinning.
    c. detect areas of corneal epithelial thinning.
    d. perform corneal pachymetry profiles.
60. A 30-year-old patient presents with blurred vision OS. The past ocular history is significant for previous LASIK OS surgery performed elsewhere 10 years earlier. With cycloplegic refraction of −1.50 D OS the patient is 20/20. Corneal topography is normal and the corneal pachymetry shows a corneal thickness of 470 µm. Just before proceeding with OS, an retreatment, an optical coherence tomography (OCT) is done and shows the flap thickness to be 240 µm and the residual stromal bed (RSB) to be 230 µm. The most appropriate treatment would be to:
    a. lift the flap and perform laser treatment on the bed
    b. perform radial keratotomy.
    c. do a clear lens extraction.
    d. perform photorefractive keratectomy (PRK) on the flap.
61. Subepithelial corneal haze developed years after uneventful photorefractive keratectomy (PRK) following a traumatic corneal abrasion. The event described below that contributed the most to trigger the development of haze was:
    a. The long period of time after original surgery.
    b. Corneal trauma without injury of corneal basement membrane.
    c. Corneal trauma with injury of corneal basement membrane.
    d. The original surgery was performed without mitomycin-C (MMC).
62. In which condition would you prefer LASIK over surface treatment?
    a. Dry eyes
    b. Deep set eyes
    c. Lattice dystrophy
    d. Surfer and smoker
63. In which of the following situations can the surgeon proceed with LASIK?
    a. Shredded flap
    b. To paracentral buttonhole
    c. Irregular stromal cut
    d. Epithelial defect

64. Considering Case 90 as described, the major factor contributing to post-LASIK corneal ectasia was:
    a. The use of a mechanical microkeratome.
    b. The planned flap thickness associated with the laser ablation.
    c. The actual flap thickness associated with the lasered ablation.
    d. The amount of tissue to be removed to correct the patient's ametropia.
65. The following is not an advantage of the femtosecond laser for flap creation.
    a. Actual flap thickness is closer to intended flap thickness.
    b. Flap diameter can more easily be controlled.
    c. Corneal ectasia does not occur.
    d. The flap quality is not dependent on corneal contour.
66. The added risk of LASIK in a diabetic patient does not include which of the following:
    a. The refraction may not be stable.
    b. The epithelium might be friable.
    c. Increased intraocular pressure (IOP) may increase the risk of retinal ischemia.
    d. There is an increased risk of neovascular glaucoma due to LASIK.
67. A busy executive is returning from Europe on Friday and leaving on an important trip to Brazil the following Wednesday for 2 weeks. She would like to have her LASIK surgery on Monday between her two trips. Which of the following is true?
    a. If you don't accommodate patients' work schedules, you will not develop a refractive practice.
    b. As a refractive surgeon, you often have to compromise to get cases done.
    c. The best way to develop a great reputation is to provide outstanding care and not compromise on excellent preoperative, intraoperative, and postoperative care.
    d. Print and radio ads are far more important for marketing than patient-to-patient referrals.
68. Diffuse lamellar keratitis (DLK) following femtosecond laser LASIK surgery is usually caused by:
    a. excessive energy settings on the femtosecond laser.
    b. a large treatment zone with the excimer laser.
    c. a thin preoperative cornea.
    d. slightly more challenging flap elevation.
69. Which of the following statements about epithelial ingrowth after LASIK is false?
    a. Epithelial ingrowth is more likely to occur after flap lift retreatment.
    b. Increasing steroid postoperatively can reduce the risk of epithelial ingrowth.
    c. Epithelial ingrowth can lead to flap melt and can cause blurred vision.
    d. Ingrowth should be treated if it has progressed and is >2 mm from the flap edge.
70. Which of the statements about diffuse lamellar keratitis (DLK) is untrue?
    a. It is difficult to treat and usually results in severe vision loss.
    b. It usually responds to frequent topical steroids especially in the early stages.
    c. It may result in a poor refractive result even when inflammation completely clears.
    d. An early flap lift and gentle scrape of the stromal bed and flap can effectively clear the cornea and may prevent vision loss.

Answers

1. **Answer (d).** To obtain the correction corresponding to the cycloplegic refraction, a nomogram-adjusted correction is entered into the VISX laser. The larger the myopic correction and the older the patient, the greater the reduction in the myopic power of the sphere. The 250-µm minimum is a rule of thumb only. It has not been proven and some patients may require a thicker residual bed to prevent ectasia. LASIK is not always safer than photorefractive keratectomy (PRK). In the presence of epithelial basement dystrophy, PRK may be the preferred refractive procedure.

2. **Answer (b).** A central thickness of 635 µm is thicker than normal. However, the endothelium may be normal. A normal cell count, cell shape, and size as measured with specular microscopy would suggest that endothelial dysfunction is not the cause of the thicker-than-normal cornea. If the surgeon felt the thick cornea was due to endothelial dysfunction, the patient would not be a candidate for LASIK surgery. The other tests would not help evaluate the corneal endothelium.
3. **Answer (a).** It is best to abort the laser surgery at this point, because the full laser treatment cannot fit under the incomplete flap. It would be unwise to attempt to recut a deeper flap during the same surgery. Photorefractive keratectomy (PRK) over a flap is associated with an increased risk of stromal haze.
4. **Answer (d).** Most microkeratomes have several microkeratome heads or spacer plates to insert to help create thinner or thicker flaps. Studies have also demonstrated that the faster the microkeratome pass, the thinner the flap that will be created. Other studies have shown that the average corneal flap is thinner in the second eye than the first eye, presumably due to the microkeratome blade getting duller after the first pass.
5. **Answer (d).** There are no published studies that can confirm the absolute safety of maintaining a residual stromal bed (RSB) of 250 µm. There are many published cases of ectasia in patients with an RSB of >250 µm, and cases from the early days of LASIK surgery with <250 µm of RSB that have not developed postoperative ectasia. The RSB is more accurate when calculated using the non–nomogram-adjusted refraction and intraoperative pachymetry. It is believed that several factors might influence the development of ectasia including a subclinical keratoconus, wider ablation diameters, and individual patient healing factors. Please read the following excellent review article on this subject: Binder PS. Ectasia after laser in situ keratomileusis. *J Cataract Refract Surg*. 2003;29:2419–2429.
6. **Answer (c).** The Moria microkeratomes must utilize the high-vacuum setting during the actual creation of the LASIK flap. The period of high vacuum is when the optic nerve is most vulnerable to damage, especially if the patient has underlying glaucoma. The low-vacuum setting should not cause optic nerve damage. It is utilized for maintaining control of the globe during laser ablation. The low-vacuum setting does not have any effect on the flap thickness or postoperative dry eye syndrome.
7. **Answer (a).** The flap thickness varies with each microkeratome head, and even from patient to patient with the same head. Studies have demonstrated that there can be significant variability in flap thickness with each cut. The stromal beds are equally smooth with the manual and automated microkeratomes. Flap complications can occur with any type of microkeratome. One of the main advantages of the manual microkeratome is the ability to vary the translation speed and thereby create thinner or thicker flaps.
8. **Answer (b).** Thinner corneas result in thinner flaps. Thicker corneas result in thicker flaps. This was verified when six different microkeratomes were studied to determine the depth and size of the flap that was cut. A flatter cornea results in a smaller flap for the same size ring, and a steeper cornea results in a larger flap for the same size ring.
9. **Answer (a).** The femtosecond laser has many advantages over the blade microkeratome. Because the laser is created using applanation rather than by drawing corneal tissue within a suction ring, it is less dependent on corneal contour. The risks of buttonhole and free-flap that might be seen with a steep cornea or flat cornea, respectively, are not a concern with the laser. The surgeon has more control over the flap diameter with the laser. Remember with the blade microkeratome flap diameter will depend on internal ring diameter and corneal contour. Peripheral neovascularization can lead to problematic bleeding when a blade is used to

create a flap. This is less of a problem with the laser. The overall time to create a laser flap when you add in the application of suction is not much different than with the blade.

10. **Answer (b).** The Bansal-Kay nomogram adjustment is dependent on the age of the patient. It is calculated based on the spherical equivalent. The adjustment, once calculated, is subtracted from the sphere. Nomogram adjustment is not dependent on corneal contour. Always use the non-nomogram adjusted correction to calculate ablation depth
11. **Answer (a).** A single-piece microkeratome does not require a higher elevation of intraocular pressure (IOP) than a multiple-piece microkeratome. A single-piece microkeratome can offer the advantage of creating either a nasal or superior-hinged flap without causing a prolonged period of elevation of IOP that can result from time necessary to assemble the microkeratome on the eye. With all microkeratomes the assembly must be verified and the IOP must be checked prior to creation of the corneal flap.
12. **Answer (b).** When a small epithelial defect is noted after the LASIK flap has been created on the first eye, it is not necessary to abort the LASIK procedure. The flap should be replaced after the laser treatment is performed and carefully repositioned. After an adequate period of time has transpired and the flap is in position, a bandage contact lens should be placed on the eye and topical prednisolone acetate should be started.

    An intraoperative epithelial defect can result in diffuse lamellar keratitis (DLK) during the early postoperative period. It is important for the surgeon to recognize this potential complication and initiate topical prednisolone acetate early. Because the presence of a bandage contact lens and an epithelial defect put the patient at risk for possible bacterial keratitis, it is necessary to concomitantly treat the patient with a broad-spectrum antibiotic also.

    For the second eye, care should be taken to avoid an epithelial defect. A methylcellulose-based lidocaine jelly can be placed on the cornea prior to placement of the microkeratome, and the microkeratome should be lubricated with a glycerin-based sterile artificial tear solution while it is advancing forward. After the microkeratome has advanced forward completely, suction can be released and the microkeratome can be gently removed, allowing the flap to slide out of the microkeratome without the epithelial trauma induced by reversal of the microkeratome head.
13. **Answer (b).** Extreme caution is advised in communicating the proper concentration and in accurate compounding of the MMC. The two concentrations of 0.02% and 0.2 mg/mL are equivalent.
14. **Answer (b).** Steep corneas, particularly with keratometry readings >47.00 D, are more likely to buckle centrally during the microkeratome pass, creating a buttonhole. Buttonholes can occur in corneas with keratometry readings <47.00 D, but are less likely. Do not proceed with the laser ablation if a buttonhole is detected in the ablation zone.
15. **Answer (d).** The Orbscan can provide a pachymetric map of the cornea. The values should not be used in calculating ablation depth. It provides elevation data and is useful in identifying early keratoconus. The Pentacam topography system uses Scheimpflug photography.
16. **Answer (d).** The Zyoptix (Bausch & Lomb) system for custom LASIK is not currently approved for treatment of hyperopia, mixed astigmatism, or myopic treatment above −7.00 D. It is approved for myopia with astigmatism where the astigmatic component is not > −3.00 D and the spherical equivalent does not exceed −7.50 D.
17. **Answer (a).** The Technolas 217 laser utilizes an active tracking system, but does not track cyclotorsional movements. While it has a customizable optical zone size, the blend zone size cannot be customized. The system is FDA-approved for hyperopia with or without astigmatism.

18. **Answer (c).** Mitomycin-C (MMC) inhibits scar formation because of its effect on DNA synthesis. It is derived from *Streptomyces caespitosus*, a fungus, and is not an antifungal or anti-inflammatory agent.
19. **Answer (c).** Haze associated with photorefractive keratectomy (PRK) is more common in deeper ablations. It is less likely to occur with modern lasers, but it is unpredictable. In general, it is less common in low myopic ablations, but the incidence is probably more closely related to ablation depth than to the degree of myopia. PRK haze can occur with LASEK.
20. **Answer (c).** Most cases of clinically significant diffuse lamellar keratitis (DLK) have been a result of laser settings that were too powerful, resulting in interface inflammation. While pretreatment with topical steroids is important to some, it is less important than making sure the raster energy and side cut energy are properly set. Nonsteroidal agents and doxycycline have not been shown to be important components in prevention of DLK.
21. **Answer (a).** Although it has been suggested that IntraLase causes fewer dry eye problems postoperatively, a patient with severe dry eye should not undergo LASIK. In those patients with moderate dryness, Restasis and punctal plugs may control the condition and allow for LASIK to be performed safely. Despite the ability of an IntraLase flap to create consistently thinner flaps than a blade microkeratome, the −12.00 D myope would not be a good candidate for LASIK with either technique—the cornea is too flat and the correction needed is too great. A young healthy male has an excellent chance to have a good flap with a standard microkeratome. However, in a postmenopausal woman, the incidence of epithelial sliding with blade LASIK is much higher than with the IntraLase, and as such would be the preferred method of flap creation.
22. **Answer (c).** A small palpebral fissure can make it difficult to obtain proper suction. At times suction can be better acquired by not using a speculum. Multiple attempts at achieving suction may result in the conjunctiva becoming chemotic with adequate suction becoming impossible to obtain. An occasional faulty suction ring may need to be replaced. Brimonidine (e.g., Alphagan) drops may actually help obtain better suction because it can quiet the conjunctiva, but should be avoided nonetheless because of the increased risk of flap displacement postoperatively.
23. **Answer (d).** The IntraLase creates a lamellar flap via the process of photodisruption.
24. **Answer (a).** Photorefractive keratectomy (PRK) cannot be performed with an IntraLase. Stromal channels can be made with the laser for insertion of intrastromal ring segments. The laser has also been used experimentally for corneal trephination in penetrating keratoplasty and deep lamellar dissections for the deep lamellar endothelial keratoplasty (DLEK) procedure.
25. **Answer (d).** It is imperative that a patient refrain from contact lens use long enough for the cornea to return to its original shape. Although 1 to 2 weeks for a soft lens and 1 month for a gas-permeable contact lens is usually sufficient time for the cornea to resume its normal shape, this reversal of the contact lens effect can be quite variable. Therefore, the surgeon should wait until refractive and topographic stability can be documented before attempting refractive surgery.
26. **Answer (b).** It is not uncommon for the cycloplegic refraction (CR) to differ from the manifest refraction by 0.75 D in a 26-year-old myope. Although there is always a risk of ectasia in every LASIK patient, having an adequate corneal thickness and normal topography and Orbscans probably portends a low risk of ectasia despite the high myopic correction needed. Astigmatism measured by keratometry is usually slightly greater in magnitude than astigmatism measured in a manifest refraction. The 0.50 D difference in this case is within the expected range. To fully correct this patient's myopia, approximately 9 D of refractive correction is needed. Each

diopter of correction will flatten the cornea approximately 0.8 D. Therefore, this patient's cornea will be flattened approximately 7.25 D. Her average preoperative keratometry was 41.00 D; thus her preoperative keratometry will be 33.75 D, which is too flat. Corneas with an average corneal power <35 D have a degradation of vision due to the loss of the normal prolate corneal shape, and this makes this patient a poor candidate for LASIK.

27. **Answer (c).** Loose epithelium after the microkeratome pass may mean that the patient has an occult corneal epithelial basement membrane dystrophy. This can lead to a number of postoperative problems, including diffuse lamellar keratitis (DLK), epithelial ingrowth, delayed epithelialization of the cornea, and irregular astigmatism secondary to an irregular epithelial surface. Although the surgeon must anticipate these problems, continuing with the planned LASIK procedure and then applying a bandage contact lens is still the best treatment option. The chance for DLK and epithelial ingrowth exists once the flap is created whether the laser treatment is applied or not. Performing photorefractive keratectomy (PRK) over a freshly cut laser flap can lead to both DLK and intense corneal haze. Amputation of the flap is excessive and not necessary. Therefore, continuing with the planned ablation under the LASIK flap is the best option in this difficult situation. The ideal scenario would be to recognize the epithelial basement membrane abnormality preoperatively and treat the patient with PRK instead of LASIK.
28. **Answer (b).** Blanching of conjunctival vessels is not a sign of increased intraocular pressure (IOP). The surgeon should use all of the other clues to be certain adequate suction exists prior to creating the flap with the microkeratome. Some surgeons use finger tension instead of a tonometer; however, finger tension may not be as accurate. Surgeons should listen for a hissing sound, which indicates lack of proper suction. If the machine does not indicate adequate suction is achieved, it isn't. However, the converse is not true. Just because the machine indicates adequate suction, it may not actually exist. The suction port may be blocked by conjunctiva, causing the machine to indicate adequate suction without necessary intraocular pressure (IOP) elevation. This scenario is termed *pseudosuction*.
29. **Answer (d).** Free caps need to be recognized immediately, prior to removing the microkeratome from the surgical field, to have the best chance of locating the free cap. In the event of a free cap, the cap needs to be found and stored in a safe place until it is needed. It can be placed epithelial side down on a moist 4 × 4 gauze pad or on the conjunctiva, ideally not hydrating the stroma. If the epithelial marks are fading, they can be augmented at this time. These marks are critical to correct orientation of the cap when it is replaced on the stromal bed. Once the cap is located, remarked if necessary, and safely stored, the surgeon needs to decide whether the laser ablation can proceed. Generally, if the stromal bed is uniform, well centered on the pupil, and large enough to accommodate the intended ablation, the laser treatment can proceed. The cap is then placed back on the stromal bed, being very careful to line up the epithelial marks. If the marks were placed asymmetrically, then the cap cannot be placed upside down. The interface is gently irrigated and the cap allowed to adhere. Some surgeons will place one to four interrupted sutures to secure the cap. Most will simply place a bandage soft contact lens on the eye. Corneas with keratometry readings flatter than approximately 40 D are thought to be at greater risk of a free cap. Larger suction rings should be used in eyes with lower keratometry readings. The femtosecond laser is advantageous in patients with flat corneas to reduce the risk of free cap.
30. **Answer (c).** Older patients, patients whose fellow eye has had an epithelial adherence issue, those with anterior basement membrane dystrophy, and those with a history of recurrent erosions are at

greater risk for epithelial loosening or defects during LASIK. The type of refractive error probably plays no role.

31. **Answer (c).** Once an epithelial irregularity, such as a loosening or frank defect, is noted in the flap during LASIK, it is very important to determine the integrity of the flap stroma. If the flap stroma is normal and the bed is normal, then laser ablation can proceed in this eye. If a large epithelial irregularity is noted in the first eye, it is often best not to proceed with surgery on the fellow eye the same day. Fellow eyes have a similar tendency to epithelial irregularities. Prolonged visual rehabilitation may be required for eyes with epithelial abnormalities. A bandage soft contact lens is often used for comfort and to aid in epithelial healing in the presence of epithelial loosening or a defect. The lens is usually kept in for 3 to 7 days. Close follow-up is warranted in these patients because they are at higher risk for postoperative problems such as diffuse lamellar keratitis (DLK) and epithelial ingrowth. The Hansatome Zero Compression head or the femtosecond laser may both reduce the risk of epithelial damage during LASIK surgery.
32. **Answer (a).** Corneal thinning that is greater in the inferior periphery than in the center is indicative of an abnormal cornea and predisposes the refractive patient to ectasia. High keratometry readings, asymmetric inferior steepening, and thin residual stromal bed (RSB) are all risk factors for ectasia after LASIK.
33. **Answer (b).** Mild diffuse lamellar keratitis (DLK) can be treated with increased topical steroids or close follow-up, so it can be treated promptly if it worsens. Moderate DLK is usually treated with increased topical steroids, for example, every 1 to 2 hours, and close follow-up. Severe DLK is usually treated with either hourly topical steroids or flap lift with or without scraping of the bed to remove inflammatory debris. If an infiltrate is present or suspected, the flap should be lifted, the bed scraped for smears and cultures, and the interface irrigated with antibiotics. Depending on the level of suspicion for infection, the eye should be treated with antibiotics and steroids and seen later the same day or the following day. Some doctors use a short tapering dose of oral steroids in moderate to severe cases of DLK. Injections of steroid are not generally used in the management of DLK.
34. **Answer (b).** Epithelial ingrowth can usually be followed unless it is affecting vision or the health of the flap. When removal is required, it needs to be removed from the stromal bed and the underside of the flap. A sharp blade (e.g., an Alcon 67 or Beaver #15) or a semi-sharp (e.g., Tooke) knife can be used to remove the epithelium. Care needs to be taken not to damage the flap when the epithelium is removed from its underside. In cases of primary epithelial ingrowth, flap lift and epithelial removal from both sides of the interface are probably adequate. In cases of recurrent epithelial ingrowth, simple flap lift and scrape can be performed, or sutures or fibrin glue can be used to secure the flap edge in an attempt to prevent recurrent ingrowth.
35. **Answer (a).** The cornea can be gently applanated on postoperative day (POD) 1 if necessary. However, the intraocular pressure (IOP) does not typically need to be measured on POD 1 and is typically deferred unless an abnormal IOP is suspected. Postoperative IOP measurements are routinely performed beginning at the 1-week visit. Thinner corneas tend to give falsely low applanation IOP measurements, and the thinner the cornea, the lower the measurement. Elevated IOP after LASIK, often a steroid response, can cause a diffuse lamellar keratitis (DLK)-like picture, which does not respond to steroids and is made worse by steroids. Elevated IOP can also cause a fluid cleft between the stromal bed and the flap. Applanation over this fluid cleft will give an extremely low IOP measurement, masking the true problem. Either a peripheral applanation or a peripheral TonoPen measurement will usually reveal the high IOP.

36. **Answer (d).** Many patients develop contact lens intolerance due to dry eyes and seek refractive surgery. Patients with dry eyes can have excellent results after LASIK, but they are at increased risk for slower visual rehabilitation and temporary to prolonged increased dry eye symptoms. Patients with signs and symptoms of ocular surface disease should be evaluated preoperatively for conditions such as dry eyes and blepharitis with tests such as Schirmer test, tear break-up time, and lissamine green or rose bengal staining. They should be treated for any existing conditions to optimize the ocular surface prior to LASIK. A healthier surface should improve the accuracy of the refraction and aid in postoperative healing. Artificial tears, topical cyclosporine 0.05%, and punctal occlusion can be helpful in many patients both pre- and postoperatively. While most patients are troubled by worse dry eye–type symptoms for a maximum of 3 to 6 months after LASIK, some patients are bothered for years. Surface ablation, such as photorefractive keratectomy (PRK), tends to induce fewer dry eye–type symptoms than LASIK.
37. **Answer (d).** While the exact relationship of pupil size and glare, haloes, and night vision symptoms is not known, many surgeons believe that large pupils increase the risk, at least in some patients. Consequently, pupil size should be measured preoperatively, and if the pupils are large (generally considered to be greater than about 6.5 mm in the dark), patients should be counseled that they may be at increased risk for increased glare, haloes, and night vision symptoms compared to preoperatively. This is also true for patients with high myopia and/or high astigmatism. All patients should be told that they could have worse glare, haloes, and night vision symptoms after LASIK surgery. Most surgeons do not have an absolute cutoff for pupil size. Topical Brimonidine (e.g., Alphagan) and low-dose pilocarpine (1/2% to 1/32%) can be helpful in reducing glare, haloes, and night vision symptoms. It can be used several times a day or just before driving home in the evening.
38. **Answer (d).** This patient had a large correction. No retreatment should be planned until at least 3 months to allow adequate time for full recovery. In addition, no retreatment should be performed until two cycloplegic refractions, at least 1 month apart, are the same.
39. **Answer (b).** This patient is in the presbyopic age group, and the complaints are in the nondominant eye. She has a spherical equivalent of about −1.00. A limbal relaxing incision (LRI) would eliminate the oblique astigmatism and convert her to monovision at little risk. If she continued to be unhappy, a laser retreatment could still be performed. One could argue that a trial fit with a contact lens would determine whether she would like monovision, but a conventional soft lens would not give her good enough vision to make a good decision.
40. **Answer (d).** In this case, the inability to improve vision with a contact lens in a patient with a normal cornea indicates that surface irregularities were not likely a cause of the decreased vision. Under this circumstance, a surface treatment would be of questionable visual value with a potential for haze, regardless of whether mitomycin was used. Conventional retreatment under the flap would also be of questionable value because simple refraction did not improve the vision. A wavefront measurement is taken with the VISX WaveScan analyzer and can be used to cut a PreVue lens. The PreVue lens allows the doctor and the patient to reasonably decide whether custom retreatment would be potentially beneficial. In the absence of clear subjective improvement with the PreVue lens, the best course would be continued observation.
41. **Answer (a).** Given the pupil size of 7.0 mm, a 6.5-mm treatment zone with a blend zone would be used. The per-diopter ablation depth for a 6.5-mm treatment zone is 15 µm/D. The spherical equivalent of the cycloplegic refraction

is 3 D. So the ablation depth would be 45 µm plus an additional 8 µm for the blend for a total estimate of 53 µm. Always use the non–nomogram-adjusted refraction to estimate ablation depth. The laser computer should not be used for the estimate if a nomogram-adjusted treatment is entered into the computer.

42. **Answer (d).** The software allows for a 10% nomogram adjustment. Neither the axis nor the magnitude of the cylinder can be changed. When the nomogram adjustment is changed, this changes the entire treatment by whatever percent is entered. The software also gives the surgeon the ability to change the magnitude of the sphere by ±0.75 D.
43. **Answer (c).** The RMS value is a number that is calculated to determine the overall higher order aberrations (HOA) of the eye. This number is not used to determine treatment. It can be used to observe the net result of HOA changes, which occur as a result of surgery. VISX is FDA-approved for custom treatment of mixed astigmatism.
44. **Answer (b).** The postoperative keratometry value should be kept at 35 D or above in myopic treatments. The surgeon should attempt to calculate this by multiplying the total spherical equivalent to be treated by 0.7 or 0.8 and subtract that value from the preoperative keratometry value. This will give the surgeon a rough estimate of the final keratometry.
45. **Answer (c).** When there is a significant difference in the manifest and the cycloplegic refractions in hyperopic patients, these patients can be difficult to treat with or without CustomVue. The significant amount of latent hyperopia makes it hard to determine the correct refractive error to treat. An attempt should be made to see if the patient can relax into the increased amount of hyperopia with either spectacles or contact lenses. If they can tolerate the increased amount of hyperopia and the WaveScan refraction is consistent with the latent amount, then a WaveScan treatment can be performed. If the WaveScan is more consistent with the refractive error that does not reflect the latency, then a WaveScan treatment should not be performed.
46. **Answer (a).** Hexagonal keratotomy has been abandoned due to lack of predictability and safety. Provided the anterior chamber is deep enough, a phakic IOL could be considered. Clear lens exchange is an option even if the anterior chamber angle is somewhat shallow, because the surgery will lessen the risk of angle closure by deepening the anterior chamber. A multifocal or accommodating IOL should be considered to preserve accommodation. Of the keratorefractive techniques, photorefractive keratectomy (PRK) is a better option than LASIK because there is less regression after PRK; therefore, the treatment will not need to exceed approved levels. The accuracy of keratorefractive surgery falls off at this level of hyperopia, and the patient should be warned of the potential loss of best-corrected visual acuity (BCVA).
47. **Answer (d).** Bioptics has come to mean the combination of refractive surgery techniques in order to maximize the visual function. Bioptics extends the limits of refractive surgery without excessive treatment in the cornea.
48. **Answer (b).** Intacs can be used to treat low myopia. They can improve best-corrected visual acuity (BCVA) and improve contact lens tolerance in some keratoconus patients; and they can also be used to treat ectasia after LASIK or photorefractive keratectomy (PRK). They cannot be used to treat hyperopia, which is the consequence of progressive effect. They are not inserted at the limbus, but within a 7-mm-diameter ring around fixation. The "living contact lens" refers to epikeratoplasty.
49. **Answer (d).** Conductive keratoplasty is performed with a radiofrequency probe that causes shrinkage of tissue even in the deep stroma. The femtosecond laser is used to create a LASIK flap. The holmium-YAG laser has been used in a contact and non-contact device for hyperopic treatment, but the results were transient. The argon laser is not used to correct hyperopia.

50. **Answer (c).** The effect of the toric IOL is permanent provided the lens does not rotate. It is dependent on accurate placement in the axis of the plus cylinder on keratometry. Because the refraction is based in part on lens-induced astigmatism, it should not be used in the calculation or alignment of the lens.
51. **Answer (b).** A flap created with the Hansatome 160-µm plate is typically thinner and not thicker than 160 µm. The flap is typically 120 to 130 µm in thickness. The meniscus flap is thicker in the periphery and thinner in the center.
52. **Answer (b).** A flap created with the Moria M2 microkeratome using a 130-µm plate is typically thicker than 130 µm. The variance is typically > ±10 µm. The flap is thicker in the periphery than it is in the middle.
53. **Answer (a).** Current keratometers, topographers, and tomographers make assumptions that do not hold true after the corneal curvature is reshaped with the excimer laser and therefore do not accurately measure the central corneal power, although newer generation tomographers, such as Scheimpflug imagers and optical coherence tomography (OCT), are getting better and better at it. The axial length can still be accurately measured after LASIK and photorefractive keratectomy (PRK). Changes in epithelial thickness, as long as they are stable, do not affect the accuracy of corneal curvature measurements. Superficial punctate keratopathy can affect the corneal curvature measurements in any eye, whether it has had refractive surgery or not.
54. **Answer (c).** A myopic shift after LASIK or photorefractive keratectomy (PRK) can be due to a number of causes. Regression of effect from slight steepening of the cornea usually occurs within the first few years after surgery, but can occur at any time. Corneal ectasia generally causes irregular astigmatism and poor uncorrected distance and reading vision. At age 61, a nuclear sclerotic cataract should be high on the list of causes of decreased vision, especially if there is a myopic shift. These cataracts often do not have the classic yellow color but are often creamy or white, so are often overlooked. An epiretinal membrane tends to affect both distance and reading vision.
55. **Answer (d).** The clinical history method requires both preoperative manifest refraction and keratometry readings and a stable postoperative manifest refraction. The hard contact lens method does not require any preoperative information. IOL power calculations are equally inaccurate after LASIK and photorefractive keratectomy (PRK). The American Society of Cataract and Refractive Surgery (ASCRS) IOL Calculator is available at http://iol.ascrs.org. It is an excellent tool to help select the most accurate IOL power after keratorefractive surgery.
56. **Answer (b).** It is a photochemical reaction that results in collagen cross-linking.
57. **Answer (c).** The minimum allowable stromal thickness to prevent endothelial cytotoxicity is 400 µm.
58. **Answer (d).** A thin LASIK flap is not a risk factor for corneal ectasia; in fact, a thin flap could reduce the risk of ectasia, because the residual stromal bed (RSB) would be thicker.
59. **Answer (a).** Optical coherence tomography (OCT) imaging provides an excellent pachymetric profile map of the cornea, which is helpful in detecting corneal asymmetry suspicious for forme fruste keratoconus and can also detect focal corneal stromal or epithelial thinning, which may be early signs of ectasia. However, OCT cannot measure corneal elevation data and thus cannot detect corneal steepening. In order to do that, a corneal topography or tomography is necessary. However, in some cases, the first findings in corneal ectasia may be areas of focal thinning rather than steepening, so OCT is a valuable addition to the screening process.
60. **Answer (d).** The concern for corneal ectasia is increased when the residual stromal bed (RSB) is <250 µm, and the ability to perform optical coherence tomography (OCT) imaging shows the unusually thick flap and unexpectedly thin residual

bed. As such, the safest treatment would be to do photorefractive keratectomy (PRK) on the flap with or without the use of topical mitomycin. A radial keratotomy is not a good procedure in a patient following LASIK, and a clear lens extraction is not recommended in general and specifically in a 30-year-old with good accommodation.

61. **Answer (c).** The penetration of epithelium-derived mediators and growth factors into the stroma only occurs at significant levels if the basement membrane is damaged or removed. The cytokines bind to their respective receptors on keratocytes and bone marrow–derived cells, and trigger a variety of biologic responses, which is part of the complex cascade of wound healing. Mitomycin-C (MMC) treatment probably does not have long-term effects in preventing haze associated with epithelial and basement membrane trauma.
62. **Answer (d).** In the setting of excess sun exposure and irritation from smoking, post–photorefractive keratectomy (PRK) haze risk would be increased.
63. **Answer (d).** LASIK can be done if the stroma is smooth and the flap is covering the treatment zone. Still careful irrigation and flap alignment plus a bandage contact lens and frequent lubrication would be needed to decrease the risk of striae and epithelial ingrowth if a significant epithelial defect is present.
64. **Answer (c).** The laser ablation itself would not have created biomechanical instability extensive enough to create an ectasia. Previous studies have demonstrated that cohesive tensile strength is inversely correlated with stromal depth, and that the anterior 40% of the corneal stroma has significantly greater cohesive tensile strength than the posterior 60% of the corneal stroma. Thus, it could be that the depth of a LASIK flap cut relative to total corneal thickness is a better predictor of ectasia risk than absolute flap thickness.
65. **Answer (c).** Corneal ectasia can still occur even when LASIK is performed with the femtosecond laser. The other choices are advantages of the femtosecond laser.
66. **Answer (d).** There is no increased risk of neovascular glaucoma with LASIK surgery. The other possibilities do exist, particularly in long-standing diabetes. Keratorefractive surgery is probably ill-advised in a patient with advanced retinopathy. If refractive surgery is to be performed in a diabetic, always be certain the refraction is stable.
67. **Answer (c).** The best way to develop a great reputation is to provide outstanding care and not compromise on excellent preoperative, intraoperative, and postoperative care. Never compromise if it leads to substandard care. Patients will not remember that they pressured you to proceed. All the responsibility for a poor outcome will belong to the surgeon after surgery.
68. **Answer (a).** Excessive energy settings on the femtosecond laser are the most common cause of post-LASIK diffuse lamellar keratitis (DLK). A slightly more challenging flap lift is usually related to energy settings that are on the lower side. The excimer laser does not usually cause DLK, and a thin cornea is not more likely to develop DLK.
69. **Answer (b).** Steroids do not prevent epithelial ingrowth. Care should be taken during flap lift retreatment to be certain the stromal bed is free of epithelium. Ingrowth can lead to blurred vision and to flap melting and should be treated if progressive or if >2 mm from the flap edge.
70. **Answer (a).** Early recognition of diffuse lamellar keratitis (DLK) with aggressive steroid treatment can result in favorable results. If one is contemplating a lift and scrape procedure, it is better to do it sooner in the course than later to reduce the likelihood of a poor refractive outcome.

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