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STEP BY STEP

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# LASIK SURGERY

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RASIK B VAJPAYEE  
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# *Step by Step LASIK Surgery*



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*To My wife Madhu and children Mihika and Shubhankar*

—Rasik B Vajpayee

*To My Patients*

—Namrata Sharma

*To Rania, Philip and Alexander, My teachers at the Massachusetts Eye and Ear Infirmary, My wonderful staff at the Boston Cornea Center*

—Samir AMelki

*To My wife Lara and children Veronica and Darcy*

—Laurence Sullivan



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## ***Foreword***

*“When you set out on your journey to Ithaca,  
Pray that the road to is long,  
full of adventure, full of knowledge,  
Pray that the summer mornings are many,  
when with such pleasure,  
With such joy will enter ports seen for the first time...”*

As this passage quotes- written by a famous Greek poet Constantine Cavafy -I find many similarities with its content with the long itinerary of the LASIK from its birth, in the early 1990's as a rudimentary technique to what it has become nowadays a well thought, elaborated, and world wide accepted one.

A decade after the introduction of the LASIK technique in the refractive surgery, a number of issues have been addressed. The technique has reached its maturity. The initial enthusiasm was replaced by a more conservative approach, which contributes to a better patient selection and the reduction of intraand post-operative LASIK complications leading to increasing patients' satisfaction and physicians' confidence.

In this concept, this book reveals another dimension of LASIK in the contemporary ophthalmologist's armamentarium, showing the width and the diversity of LASIK applications in a vast number of ophthalmology subspecialties. The large collection of esteemed co-authors of the different topics by virtue of their knowledge and expertise not only contribute to the clarification of ambiguous issues about this technique but also stimulate the reader to search in the literature for additional contents. It is thoroughly researched and easy to read. The outline form of the book is well organized and provides the reader with state-of-the-art information regarding LASIK technique.

Prof. Vajpayee and his co-authors have succeeded in writing a timely and concise book on many interesting entities of LASIK technique. I think that this book will provide an organized reference to aid the residents and practicing ophthalmologists who want to start their journey in refractive surgery.

I congratulate the authors for their successful work.

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## ***Preface***

The subject of developing ideal cures for naturally occurring defects in the human body has always fascinated medical scientists. Refractive errors are such a naturally occurring defects and have required the use of external aids like spectacles or contact lenses. These devices have their own inherent flaws as regard to cosmesis and comfort. Refractive surgery has emerged as a new subspecialty in ophthalmology designed to develop an ideal surgical technique to help people reduce their dependency on their external visual aids.

Radial Keratotomy was the first refractive surgery that was tried on a large scale. Ten years later, it was realized that the technique was not as safe and effective as it initially appeared to be. Excimer Laser Photorefractive Keratectomy was the next popular technique and subsequently gave way to LASIK due to its obvious advantages of minimal pain, fast visual rehabilitation and absence of corneal haze. Presently LASIK remains the most widely practiced surgical technique of refractive surgery. Each day a newer modification is being developed and the LASEK is the latest addition in the armamentarium of refractive surgeons using excimer laser. There are various excellent textbooks published in the field of LASIK surgery and we were a little perplexed when approached by our publisher as to whether there is a need of one more book on this subject. However, after initial hesitation we were convinced that there is a need for a simple source document that can provide readers useful practical information regarding the various aspects of LASIK surgery. Experienced LASIK surgeons from different parts of world have contributed their thoughts to this book and have shared their experience about the various aspects of this state-of-the-art surgical technique. We are grateful to all the contributing authors for the time and effort they put in and worked hard to finish their chapters before the Christmas.

The book has been organized in a simple and effective style of stepwise approach to LASIK surgery and includes information about the latest microkeratomes and excimer laser machines. There are chapters on specific surgical techniques like LASEK, LASIK for post-penetrating keratoplasty, ametropias and wavefront guided LASIK.

Overall our book provides comprehensive and easy to read information to refractive surgeons and general ophthalmologists. Happy reading!

**Rasik B Vajpayee  
Namrata Sharma  
Samir A Melki  
Laurence Sullivan**



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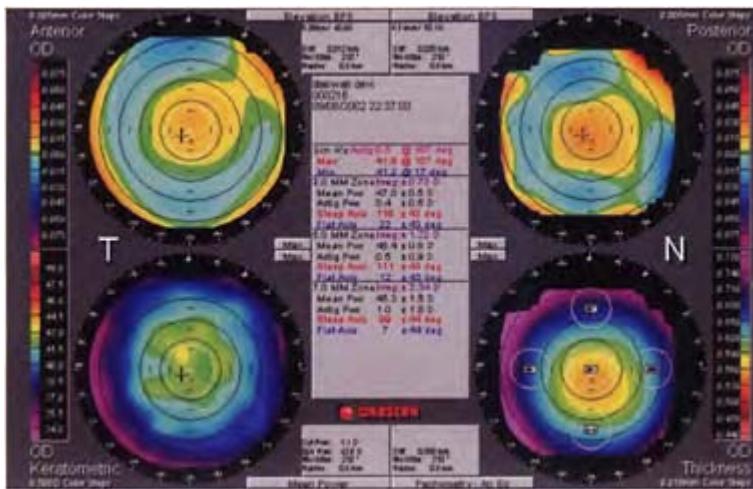
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# Section 1

## Preoperative Considerations



# 1

## *Landmarks in LASIK Surgery*

**M Vanathi, Namrata Sharma**

The history of modern refractive surgery dates back to 1949 when Jose Ignacio Barraquer (Fig. 1.1) proposed the surgical modification of the refractive status of the eye by changing the radius of curvature of the anterior corneal surface<sup>1-4</sup>. He refined his ideas of performing lamellar keratoplasty for refractive purposes to correct spherical myopia. In 1958 Barraquer experimented on performing a free hand lamellar dissection of the corneal stroma to create a lamellar corneal disc and then attempted a refractive cut by removing stromal tissue from the bed (keratomileusis *in situ*) or the stromal surface of the corneal disc.<sup>1</sup> He dissected the lamella to about half the thickness with the use of a corneal dissector or Paufique knife. He then considered freezing the lamellar corneal disc and used the cryolathe to modify the corneal disc. In the same year, he performed the first resection *in situ* using a prototype keratome with cutting angle of zero degree.

In 1962, Barraquer used the more accurate microkeratome and also invented the suction ring, dovetail guides between rings, applanation tonometer and first intraoperative keratoscope.

Krumeich, Swinger and Barraquer developed a new instrument in the early 1980s called the BKS



**Figure 1.1** Jose Ignacio Barraquer

1000 to perform a non-freeze refractive cut (nonfreeze or BKS technique)<sup>5</sup>. In the late 1980s, Luis Ruiz developed an automated microkeratome and reported that the refractive effect of stromal resection can be altered by varying its diameter and depth. The development of this microkeratome was a major advancement in the field of lamellar

refractive surgery and the surgery came to be known as Automated Lamellar Keratoplasty [ALK]. This microkeratome rendered a much smoother stromal bed due to the controlled speed of the advancement of the keratome head and the very high speed of oscillation of the blade. However, ALK had inherent complications such as lost or displaced caps, irregular astigmatism and was not a very predictable procedure. Furthermore, the technique of ALK had a long learning curve and required considerable surgical skill and experience.

Trokel (Fig. 1.2) and Srivinivasan<sup>6</sup> in 1983 suggested the first corneal application of the excimer laser and in 1988 the first surgical applications in the form of photorefractive keratectomy were performed by McDonald and Kaufman.<sup>7</sup>



**Figure 1.2.** Stephen Trokel

In 1989, Lucio Buratto<sup>8,9</sup> presented the technique of intrastromal keratomileusis using the excimer laser or photokeratomileusis (Fig. 1.3). He performed the refractive cut with laser ablation on either the free lamellar corneal disc (cap) or in situ ablation (excimer laser intrastromal keratomileusis [ELISK])



**Figure 1.3.** Lucio Buratto



**Figure 1.4.** Ioannis G Pallikaris

on the exposed stromal bed or cap). The keratomileusis is simple and safe when the ablation is performed on the cap because the mechanical fixation of the corneal disc is not required.

Pallikaris and his colleagues<sup>10</sup> in 1990, made the next major advancement in the field of LASIK surgery when they introduced the ***hinge technique*** for LASIK, by using a flap with a nasal hinge instead of a free flap (Fig. 1.4). The tissue flap is lifted and an in situ refractive procedure on the underlying stroma is performed. This variation in the technique makes keratomileusis faster and simpler.

Buratto in 1996 started the ***down-up LASIK***<sup>11</sup> with a vertical cut from below upwards resulting in a superior hinge. The use of Hansatome (Bausch and Lomb Surgical, Claremont, CA) to create superior hinges allowed this technique to be widely used.

Relasik as an enhancement procedure for residual myopia was first reported by Perez et al.<sup>12</sup> In the initial studies reablation was done on the bed. However, more recently, reablation on the cap has also been advocated.<sup>13</sup>

The advent of epithelial LASIK or laser assisted subepithelial keratomileusis (LASEK) by Massimo Camellin in 1999, further broadened the indications of excimer laser surgery (Fig. 1.5). This enabled performance of laser ablation for relatively thin corneas with higher myopic refractive errors.<sup>14</sup> LASEK is a relatively new refractive surgical techni-



**Figure 1.5.** Massimo Camellin

que that combines the advantages of laser in situ keratomileusis (LASIK) and photorefractive keratectomy (PRK). LASEK may also prove to be superior to LASIK in customized ablations.

A number of major advancements have taken place in excimer laser machines in form of custom laser ablations<sup>15</sup> and wavefront guided custom ablations.<sup>16</sup> Methods of detection of wavefront aberration or aberrometry was an important discovery which laid the foundation of the future customized ablations. Based on the interferometry, Hartmann<sup>17</sup> and Tschering<sup>18</sup> constructed and described an apparatus by the name of “aberroscope” from a grid superimposed on a 5 diopter spherical lens. Twenty years later this aberroscope was used to investigate and characterize monochromatic aberrations and this study also introduced the concept of Zernicke polynomials.<sup>19</sup> More recently, Webb and colleagues implemented a method which computes the *wave aberrations* and reduces it to Zernicke polynomials.<sup>20</sup>

Hartmann Shack wavefront sensor, a method initiated in the astronomy to analyze the aberrations of the atmosphere above a telescope in real time was adapted by Bille and Liang to image the human fundus by removing the aberrations of the eye with a definable mean.<sup>21</sup> Josef Bille from Heidelberg, Germany is the father of wavefront technology. Theo Seiler is credited with the first wave front guided LASIK in 1999.

## LASIK: IMPORTANT MILESTONES

1958	- Keratomileusis	- JI Barraquer
1962	- Manual Microkeratome	- JI Barraquer
1977	- First Keratomileusis in USA	- JI Trouton
1980–83	- BKS technique	- JH Krumeich
1983	- Corneal application of Excimer laser	- SL Trokel
1983–86	- Keratomileusis in situ	- L Ruiz
1988	- First successful PRK	- MB McDonald
1989	- LASIK in normal human eye	- L Buratto
1990	- Hinge technique in LASIK	- IG Pallikaris
1996	- Down-up LASIK	- L Buratto
1999	- Relasik	- JI Perez-Santos
1999	- LASEK	- M Camellin
1999	- Wavefront Technology	- Josef Bille
1999	- Wave front guided LASIK	- Theo Seiler
2002	- Relasik-undersurface ablation of flap	- MJ Maldonado

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## 2

# ***Indications and Contraindications of LASIK***

**Jeewan S Titiyal, Rakesh Ahuja, Namrata Sharma**

Laser in situ keratomileusis (LASIK) is one of the most popular techniques for the correction of refractive errors myopia, hyperopia and astigmatism. However, a proper patient selection is of vital importance in accomplishing optical visual outcomes. A patient is selected to undergo LASIK on the basis of proper ophthalmologic screening and personal requirements.

## **INDICATIONS OF LASIK**

The most common indication for LASIK surgery in the present times is myopia, although it is also being increasingly utilized to treat hypermetropia and astigmatism.<sup>1-7</sup> Other indications in which LASIK may be performed are anisometropia, induced refractive errors after other surgical procedures such as penetrating keratoplasty, radial keratotomy or cataract surgery.<sup>8</sup> Recently, LASIK has also been undertaken to treat presbyopia although the option of mono vision is also possible in these patients and may be offered to them.<sup>9-12</sup> Irrespective of the indications a patient who undergoes LASIK has certain basic requirements to be fulfilled (Table 2.1)

### **Myopia**

Laser-in-situ keratomileusis (LASIK) has been used to treat myopia ranging from -1 to -29 dioptres.<sup>13</sup> However the optimum correction is done for myopia up to -12.00 diopters since correction of myopia of more than -12 diopters (depending on the corneal thickness) entails excessive stromal ablation with a danger of producing corneal ectasia. It is important to remember that the amount of myopic correction possible in a particular patient is determined by the central corneal pachymetry and correction of myopic refractive errors in excess of -12 dioptres may not be possible if the central pachymetry is less than 500  $\mu\text{m}$ . For myopia, we recommend that treatment be done up to -12 diopters, if corneal thickness allows the desired ablation with a residual bed thickness of 250  $\mu\text{m}$  or preferably of 300  $\mu\text{m}$  as cases ectasia has been noted in cases of residual bed thickness of >250  $\mu\text{m}$ .<sup>14</sup>

## **Hypermetropia**

LASIK has been used for the correction of +0.50 to +8.0 diopters of hyperopia. The treatment of hyperopic refractive errors with LASIK started much later as compared to myopia. However, LASIK results are more predictable for corrections upto +4 dioptres. With the availability of newer algorithms and ablation profiles specific for hyperopia, the predictability of hyperopic correction has improved in the recent years.

## **Astigmatism**

It has now become possible to treat myopic and hyperopic astigmatism with LASIK. Correction has been attempted in astigmatic errors ranging from 0.5 to 10 diopters. Newer machines with upgraded technology such as LADARvision (Alcon, Fort Worth, TX) has reported success in myopic and hyperopic astigmatism upto 6 dioptres.<sup>15</sup>

In eyes with mixed astigmatism it may not be possible to correct the entire error in a single ablation, and the refractive error may be segregated into 2 components. For example, if the refractive error is  $-2\text{D sph} + 4\text{D cyl X } 180^\circ$ , half of the cylinder is separated out such that the sphere and the cylinder are equal in magnitude but opposite in sign. Therefore the two components are

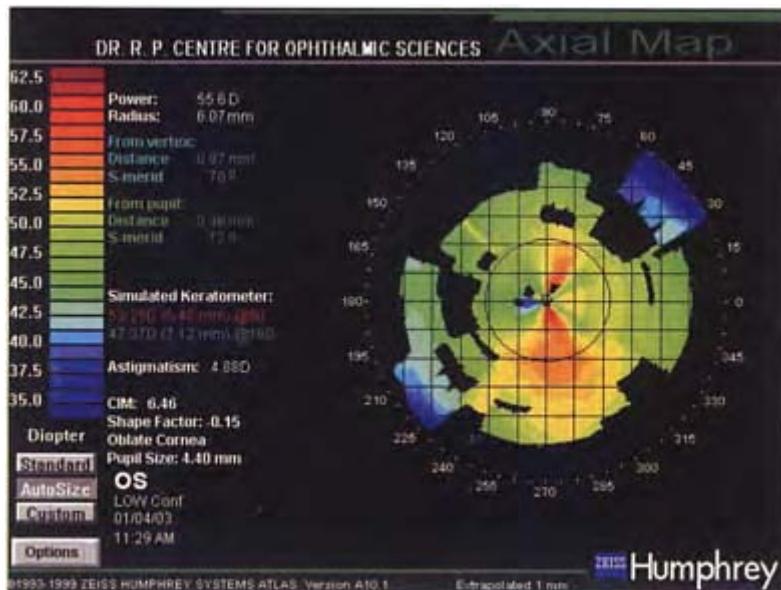
- I.  $+2\text{D cyl X } 180^\circ$  and
- II.  $-2\text{D sph} + 2\text{D cyl X } 180^\circ$ .

Now (II) is transposed to obtain  $-2\text{D cyl X } 90^\circ$ . This is the first laser treatment, while the remaining

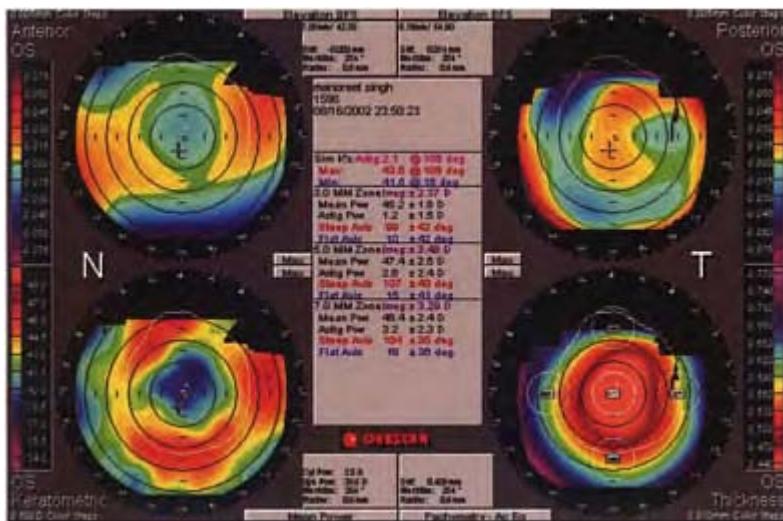
**Table 2.1: An ideal patient for LASIK**

- Is 18 years of age or older, preferably 21 years or more.
- Prefers to have surgery over wearing glasses or contact lenses.
- Has a stable refractive error.
- Be free of any diseases of the outer eye/ cornea, posterior segment or lids.
- Not be pregnant or nursing or not planning to conceive in next 6 months to 1 year,
- Not have any systemic or auto-immune diseases such as lupus,
- Is able to handle the financial commitment.
- Is willing to commit to post-operative instructions and care plan.
- Has realistic expectations about the outcome of the procedure.
- Is informed about the possible complications and is willing to take the risks.

cylinder ( $+2\text{D cyl X } 180^\circ$ ), i.e. component (I) constitutes the second laser treatment.



**Figure 2.1** Videokeratography in a case of keratoconus



**Figure 2.2.** Orbscan showing thin cornea—Contraindication for LASIK

## **Residual Refractive Errors after Previous Surgical Procedures**

LASIK has also been used to treat residual refractive errors after radial keratotomy, penetrating keratoplasty, epikeratoplasty and cataract surgery<sup>8</sup>. Although there are no separate nomograms for LASIK after these procedures optimal surgical results have been reported by various authors. It is vital to ensure adequate wound healing and rule out corneal thinning prior to considering LASIK surgery in these patients.

## **CONTRAINDICATIONS OF LASIK**

Since LASIK is an elective surgery, any condition that would counter a safe result post-LASIK should be looked for and patient counseling should be done to deter the patient from having surgery, thereby avoiding complications, unfavorable results and a dissatisfied patient. Contraindications of LASIK include absolute and relative conditions (Table 2.2).

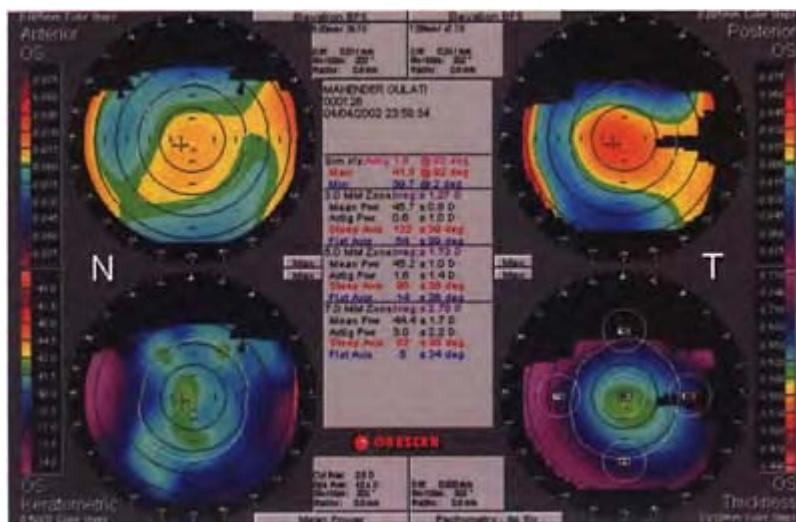
**Table 2.2: Patient exclusion criteria for LASIK**

1. Ectatic corneal disease
2. Thin corneas
3. Active ocular infection
4. Dry eye
5. Glaucoma (especially if a large bleb is present)
6. Blepharophimosis
7. Monocular patients
8. Large pupil size
9. Systemic or retinal vascular disorder
10. Autoimmune disease
11. Pregnancy

### **Absolute Contraindications for LASIK**

In certain cases, LASIK is absolutely contraindicated and should not be undertaken.

*Refractive instability* is important to document, as results are not predictable in such eyes and the patient may become dissatisfied due to requirement of glasses soon after surgery.



**Figure 2.3.** Orbscan showing posterior corneal elevation more than 40  $\mu$ m

Conditions such as **ectatic corneal diseases** like *keratoconus* (Fig. 2.1), *Terrien's* and *pellucid marginal degeneration*<sup>16–18</sup> may be aggravated by LASIK and lead to severe ectasia and decrease in the best corrected visual acuity. LASIK should also not be performed in forme fruste keratoconus or subclinical cases of keratoconus. Further, the posterior corneal elevation pre-operatively should be greater than at least 40  $\mu$ m.<sup>19</sup>

Patients with a **thin cornea** of thickness of less than <490  $\mu$ m should not undergo LASIK since there is not enough cornea available to ablate and correct the refractive error (Fig. 2.2). It may lead to ectasia and associated problems. LASIK surgery is also contraindicated in any case where preoperative corneal thickness does not allow 250 or preferably 300  $\mu$ m of residual stromal bed following laser ablation. The posterior corneal elevation before LASIK should be less than 40  $\mu$ m. This is important to avoid occurrence of posterior ectasia of the cornea. LASIK surgery is also contraindicated in any case where preoperative corneal thickness does not allow 250 or preferably 300  $\mu$ m of residual stromal bed following laser ablation. This is important to avoid occurrence of posterior ectasia of the cornea.

Presence of any other **active corneal pathology** and **severe ocular surface disease** like Steven-Johnson's syndrome and ocular cicatricial pemphigoid is an absolute contraindication for LASIK.

LASIK should not be performed in cases of **glaucoma**, either known previously or diagnosed immediately prior to surgery, as during the suction ring application the intraocular pressure raises to greater than 65 mm Hg. This may lead to further damage to the optic nerve and loss of vision.

In **pregnant or nursing women** or women planning to conceive in the next 6–12 months, LASIK is not predictable because of change in corneal hydration and refraction. Hence, it should not be performed.

## Relative contraindications for LASIK

Patients on certain medications like ***oral or topical steroids*** or taking ***hormone replacement therapy*** are likely to have delayed healing which may interfere with the results of LASIK surgery. In such cases, the indication for taking steroids should be discussed and the patient advised to refrain from undergoing surgery.

Patients with disorders like ***diabetes, collagen vascular disease, autoimmune or immunodeficiency diseases***, patients with a history of ***keloid*** formation, or in patients with a tendency to form scars, which are likely to lead to unpredictable results after LASIK, should be not be operated.

Patients with any previous history of ***Herpes simplex*** or ***Herpes zoster*** in the eye may not be operated, since these may be reactivated by LASIK.<sup>20</sup>

In ***blepharophimosis*** and patients with small ***palpebral apertures***, LASIK may be more difficult to perform with the currently available microkeratomes. This may change with the introduction of newer techniques of flap making using femto-second laser, which does not require placement of suction ring.

Any ***active ocular infection or inflammation*** like conjunctivitis and scleritis is a contraindication for performing LASIK. Local diseases like blepharitis, meibomitis, severe atopic disease, and a poor ocular surface, which are likely to lead to tear film instability after LASIK may not be operated. ***Corneal neovascularization*** within 1.0 mm of the ablation zone is also a relative contraindication, since there is increased risk of interface hemorrhage. LASIK should preferably be avoided in ***monocular patients***. ***Dry eye, sunken eye, a pupil size larger than the optic zone*** for the laser ablation, ***systemic or ocular vascular disease*** are some of the other relative contraindications for LASIK.

LASIK may be contraindicated in certain ***occupations*** and both the current and the future occupational requirements of the patient are an important criterion in determining whether one should undergo LASIK surgery. ***Armed forces, fighter pilots*** as well as ***the Railways*** have certain regulations regarding visual fitness, which should be obtained from the source and referred to by the patient.<sup>21</sup> These regulations may or may not allow performance of LASIK to obtain a 6/6 vision. Depending upon these regulations, a particular patient may or may not be operated.

Patients indulging in ***contact sports or athletes*** should be explained the risk of flap dehiscence and globe rupture from a minimal or trivial trauma. ***Professional scuba divers*** should be informed that waiting a minimum of one month would be required before resuming diving after LASIK. This is important since they may have potential complications like globe rupture from facemask barotraumas, interface keratitis and flap displacement from interface bubbles.

Of particular importance are the patients whose ***occupation is dependent on the quality of the visual function*** based on contrast sensitivity and glare. The contrast sensitivity may decrease after LASIK. So, it is possible that following LASIK treatment, patient may find it more difficult than usual to see in very dim light, rain, fog, or experience glare from oncoming vehicles at night. Visual performance may be worsened by a larger mesopic pupillary size.

Hori-Komai have analyzed the reasons for not performing laser in situ keratomileusis (LASIK) or photorefractive keratectomy (PRK) in 2784 patients who requested surgical correction of their refractive errors.<sup>22</sup> Out of these, 2079 patients (74.7%) had PRK or LASIK and 705 patients (25.3%) did not. The reasons they did not receive refractive

surgery (PRK or LASIK) were myopia greater than  $-12.0$  diopters and/or high astigmatism (20.7%), insufficient corneal thickness (8.2%), keratoconus (6.4%), cataract (5.7%), and hyperopia and/or hyperopic astigmatism (4.1%).

In conclusion, the safety and effectiveness of the excimer laser have not been established in patients with unstable or worsening myopia or astigmatism, higher degree of refractive error, diseased or abnormal corneas and any previous insults to the cornea. In such cases, LASIK should not be performed.

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## 3

# ***Patient Counselling***

**Namrata Sharma, Rakesh Ahuja, Rasik B Vajpayee**

The discussions between the patients and the surgeon before the actual surgical procedure represent the most important aspect of a pre-op refractive surgical evaluation. All other aspects such as the testing of the eye and the ocular examination are objective. The patient counseling is a subjective entity and the details on the patient personality and the expectations can be easily overlooked if the proper attention is not given.

### **Informed Consent**

The informed consent before LASIK surgery is mandatory as it minimizes the liability risk. Informed consent is the process by which the patient becomes aware about the procedure's risks, benefits, complications and alternatives so that he or she can make an informed decision whether to have the procedure.<sup>1-5</sup>

Informed consent does not release the doctor from the responsibility to ensure that the patient undertakes an informed decision, whether the surgeon personally undertakes the education process or delegates it in part to an assistant or media material (e.g. educational procedures, videotapes, websites etc).

Communication with the patient or building of a treatment alliance with the patient is a must and this begins preoperatively and continues throughout the postoperative period of patient care.

Informed consent should include appraising the patient of both the surgical and the non-surgical refractive options; the risks, benefits, side effects and expected outcome of the procedure; and a discussion of enhancement procedures. *It is critical to ensure that the patient's expectations are realistic.* The patient who meets medical and surgical criteria for keratorefractive procedure but *who has unrealistic expectations is not a good candidate for LASIK surgery.*

That the risks, benefits, complications were discussed in detail with the patient and that the patient understands and accepts these options should be *documented* in the medical records of the patient.

### **Timing of Consent Signing**

The patient should receive a copy of the informed consent document well in advance of the planned surgery and should be encouraged to take it home to read and formulate any further questions. Signing the consent document on the day of the surgery is acceptable if the patient has been given the document for review ahead of time. A part of this document may be objectively made in the form of true/false questions, which serve to further educate the patient about this elective procedure.

### **Presbyopia**

The patient should be made aware that the refractive surgery usually does not eliminate the need for additional reading correction, once the patient has entered the presbyopic age group. Further, for the patients nearing the presbyopic age group, the choice of monovision should be discussed. This may also be demonstrated (in the appropriate age group) with either a trial spectacle correction or more effectively with temporary contact lens.

### **Patient Expectation**

It is crucial for the surgeon to evaluate and assess the patient's expectations of LASIK surgery and to make sure that they are realistic. The patient needs to be aware that the goal of any keratorefractive procedure is to make them less dependent on glasses or contact lenses. This may be demonstrated to them by having them look thorough a phoropter or trial frame with a refraction that enables them to see 20/ 40 or 20/30 line clearly, but shows slightly defocused 20/25 and 20/20 lines. The patient is then allowed to compare this refraction with his or her current or best corrected visual acuity.

Further, it should be explained that although many patients achieve better postoperative vision, their uncorrected postoperative visual acuity may not be as sharp/crisp as their preoperative best corrected visual acuity due to decreased contrast sensitivity. The patient should also be made aware of what to expect after surgery (Table 3.1).

### **Complications**

The patient should be well informed about the complications. The surgeon should emphasize that a specific refractive outcome is purely a statistic and not guaranteed for any one patient.<sup>4</sup> A poor outcome for a specific patient is 100 percent for that patient.

The use of the microkeratome in the LASIK procedure adds the additional risks which may occur due to its stoppage/malfunction. The same holds true for the laser machine, which may stop or malfunction in between. Risk of infection, overcorrection, undercorrection, regression, loss of best-corrected visual acuity, haze and dry eye should also be explained.

### Table 3.1: What to expect after surgery

The following problems can occur in the postoperative period:

*Upto 3 days*

Mild pain and discomfort

Teaaring or watery eyes

*Upto 1 week*

Sensitivity to light

Hazy or blurred vision

*Upto 4 weeeks*

Dry eyes

Glare, difficulty driving at night

*Upto 6 months*

Fluctuations in vision

### Side Effects

The common side effects of LASIK procedure include mild postoperative discomfort or pain, glare and the star-burst or halo symptoms.

### Need for Further Surgery

The concept of the enhancement procedure in 5 to 10 percent of cases and the need for further surgery should also be discussed with every patient.

### Alternate Options and Future Technology

The patient should be informed about the other surgical refractive modalities such as photorefractive keratectomy, intracorneal intrastromal corneal ring and phakic intraocular lenses as well as other non-surgical therapeutic options, including glasses and contact lenses. The patient must also be apprised of the newer technologies which may become available in the near future.<sup>4</sup>

### CONCLUSION

Informed consent is a continuous process and building of mutual trust and rapport with the patient and not merely the signing of a form. A key goal of the informed consent process is to let the patient know that specific outcomes cannot be guaranteed. Careful documentation of all patient interactions is a must. The surgeon bears the ultimate responsibility of the patient.

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## Appendix (Model Consent Form)

THE EXCIMER & LASIK CLINIC	
Date:	
INFORMED CONSENT FOR EXCIMER LASER SURGERY	
Name: _____	Age/Sex: _____
OPD No.: _____	Clinic No. _____
Address: _____	
Tel. No. _____	
Date: _____	
<p><i>The aim of this consent form is to educate you about the LASIK surgery highlighting its advantages and limitations. Most of the problems may not occur in most cases; some have not occurred in any LASIK patient worldwide. Nevertheless, our policy is to provide full disclosure.</i></p> <p><i>The information hereafter in this 'CONSENT FORM' is provided so that a prospective LASIK Surgery candidate can make an informed decision. It is advised to read the form carefully and clarify any and all doubts that may be there.</i></p> <p>There is a balance between the risks of LASIK and its benefits. For a successful experience one must accept responsibility for this decision. The only way to avoid surgical risk is to refuse surgery. Informed consent does not protect you from complications nor release your doctor from his/her obligation to maintain the standard of care. It serves to certify, educate, and counsel you regarding the intervention you are contemplating.</p> <p>LASIK is a highly evolved procedure and improvements in the technique are ongoing. Application of an excimer laser to corneal stroma has been in existence for only ten years. Hence, one cannot guarantee or assure the long-term consequences of this intervention.</p>	

**Preoperative and Postoperative Instructions**

I understand that all instructions and restrictions given preoperatively and postoperatively are to be followed meticulously. Failure to comply may jeopardize the final visual results. If I am a contact lens user, I have to refrain from wearing soft contact lenses for no less than 2 weeks before LASIK. Hard (RGP) lenses have to be strictly discontinued one or more months prior to surgery. I understand that I should not restart the use of contact lenses in the duration between my evaluation and LASIK surgery.

I understand that after LASIK, the eye may be more susceptible to blunt trauma from impact. There may be a need to wear protective eyewear while engaging in contact sports or athletic activities. However, the effect of atmospheric extremes (high altitudes, diving, etc) have not been adequately investigated and hence, caution is mandatory in these conditions.

*Nature of the LASIK procedure:* LASIK (*Laser Assisted in situ Keratomileusis*) reshapes the *cornea*, the clear front surface of the eye. The procedure is performed under local anaesthesia with eye drops. LASIK involves raising a thin layer (flap) of corneal tissue using an instrument called 'microkeratome' and remodeling of corneal shape using Excimer laser. The flap is repositioned without there being need of any sutures.

*Expected benefit:* I understand the purpose of LASIK surgery is to reduce short-sightedness, long-sightedness and/or astigmatism to provide me much better unaided vision than I presently have without spectacles and/or contact lenses. I understand that there is no guarantee of 20/20 vision in all cases. This is because there is biological variation and the lack of predictability in virtually all surgical and medical procedures.

*Presbyopia:* I understand that LASIK does not address the changes that occur in the human crystalline lens. Aging progressively decreases the amplitude of accommodation making it more difficult to see near objects (without glasses) despite a clear view of distance objects.

I understand that if I am currently using reading glasses, I will still need reading glasses after LASIK and it is possible that dependence on reading glasses may increase as the power of the reading glass may increase. If I currently do not require reading glasses and am over 40, I may probably require reading glasses immediately or soon after LASIK (even if I can currently take my glasses off and read). If I am younger it is possible that need for reading glasses will occur at an earlier age.

*Recovery:* I understand that it is not possible to estimate how quickly the healing will occur. The rate of visual recovery can not be predicted or guaranteed. This includes when I may safely drive, use a computer, return to work, etc. There is a considerable fluctuation during the first weeks following surgery. Complete recovery may take six months or more.

*Alternative treatments:* I understand that there are other methods of correcting my refractive error. These alternatives may include, among others, eyeglasses, contact lenses, PRK (photorefractive keratectomy) and intra-corneal rings.

*Undercorrection or overcorrection:* I understand that calculations used in this surgery are based on previous experience on large number of patients and they use average values. Thus depending on individual variations in response to the procedure there might be some undercorrection or over-correction. As a result I may require some spectacles to achieve best possible vision for distance and/or near. If re-treatment may be required then a period of six months must elapse between it and the original surgery. However, this may or may not be amenable to one or more enhancement procedures. If a resurgery is not feasible, this may require the use of glasses and/or contact lenses for reading and/or for distance vision some or all of the time.

*Decrease in best corrected visual acuity:* I understand after LASIK surgery some patients find that their vision with best spectacle correction is not as good as it was with spectacles on before the procedure. This may occur as a result of irregular tissue removal, reparative processes in the cornea and very rarely infection.

*Glare, starbursts, double vision:* There may be glare, "starbursting" or halo effect around lights or double vision which usually diminishes with time, but could be permanent. Further, the post-operative vision may not be as crisp at night as during the day. There may be problems in driving or performing other high visual demand tasks.

#### **Vision Threatening Complications**

There is always a possibility that the *microkeratome or the excimer laser can malfunction* (for a variety of reasons), requiring the procedure to be abandoned. Depending on the type of malfunction, this may or may not be accompanied by temporary or permanent visual loss.

Further, *decentration* of the laser energy may result in a sub-optimal visual results. Another procedure or intervention may be required to ameliorate these symptoms.

Additionally, *fibers and/or epithelial cells* (epithelial ingrowth) may accumulate inadvertently beneath the corneal flap. This may require one or more additional procedures to remove them. This can delay visual recovery and possibly cause temporary or permanent visual loss.

*A corneal flap may be lost intraoperatively or postoperatively* which may result in temporary and possibly permanent visual loss.

Further, *irregular healing* of the flap may cause irregular astigmatism with the resultant decrease in visual acuity, despite the use of glasses and/or contact lenses. This is called loss of best corrected visual acuity. If the visual distortion is sufficiently severe, a corneal transplant may be required to restore visual acuity.

Rarely *perforations of the cornea* may occur causing devastating complications, including loss of some or all vision in that eye. A similar loss can be caused by an *internal or external ocular infection* that does not adequately respond to antibiotics or other interventions.

Further, other complications may occur after LASIK such as *corneal ectasia (bulging), corneal melt (thinning / perforation), corneal haze, corneal scarring, loss of endothelial cells, cataract formation, glaucoma, dry eye, contact lens intolerance, strabismus (crossed-eyes), diplopia (double vision), total blindness of the eye, loss of the eye (globe) itself, and death.*

I understand that although this list is be practically complete, it may not include unforeseen side effects, risks and complications of LASIK.

I hereby give permission to release/publish medical data and or video/audio recording/photographs of the procedure or the subsequent treatment for purposes of research and advancement of medical knowledge.

In signing this consent form for LASIK surgery, I am stating that I have read this consent form (or it has been read to me) and I fully understand it and the nature, purpose, and possible side effects risks and complications of LASIK. Also I have had all my questions answered to my satisfaction.

I give permission to Dr \_\_\_\_\_ to perform LASIK procedure on my \_\_\_\_\_ eye(s).

Patient's Signature : \_\_\_\_\_ Date : \_\_\_\_\_

Name \_\_\_\_\_

Witness's Signature : \_\_\_\_\_ Date : \_\_\_\_\_

Name. \_\_\_\_\_

Translated/read to the patient by the undersigned in the \_\_\_\_\_ language / dialect.

Translator's Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Name: \_\_\_\_\_

## 4

# ***LASIK: Preoperative Assessment***

**Michael S Loughnan**

## **GENERAL PRINCIPLES**

Aside from the obvious need to adequately assess the patient's refractive error a thorough ophthalmic and general medical *history* as well as *ophthalmic examination* and several *special investigations* are necessary to adequately assess the pre-operative patient's suitability for LASIK. The refractive error and pachymetry results can then be used to ensure that the surgical plan does not breach any *surgical technical exclusions*.

Many patients at a heightened risk of developing an intraoperative or postoperative complication can be identified preoperatively due to the presence of one or more risk factors. A comprehensive targeted history and clinical examination needs to be a part of every preoperative assessment to ensure any such risk factors are identified.

Some risk factors such as blepharitis or minimal dry eye can be modified allowing surgery to proceed while others such as a thin cornea or keratoconus represent an absolute contraindication to LASIK surgery.<sup>1-4</sup> Obviously not all patients with a risk factor will develop a complication however good clinical management dictates that with such an elective procedure it is better to exclude some patients who may have a successful outcome to protect those at a heightened risk of a significant complication.

Remember it is always easier to explain to a patient why they can't have surgery than why they developed a significant complication. To a large extent the mark of a good refractive surgery practice is the rigor of its exclusion criteria.

Most surgeons hold the general principles underlying exclusion criteria listed below. However the exact numerical value at which patients are counselled not to have surgery often varies depending upon the individual surgeon.

## **HISTORY**

A directed ocular and general history should be taken to identify any refractive instability or the presence of any specific risk factors.

## Refractive History

A history of a stable refraction is essential, no more than a 0.5D shift over the past 2 years is usually required. Refractions need to be performed after adequate time following removal of any contact lens, usually 1 week for soft and 4 weeks for a rigid lens. Late onset myopia (after age 15years) may be an indication of keratoconus, while onset in the 30's may be an indication of pellucid marginal corneal degeneration.

## Contact Lens Wear

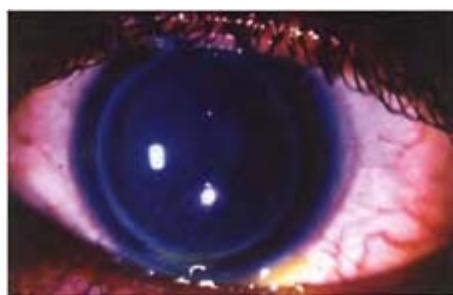
Contact lens wear can cause reversible changes in the refractive status of an eye due to its effect on the corneal curvature. Therefore, contact lens wearers are advised to discontinue the use of their lenses (for at least one week in the case of soft lens users and four weeks in case of hard RGP (rigid gas permeable) lens users prior to the preoperative evaluation and surgery (Fig. 4.1). In the case of hard/ RGP lens users, if there is a change in the initial refraction of more than 0.5D during the check-up at 4 weeks, the refractive status should be reassessed after 8 weeks or until the refraction is found to be stable. Sometimes corneal warpage occurs because of contact lens wear.<sup>5,6</sup> In such a case, the preoperative evaluation may need to be deferred for some months after the patient has discontinued the use of contact lenses.

## Past Ocular History

### Corneal Dystrophies

*Ectatic corneal dystrophies:* the presence of keratoconus (Fig. 4.2), pellucid marginal corneal degeneration or keratoglobus is an absolute contraindication to LASIK.<sup>7-11</sup>

*Stromal corneal dystrophies:* Granular, Macular and Lattice stromal dystrophies are usually not treated



**Figure 4.1.** Rigid gas permeable contact lens to be discontinued 4 weeks before investigations



**Figure 4.2.** Keratoconus—contraindication for LASIK

with LASIK as this technique does not remove the corneal opacity. Rarely with anterior variant granular dystrophy a PTK (Photo therapeutic keratectomy)/PRK (Photorefractive keratectomy) maybe appropriate.

*Epithelial dystrophies:* Reis-Bucklers dystrophy and epithelial basement membrane dystrophy (Cogans Map Dot dystrophy) are also a contraindication for LASIK because of the increased risk of an epithelial defect and sub-flap epithelial ingrowth.

#### ***Corneal Thinning Disorders***

LASIK is contraindicated in all corneal thinning disorders such as Mooren's ulcer and Rheumatoid associated keratolysis.

#### ***Dry eye***

Ocular surface disease, especially dry eye, is a relative contraindication to LASIK because of the risk of flap related complications and exacerbation of the dry eye problem in the first few months following surgery.<sup>12,13</sup> Treatment of any tear film deficiency should be optimised pre-operatively. PRK should be considered if the refractive error is less than 5 to 6D of myopia and there is a significant dry eye.

#### ***Previous Corneal Graft***

While PRK is contraindicated following a corneal graft, LASIK may be performed once the refraction is stable.<sup>14</sup> It is important to wait until the graft/ host junction is fully healed, usually at least a year following removal of all sutures.

#### ***Previous PRK***

LASIK may be performed in an eye that has previously been treated with PRK.<sup>15</sup>

### ***Previous Radial Keratotomy***

LASIK may be performed in an eye that has previously been treated with radial keratotomy (RK). It is important to wait several years following healed.<sup>16,17</sup> RK to ensure that the radial incisions are sufficiently

### ***Previous Cataract Surgery***

LASIK may be performed in an eye that has previously had cataract extraction and lens implantation. Usually the procedure is not performed until several months following the original cataract surgery.<sup>18</sup>

### ***Previous Herpes Simplex Keratitis***

LASIK may uncommonly lead to reactivation of herpes simplex keratitis.<sup>19,20</sup> For this reason the patient treated for a week following surgery with either an oral or topical antiviral agent such as acyclovir.<sup>21</sup>

### ***Previous Microbial Keratitis***

LASIK may be performed following an episode of microbial keratitis if the area of thinning and opacity is mild and peripheral. Because of the risk of increased postoperative inflammation, surgery should be postponed for approximately 6 months from resolution of the infection.

### ***Previous Retinal Surgery***

Previous retinal surgery with an encircling band is a relative contraindication to LASIK because of the observed unpredictability of the refractive outcome.<sup>22,23</sup>

### ***Nystagmus, Tropia, Amblyopia***

Nystagmus, tropia and amblyopia are all relative contraindications for LASIK surgery.

### ***Age***

The refractive error is rarely stable in patients less than 21 to 25 years of age and as such LASIK is rarely performed on patients younger than their early twenties.<sup>24</sup>

Presbyopia of itself, is not a contraindication for corneal refractive surgery; however monovision is an option especially in a presbyopic or peri-presbyopic patient. In the presbyopic patient it is important to look closely for any sign of cataract formation. Even with a minimally cataractous lens a cataract extraction and intraocular lens implantation may be a better option than LASIK.

## General History

### *Pregnancy/Lactation*

Pregnancy and lactation represent a relative contraindication to LASIK both because of the refractive changes that can occur with both, and also because of the concern of any unnecessary medication usage especially during the first trimester.

### *Systemic Disease*

Systemic diseases of some concern with regard to LASIK include diabetes mellitus (if the blood glucose level is significantly raised), Sjogren's syndrome, rheumatoid arthritis and collagen vascular disorders.<sup>1-4</sup>

### Family History

Any history of keratoconus in a first degree relative is of concern with regard to the possibility of the development of iatrogenic keratectasia. As such PRK should be considered if the patient is a low myope.

### Patient Expectations

It is essential the patient has realistic expectations of the likely refractive outcome of the procedure.<sup>25</sup>

### Patient Employment

Some professions (such as an aircraft pilot) require a person to work to a high level of visual performance under mesopic conditions.<sup>26</sup> Such patients may be unsuited to higher degrees of correction, especially if they have a larger pupil diameter, because of the risk of halo and glare under mesopic conditions.

## CLINICAL EXAMINATION

### **Uncorrected and Best Corrected Visual Acuity**

Uncorrected visual acuity (UCVA) both for near and distance should be recorded for all patients including those with high refractive errors. The appropriate correction is then put in the trial frame and the Best corrected visual acuity (BCVA) is measured. In moderate and high myopia, the BCVA may be measured using a soft or preferably hard contact lens, having a spherical equivalent as close as possible to that of the patient's refraction. Internally or externally illuminated visual acuity charts are best for this purpose. For accurate and meaningful statistical evaluation, the number of letters in each line of a LOGMAR chart read by the patient, should be recorded.

## Refraction

The refraction should be assessed at a minimum of 1 week following the removal of soft and 1 month following removal of a rigid contact lens. Occasionally longer period may be required for the refraction to stabilize, especially following long-term rigid contact lens usage. The refraction may be unstable during pregnancy and during times of raised serum glucose in diabetics.

Acycloplegic refraction is performed 30 minutes following instillation of a drop of tropicamide 1%. This is very important especially in younger hyperopes but less so in myopes where the manifest refraction alone is treated.

The maximum degree of myopia, hyperopia or astigmatism that is able to be treated depends on several factors including the corneal thickness and curvature, specific laser being used, whether a wavefront or non-front ablation is performed and the pupil size (see *Surgical Technical Exclusions* below).<sup>27,28</sup> Indicative guidelines for an average thickness cornea and curvature and pupil size are:

*Myopia:* up to -11D

*Astigmatism:* up to 5D at any axis

*Mixed astigmatism:* up to 5D at any axis

*Hyperopia:* results deteriorate significantly above usually only less than 3 to 4D (dependent on the specific laser machine, best results are seen with a small diameter flying spot with active eye tracking).

## Slit Lamp Examination

### *Eyelids*

Active blepharitis may predispose to diffuse lamellar keratitis (DLK).

A narrow palpable fissure may make application of the microkeratome footplate difficult.

### *Tear Film*

The tear film should be examined for signs of aqueous tear deficiency or a reduced tear break-up time suggestive of dry eye.

### *Corneal Disease*

Superficial keratopathy may be seen with dry eye.

The epithelium should be examined for signs of epithelial basement membrane dystrophy as this may predispose to sub-flap epithelial ingrowth.

Signs of keratoconus should be sought.

The corneal stroma should be examined for signs of old herpes simplex keratitis (HSK), microbial keratitis, a stromal dystrophy or a traumatic scar.

### ***Crystalline Lens***

The lens should be closely examined with a dilated pupil for any signs of cataract formation.

### ***Intraocular Pressure***

The IOP should be recorded to exclude unsuspected glaucoma.

### ***Keratometry***

The power and axis of the steepest and flattest meridian of the cornea is determined by keratometry. Keratometry is performed to determine the axis and magnitude of the corneal component of the astigmatism. It can also detect irregular astigmatism, which characterises subclinical keratoconus. Keratometry readings should be used in conjunction with the corneal topography. The possibility of a free flap increases with a flat cornea ( $K<40D$ ) and the possibility of a buttonhole is more in a steep cornea ( $K>46D$ ). Such patients should be warned about the increased risk of microkeratome related complications.

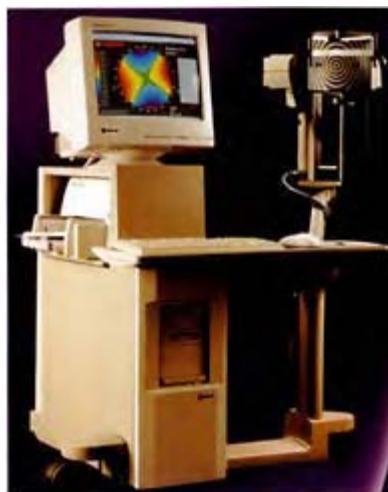
### ***Posterior Segment Examination***

A dilated fundus examination should be performed. This is especially important in high-myopes where peripheral retinal disease may pre-dispose to a retinal detachment, although LASIK itself has not been found to be associated with an increased risk of retinal detachment. In case of treatable peripheral retinal lesion, LASIK is deferred for 6 weeks after prophylactic cryopexy/photocoagulation.

## **SPECIAL INVESTIGATIONS (VIDEOKERATOSCOPY AND PACHYMETRY)**

### ***Pachymetry***

If the cornea preoperatively is too thin or if there is mild keratoconus or forme fruste keratoconus LASIK may lead to iatrogenic keratectasia. The measurement of corneal thickness can vary considerably depending on technique and the individual instrument used.<sup>29</sup> While an ultrasound pachymeter is probably more accurate than optical measurement with the Orbscan (Fig. 4.3) the latter has the significant advantage of providing a topographical pachymetric map of the central 6 to 9 mm of the cornea (Fig. 4.4). It has been seen that the optical pachymetry incorporated into corneal topography systems (such as the Orbscan) gives a much higher value as compared to ultrasonic pachymetry. Some surgeons also do an intraoperative pachymetry to



**Figure 4.3. Orbscan II machine**

assess the thickness of the flap created by the microkeratome and the residual thickness of the stromal bed, before and after the ablation. The following are generally accepted as being the limits of minimum corneal thickness for LASIK and PRK.

Any area  $<500$  microns is a contraindication for LASIK.

Any area  $<450$  microns is a relative contraindication for surface laser.

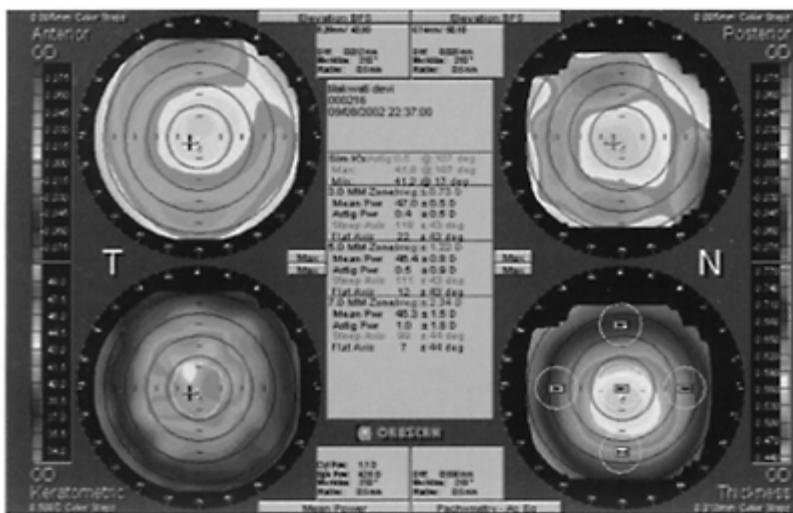
#### **Topography (CAVK) and Anterior Corneal Elevation**

While the computer assisted videokeratoscopy (CAVK) (Fig. 4.5) identification of either keratoconus (Fig. 4.6) or forme fruste keratoconus relies pattern recognition the following are generally accepted limits for what is acceptable for proceeding with LASIK.<sup>30,31</sup>

Difference<sup>3</sup> 1.5D at locations 3 mm above and below the visual axis

Too steep: mean central keratometry<sup>3</sup> 47D

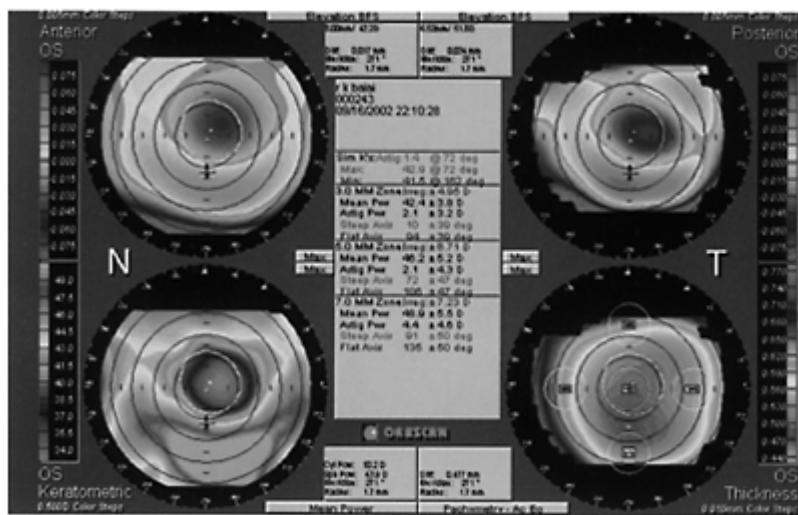
Difference in central corneal power between the 2 eyes  $>1$ D.



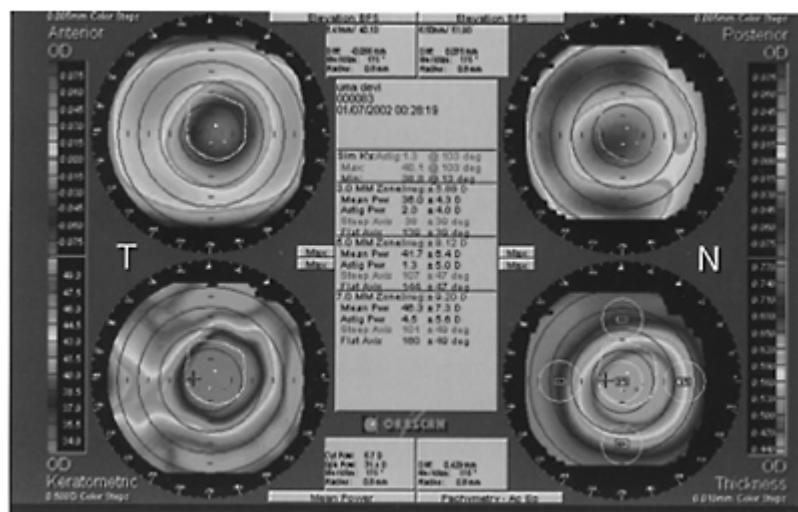
**Figure 4.4.** Normal Orbscan map



**Figure 4.5.** EyeSys Topography



**Figure 4.6.** Orbscan in a case of inferior corneal steepening



**Figure 4.7.** Orbscan showing posterior corneal elevation >40  $\mu$ m

#### Posterior Corneal Elevation (Orbscan measurement)

Any area of >40 microns elevation is suspicious (Fig. 4.7) and >50 microns highly suspicious of posterior ectasia.<sup>32</sup>

## Concurrent Examination of Elevation and Pachymetric Maps (Orbscan measurements)

While one individual measurement may be borderline it should be viewed in the context of the rest of the corneal results. For example a thinnest area of 505 microns where there is an underlying posterior elevation of 40 microns and an anterior keratometric raised area of 1D when taken together probably represents an area of mild ectasia and as such is a contraindication to LASIK (though not PRK).

### Pupils

The pupils should be measured under dark mesopic conditions; a larger mesopic pupil size (7 mm) may indicate the need for a larger treatment and transition zone.<sup>3</sup> The pupil can be measured using either a hand held pupil ruler or specialised pupil-measuring device. The Colvard infrared pupillometer is an ideal device for such measurements.

The other tests which may be of academic interest include intraocular pressure (IOP), corneal endothelial specular microscopy, glare, contrast sensitivity and ocular biometry.

### **Surgical Technical Exclusions**

The following are generally accepted as being the limits of central corneal thinning and alteration in central corneal curvature that can safely be induced by LASIK.<sup>1-4</sup>

#### ***Calculated Residual Corneal Bed Thickness***

At least 250 microns [some prefer 300 microns]<sup>33</sup> At least half the original corneal thickness.

#### ***Postoperative Central Corneal Curvature***

Minimum central corneal curvature not less than 35D (myopic LASIK).

Maximum central corneal curvature not greater than 49D (hyperopic LASIK).

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## Section 2

# Equipment and Instrument



# 5

## ***Excimer Laser Machines***

**Namrata Sharma, Rakesh Ahuja, Rasik B Vajpayee**

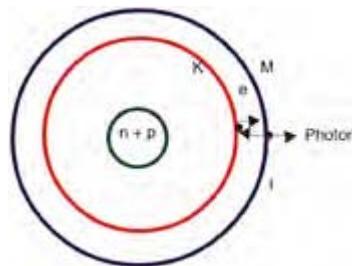
Excimer laser machines generate the ultraviolet Argon-Fluoride 193-nm laser and provide for its optical manipulation, computerized control, and final delivery to the cornea. In order to understand the laser machines, one should understand the fundamental concepts of the excimer laser. The word LASER stands for “Light Amplification by Stimulated Emission of Radiation”. The word “excimer” comes from “excited dimer”.

### **Spontaneous Emission and Stimulated Emission**

Whenever an electron from a lower orbit moves to a higher orbit, it cannot stay there for too long and hence, it comes back to its original orbit, but in the process, it gives off a photon of light and this is called spontaneous emission. If the electron is energized and sent to a higher orbit by another photon that has an identical wavelength to that which the atom will produce, this is called as “*stimulated emission*” (Fig. 5.1). These photons then hit other atoms leading to the amplification process.<sup>1</sup>

### **Laser Media and Pumps**

The laser media, which in the case of excimer laser is a rare gas-halide medium, contains the atoms that



**Figure 5.1.** Spontaneous emission, n-neutron, p-proton, e-electron K-lower orbit, M-higher orbit

conduct the lasing process. The argon fluoride 193-nm is a pulsed laser which creates an accurate and precise excision of the corneal tissue to an exact depth, with minimal disruption of the surrounding tissue. Its wavelength practically does not heat the tissue but breaks the inter and intramolecular bonds.

The laser pump is the source of energy for the electrons which can be in the form of electrical discharge or current or light energy produced by either flash pumps or other lamps. In order for lasing action to occur, the pumped medium must be in a state of population inversion, i.e. when more than half of the atoms in the medium are energized in the excited state which facilitates the amplification process.

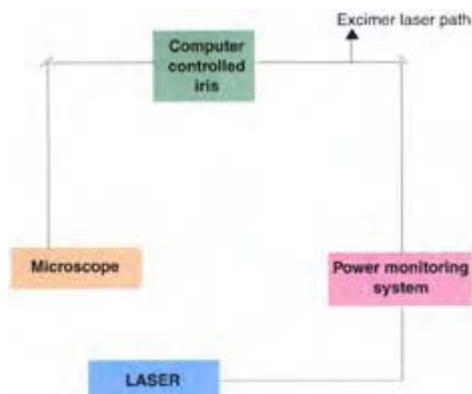
### Excited Dimer

Molecules made up of two identical atoms are called dimers. If two systems (atoms or molecules) do not form a strong chemical bond when they are in their ground state, but form a strong chemical bond when one of them is in the excited state, then the excited state is called an “excited dimer”. On dissociation of the excimer (argon fluoride), population inversion occurs and this releases the ultraviolet laser.

### Excimer Machine

The basic design of an excimer laser machine is shown in Figure 5.2.

Excimer laser usually consists of a large aluminium box which is filled with an appropriate gas mixture. There are 2 metal electrodes spaced 2 to 3 cm apart to which the energy is sent through the capacitors charged to serve tens of kilovolts. The electrical discharge through the gas between the electrodes ionizes the gas and allows excimer molecules to form so that lasing occurs. This beam passes through the power monitoring system and is then directed via the mirrors on to the patient's eye.



**Figure 5.2.** Basics of laser machine

## Fluence

Fluence means the amount of energy applied to the area which is ablated. It is expressed as millijoules/ sq cm and varies according to the laser. It determines the amount of tissue which is ablated with each pulse, e.g. for Summit excimer—160 mJ/cm<sup>2</sup>. Chiron –130 mJ/cm<sup>2</sup>, and Nidek –130 mJ/cm<sup>2</sup>.

## Homogeneity

This indicates the pattern of energy distribution within the area. This may be depicted as microhomogeneity, i.e. variability in the energy beam density, i.e. hot areas with the beam which represent the highest energy density and cold areas which highlight the lowest density areas. Macro-homogeneity refers to the overall energy beam profile which may be **gaussian**, **homogenous** or **reverse gaussian**.<sup>1</sup> In a gaussian profile, the maximum amount of energy density is located centrally, in homogenous profile it is equal throughout the beam and in reverse gaussian profile, the energy density is minimum at the center.

Where gaussian beams are applied next to each other, the amount of overlap that can be predicted allows for a smooth surface. When small-truncated beams are applied next to each other, they must be aligned perfectly to prevent the occurrence of a trough and peak next to each other and hence some irregularity may be induced by a top hat beam. In a comparison between the 2-mm top hat beams with 1-mm gaussian beams it was concluded that the 1-mm gaussian beams showed smoother corneal surface whereas with larger top hat beam, significant degradations of the optics with higher frequency deviations in the treatment occurred.

## Munnerlyn's Formula

Each excimer laser ablates a different amount of stromal tissue per diopter of refractive correction due to differences in the ablation zone diameters, amount of pre-treatment and the ablation protocols. The Munnerlyn formula (depth of ablation= diopters of correction X ablation diameter<sup>2</sup>) indicates that each spherical equivalent diopter of myopic correction performed at a 6 mm single zone will ablate 12 microns of the tissue.<sup>2</sup> Depending on the ablation profile, the currently available lasers cut different amounts of tissue per diopter of correction.<sup>3</sup>

## Excimer Laser Delivery Systems

The excimer laser delivery system delivers or directs the laser beam onto the eye. There are three types of laser delivery systems i.e. the broad beam, scanning slit beam and the scanning flying spot lasers.

### Broad Beam Lasers

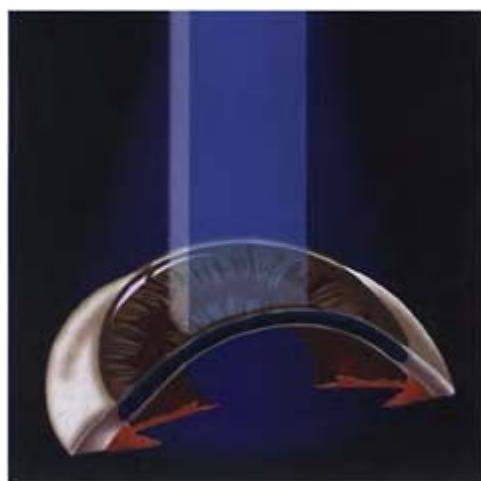
The broad beam system is akin to the projection system for a 35 mm slide system. The broad beam delivery system projects the entire beam on the stromal surface. An iris

diaphragm or variable aperture system is used to control the broad beam on the stromal surface and create the ablation pattern required.<sup>4</sup>

The principle feature of the wide-field ablation delivery system is the use of a stationary, broad and circular beam (6.0 to 8.0 mm) of the excimer laser for corneal ablation (Fig. 5.3). This was the first generation laser delivery system and has the longest track record. Since a broad beam is used, the exact alignment of the eye and tracking systems are not required. The broad-beam laser results in the shortest procedure time. However, this system requires a high energy to achieve the required ablation and delivers a greater acoustic shock to the cornea. The high output energy requirement results in a more frequent maintenance of the optical components and increase in the overall running cost. The shorter duration of surgical time creates less likelihood of over-correction and decentration, which is caused by movement of the pupil.

A disadvantage is an increased possibility of central islands—a complication related to ablation. The incidence of central islands has decreased by using several short laser pulses to ablate the cornea instead of one longer one. These were the first generation lasers.

Currently, *VISX* is the only machine which uses the concept of a modified broad beam. Its beam has



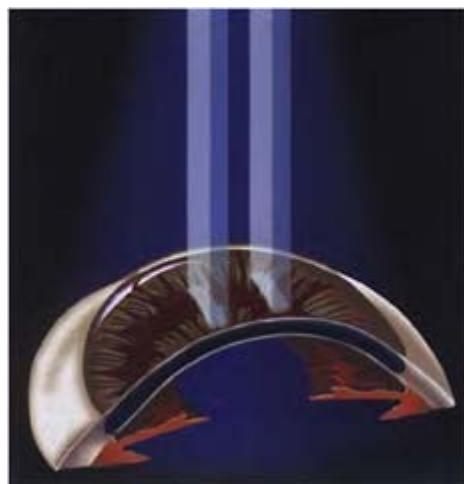
**Figure 5.3.** Principle of broad beam laser (Modified—Courtesy of Benjamin F. Boyd, Highlights of Ophthalmology)

been split into seven small diameter beams of 0.65 to 6.5 millimeters which rotate very quickly on the cornea.

### Scanning Lasers

The scanning beam is a smaller, and a more homogenous beam; it requires a less powerful laser head. The scanning system uses either a *slit beam or small spot* to scan the surface of the cornea. In the scanning system, an eye tracking system is mandatory, as it is less forgiving for even small decentrations since the beam is smaller.<sup>5-7</sup>

*Slit scanning lasers* Scanning slit ablation is the second-generation photorefractive delivery system. A slit-scanning laser uses a rectangular slit shaped beam of light that scans across an aperture within the path of the beam and uniformly removes the corneal tissue with several successive pulses of laser (Fig. 5.4). The amount of tissue removed varies depending on the amount of overlap between the pulses. A uniform beam and potentially smoother ablations characterize slit-scanning lasers because of the small area ablated with each pulse. This small area of ablation produces smoother ablative surface



**Figure 5.4.** Principle of Slit Scanning Laser (Modified—Courtesy of Benjamin F. Boyd, Highlights of Ophthalmology)

and also reduces the complications of central islands. The **Nidek EC-5000** and **Meditec MEL 80** use this technology.

*Spot scanning lasers* This is the third generation photorefractive laser delivery system. This performs scanning with flying spots in multiple directions to remove a uniform layer of corneal tissue (Fig. 5.5). Flying spot lasers have a small circular or elliptical spot 1 mm to 2 mm in diameter that is moved across the surface of the cornea by computer controlled galvanometric mirror. The scanning technology increases the flexibility in the ablation profile or algorithm. It can produce aspheric rather than only spherical ablations.

Some patients with asymmetrical corneas such as surgically induced astigmatism after keratoplasty or post-cataract surgery or keratoconus may benefit from these.

It allows a multifocal treatment unlike broad beam lasers which treat all corneas alike and do not take asymmetry or irregular astigmatism into consideration. It allows for a custom designed ablation and uses the lowest energy output. The main



**Figure 5.5.** Principle of Spot Scanning Laser (*Modified—Courtesy of Benjamin F. Boyd, Highlights of Ophthalmology*)

disadvantage is that it requires the longest operating time and therefore precise eye tracking systems are required.

The **Novatec Light blade** (non-excimer solid state laser), **Laser Sight Compak 200, and the Chiron Technolas Keracor 117 and 217** are examples of the machines, which use the flying spot technology.

### Eye Trackers

Eye trackers are the devices which position the ablation beam accurately onto the corneal surface and compensate for patient head and eye movements during the surgery.<sup>8,9</sup> These devices have especially gained importance due to the emergence of customized corneal ablations—smaller beam sizes, faster repetition rates and greater precision of correction.

The eye tracking system has the following devices:

1. *Sensing device* such as a camera or photodiode (or a combination) which acquires the image.
2. *Processing subsystem* which calculates the position of the eye (usually defined as the centre of the pupil or the center of the limbus) from that image.
3. *Control system*, which moves the laser beam to compensate for any change in the eye position, thereby maintaining alignment.

The disadvantage of the eye tracking system includes the necessity of a specific illumination system (e.g. infrared lasers or diodes) and the sensitivity to changes in pupil size, corneal surface and illumination characteristics during the course of treatment.

An *ideal eye monitor* should be fast, reliable, non-invasive, effective in all iris colours, and be insensitive to alignment lights and to removal of tissue from the cornea.

There are three principles on which the eye tracking systems in refractive surgery are based.

These include:

1. Photoelectric technique
2. Video-based eye tracking
3. Laser radar eye tracking.

### Photoelectric Techniques

These techniques detect eye movements from changes in the reflected light. Focussed spots, slits or rings of light are projected either on the cornea, pupil iris border or on the limbus and the response from the multiple light detectors are analyzed using analog signal processing techniques.

If the pupil is tracked, it is generally backlit to maximize contrast and dilated to decrease interference from the procedure itself. The limbus does not have these limitations, as it is far away from the surgical zone. This technique is sensitive to the iris colour and cannot detect torsion.

### Video Eye Tracking

In video tracking, or the **open loop system** infrared light illumination is used to illuminate the eye and image of the eye is acquired by the infrared sensitive camera (Fig. 5.6). If the axis of the illumination and the cornea differ significantly, the pupil is a sink for infrared light and appears dark on the image. The sampling rate of the video-based trackers is limited by the frame rate of the camera, which averages 60 Hz.



**Figure 5.6.** Video-based tracker:  
Chiron Technolas 217C

It is believed that a video-based system requires to send out a signal first, which limits its speed compared to the laser radar tracker. A detection signal leads to a response in mirror alignment so that there is a lag time due to the movement of the mirrors.

Video based techniques require an image of the eye to be integrated on the image sensor, which takes 16.67 ms (NTSC) or 20 ms (PAL) using standard video cameras. Following the acquisition of the image, this is transferred (by a video or digital data signal) from the camera to the image processing system which requires another 16.67 ms (NTSC) or 20 ms (PAL). Even if the image is processed during this transfer, the eye position can only be provided with a delay of 33 ms (NTSC) or 40 ms (PAL) to control the mirror system. During the delay time, however, the eye continues to move and by the time of detection and execution, a significant positioning error of the laser onto the eye may occur.

### Laser Radar Eye Tracking

Laser radar eye tracking or *closed-loop system* eye tracker which is present with the Alcon-Summit/ Autonomous LADARVision scans the eye to find various contrast boundaries of the pupil and/or iris to allow for exact eye tracking (Fig. 5.7). It is believed that there is a close association between the detection of the pupil and the response of the mirrors which results in moving of the mirrors synchronously with sampling so that there is no



**Figure 5.7.** LADARTracker—Laser radar tracker system

delay in realignment of mirrors. Following this, the accurate center of the eye is calculated. The response time range from 0.04 seconds for small corrections to 10 ms for large corrections. This enables pin point placement of laser even during in eye movements which includes drifts and saccades.

However, during maximal eye movement, the high speed closed loop position bandwidth of the LADARVision system delivers a maximum laser spot placement error of 37  $\mu\text{m}$  using a gaussian beam with a mean diameter of 0.8 mm which translates to a maximal spot placement error of 4 percent. On the other hand, a video-based tracking system sampling eye movement at 60HZ, delivers a laser spot placement of approximately 600 mm which is nearly 16 times less than the laser radar tracking devices.

Some of the commercially available machines will now be discussed in the subsequent section.

### **Bausch and Lomb Technolas 217 Excimer Laser with PLANOSCAN**

#### **Laser System**

This laser system uses a flying spot technology. A scanner feedback mechanism ensures quality control during the procedure by monitoring the accuracy of each pulse.<sup>10</sup> It utilizes Piano Scan 2000 software for precise scanning spot technology (Fig. 5.8). This laser uses a repetition rate of 50 Hz, pulse duration of 18 ns, and fluence at eye of 120 mJ/cm<sup>2</sup>. The beam diameter is 2 mm and the beam placement is controlled by two scanner mirrors with active feedback control. Centration is accomplished by an active “pupil” tracking mechanism which locks on to the pupil image such that the laser follows any movement by the patient’s eye.

#### ***Eye Tracker***

There is a video-based active Infrared Eye Tracker which interrupts laser beam on movement in excess



**Figure 5.8. Bausch and Lomb Technolas 217 Excimer Laser**

of 3 mm range (1.5 mm radius). It captures the geometric center of the undilated pupil at a sampling rate of 120 Hz and also has a scanning system to respond and compensate for any pupil movement found by the cornea within 2.4 ms. The overall reaction time is 10.7 ms, which includes 8.3 ms camera sampling (=120 Hz) plus 2.4 ms scanner reaction time.

According to FDA studies, this laser has the least night vision problems amongst the various lasers.

### **VISX STAR™ Excimer Laser System**

The STAR™ S3 version (Fig. 5.9) has a standard 6 mm optical zone, which is expandable to 8 mm for future applications. The mask for simple myopia is an f-stop like mechanism located internally in the beam path. The astigmatic module masks and hyperopic module masks are located internally in the beam path. The hyperopic module has an ablation zone of 9 mm.

#### ***Laser System***

The recently launched STAR S4 with threedimensional ActiveTrak™ features a seven-beam scanning system with an infrared, video-based eye tracking system. By splitting the broad beam into seven small diameter beams of 0.65 to 6.5 millimeters, the laser system is able to rotate across



**Figure 5.9.** Visx STAR S3 laser system

the cornea quickly, thus softening the treatment pattern and leaving the treated area smoother.

It also has a Variable Spot Scanning (VSS™) technology which allows larger ablation zone as an additional blend zone is added to the ablation zone by 51 percent, increasing the overall diameter of the ablation to 8 millimeters.

#### ***Eye Tracker***

The infrared, video-based tracking system monitors eye movement in all three dimensions i.e. in x, y and z axis at a rate of 60—120 times a minute and does not require

pupillary dilation. The eye position is verified and safety checked before each laser pulse, so that it is not required for the patients to stay completely focused.

### **Nidek EC-5000 CX II**

#### ***Laser System***

It is a scanning slit laser hybrid which has a dynamic rotating and overlapping delivery system, designed to perform refractive and therapeutic treatments over a large ablation area<sup>11,12</sup> (Fig. 5.10a). The multi-point ablation module divides the rectangular shaped laser beam in to six equal spots of 1 mm in diameter, which can be individually or simultaneously projected onto the cornea for precise ablation. The small spots are used for the precise initial ablation of higher order ablations for customised surgery and the slit beam is used for ablation of the larger amounts of corneal tissue. The combination of small spots and slit beam leads to a better control of tissue hydration and a faster ablation time with a lower number of pulses.

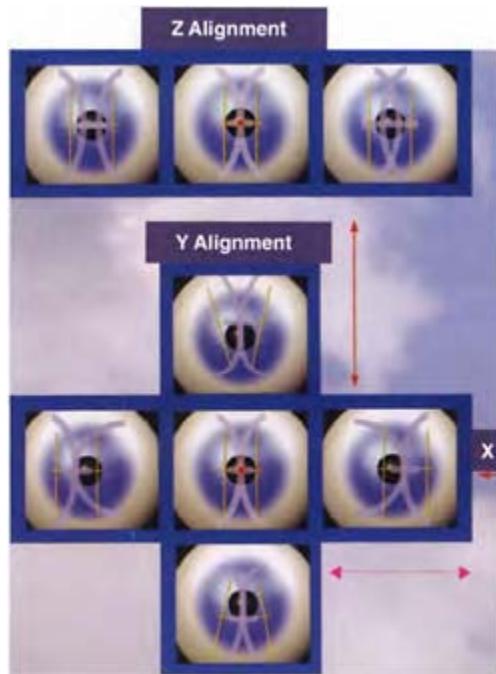
It also has a three dimensional motorized joystick along with improved illumination and aiming beams which provide precise control of laser beam delivery arm (Fig. 5.10b).

#### ***Eye Tracker***

The eye tracker safeguard stops the procedure if the patient's pupil moves outside a fixed centration zone. Nidek's eye tracker uses a high-speed digital video camera technology to enable laser alignment during a procedure. The image sensor uses a CCD video camera and image processor, which locks onto



**Figure 5.10a.** Nidek EC 5000 CX II



**Figure 5.10b.** Three dimensional eye alignment system of Nidek EC 5000 CX II

the pupil's center. The tracking system needs 39.34 microseconds to acquire and relay information. If the difference between the pupil position and excimer laser shooting point exceeds about 250  $\mu\text{m}$ , the laser automatically stops ablating. The eye tracker also has a function that allows offsetting of the treatment center position to the pupil center.

#### **Zeiss Meditec MEL 80**

MEL 80 has a very small spot of only 0.7 mm with Gaussian beam profile (Fig. 5.11). This allows finest corrections even of higher order aberrations without loosing the benefit of smooth ablations. The footprint of the system is small and occupies less space. It is a roll-on-roll-off laser, which is mounted on wheels and is more easily portable than other lasers.



**Figure 5.11.** Zeiss Meditec MEL 80 excimer laser system

#### NOVATEC LASER SYSTEMS INC

Lightblade (TM) is a solid state 208 nm non-excimer scanning system based upon the fourth harmonic of a titanium sapphire crystal. The scanning beam is a 200–300  $\mu\text{m}$  variable size spot. The centration is accomplished by an active tracking mechanism which locks to have the laser follow movements by the patient's eye.



**Figure 5.12a.** LADARVision 4000 Excimer Laser System

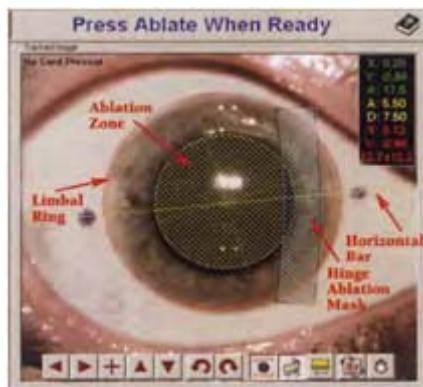
## LADARVision 4000 Excimer Laser System

The Autonomous LADARVision® 4000 with LADAR Tracker use a small-beam excimer laser system with active eye tracker.

### Laser System

The LADARVision® system employs a flying smallspot laser beam (also called a small-spot scanner) which is 0.8 mm wide (Fig. 5.12a). This means that corneal tissue removal can be closely calibrated to remove the least amount of tissue necessary for the correction of refractive errors.<sup>13,14</sup> The combination of the smaller beam and spot placement in a non-sequential pattern allows corneal tissue to “relax” between pulses, thereby avoiding the effects of laser plumes and minimizing tissue damage. The spot placement in non-sequential pattern prevents the formation of laser “plumes” or corneal fluid migration and hence the formation of central “islands” or surface irregularities is negligible unlike the broader beam lasers. Further, optic zones upto 10 mm in diameter may be used, which greatly reduces the chance of night-time glare or halos.

It uses a *Gaussian beam profile*, which produces a smooth surface on the cornea.



**Figure 5.12b.** Hinge ablation mask software by LADARVision

The *hinge protection system* is an internal blocking system of the laser that can be adjusted to different sizes and shapes (Fig. 5.12b). Whether a nasal or a superior hinge is created, the hinge protector can be moved to any position around the cornea. It protects the hinge from being ablated and eliminates the need for using sponges or foreign objects to protect the hinge. In the event of a technical or operational problem occurs before or during the surgery, laser-programming components automatically suspend operation.

### Eye Tracker

The eye tracker helps to direct the laser beam onto the cornea in the correct spot. With the LADAR Vision® tracker, the eye is followed every second of the procedure, and is

tracked 4,000 times per second (see Fig. 5.7). This leads to a response of less than 3-sec rise time. Hence this enables pinpoint placement of the laser, even during rapid involuntary eye movement including drifts and saccades while the laser ablation continues. The very fast eye tracking allows fixation related saccades adequately. The following can occur 5 times/second with a magnitude of upto 1-mm and a speed of 100 mm per second. This is especially important because poor fixation—either due to patient fatigue, body movement or voluntary/involuntary eye movements may cause decentered treatments and suboptimal surgical results due to inaccurate placement of the laser beam. The LADARVision eye tracker cannot be switched off during the laser ablation.

## **Laser Scan LSX Excimer Laser**

### ***Laser System***

The Laser Scan LSX marketed by Laser Sight Technologies, Inc uses a flying spot scanning system to deliver a 1-mm low energy in a alternating multizone, multipass strategy (Fig. 5.13). With each pass, about 2 microns of tissue are precisely removed to produce a finely polished corneal surface.

The LaserHarmonic-1 and LaserHarmonic-2 are solid state lasers still in the development stage. The former is flash lamp pumped and employs the fifth harmonic of a Nd:YAG at 213 nm, and the latter is a diode pumped fifth harmonic Nd:YLF laser at 209 nm.

### ***Eye Tracker***

AccuTrack, LaserSight's eye tracker uses a video camera to track the pupil using infrared light in the Laser Scan LSX system. The image is acquired and relayed in about 16.7 milliseconds through a direct cable link similar to a computer direct subscriber line.

## **Allegretto LASIK Laser System**

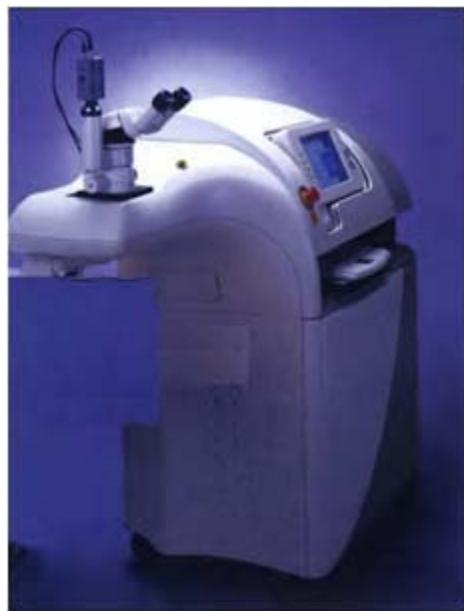
### ***Laser System***

Allegretto LASIK laser system uses a non-sequential flying spot technology (smallest beam diameter 0.95 mm) with a repetition rate of 200 Hz. It has a Gaussian beam profile and the optical zones may vary upto 10.0 mm (Fig. 5.14).

The system also has a large vacuum apparatus, which evacuates the plume, both for the operative team safety as well as the better accuracy of the consecutive spot treatments.

### ***Eye Tracker***

It uses a video-based eye tracker which is pupil based. The infrared cameras have three additional illumination modules to sense eye movement with a detection frequency of 250 Hz and a reaction time of 6 to 8 ms.



**Figure 5.13.** Laser Scan LSX excimer laser system—Laser Sight Technologies Inc.



**Figure 5.14.** Allegreto Wave LASIK Excimer Laser System

## ESIRIS Scanning Spot Excimer Laser

### *Laser System*

This laser system is marketed by Schwind. It is a customized scanning spot excimer laser with a pulse frequency of 200 Hz with a 1 mm spot diameter and has a Gaussian beam profile. It has 29 cm working distance for LASIK between the eye of the patient and the arm of the laser (Fig. 5.15).

### *Eye Tracker*

It has a 300 Hz active eye tracking system.



**Figure 5.15.** ESIRIS Scanning Spot Excimer Laser

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## 6

# *Microkeratomes*

**Rasik B Vajpayee, Namrata Sharma**

A microkeratome is the basic instrument required to create a uniform and a homogeneous corneal flap by cutting across the stromal corneal lamellae. The cutting action of microkeratome is derived from a blade, which is powered by an electromechanical system (or turbine system). The microkeratome motor is powered through a cable and activated by a foot pedal control.

An ideal microkeratome should be simple to assemble and operate, easy to clean and reassemble or readily disposable, allow visibility of the cornea during creation of the flap and demonstrate dependability, durability and repeatability in several consecutive cases.

A number of different microkeratomes have been developed by various scientists around the world and are available for clinical use (Tables 6.1 and 6.2). The following section gives a brief description of the various microkeratomes used for LASIK.

### **Barraquer Microkeratome**

Jose Ignacio Barraquer<sup>1,2</sup> designed the original microkeratome that served as the basis for the development of all subsequent microkeratomes. Barraquer's original microkeratome consisted of a head with a steel blade that was passed manually over the cornea. The system had a blade, a thickness plate, which allowed the surgeon to set the depth of the lamellar cut, and a suction ring, which helps in fixing of the eyeball and raising the intraocular pressure (IOP) to facilitate creation of the corneal flap.

### **Automated Corneal Shaper**

Automated Corneal Shaper (ACS) (Fig. 6.1) was designed by Luis Ruiz and marketed by Baush and Lomb Surgical. The microkeratome head has three gears on one side and is driven by an electric motor which is present in its handle at the rate of 8000 rpm. A stopper mechanism limits the complete run of the microkeratome along the track. The depth of the corneal cut is controlled by the thickness plate that is fitted in the designated groove, on the anterior portion of shaper head. The suction ring is available in various sizes (upto 9.0 mm)



**Figure 6.1.** Automated corneal shaper

Two separate foot pedals are supplied with the control unit—a suction pedal and a power pedal. To initiate and maintain the suction, simply depressing and releasing the suction pedal activates the suction pump. After the completion of the LASIK procedure, the suction is disengaged and the pneumatic ring released by pressing and releasing the suction pedal for a second time. The power pedal has two parts—one to activate and advance the microkeratome across the cornea to create the corneal flap, and the other to reverse the microkeratome after the completion of the corneal cut.<sup>3</sup>

#### **Hansatome**

The Hansatome is a four-piece unit (Figs 6.2a to 6.2e), which is being marketed by Baush and Lomb Surgicals. It is a device that further refines the ability of the ACS devised by Ruiz and is currently a popular microkeratome for LASIK surgery.<sup>4</sup>

The body of the instrument has a gear system engaging over a curve rail track placed laterally in



**Figure 6.2a.** Hansatome suction ring assembly



**Figure 6.2b.** Hansatome console



**Figure 6.2c.** Microkeratome heads 160  $\mu\text{m}$  and 180  $\mu\text{m}$



**Figure 6.2d.** Suction rings 8.5  $\mu\text{m}$  and 9.5  $\mu\text{m}$

the ring. The displacement over it is guided by the same motor that handles the cutting blade. The microkeratome head has a fixed depth plate and a permanent non-adjustable stop device. It utilizes a disposable metal blade, which comes with an integrated plastic holder. The blade oscillates at a



**Figure 6.2e.** Hansatome blade being assembled

speed of 8000 revolutions per minute and is inclined at an angle of 26 degrees.

The unit has two suction rings (8.5 mm and 9.5 mm) that have an elevated, curved gear rack that aligns with the single gear of the Hansatome. It creates a superiorly placed hinge at 12 O' clock position. Three heads with fixed thickness plates are provided which cut flaps of preset thickness 160  $\mu\text{m}$ , 180  $\mu\text{m}$  and 200  $\mu\text{m}$ . There is a left/right eye adapter that fits over the microkeratome head and the motor is positioned vertically, which enables the microkeratome head to pass over the suction ring on an elevated track away from the speculum and the eyelids. The cutting action of the microkeratome does not start until the appropriate vacuum level is reached and the cutting stops if the vacuum falls below a certain level.

Newer design of the Hansatome microkeratome with a zero-compression head reduces the occurrence of postoperative epithelial defects. Smaller diameter rings are now also available allowing easier access to deep-set eyes.

#### **Moria LSK Carriazo-Barraquer Microkeratome**

This is a popular keratome currently in use by many LASIK surgeons. The hand piece and the blades, both are made up of stainless steel (Fig. 6.3). The functioning of this microkeratome may be manual or automated.



**Figure 6.3.** Moria Carriazo-Barraquer microkeratome reusable

The steel blade makes 14,000 oscillations per minute and advances at the rate of 3.7 mm/second. The blade angle is 30 degree. It can cut flap diameters ranging between 7 mm and 10.5 mm. The flap depths can be of 160  $\mu\text{m}$  or 180  $\mu\text{m}$ . A variable flap orientation is possible with this microkeratome. The automated machine works through an electric motor while the manual keratome functions on the nitrogen gas turbine.

Recently the original Carriazo-Barraquer system has been modified so that the system is disposable, the blades are reusable without the gears in the head (Fig. 6.4). This Carriazo-Barraquer -2 microkeratome can be used manually or automatically.



**Figure 6.4.** Moria Carriazo-Barraquer microkeratome single use

### **Moria One**

This manual microkeratome is made of stainless steel and is gearless (Fig. 6.5). A nitrogen turbine yielding high torque and speed of 15,000 revolutions per minutes or 30,000 blades oscillations per minute powers these units. The power unit has two vacuum

pumps so that the second pump acts as a back up and becomes automatically on, when it detects that the first one has failed. It has a one piece pre-assembled head so that the risk of pre-surgical assembly of the device is obviated. The flap depths obtainable are 130  $\mu\text{m}$ /160  $\mu\text{m}$ /180  $\mu\text{m}$ . It has a low vacuum mode which prevents any possible compromise of the retinal vascular flow.



**Figure 6.5.** Moria One reusable microkeratome

#### **Moria One Use—Disposable**

The basic principles of its working are similar to that of the basic model, i.e. Moria One except, that it consists of a one piece plastic molded head with one blade inserted which is not amenable to removal (Fig. 6.6). The heads are available for 160 or 180  $\mu\text{m}$  cut and are powered by the same turbine as the one with a reusable head at the rate of 15,000-rpm oscillation.



**Figure 6.6.** Moria One Use Disposable microkeratome

The stopper is positioned upwards on the ring so that the head position in relation to the surgeon is visualized, which avoids false stops due to speculum or any other obstruction. Three rings -1, 0 and H are available which allow flap diameters of upto 10 mm and the hinge position can be varied.

### **Moria M2**

This is an automated microkeratome which does not have any tracks or gears (Fig. 6.7). It comes in a compact design with preset parameters. It has two independent motors.



**Figure 6.7.** Moria M2 microkeratome

### **Amadeus**

Amadeus is a newer generation microkeratome, which is being marketed by Advanced Medical Optics. It comes as a pre-assembled device and requires a one-handed operation. It has an ergonomically designed titanium hand piece, which houses the motor unit, the blade and the suction ring (Figs 6.8a and b). At present the device has no gears so that the chances of jamming are minimized.



**Figure 6.8a.** Amadeus microkeratome



**Figure 6.8b.** Amadeus console

The suction ring sizes available are 8.5 mm and 9.5 mm (Fig. 6.8c); 9.0 mm and 10 mm sizes will be available very soon. The microkeratome head sizes available are 140  $\mu\text{m}$ /160  $\mu\text{m}$ /180  $\mu\text{m}$ . It has a customizable blade oscillation speed, which varies from 4000 to 20,000 revolutions per minute (Fig. 6.8d). The nasal hinges are obtained by this microkeratome and the cornea is visible throughout during cutting.



**Figure 6.8c.** Amadeus suction ring



**Figure 6.8d.** Amadeus blade holder

There are separate motors for suction and blade advancement. The suction can be reduced/turned off for reverse pass due to a new software upgrade, which has been incorporated. If the suction is broken, it stops cutting and advancing.

#### **MK- 2000 Keratome System**

This is being supplied by Nidek. It is fully automated and comes as a one piece design for one-handed operation (Fig. 6.9). An audible vacuum indicator is there which makes the surgeon aware of the status of the vacuum. It incorporates two separate motors. One provides a high cutting blade oscillation frequency (18000 cuts). The second motor controls the blade advancement to create a smooth incision. A low profile design allows the tonometry measurements and visualization. The constant oscillation speed is 7,000 rpm which allows for cutting of the smooth flap with diameters of 8.5 and 9.5 mm and depths of 130  $\mu\text{m}$ /160  $\mu\text{m}$ /180  $\mu\text{m}$ . There is complete visualization of the flap when it is being cut.<sup>5-7</sup>

It has a sliding guide around the suction ring, and the ring itself has dual suction ports that provide continual vacuum readings and consistent pressure measurement.



**Figure 6.9.** Nidek MK 2000 keratome system

### Schwind Microkeratome

The Schwind microkeratome is produced by Herbert Schwind and has been designed and developed by Hoffmann and Seiler. The device comes as a single unit with accompanying power pack and foot controls. The microkeratome blade is reusable and is made up of sapphire. Each blade can be used approximately for 400 cuts. The angle of contact of the blade with the cornea is 0 degree as compared to 26 degree angle of other microkeratomes, which allows for a low oscillation speed (1600–1800 rpm) during the cut. The blade is electrically propelled and its progression is automated. Its movement is straight and harmonic. The progression speed of the blade is 1.33 mm/sec for a total of 6 seconds.

The thickness plate is fixed and only allows corneal cuts of 150 mm depths. Both anterior and posterior parts of the plate are transparent and the surgeon can directly view the action of the blade on the corneal tissue during the entire procedure.

The vacuum system of the unit contains two suction rings. The rings are fixed and non-adjustable. One ring fixes the eyeball in the peripheral cornea and the other stabilizes the corneal flap during the incision.

The electrical motor system of the device is situated in the instrument's console and two metal drive cables transmit the advancing and oscillatory movements of the blade. This microkeratome cuts a 150  $\mu\text{m}$  thick flap of 9 mm diameter with a 0.5 mm hinge.

The disadvantages of this keratome are the marked vibrations of the instrument, the low oscillation speed of the blade and the use of metal cables to transmit power.

### Carriazo-Pendular Microkeratome

This third generation microkeratome has a ball shaped surface with a ***pendular movement***. It is marketed by Schwind Eye-tech-solutions. The pendular movement distributes the pressure mainly to the centre of the eye and protects the corneal centre during the cut (Fig. 6.10).

The size of the suction ring is 19 mm and it can be used in deep set eyes and eyes with small



**Figure 6.10.** Carriazo-Pendular microkeratome

palpebral apertures. The hinge can be placed at any position. There are two separate motors, one for the pendular motion and the other for blade oscillation. It has an integrated mechanical stop and there are no permanent internal gears in the cutting head.

### **Turbokeratome (SCMD Microkeratome)**

Under the aegis of SCMD Ltd. this turbine microkeratome has been developed by John Livecchi. The microkeratome head is fixed and does not have a thickness plate. The microkeratome produces 130–150  $\mu\text{m}$  flap thickness. There is a bifaceted blade made up of metal. The angle of attack on the cornea is 20 degrees and its oscillating cycles range from 10,000 to 24,000 rpm, although the recommended oscillation speed of operation is 13,800 rpm. The direction of blade movement is sideways.

The microkeratome is independent of electrical power and a turbine with nitrogen protoxide propulsion powers the oscillations of the blade and it does not have an automated progression system and is advanced manually by the surgeon.

A digital micrometer with adjustment screws between the handle and the head of the microkeratome permits the surgeon to set the stop point and therefore determine the length of the cut.

The unit has multiple suction rings (four) and can create flaps of varying diameter and there are four stop rings that give varying hinge dimensions.

### **Innovatome**

This microkeratome has been developed by Innovative Optics Inc. It is a lightweight, molded plastic microkeratome, weighing only 37 gm on the eye. It has an automated advancement system and is driven by a single flexible cable. There are no gears or mechanical assemblies.

The suction ring is integrated with a unique port chamber design placed nasally. The pneumatic fixation ring is integrated in the device and is mechanically grooved to provide infinite points of suction. The unit has a disposable steel blade that is electrically driven and has a oscillation speed of 12,000 rpm. It allows the creation of either horizontal or vertical flaps the diameter of which ranges from 8.5 mm to 10 mm and depths are of 170, 190 or 220  $\mu\text{m}$ .

A clear sapphire applanator is present which allows the surgeon to directly view the operative field so that the surgeon can predict the location of hinge.

### **Meditronic Solan Flap Maker Disposable Microkeratome**

This microkeratome is being manufactured and distributed by Refractive Technologies Inc, Cleveland, Ohio.

The device comes as a preassembled, single-use, molded plastic unit and is completely disposable (Fig. 6.11). It does not have any gears and is driven by flexible shafts that provide a uniform motion of the microkeratome. It has a metal blade made from surgical stainless steel with an oscillation speed of



**Figure 6.11.** Flap maker disposable microkeratome

12,500 cycles per minute. It is driven across the cornea at 6.8 mm per second and only oscillates in the forward motion. The resection depth is variable from 160 to 220  $\mu\text{m}$  and the flap produced has a diameter of 10.5  $\mu\text{m}$ . The unit is made of injection-molded polycarbonate and allows the surgeon to directly visualize the operative field.

#### **Clear Corneal Molder**

Dr Ricardo Guirnaraes of Brazil has developed this microkeratome for use in LASIK. It comes as a single-piece integrated instrument unit that includes the head with a dual axis motor, the handle, the suction ring and the plate. It has a diamond or steel blade which is powered by an electrical motor and has an oscillation rate of 12,000 per minute with a 0 degree angle of attack on the cornea. The diameter and the thickness of the corneal flap cut by the device can be varied. Only one pneumatic fixation ring is present and the height is adjustable in relation to the blade.

It also has a transparent surface, which allows the surgeon to directly visualize the operative field during the surgery. The blade movement can be stopped at a preset point with a lever on the handle of the microkeratome, which allows both free caps or hinged flaps to be obtained.

#### **ML MICROKERATOME (A AND M)**

The Med-Logics microkeratome may be automated (A) or manual (M). It is made up of a titanium hand piece and uses stainless steel blades to create the flap (Figs 6.12a and b). The blade angle is 24 degrees, the oscillation frequency varies between 9000 and 15,000 oscillations per minute and the rate of advancement of the blade is 3.5 to 5.0 mm/sec. The diameter of the flap created by this microkeratome is between 8 mm and 10 mm and the flap orientation is variable. Two suction rings sizes are provided and the depth of the flap created is 160  $\mu\text{m}$  or 180  $\mu\text{m}$ .

## MICRATOME ADVANCED REFRACTIVE INSTRUMENTATION

The MICRA ACRI microkeratome is a manual instrument. The hand piece is made up of titanium or steel.



**Figure 6.12a.** Med-Logics microkeratome



**Figure 6.12b.** Med-Logics console

A stainless steel blade cartridge is used as the cutting mechanism and the blade angle is 25 degrees. Nitrogen gas is used as the power source and the oscillation speed of the blade is 15,000 oscillations per minute. A universal suction ring is provided and the depth of the flap can be 130, 160 or 200  $\mu\text{m}$ . The flap diameter is variable up to 10 mm but the flap orientation is fixed.

### Paradigm K-tome

This microkeratome has one size, which fits all suction rings. There are two microkeratome heads—one to treat myopia and the other to treat hypermetropia. The speed of oscillation is 12,000 revolutions per minute. It creates nasal hinges. Visualization during cutting of the cornea is possible. There are separate motors for blade excursion and the suction. A break in the suction automatically stops the excursion of the microkeratome.

It has an etched sapphire applanation plate. There are dual suction ports. There are no gears and due to the high walls of the suction ring the speculum may not be required.

**BD K-3000 Microkeratome**

The Becton Dickinson K-3000 microkeratome comes as a pre-assembled device with corneal visualization during the flap creation. The one-piece suction ring is composed of titanium, and fixation is achieved with a 360-degree suction port and a special vacuum system. The three-point gearless guiding system reduces sticking. The 9-mm ring holds three applanation sizes, 8.5 mm, 9 mm, and 9.5 mm and the 10-mm ring holds three applanation sizes, 9.5 mm, 10 mm and 10.5 mm. Recently the newer model BD K-4000 has been launched (Figs 6.13a and b). New safety modifications introduced with the K-4000 model are real-time monitoring of the system and automatic preoperative testing of the motors and the blade.



**Figure 6.13a.** Becton Dickinson K-3000 microkeratome



**Figure 6.13b.** Becton Dickinson K-4000 microkeratome

**VISIJET HYDROKERATOME**

This keratome uses a *Water jet* technology to create a *cleavage* in between the corneal lamellae. This is accomplished by fissuring and breaking the collagen bonds between the corneal lamellae while pre-serving the integrity of the lamellae and the keratocytes so that they are not actually cut. Hence this procedure is less traumatic and much safer as compared to the mechanical microkeratomes, which cut across the corneal tissues.

The anticipated advantages of the hydrokeratome are a decrease in epithelial ingrowth, irregular astigmatism, haze, regression and flap or suction related complications.

The Visijet hydrokeratome uses a continuous beam of ultrahigh pressure saline that is only 36 microns in diameter, to cut a flap across the cornea (Fig. 6.14). The key to the hydrokeratome's success is the extreme high pressure (over 15,000 psi) combined with a tightly collimated water jet beam. Under these "ultrafluidic conditions" the water molecules leave the orifice of the instrument at a speed in excess of 800 mph and take on almost metallic properties.

A hand piece translates the water jet across the cornea and the angle of attack of the water beam is 0 degree. The surgeon depending on the selected hinge length and flap diameter preprograms the end point of water jet operation.

The flap thickness can be varied from 100 to 200 microns, depending on the thickness plate used and the diameter ranges from 8 to 11 mm.

The applanating surface is made up of lexan, a special plastic and has a diameter of 12 mm. The



**Figure 6.14.** Visijet hydrokeratome

**Table 6.1: Microkeratomes: desi**

<i>Microkeratome</i>	<i>Function</i>	<i>Cutting mechanism</i>	<i>Oscillations per minute</i>	<i>Suction ring</i>	<i>Head sizes</i>
<b>Bausch and Lomb Surgical</b> Automated corneal shaper	A	Blade	8,000	Variable up to 9.0 mm	160 µm
<b>Bausch and Lomb Surgical</b> Hansatome Microkeratome	A M/A	Blade Blade	7,500 15,000	Fixed at 8.5 or 9.5 mm -1, 0, +1, +2	160 µm or 180 µm 130, 160 µm
<b>Moria CB Single use</b>	M	Blade	15,000	-1, 0, +1, +2	130, 160, 180 µm
CB Reusable					

<b>MZ</b>	A	Blade	15,000	−1, 0, +1, +2	130, 160 µm
One use	M	Blade	15,000	−1 and 0; +1 (soon)	130, 160 µm; H head (soon)
<b>Amadeus</b>			Customizable 4000–20,000	8.5, 9.5; 9.0 and 10.0 mm (soon)	140, 160, 180 µm 120 (soon)
<b>Nidek MK-2000</b>			7000	8.5, 9.5 mm	130, 160, 180 µm
<b>Herbert Schwind Supratome</b>	B	Sapphrie Blade	16,000–18,000	7.0–10.0 mm	160 µm
Innovative Optic Innovatome	A	Blade	24,000	8.9–9.2 mm (myopia) 9.4–9.6 mm (hyperopia)	130, 160 or 190 µm
Solan ophthalmic products	A	Stainless steel blade	12,500	8.5, 10.5 mm	130–220 µm
Flapmaker					
Med-logics ML Mkrokeratome A	A	Blade	8,000–12,000	8, 8.5, 9.0, 10 mm	130, 160 or 200 µm
Micra Micratable Advanced					160 or 180 µm
Paradigm K-tone	–	Blade	12,000	One size fits all	Myopic and hypermetropic
Visijet hydrokeratome Water jet	A	Water beam	NA	7.0–11.0 mm	120–200 µm
Medjet hydroblade keratome Laser	A	Circular water beam	NA	Adjustable up to 9.0 mm	Adjustable to 9.0 mm
Intralase femtosecond laser					
Microkeratome	A	Laser photo disruption	NA	10.0 mm	Variable
Novatec laser microkeratome	A	Transmissive wavelength	NA	Creates intrastral bubbles and flaps	Infinitely adjustable
New United Development Corp Tubokeratome (SCMD)	M	Blade	13,800	7.5, 8.25, 8.75, 9.25 mm	130–150 µm

Becton-Dickinson BD-K3000	MA	12,000	8.5, 8.8, 9.0, 9.5, 10.0 mm	130, 160, 180 μm
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NA—Not available

A—  
Automated  
M—Manual**Table 6.2: Microkerotomes: Functional aspects**

<i>Microkerotome</i>	<i>Hinge type</i>	<i>Visualization of cornea during cutting</i>	<i>Separate motors (Blade &amp; suction)</i>	<i>Blade stops during retraction</i>	<i>Suction during reverse pass</i>	<i>Safety mechanism when suction is broken</i>	<i>Other features</i>
Automated corneal shaper	Nasal	No	No	No	No	—	—
Hansatome Microkeratome	Superior	No	No	No	Yes (Not recommended)	Stops immediately	Zero compression heads protect epithelium
Moria CB Single use	360° placement	Yes	No	Yes	No	Automated alarm	Disposable
Moria CB Reusable	360° placement	Partially	No	Yes	No	Automated alarm	For small, deep set eyes
Moria M2	360° placement	Partially	No	Yes	No	Automated alarm	Compact and flexible
Moria One use	Nasal	Yes	No	Yes	No	Automated alarm	Disposable
Amadeus	Nasal	Yes	Yes	Yes	Software upgrade customizes to decrease suction	Stops cutting and advancing	One hand assembly
Nidek MK-2000	360° hinge placement	Yes	Yes	Yes	Yes	Audible alarm	Single hand piece
Med-logics ML Microkeratome A	Nasal	No	Yes	Yes	NA	Cutting and advancement stop	Fine vacuum slits for vacuum

Paradigm K-tone	Nasal	Yes	Yes	Yes	No	Stops automatically	Ethed sapphire applanation plates. Speculum not required
Becton-Dickinson BD-K3000	Nasal	Yes	Yes	Yes	Yes (not recommended)	Blade stops oscillating	Dual vacuum pumps. Low vacuum option

surface is transparent and the surgeon has a full visualization of the visual axis at all times.

## **LASER MICROKERATOME**

The laser microkeratome is based on the newer technology. The INTRALASE Femtosecond Laser Microkeratome is an example of laser keratome.

The Femtosecond laser pulses are produced by a solid state, Nd:Glass laser, operating at 1.06 nm wavelength and 450 femtosecond pulse duration. The system consists of a laser oscillator, a pulse stretcher, a regenerative amplifier, and a pulse compressor. The oscillator is mode-locked by a solidstate saturable absorber and produces a train of 250 femtosecond pulses at a repetition rate of 120 MHz. Pulses from the output of the oscillator are selected at a few KHz repetition rate and stretched to a 60 picosecond pulse duration. The pulse is then amplified in a diode-pumped regenerative amplifier and then recompressed to 450 femtosecond pulse duration. Laser energy can varied from 1 to 25 mJ.

The laser microkeratome is used as an intrastromal cutting tool based on picosecond intrastromal photodisruption. It causes separation and removal of a small amount of stromal collagen from within the cornea by focusing highly transmissive infrared laser light through the cornea. Each pulse creates a micro-cavitation, which are few microns in size. These pulses are delivered with a computer controlled scanning system.

### **Pulsion Femtosecond Laser**

This creates a 3-micron spot size, which creates the flap. The hinge position may be temporal, nasal or superior. The flap diameters created may be 8.0/ 8.5/9.0/9.5 mm and the flap thickness may be 150/ 160/170/180  $\mu\text{m}$ . These laser pulses are delivered in close proximity of each other in a spiral pattern and the uncut region of the flap is pre-programmed to fashion the hinge.

The main advantages of this technique are the precision and reproducibility of the laser in producing flaps of uniform thickness and the smoothness of the flap interface.<sup>8,9</sup>

Suction rings and the cutting blades are also not required in this procedure. Currently, the limitations of this laser technology are the small flap diameter, poor centration, increased intraoperative time and difficulty in dissection. Research is on to develop a solid-state ultraviolet laser, which can be, used both for cutting the flap and intrastromal ablation.

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# 7

## ***LASIK Ancillary Instruments and Operating Environment Variables***

**Rakesh Ahuja, Jeewan S Titiyal**

The basic equipment required for LASIK are a micro keratome and excimer laser machine. However, several other instruments are required to safely perform this surgery. These instruments are categorised in Table 7.1.

These instruments are required for the exposure of the globe, marking of cornea and safe handling and repositioning of the corneal flap.

### **Instruments for Exposure**

#### ***Eye Speculum***

The eye speculums used for LASIK are of various types (Fig. 7.1). A *wire lid speculum* provides excellent exposure of the eye. The wire design is preferred over the solid blade type since it does not interfere with placement of the suction ring and excursion of the microkeratome. *Lieberman aspirating eye speculum* (Fig. 7.2), has an adjustable mechanism. The open wire blades are designed to retain the surgical drape under the eyelids. Suction allows continuous aspiration of fluids for a debris free stroma, which can interfere with laser ablation.

**Table 7.1: Ancillary Instruments for LASIK**

*Instruments for exposure*

Eye Speculum

*Instruments for marking the cornea*

LASIK Corneal Markers

*Barraquer Applanation tonometer*

*Instruments for Flap management*

Flap elevator and repositor

Irrigating cannula

Cellulose Sponges and LASIK drain

Flap protector

*Instruments for Re-surgery*

Flap edge locators

Flap forceps

*Ultrasonic Corneal Pachymeter*

*Operating room instruments*

Air purifier with ionizer

Digital Thermo-hygro-meter

**Instruments for Marking the Cornea—LASIK Markers**

Accurate marking of the cornea is most important for proper flap centration, flap alignment and flap repositioning after excimer laser ablation. A proper alignment guards against inadvertent flap folds and iatrogenic astigmatism due to improper placement. Moreover, the markings are invaluable in proper



**Figure 7.1.** Wire speculum



**Figure 7.2.** Liebermann Temporal aspiration speculum—Six ports on each blade allow continuous aspiration for a debris free stroma

replacement of a free cap. These markers are dipped in 1 percent gentian violet and then placed on the cornea. Various designs available attempt to provide a unique marking pattern to minimize any errors on the part of the surgeon.

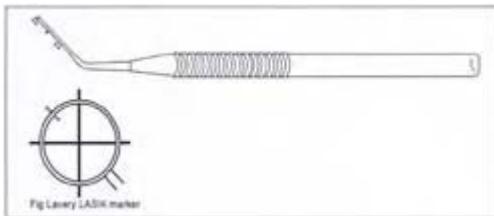
1. *Optic zone corneal marker*: It can be used to mark the cornea before microkeratome cut (Fig. 7.3). The ring gives better alignment of the flap. Marking the cornea at three meridians, 3, 6, 9 O'clock is used. In the event of free cap, this



**Figure 7.3.** Optic zone corneal marker

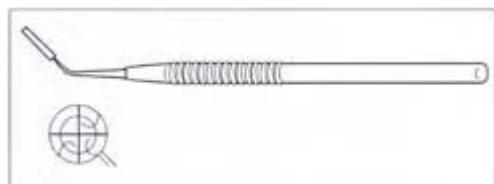
may provide better guideline for replacement of the flap.

2. *LASIK flap marker*: has an optical zone 8 mm with 3 marking lines which are asymmetrical to ensure correct placement of corneal flap.
3. *Lavery LASIK marker*: It has an optical zone of 8 mm, with five marking lines which are asymmetrical, to ensure right placement of corneal flap (Fig. 7.4). It has an optical centre sight for surgeon's convenience.



**Figure 7.4.** Lavery LASIK marker

4. *Antzoulatos LASIK marker*: It has an optical zone 8 mm with half circles (Fig. 7.5). It is used for guarding against flap displacement, flap centration and to avoid placing a free flap upside down.



**Figure 7.5.** Antzoulatos corneal marker

5. *The LASIK marking pen:* It uses gentian violet for freehand marking of the cornea in single or multiple radial marks (Fig. 7.6). It can also be used for marking the center of the cornea.



**Figure 7.6. LASIK marking pen**

6. *Mendez Corneal Marker:* It has an 8 mm optical zone with central cross hair guide for identifying the optical centre of the cornea.

7. *Chayet Corneal Marker:* It has three asymmetrical circles which allow for easy identification and realignment.

8. *Lu Corneal Marker:* This has 8 mm optical zone with two single lines and one double line as the marking pattern.

9. *Dulaney Corneal Marker:* This has one small and intersecting bigger circle providing a unique marking pattern.

10. *Epstein-McHenry optical centre LASIK Marker:* It is used with fluorescein for identifying the center of the optical axis.

### **Barraquer ApplanationTonometer**

The Barraquer applanation tonometer (Fig. 7.7) is based on the Maklakov's principle of applanation tonometry. It consists of a convex dome with an inscribed applanation ring on its flat, applanating surface. Measurement of IOP is done by applanating the cornea using the flat lower surface of the Barraquer tonometer. The weight of the



**Figure 7.7. Barraquer applanation tonometer**

tonometer applanates an area of cornea in direct relation to the intraocular pressure. The meniscus rings can be compared to determine intraocular pressure. The diameter of the ring is calibrated to represent intraocular pressure of 65 mm Hg. Before starting the

microkeratome for making the flap, IOP should be at least 60 to 65 mm Hg. This is important since a lower IOP may result in higher risk of flap complications, like thin flap, buttonholed flap, or even perforation of the cornea.

### Instruments for Flap Management

1. *LASIK Flap elevator spatula*: These are used for lifting the flap after the microkeratome cut and also for replacing the flap after the excimer ablation (Fig. 7.8). These are imperative for LASIK enhancement surgery to relift the flap.



**Figure 7.8.** LASIK flap spatula

- Fukasaku LASIK spatula*: It has rounded anterior and flat posterior surface with dissecting tip and is used for lifting and dissecting the corneal flap (Fig. 7.9).



**Figure 7.9.** Fukasaku LASIK spatula

- Guimaraes LASIK spatula* has gently curved, bi-convex, semi-sharp edges (Fig. 7.10).



**Figure 7.10.** Guimaraes LASIK spatula

- Alio-Rodriguez dual LASIK Spatula*: It has dual 12 mm long 0.25 mm diameter arms (Fig. 7.11).



**Figure 7.11.** Alio-Rodriguez LASIK spatula

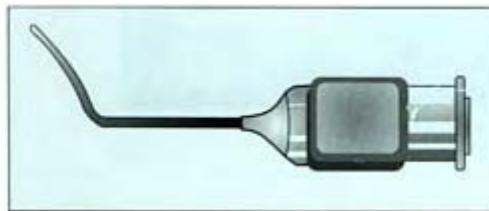
d. *Maddox LASIK spatula*: It combines a flat spatula and a cylindrical spatula and is used for elevating and repositioning the flap (Fig. 7.12).



**Figure 7.12.** Maddox LASIK spatula

2. Irrigating cannula: It is used for irrigating the interface of LASIK flap and stroma. It helps to dislodge any particles from the corneal interface. Multidirectional cannula help to irrigate the interface in one single sweep. A range of designs is available with openings ranging from 2 to 8 per cannula.

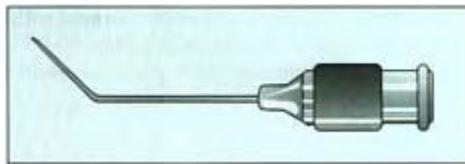
a. *Spatulated LASIK cannula*: It has a flattened spatulated tip with end opening of 26 gauge (Fig. 7.13).



**Figure 7.13.** Spatulated LASIK cannula

b. *Fukasaku LASIK cannula* with a low profile tip and an end opening of 23 gauge (Fig. 7.14).

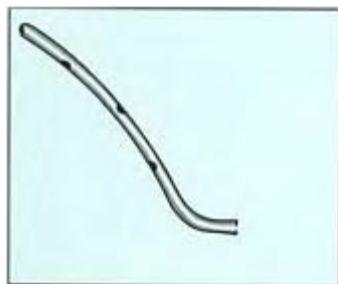
c. *Gimbel LASIK fountain cannula* has a smooth bullet shaped tip with a single center port of



**Figure 7.14.** Fukasaku LASIK cannula

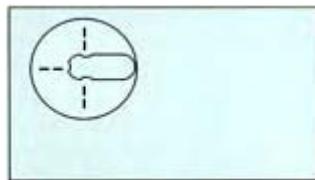
25 gauge for directing fluid toward the superior hinge.

d. *Banaji LASIK Cannula* has a bullet shaped tip and 6 ports of 25 gauge size for multi-directional irrigation (Fig. 7.15).



**Figure 7.15.** Banaji LASIK cannula tip

- e. *Brierley LASIK cannula* has a closed spatulated tip with 6 ports with a size of 25 gauge for multi-directional irrigation.
- f. *Carter LASIK cannula* has an end opening flattened tip of 25 gauge.
- g. *Buratto LASIK cannula* has one front and two side ports. These are designed for equal flow in all the three directions (Fig. 7.16).



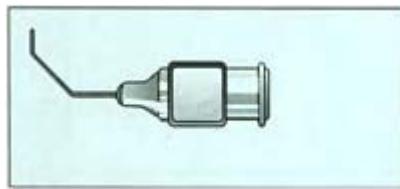
**Fig 7.16.** Buratto LASIK Cannula tip

- h. *Vidaurri LASIK cannula* is double-armed with 8 irrigating ports in size of 25 gauge.
- i. *Cobra LASIK cannula* has 6 ports for multi-directional irrigation with a size of 23 gauge (Fig. 7.17).



**Figure 7.17.** Cobra LASIK cannula tip

- j. *Gimbel LASIK polishing cannula* has a flattened textured tip in a size of 30 gauge. It is used for dislodging and irrigating particles from the corneal interface (Fig. 7.18).



**Figure 7.18.** Gimbel LASIK polishing cannula

3. *Cellulose sponges and LASIK drain:* Cellulose sponge spears used in LASIK should be of high quality and should not leave behind any remnants like fibres. These are provided sterile for single use and should be disposed of after surgery.

- i. *Merocel spear sponges (Xomed, Jacksonville FL)* It is made of lint free PVA with a triangle shaped spearhead set on a malleable, polypropylene handle. The sponges are soaked in proparacaine 0.5 percent solution for anaesthetizing the conjunctival fornices. A dry spear is used to clean any debris from the conjunctival surface, wipe excessive moisture from corneal surface in between ablation and to remove excess moisture from borders of replaced flap for proper adherence to the stromal bed. A wet sponge is used to keep the reflected flap hydrated, wipe the corneal stromal bed and also to iron back the flap on to the bed after ablation is complete. This ironing is done from the side of the hinge towards the non-hinge area till the flap is free of striae and properly adherent to corneal stromal bed.
- ii. *LASIK drain:* It is made of thin synthetic PVA sponge and completely encircles the cornea. It is used for preventing excessive hydration of stromal bed during laser ablation,

- a. *Chayet LASIK Drain:* It has a central 10-mm opening and is designed for nasally hinged flaps (Fig. 7.19).



**Figure 7.19.** Chayet LASIK drain

- b. *Gimbel-Chayet LASIK drain:* It has a central opening of 9.5 mm and is designed for both nasally as well as superiorly hinged flaps (Fig. 7.20).



**Figure 7.20.** Gimbel-Chayet LASIK drain

4. *Flap protector:* A flap protector shields the everted flap from inadvertent ablation by the excimer beam, which is an iatrogenic complication (Fig. 7.21). A corneal paper shield fashioned using scissors may be used for the same purpose,

a. *Buratto LASIK flap protector:* It is used for retracting and protecting nasally hinged



**Figure 7.21.** LASIK flap protector

corneal flaps (Fig. 7.22). Buratto flap protector is also available with blades angled at 15° for retracting and protecting superiorly hinged corneal flaps.



**Figure 7.22.** Buratto LASIK flap protector

b. *Mannis-Buratto LASIK flap protector:* It has blades angled 45° used for retracting and protecting superiorly hinged corneal flaps (Fig. 7.23).



**Figure 7.23.** Mannis-Buratto LASIK flap protector

c. *Rowen combination instrument:* It has a LASIK flap protector on one side and a spatula on the other side. It is used for protecting the flap as well as a spatula (Fig. 7.24).



**Figure 7.24.** Rowen combination instrument

### Instruments for Re-LASIK

#### 1. Flap edge locators

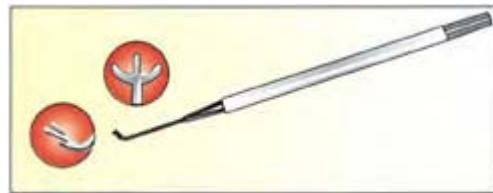
- a. *LASIK flap manipulator*: It has a delicate, smooth polished olive shaped tip (Fig. 7.25). This tip is used to gently depress the cornea to locate the flap edge. Once located, the olive



**Figure 7.25.** LASIK flap manipulator

tip can then be used to engage the edge and slide it around the rim to partially open the flap.

- b. *Fox LASIK Flap Edge Dissector*: It has a three pronged tip which is used for finding the edge of flap in LASIK enhancement surgery (Fig. 7.26).



**Figure 7.26.** Fox LASIK flap edge dissector

- c. *Maddox LASIK spatula*: It combines a flat spatula and a cylindrical spatula. It is used for elevating and repositing the flap in enhancement surgery.
- d. *Banaji LASIK flap spatula*: It has extremely thin duckbill shaped tip at one end curved and the opposite end is angled.
- e. *Katzen LASIK flap “Unzipper”*: It combines a modified sinskey Hook and a bi-convex spatula with beveled notches. It is used for lifting and dissecting the corneal flap in enhancement surgery.

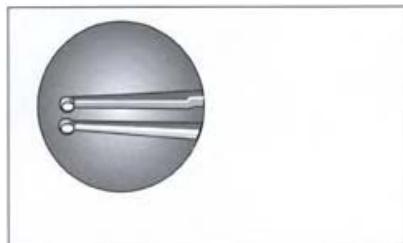
2. LASIK flap forceps

- a. *Collibri, Pierse forceps*: These forceps are used for reflecting and repositioning the hinged flap in re-surgery as well as for handling a free cap in case of complete resection.
- b. *Mendez Multi-Purpose LASIK forceps*: It has spatulated jaws and tips with smooth grasping surfaces, vaulted (Fig. 7.27). It may be used for lifting, dissecting and grasping the corneal flap.



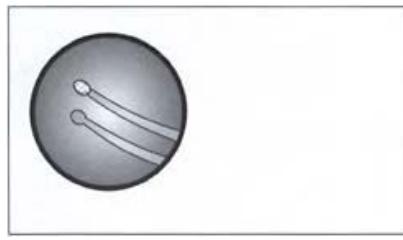
**Figure 7.27.** Mendez multi-purpose LASIK forceps

- c. *Fechtner conjunctiva forceps*: is very delicate with ring shaped tips having a tying platform (Fig. 7.28).



**Figure 7.28.** Fechtner conjunctiva forceps tip

- d. *Buratto LASIK flap forceps*: It is disc shaped with serrated jaws for manipulating the flap (Fig. 7.29).



**Figure 7.29.** Buratto LASIK flap forceps tip

### Ultrasonic Corneal Pachymeter

Corneal pachymetry is necessary in each case prior to LASIK for determining suitability for surgery. We use the Sono Gage corneal pachymeter to perform ultrasonic pachymetry (Fig. 7.30). It has a 50 MHz transducer with multiple examination modes. Proper vertical placement of the probe onto an anaesthetized cornea gives highly accurate readings of corneal thickness. The readings of corneal pachymetry obtained with ultrasonic method are much more reliable as compared to the Orbscan and Optical pachymetry.



**Figure 7.30.** Sono Gage corneal pachymeter

Performing intraoperative corneal pachymetry gives the stromal bed thickness from which the flap thickness may be derived by simple subtraction. Thin flaps, less than 100 mm, should preferably not be re-lifted in LASIK retreatment/enhancement procedures. In such cases a second microkeratome cut is made and enhancement done.

### Operating Room Environment Variables

Operating room environment, including temperature and more particularly humidity are important controllable parameters for LASIK surgery. The proper laser room environment is critical for optimal laser performance. These variables should be set to the manufacturer's recommendations for the particular machine. In general, the temperature should be maintained between 18 to 24°C, and the humidity should be kept below 50 percent.

Environmental factors that can affect final LASIK correction include the temperature, humidity and altitude of the laser center, as well as the amount of particulate matter created by plumes.<sup>1</sup> Humidity may be more significant than temperature in controlling excimer laser ablation. The corneal stroma can hydrate and swell up after removal of flap, while the light of operating microscope leads to superficial dehydration. Lower levels of humidity are likely to result in a drier stromal bed, which may result in more than intended excimer laser ablation.<sup>2</sup>

Humidity and temperature should be meticulously measured using manufacturer recommended and certified scientific instruments. The ***digital thermo-hygro-meter*** (Fig. 7.31) gives instant digital reading of the temperature and humidity. Both these parameters

should be noted down in LASIK surgical notes for each individual patient. This becomes particularly important when the attempted correction and final outcome in a patient do not match.

The excimer laser optics are highly sensitive to dust and other such particles. The **Air - purifier with ionizer** is used for filtering air and removing particles from the operating room environment. It removes any particulate matter down to a size of 0.1 mm, including the bacteria. An inbuilt activated carbon filter helps to remove any odors. The ionizer device releases negatively charged ions which help



**Figure 7.31.** Digital thermo-hygrometer

reduce the static electricity created by the computer screen.

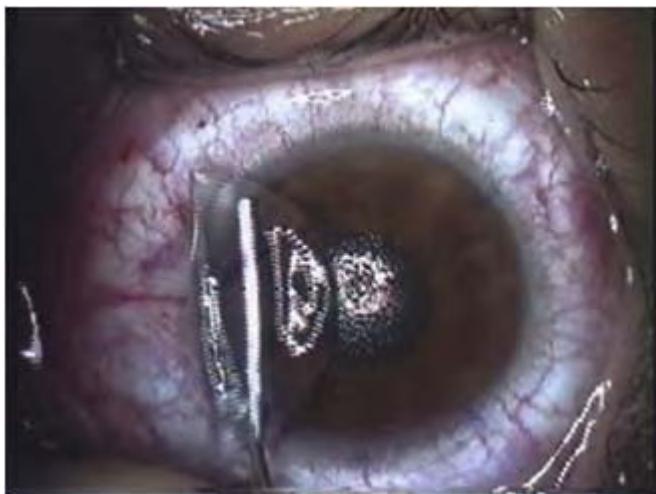
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# Section 3

## Surgical Technique



## 8

# ***Presurgical Preparation and Exposure***

**Prashant Bhartiya, Namrata Sharma, Rasik B Vajpayee**

Once the patient has been through the selection process for undergoing LASIK, he or she is prepared for the surgery. During the selection process the patient should have been well informed about the nature of the procedure, expectations and results. The patient is allowed to have a light breakfast early in the morning if the surgery is planned for the day.

It is most important to ensure that the consent form has been read and signed by the patient before proceeding further. Two important parameters to be rechecked in the operating room (OR) are the central corneal thickness (pachymetry) and the scotopic pupil size, as the ablation zone diameter is determined by these parameters in relation to the refractive error to be corrected. A final ocular examination is conducted to rule out any local contraindications like blepharitis and conjunctivitis. The patient is asked to wash his face with soap and water. The eyelids are cleaned with 5 percent povidone iodine solution and topical 0.3 percent ciprofloxacin eyedrops are instilled one hour prior to the procedure. The patient is given a sterile gown and cap to wear. A tag mentioning the patient's name, identification number and the refractive error is placed on the patient's gown to allow for any cross checking needed inside the OR.

In the operating room a quick checklist is run through (Table 8.1). Before starting the surgery, the operative room temperature and humidity are noted. The temperature is maintained between 15 degree Celsius and 25 degree Celsius, and the humidity level less than 50 percent. This is important because any change in the temperature or the humidity may alter the amount of tissue ablated and hence the refractive results and the outcome. The laser fluence levels, microkeratome, surgical instruments and footswitch position are all rechecked.

**Table 8.1: Operating room checklist**

- Consent form completed
- Final ocular examination
- Patient's parameters in the LASIK machine computer
- Laser fluence levels
- Operating room temperature and humidity
- Microkeratome suction ring assembly
- Surgical instruments

- Footswitch positon

### **Positioning the Patient**

The patient is gently seated and then positioned under the laser's microscope. The patient has to be instructed to remain still during the procedure. The head should be positioned in a manner so that the cornea is perpendicular to the aiming beam of the laser.

### **Anesthesia**

General anesthesia is rarely ever required for LASIK especially since the procedure is mainly done in adults. Infiltration anesthesia has the disadvantages of inability to fixate the eye centered on the visual axis, chemosis preventing proper placement of the suction ring, and the discomfort of the injection and possibility of complications like hemorrhage.

Topical anesthesia with proparacaine, lidocaine or tetracaine is preferred. 0.5 percent proparacaine or 4 percent lidocaine eyedrops are instilled 5 minutes before and then immediately prior to the procedure. All these agents have epithelial toxicity and hence excessive application must be avoided.

Whereas older children may cooperate for topical anesthesia, younger children may require general anesthesia for LASIK surgery. The nitrous oxide, oxygen and halothane are delivered via mask, which may need to be displaced to allow adequate positioning of the suction ring during the LASIK procedure. However, this may at times result in the leakage of the anesthetic gases, causing the excimer laser to malfunction during the surgery. The anesthetic technique has now been modified and a laryngeal mask airway is advocated.

### **Instructions to the Patient**

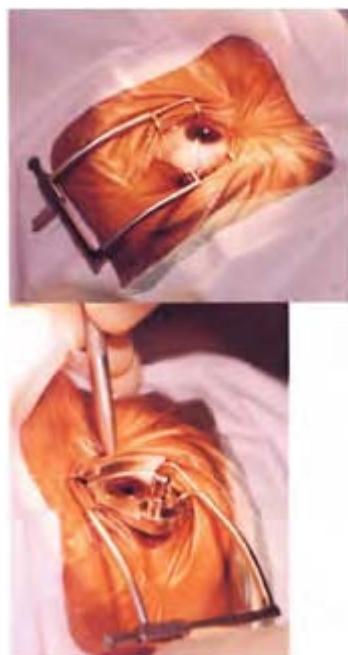
The patient is informed about the fixation light and asked to look straight into it throughout the procedure unless mentioned otherwise. The patient is instructed not to squeeze the eyelids and also to keep his or hands away from the operating field. The patient is informed and reassured regarding the feeling of pressure when the suction ring is applied.

### **Draping the Eye**

A 5 percent povidone iodine solution is painted on to the lashes and the surrounding skin with a swab stick soaked with the solution. A sterile self-adhesive plastic drape is placed in such a manner that the lashes are covered by it. It is fenestrated in the center to provide for placement of the speculum. The other eye and the nose are kept open by placing the opposite tracker under the plastic drape to avoid suffocation. Temporal lashes that may be jutting out may be tucked in with the help of steristrips <sup>TM</sup> or may even have to be cut or epilated.

### Exposure of the Globe

A self-retaining adjustable and locking speculum is used to retract the lids covered by the plastic drape that keeps the lashes away as mentioned above (Figs 8.1a and b). In extremely deep-set eyes a retrobulbar injection of balanced salt solution or anesthetic agent may be used to protrude the globe although this may lead to unwanted chemosis preventing proper placement of the suction ring.<sup>1</sup> The placement of a retrobulbar injection can lead to severe sight-threatening complications also.



**Figures 8.1 a and b.** Proper exposure of the eye

In some cases a Barraquer's wire speculum may be needed if the orbit appears small that may not allow larger speculum to be used. Inadequate exposure leads to difficulty in placement of the suction ring and hence may hinder the movements of the microkeratome.

We advocate the removal of the lid speculum and placement of the 8.5-mm suction ring after opening the eyes with the index finger and the thumb, in cases of inadequate exposure.<sup>2</sup> The Hansatome, with a 180- $\mu\text{m}$  thickness plate, is then placed on the suction ring and the LASIK flaps may then be created. The presence of the lid speculum decreases the potential space in the fornices, especially in eyes with narrow palpebral apertures. However, the use of the Hansatome without the speculum requires caution and should be only undertaken by experienced surgeons. The drapes, the lashes, and the eyelids should be spread wide apart either by the surgeon or an assistant during this

procedure to prevent inadvertent entanglement of these structures during the excursion of the Hansatome. Alternatively, a lateral canthotomy may also be undertaken in such eyes.

### **Exposure of Eye in Nystagmus**

In cases of nystagmus, a modified suction ring device may be used to stabilize the eye during corneal ablation<sup>3,4</sup>. The suction ring has a peripheral semicircular groove containing holes through which suction is applied to the globe. The notch at the margin of the suction ring is used as a shelter to protect the prepared flap from negative pressure and involuntary laser ablation. The presence of a semicircular suction ring device with a notch at the hinge provides a space for the flap, and the semi-circular suction groove fits on the globe properly, providing effective suction on the globe over the flap.

Alternatively, the newer active eye tracker software such as present in LADARVision (Alcon, Fort Worth, TX) can compensate for the movements of these eyes.

After adequate exposure of the globe is obtained the conjunctival sac is irrigated with balanced salt solution and any debris or mucus wiped out with surgical sponges.

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## 9

# ***Marking the Cornea and Creation of Corneal Flap***

**Patrick Titzé, Aghlab N Khoury, George D Kymonis George A Kounis, Ioannis M Aslanides, Ioannis G Pallikaris**

The creation of the lamellar or the corneal flap with the help of microkeratome is the first step of laser in situ keratomileusis, which requires careful attention and marked precision.

## **MARKING OF THE CORNEA**

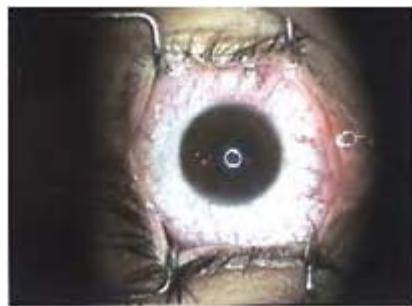
### **Before the Procedure**

All the steps of the procedure should be undertaken without interruption. It is advisable to use a new blade for every new patient. The quality of the blade should be checked under the microscope. Ensure that the microkeratome has been checked (e.g., movement of the gear, sliding of the blade without resistance, suction of the ring and advancement of the microkeratome through the dove-tail of the suction ring).<sup>1</sup> Generally, it is recommended to add some lubricating drops of Balance salt solution (BSS®) on the gears.

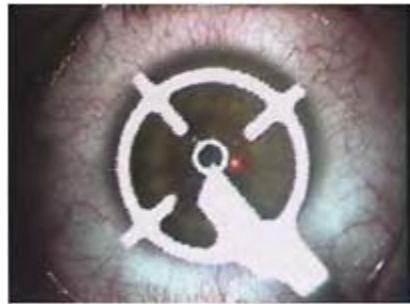
### **Patient Preparation**

Before the patient enters the surgery room, the lids should be washed. After topical anesthesia with Proparacaine 0.5% (Alcaine, Alcon, Ft. Worth, TX), the lid is scrubed with a gauze moistened with baby shampoo (half diluted with sterile water). In case of blepharitis and meibominitis, a cotton tip can be used to carefully scrub the lashes and the lid margins. Some surgeons instill diluted povidone iodine one percent solution in the eye, and prepare both lid margins with diluted povidone iodine or alcohol. The head should be covered with a surgical cap. When the patient comes into the surgery room, he should be made comfortable taking care to position his head correctly so that the body is aligned with his head. A head tilt will change the reference axis of the astigmatism. The patient's face is draped and a plastic drape is used to cover the lashes. One drop of topical anesthesia is instilled again e.g., Proparacaine 0.5% (Alcaine, Alcon, Ft. Worth, TX). The lid speculum is then inserted. Make sure that the lashes are included in the drape in order

to avoid their contact with the operative field. The speculum should provide a maximum exposure of the eye to avoid interference with the placement of the suction ring and the excursion of the microkeratome head. This will also minimize the contact of the stromal



**Figure 9.1.** Maximal corneal exposure



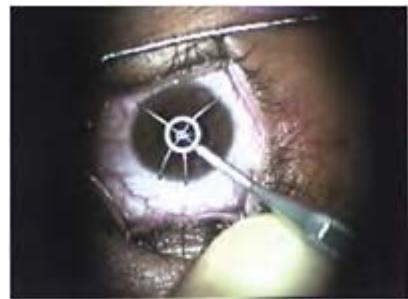
**Figure 9.3.** Marking with the Duckworth and Kent marker

bed with the lid margin. The patient is asked to look at the fixation light of the microscope and to maintain this fixation throughout the whole procedure. Figure 9.1 shows the ideal corneal exposure.

The best head position is achieved with the chin slightly up in order to centre the cornea in the palpebral fissure. The whole surgery is performed as far off from the lid as possible. The superior border of the orbit, especially in enophthalmic patients, or in patients with prominent superior orbit rim will not disturb the procedure.<sup>2</sup> This should also minimize possible contact of the stromal bed with the lid margin which could contain contaminated secretions.<sup>3</sup> Position the head and body of the patient according to the horizontal axis (marked before the surgery) to counterbalance the cyclo-



**Figure 9.2.** Drying of the corneal surface with a cellulose sponge



**Figure 9.4.** Marking with the four radial asymmetrical blade marker. Note the light reflex in the centre

torsion induced by the decubitus position.<sup>4-7</sup> The patient is asked to maintain this position during the surgery and move only according to the surgeon's instructions.

#### Marking of the Cornea

Irrigate copiously with Balanced salt solution (BSS<sup>®</sup>) for 20 to 30 seconds. During this procedure the patient reacts with a blepharospasm. If a light lid speculum is used, the superior lid margin can be held in place with the index finger. Carefully dry the surface of the cornea with cellulose microsponge (Merocel sponge<sup>®</sup>) (Fig. 9.2) to allow a clear ink mark.

Marking the cornea is probably one of the most important steps in LASIK. It enables a better

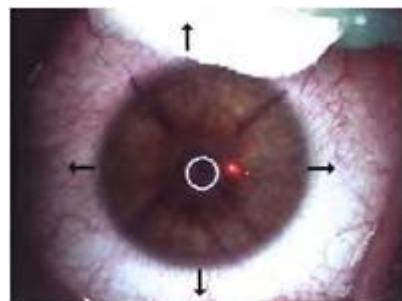


**Figure 9.5.** Peripheral asymmetrical mark pointed with the forceps

centration of the suction ring, and ensures a proper repositioning of the hinged flap at the end of the procedure. In case of a total cap, it allows better cap alignment and prevents accidental positioning of the cap with epithelial side down. In this situation it is important to use a marker with peripheral asymmetrical marks (prevents accidental positioning of the cap with epithelial side down). Many markers are on the market; we advise the use of the Duckworth and Kent (Fig. 9.3) or the four radial asymmetrical blade marker (Fig. 9.5). The gentian violet ink is well tolerated by the epithelium (Fig. 9.4).

In order to centre the marks with the visual axis, most laser microscopes have a circular axial illumination. It is easier for the surgeon to find the visual axis if the patient is asked to fixate at the light microscope. For hypermetropic patient, the reflex is slightly eccentric temporally, because of a negative kappa angle. We usually centre our mark slightly nasally to this reflex to allow a more centred ablation with respect to the corneal pupillary axis. Marks are not necessary at the hinge position.

Irrigate copiously with Balanced salt solution (BSS<sup>®</sup>) for 20 to 30 seconds to remove the excess ink. Dry carefully the surface of the cornea with cellulose microsponge (Merocel sponger). The conjunctival folds should be stretched from the limbus to the fornix in order to avoid incarceration of conjunctiva in the aspiration hole of the suction ring during the vacuum. (Fig. 9.6).



**Figure 9.6.** Stretching of the conjunctiva from the limbus to the cul de sac

This could lead to a pseudosuction with no increase of intraocular pressure, instability of the ring and suction loss during the cut of the flap. Once the suction has been achieved, some surgeons lift the whole assembly (i.e. suction ring plus the microkeratome) before the cut, in order to see how effective the suction is.

### **Creation of the Corneal Flap**

#### ***Microkeratome***

The choice of the microkeratome is made according to surgeon's experience and preference. The characteristics of each microkeratome are discussed in chapter 6. One should refer to the manufacturer specifications and nomograms. Generally, the diameter of the ring should be chosen according to the steepest K reading and the attempted diameter of the treatment zone. High K readings predispose to button hole formation, while flat K readings predispose to free caps.<sup>1,8-11</sup> In hypermetropic patients, a larger diameter is necessary.<sup>12-16</sup> The hinge position has to be chosen according to the presence of a superior pannus (superior hinge preferred) and according to the axis of the astigmatism (with the rule nasal hinge and against the rule superior hinge).

#### ***Ring Positioning***

The ring will be centred with the corneal light reflex, the ink mark and the whole cornea (Fig. 9.7).

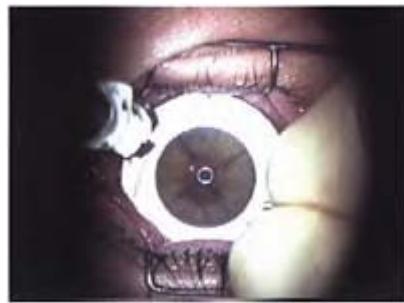


**Figure 9.7.** Ring positioning centered with the corneal light reflex



**Figure 9.9.** Pressure check with an applanation tonometer

Take care that no sclera is included in the cut. In case of superior pannus, an inferior eccentric position may be suitable. Lashes or lid margins should be as far as possible from the ring to allow a good vacuum. If necessary, the superior lid margin can be pushed away with the index finger, in order to increase the size of the palpebral fissure. For nasal hinge, the suction ring is placed slightly eccentric to the nasal side of the cornea (one mm from the centre). This will protect the hinge of the flap from accidental ablation especially in the case of large ablation zone. The same will be done for superior hinge with a ring position slightly eccentric to the superior side of the cornea by about 1 mm from the centre. For small palpebral fissures a special small ring can be used. Usually a lateral canthotomy is



**Figure 9.8.** A pressure on the ring to allow a perfect vacuum



**Figure 9.10.** Insertion of the tip of a dry air cannula underneath the flap

never required. With the mobilization of patient's head, the use of an orthostatic lid speculum or a microkeratome already mounted, the procedure should be possible.<sup>2,17,18</sup> Before the suction, warn the patient of loss of vision for a few seconds. To avoid pseudosuction, push the ring towards the globe during the vacuum rise (Fig. 9.8).

Sometimes the ring moves with the vacuum and can be eccentric. Try to reposition the ring without relieving the vacuum. The conjunctival chemosis induced by the vacuum due to repeated repositioning makes the new ring positioning more difficult. Always check the pressure with calibrated applanation tonometer (around 65 mmHg) or at least with your finger (Fig. 9.9).

### ***The Flap Cut***

Insert the microkeratome into the dove-tail of the ring. Be sure that the vacuum is not lost. Moisten the cornea with aqueous solution (BSS<sup>®</sup>) to allow a fluid movement of the microkeratome. Perform the cut by pressing on the foot pedal. Never raise your foot from the pedals (reverse foot pedal) while performing the cut, to avoid steps in the flap. When the cut is completed, press on the second foot pedal to bring the microkeratome at its initial position. In case of incomplete flap, the flap should be relifted only if a centred laser ablation is possible. The entire procedure of cutting the flap should be as short as possible. Remember that intraocular pressure is high enough to stop the perfusion of the optic nerve and the retina (patient loss of vision and pupil mydriasis during the suction). One should always be aware that the flap is created during the forward movement of the microkeratome pass, and during the reverse movement the the flap returns back to the cornea. Close attention at this point is extremely important, especially in cases where a free cap has been produced since the surgeon should know where the free cap might be located.

When the flap has been made, irrigate with Balanced salt solution (BSS<sup>®</sup>) to remove cells and debris before lifting the flap. Dry the remaining fluids with an aspiration system or cellulose sponge (Merocel sponge<sup>®</sup>).



**Figure 9.11.** Move in a wave-like motion towards the edge of the hinge

#### *Lifting of the Flap*

Lift the flap by inserting the tip of a dry air cannula underneath the flap (Figs 9.10 and 9.11).

The cannula is then moved in a wave-like motion towards the side of the hinge. One can also leave the flap folded in two to avoid excessive dryness (Fig. 9.12).

Some surgeons do not like to fold the flap, because a lengthy procedure may produce a fold print. However, a flap which has not been folded remains in contact with the lid margin and a some potential contaminated fluid from the fornix may reach the stromal bed. Dry the stromal bed carefully and remove any excessive moisture from the edges of the hinge with a cellulose sponge (Merocel sponge<sup>®</sup>) (Fig. 9.13).

Take care to remove the excessive moisture from the hinge which occurs due to pooling at the edge, with the cellulose sponge on the hinge (Fig. 9.14).

Any moisture during the ablation will diminish the ablation rate.

#### **Simultaneous Bilateral Lasik Procedure**

The simultaneous bilateral lasik procedure has now been accepted as safe and predictable.<sup>10,19,20</sup> A second procedure should be done only if the first was uneventful. The same blade can be used but in most of the cases the second cut will be thinner as



**Figure 9.12.** Flap folded to avoid excessive dryness of the flap



**Figure 9.13.** Excessive water is removed from the edge of the hinge

compared to the first.<sup>21-27</sup> The procedure for the second eye is essentially similar.

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# 10

## *Laser Ablation and Flap Repositioning*

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Prior to proceeding into a discussion of laser ablation and flap repositioning, it is important to get acquainted with laser room environment and patient preoperative preparations.

### **The Laser Room**

Best laser performance is strictly dependent upon optimal environment conditions of the laser room.<sup>1</sup> While instructions of the laser manufacturers should always be considered, ideally the laser room environment must meet the following conditions:

- Temperature should be maintained between 18° and 24°C (60°–70°F). Any increase in room temperature beyond the permitted range may cause an excessive stromal dehydration that may result in overcorrection.
- Humidity should be stable and kept below 50 percent (30–45%).
- No external airflow should be allowed in the surgery room.
- Clear atmosphere should be maintained through continuously running air filtration units.
- Perfume and strong cleaning or heavy smelling liquids are prohibited in the surgery room.
- Maintenance of a stable environment conditions within the surgery room is vital not only during the operation days at but all times.

The above guidelines should be followed for two reasons:

1. Standard treatment conditions (stable temperature and humidity levels) are mandatory for all patients.
2. Permanence of the laser optics.

### Fluence Test

Fluence test is an essential procedure performed prior to each surgery. The test is usually performed by the laser technician, and varies from one laser unit to another according to manufacturer's instructions.

This test is crucial for maximal laser performance, checking laser beam calibration, homogeneity and alignment of the beam. Fluence test is a procedure that always takes precedence to the creation of the flap.

### Laser Settings

To guide the laser set-up, usually there is a nomogram provided by the manufacturer. Over a period of time, however, the surgeon develops his/her own nomogram for laser set up that combines recommendations of the manufacturer, his previous experience with the specific kind of laser unit that is being used, the age, occupation and the needs of the patient.

Before entering the patient's data into the laser computer, the surgeon and the technician should verify the patient's name, the pupillary diameter (in scotopic conditions), the thickness of the central cornea, and the attempted correction including the sphere, the cylinder, and the axis of astigmatism.

The diameter of the optical ablation zone should be appropriate to the patient's pupillary diameter, otherwise the patient will experience glare, halos, and decrease of visual acuity in dim light situations. After LASIK, the optical zone of the cornea must cover the entrance of the pupil or else defocused light rays will impinge on the fovea and induce visual confusion.<sup>2</sup> The surgeon should always keep in mind that the depth of ablation should leave at least 250 microns of intact stromal bed (intraoperative pachymetry), to avoid the serious complication of post LASIK keratectasia.<sup>3-6</sup> The laser computer when entering the attempted correction and the diameter of the ablation zone usually calculates the depth of excimer laser ablation, but the surgeon can calculate it using the Munnerlyn formula,<sup>7</sup> which is:

$$T = (Dh^2)/3$$

where T is the depth of ablation in microns, D is diopters of refractive change, and h is the optical ablation zone in millimeters. The wider the zone and the attempted correction, the deeper the ablation will be.



**Figure 10.1.** Folding of the corneal flap

After entering the data into the laser computer, the technician and the surgeon should double check the inserted refractive correction for each eye.

### Protection of the Flap

As described in the previous chapter, following flap lifting and before ablation ensues, considerable attention is given to the protection of the flap during the procedure. This will serve for both, protecting the flap from excessive dehydration, and for protecting the hinge and the flap from laser ablation, that can lead to irregular astigmatism.

Two techniques are described:

1. Folding the flap to cover its stromal surface (Fig. 10.1). Some surgeons are skeptical about this the technique believing that it might predispose to corneal striae formation.
2. A LASIK Merocel shield is applied to cover the hinge and the stromal surface of the flap. The shield is previously soaked in balanced salt solution and squeezed to a moist, but not wet state in order to prevent over-hydration of the flap.

### Centration of the Beam

Following the creation and lifting of the flap, all of the following steps including flap protection, intraoperative pachymetry (Fig. 10.2), centration and ablation should be done as soon as possible. This is to minimize the exposure time of the bare stromal surface, which might result, as we



**Figure 10.2.** Intraoperative pachymetry

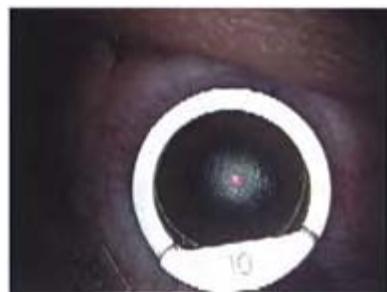
mentioned above, in stromal dehydration which eventually leads to overcorrection,<sup>8</sup> and in very rare conditions may predispose to corneal perforation.<sup>9</sup>

It should be emphasized that the centration of the beam is a surgeon's responsibility. A wellinformed patient about the procedure will help the surgeon in achieving best centration.

Usually, no sedative drugs are given to the patients preoperatively, simply because keeping the patient alert and more cooperative during surgery is an important factor for better surgical outcome.

The head position is aligned again so that the chin and forehead are in the same frontal plane, thus achieving the best exposure of the globe. In the dim light conditions of the room and the surgical microscope, focusing becomes easier for the surgeon and more comfortable for the patient. The patient is instructed to look, with the operated eye, to the fixation light of the microscope, while the surgeon observes the eye through the surgical microscope. Two points should be determined: *the center of the pupil* and *the center of corneal light reflex*. Most surgeons believe that the ablation beam should be centered on the entrance of the pupil.<sup>10-13</sup> At our center we take into consideration the nature of the refractive error for centration as follows:

For the myopic eyes, the ablation beam is centered on the center of the pupil (Fig. 10.3). For hyperopic correction, it is centered slight nasally to the corneal light reflex. In case of astigmatic patient,



**Figure 10.3.** Centration of the ablation beam at the center of the pupil

if the distance between the center of the pupil and the center of the corneal light reflex is small, the beam is centered on the center of the corneal light reflex, but if this distance is large, the beam is centered between the two points but closer to the pupillary center.

During the beam centration, the tracking system is activated.

### **Laser Ablation**

As the flap is lifted and covered, the stromal bed dried with a Merocel sponge, the head position is again aligned and the laser beam focus is achieved as described above, the surgeon can proceed with the ablation of the stromal bed (Fig. 10.4).

During ablation, the patient is instructed to breath normally, to keep both eyes open and to continue to look at the fixation light of the operative microscope with the eye undergoing the treatment (as the other eye is covered). The small saccadic eye movements are acceptable, but the surgeon needs to stop the ablation if the eye starts drifting away from the fixation target. A decentered ablation can result in irregular astigmatism causing glare, halos, diplopia, and decrease in best corrected visual acuity.<sup>14,15</sup>

The procedure should be stopped if any fluid or blood collection is detected at the hinge or the gutter. Any collection should be dried prior to continuing the ablation (Fig. 10.5).



**Figure 10.4.** The laser ablation of the stromal bed (the ring shown above is used in the tracking system of Mel 70 Aesculap Meditec Laser System)



**Figure 10.5.** During ablation, any fluid or blood collection at the hinge or the gutter should be dried prior to continuing the ablation



**Figure 10.7a.** The corneal flap is replaced onto the bed using a bent

cannula (in the opposite direction of the hinge)

It is advisable, during ablation, to keep talking to the patient (verbal anesthesia), informing and assuring the patient throughout the procedure. Always remember that the ablation should be started and finished as promptly as possible to decrease the possibility of stromal dehydration with the consequences mentioned above.

### Repositioning of the Flap

Once the ablation is completed, the corneal stromal bed is cleaned with a dry Merocel sponge (Fig. 10.6). The flap is replaced onto the bed using a bent cannula (Fig. 10.7a and b). A LASIK irrigating cannula is placed underneath the flap and irrigation



**Figure 10.6.** Drying the stroma with a Merocel sponge



**Figure 10.7b.** The corneal flap is replaced onto the bed using a bent cannula (in the opposite direction of the hinge).

of the interface with balanced salt solution is performed to remove any remaining debris (Fig. 10.8). This also facilitates the floating of the flap back into its original position.

Aggressive irrigation should be avoided, since it leads to cap edema and retraction of the flap edges. This in turn increases the incidence of epithelial ingrowth (presence of an area of poor flap adherence).<sup>16</sup>

After irrigation is completed, ironing of the flap is done using a moistened Merocel sponge starting from the hinge towards the opposite direction (painting of the flap), with mild continuous strokes over the flap (Fig. 10.9). During this maneuver, the surgeon should pay attention not to cause epithelial defect.



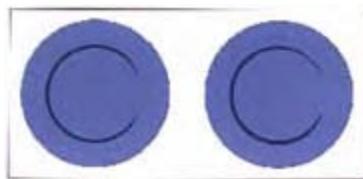
**Figure 10.8.** A LASIK irrigating cannula is placed underneath the flap and irrigation of the interface with balanced salt solution is performed to remove any remaining debris.



**Figure 10.9.** Ironing of the flap is done using a moistened Merocel sponge starting from the hinge towards the opposite direction (painting of the flap), with mild continuous strokes over the flap

For proper flap alignment, two indicators are of major importance:

1. The corneal marks should be properly aligned. Special attention should be given to cases with loose or shifted epithelium during the passage of the microkeratome over the cornea; the corneal marks might be confusing at these points.
2. The gutter symmetry, which according to some surgeons is the most important indicator of proper flap alignment. There should be a uniform gutter usually of 50 to 100 microns all around the flap (Fig. 10.10).



**Figure 10.10.** Right. Symmetric gutter around the flap. Left: Gutter asymmetry. The lower edge is wider than the upper (superior displacement of the flap).

The next step is the inspection of the flap interface for striae or retaining debris. This is preferably done under high magnification of the surgical microscope, or better, on the slit lamp unit of the operative microscope (if this facility is available). If debris is detected, the interface is washed up again. If striae is detected, stretching of the flap is performed by pulling the edge of the flap in radial direction using a dry Merocel sponge.

After the inspection of the flap for proper alignment is completed, a waiting time of three to five minutes is allowed for the flap to dry and to adhere. At our institute we use two drops of hypertonic NaCl five percent, which is immediately followed with irrigation of the corneal surface by balanced salt solution. The rapid dehydration of the flap at this stage, caused by the hypertonic saline, will facilitate a faster and more stable flap adhesion to the bed, and probably decrease the incidence of striae formation.<sup>17</sup> During this waiting time the light of the microscope is switched off.

Next, the Slade's striae test is performed to check the adherence of the flap to the stromal bed. This test is performed by a gentle pressure downwards over the corneal edge just beyond the edge of the flap (Fig. 10.11). If good adhesion is achieved, fine folds will be seen radiating into the flap and the test is considered positive.

After the successful repositioning of the flap, one drop of combined antibiotic—steroid and one more drop of local anesthetic are added. The lid speculum is removed carefully to avoid displacement of the



**Figure 10.11.** Slade's test. The test is performed by a gentle pressure downwards over the corneal edge just beyond the edge of the flap

flap. The patient is asked to blink his eyes (blink test) in a normal manner (not to squeeze them). Then the alignment of the flap is again inspected (Fig. 10.12).

In the great majority of cases no bandage contact lens is used. Bandage contact lens is used in the rare case of large epithelial defects, complicated cases of buttonhole flap and selective cases of free cap.

At the end of this procedure, the patient is instructed to wait at the patients waiting area for the next hour.

### Slit Lamp Check

It is well-known that about 90 percent of the flap displacements occur during the first 24 hours postoperatively, especially during the first hour after surgery. A slit lamp examination should be performed at this time. The purpose of this examination is to check for the presence of folds or striae in the flap, presence of possible retained debris in the interface, and to ensure the proper alignment of the flap. Slit lamp examination makes it easier for the surgeon to check for the symmetry of the gutter, to detect folds, striae and the presence of debris.

In case of flap malposition, presence of debris, folds or striae, the patient is sent back to the operating room for irrigation of the interface and/or repositioning of the flap. Early identification and treatment of folds and striae lead to better visual



**Figure 10.12.** The alignment of the corneal marks is checked at the end of the procedure

outcome and a significant improvement in patient satisfaction.<sup>17-21</sup>

### **Postoperative Medications**

- Topical combined antibiotic—steroid drops are given four times a day for a period of 15 days to prevent infection and to control inflammation.
- Topical non-steroidal anti-inflammatory drops are given four times a day for the two postoperative days for pain. Some surgeons do not give NSAIDs, as they believe it may cause the occurrence of diffuse lamellar keratitis (although not well-documented).
- Frequent use of preservatives free artificial tears is recommended for the first three months after LASIK, because the tear secretion decreases following surgery, probably due to decrease in corneal sensitivity.<sup>22</sup> The tear secretion is usually normalized by six months postoperatively.<sup>23</sup>

### **Home Instructions**

After the end of the procedure, the patient is given oral and written instructions regarding the early postoperative period.<sup>24</sup>

*Patients are instructed not to:*

- Rub their eyes (most important).
- Drive until they restore good visual acuity.
- Swim for at least three days after the operation.
- Use cosmetics (makeup, eye shadow, mascara, and eye liner) for at least three days after the operation.
- Put more drops than prescribed.

*Patients are advised to:*

- Bath very carefully so that the water does not get into the eyes.
- Stay away from any chemical substance that can cause ocular irritation (shampoo, dust, smoke, etc.)
- Avoid bending, weight lifting, and hard movement during the first three postoperative days.
- Wear sunglasses for light protection.
- Use eye shield at bedtime for the first three postoperative days (specially for patients with free cap).
- Bring the eyedrops with them on every follow up visit.
- Continue their normal activities, watch TV, read and write after the first postoperative day.

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# 11

## *Postoperative Management in LASIK Surgery*

**Kent L Anderson, Ramin Salouti, Hugh R Taylor**

Much of the success of LASIK surgery is attributed to the relatively few complications that may occur postoperatively. Although uncommon (0.7% to 11.8%), these complications may range in severity from insignificant to catastrophic resulting in irreversible visual loss and/or further surgical intervention.<sup>1,2</sup> Therefore, careful follow-up to ensure early detection is very important in the postoperative management of patients undergoing LASIK surgery. Routine postoperative management should consist of an initial postoperative evaluation performed on the same day of the surgery followed by office examinations on subsequent visits. It is also important to emphasize that many postoperative complications can be avoided by careful selection of patients preoperatively and ensuring that no contraindications to refractive surgery are present.

Irregular astigmatism and associated loss of best corrected visual acuity is one of the most common complications of LASIK.<sup>3</sup> The majority of complications are related to the corneal flap, so careful examination of the flap and the stromal bed is critical in the postoperative period. Other uncommon complications to consider include epithelial growth, diffuse lamellar keratitis, surface irregularities, and refractive error. Although rare, microbial keratitis, corneal perforation, and loss of the cap have also been reported.

### **Evaluation**

Most refractive surgeons prefer to perform the initial postoperative evaluation of their patients on the same day, often within one hour after the surgery, prior to discharging them home. Taking into account the type of microkeratome used and the location of the hinge, close inspection to detect any flap-related complications is performed. Early detection allows prompt management of vision threatening complications.

The first postoperative office examination is usually performed the first day after surgery, at which time the corneal epithelium has normally healed. Subsequent visits are then generally scheduled at 1 week, 3–5 weeks, 3 months, 6 months, and finally 1 year. Each visit should include a thorough evaluation and a complete ophthalmic examination. Complications can be divided into those presenting early within the first few days after surgery and those presenting late on subsequent visits weeks to months after the initial surgery (Table 11.1).

**Table 11.1: Complications of LASIK surgery:  
Early and late**

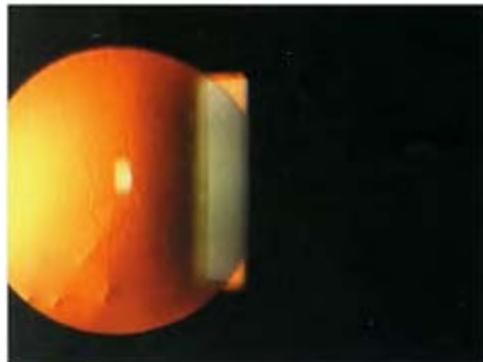
Initial	1 Hour	Improper flap apposition Uneven gap gutter Edema of the corneal flap Epithelial defects Fine punctate and/or scratch line erosions Corneal flap irregularities Folds, wrinkles, or striae Shifting, dislodgment, displacement, or instability Interface Debris
Frist Office Visit	1 Day	Need for reading glasses Epithelial defects Neurotrophic epitheliopathy Epithelial growth Corneal flap irregularities Folds, wrinkles, or striae Shifting, dislodgement, displacement, or instability Interface Debris Corneal ectasia Infectious keratitis Diffuse lamellar keratitis (DLK)
Subsequent Visits	1 Week	Infectious keratitis
	3–5 Weeks	Diffuse lamellar keratitis (DLK)
	3 Months	Refractive Error
	6 Months	Undercorrection/Overcorrection
	1 Year	Regression/Progression Corneal flap irregularities Dislocation, detachment, cap loss Central islands or peninsulas Ablation decentration Corneal ectasia Irregular astigmatisms

### **Initial Postoperative Evaluation**

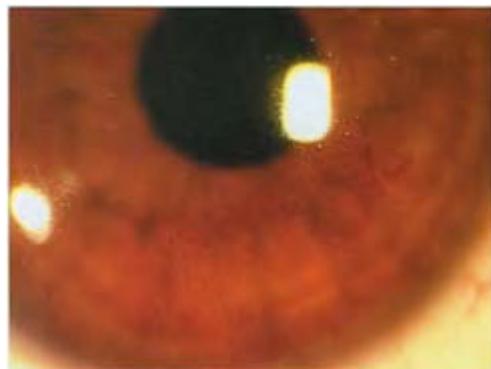
The most important parameter to assess is the clarity, stability, and adherence of the corneal flap. Thorough slit lamp biomicroscopy should be performed to ensure that the entire flap is well apposed and that the gap gutter is evenly distributed between the edge of the flap and the peripheral corneal ring. The presence of the gap gutter is a normal finding in the initial evaluation and this usually disappears by the first postoperative day. Excessive flap manipulation and irrigation intraoperatively may result in edema of the corneal flap. This usually resolves in a few hours to days without any significant long-term sequelae.

Particular attention should be directed at detecting any corneal epithelial defects. Fine punctate and scratch line erosions at the superficial surface of the corneal epithelium may be seen immediately after surgery. These signs are due to the lamellar dissection and often account for the pain, photophobia, and lacrimation noted by many patients in the early postoperative period. Early detection of epithelial defects and their careful management is indicated to avoid epithelial hyperplasia and other associated corneal surface abnormalities that may otherwise affect the quality of vision. Epithelial defects less than 3-mm tend to completely resolve within 24 hours and no additional medical care is required. However, for epithelial defects larger than 3-mm, epithelial hyperplasia may produce irregular or against-the-rule astigmatism.<sup>2</sup> Removal of excess or loose tags of epithelium and the use of lubricants and therapeutic soft contact lenses may facilitate re-epithelialization in these cases.<sup>2</sup>

The surgeon should also look for any flap irregularities, such as folds, wrinkles, or striae (Fig. 11.1), and to ensure that the flap has not shifted or become dislodged.<sup>4</sup> Even fine striae can lead to a significant loss of best corrected visual acuity, especially when they occur in the central pupil zone. Striae may arise by desiccation, contraction, misalignment, displacement, or slippage of the flap over the stromal bed. If suspected, high magnification and retroillumination through a dilated pupil optimizes detection and classification of even fine striae.<sup>5</sup> If present and visually significant, striae should be managed promptly, often on the first or second day postoperative day. Any later intervention decreases the chance of successful elimination and improving visual acuity. Gentle manipulation by lifting, irrigating, refloating, and repositioning the flap is recommended and the striae often disappear without additional procedures.<sup>6-8</sup> The flap and stromal bed may be irrigated with balanced salt solution or a hypotonic saline solution to induce a mild edema before repositioning the flap. Simple refloating of

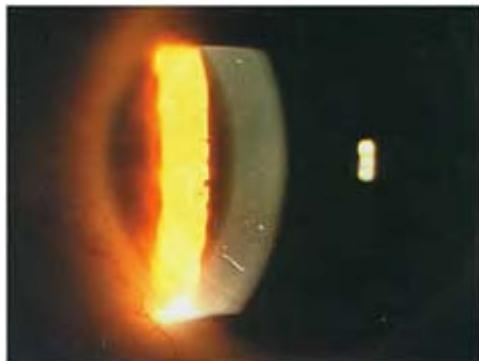


**Figure 11.1.** Flap striae



**Figure 11.3.** Hemorrhage in the interface

the flap is not sufficient.<sup>9</sup> Proper repositioning requires smoothing, stroking, brushing, scraping, ironing, or stretching the striae in a direction perpendicular to the striae or flap edge with a moist or dry sponge or other instrument specifically designed for this purpose.<sup>5-8</sup> After treatment the striae do not disappear immediately but are usually eliminated or greatly reduced after 24 to 48 hours<sup>5</sup>. If the striae do not resolve with this technique or if they have been present for more than 24 hours, then additional procedures should be performed as described.<sup>1,6-8,10</sup>



**Figure 11.2.** Lint fiber in the interface



**Figure 11.4.** Ocular surface mucus secretions in the interface

The interface between the flap and the flap bed should be closely inspected to ensure that no debris is present, as noninfectious interface opacities are common within the first few postoperative weeks. Debris is often attributed to lint fibers (Fig. 11.2), epithelial tags, blood from an incised pannus or perilimbal corneal blood vessels (Fig. 11.3), glove talc/powder, sponge fibers/particles, metal fillings from the microkeratome blade, tear film debris, ocular surface mucus (Fig. 11.4), meibomian gland secretions, lashes, and/or other foreign material.<sup>1</sup> Foreign bodies overlying the entrance pupil or debris causing inflammation should be removed by lifting the flap, irrigating the flap and stromal bed, and careful repositioning of the flap.<sup>1,10</sup>

### **First Postoperative Office Examination**

The first postoperative office examination is very important. If this examination is normal then few problems are likely to occur subsequently. Attention should be focused on the patient's subjective responses and not on objective measurements; i.e., diopters, degrees, or other numbers. Irreversible disappointment may occur if the patient is informed of a persisting refractive error on this visit regardless of how small it is measured to be. The uncorrected visual acuity is usually good and the majority of patients with low to moderate myopia demonstrate a visual acuity of 6/12 or better. Patients with presbyopia or approaching the age of presbyopia should be informed that they may demonstrate an increased need for reading glasses. These patients should be instructed that a pair of reading glasses should be obtained.

Thorough inspection of the flap edge should be performed to ensure that complete re-epithelialization has occurred and that no epithelial growth has occurred. Epithelial growth typically begins as an early, diffuse haze of the lamellar interface that may progress over time to a white, confluent plaque. It is best to observe epithelial growth that is dormant and/or asymptomatic: i.e., not encroaching on the visual axis or not producing an irregular astigmatism (Fig. 11.5). Epithelial growth within the lamellar interface that affects visual function is best managed by scraping both sides of the interface with a metal blade followed by copious irrigation with simultaneous aspiration to prevent

dislodged epithelial cells from floating back into the interface<sup>3,11</sup>. To facilitate removal of recurrent epithelial growth, light excimer laser treatment or other procedures may be required.<sup>1,10,11</sup>

Punctate epithelial erosions and moderate rose bengal staining may suggest a LASIK induced neurotrophic epitheliopathy attributed to the interruption of sensory nerve input to the epithelium of the LASIK flap. Although transient this epithe-

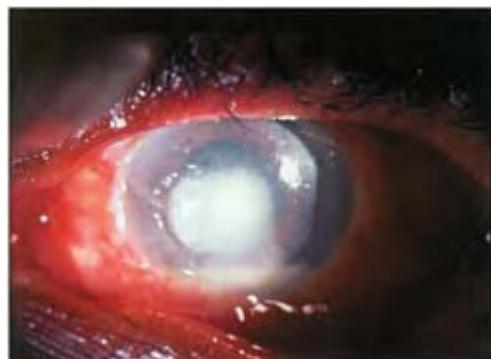


**Figure 11.5.** Peripheral epithelial ingrowth

liopathy may persist for up to six to eight months.<sup>1,2</sup> Management is reassurance and aggressive lubrication that includes frequent non-preserved artificial tears during the day and ointments at bedtime.

The flap should be attached and be difficult to discern. Examination should ensure that wrinkling, folding, shifting, or displacement of the flap has not occurred. The presence or absence of any interface debris should also be noted. The corneal epithelium should be intact with no detectable fluorescein staining. The cornea should be intact with no evidence of ectasia and the anterior chamber should be quiet.

Special attention should be directed at any evidence of early postoperative infectious (Fig.11.6) or noninfectious keratitis. If an infiltrate is noted it should be treated as infectious until proven otherwise. The incidence of microbial keratitis after LASIK surgery is reported to be between 0.1 percent to 1.2 percent.<sup>12</sup> Numerous predisposing factors have been reported which should be considered in the postoperative period.<sup>12,13</sup> These include disruption of the anatomic barriers (epithelial defects) and simultaneous inoculation of pathogens (contaminated objects or eyedrops), use of topical corticosteroids, abuse of topical drugs (anesthetics), medicamentosa (topical preservatives), immunodeficiency states (HIV infection), eyelid disorders (entropion,



**Figure 11.6.** Infectious keratitis after LASIK

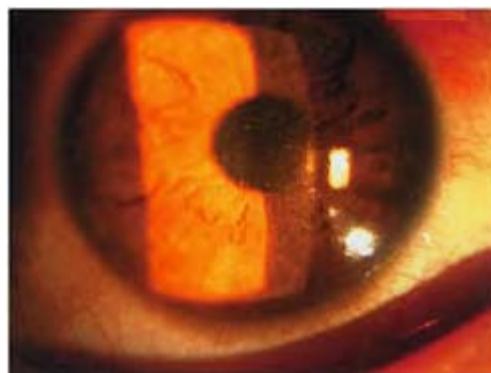
ectropion, or trichiasis), ocular adnexae infections (blepharitis or dacryocystitis), tear film deficiency from dry eyes, extended wear soft contact lenses, herpetic keratitis, and trigeminal palsy.<sup>13</sup> Rapid diagnosis and early recognition of the pathogen helps in early and appropriate intervention. Causative organisms reported have varied from bacterial (gram-positive cocci) to atypical bacterial (nocardia or nontuberculous mycobacteria), fungal, viral, and parasitic pathogens.<sup>1,12,14-16</sup> The time of presentation is most commonly two days after the surgery but this may vary between one day to several months postoperatively. Patients typically present with a deterioration of their vision that is often accompanied by lacrimation, discharge, pain, photophobia, redness, and a foreign body sensation. The infection is typically located paracentrally between the flap edge and the stromal bed and has a single or dominant focus that extends anteriorly into the flap and posteriorly into the stroma. The infiltrate usually increases over time and is often associated with stromal loss, epithelial defect, conjunctival inflammation, and a significant anterior chamber reaction.<sup>12</sup> If a microbial keratitis is suspected immediate lifting of the flap, scraping the stromal bed, obtaining cultures, irrigating with an antibiotic solution, repositioning the flap, and intensive empirical broad spectrum topical antibiotic therapy is recommended.<sup>12</sup>

Noninfectious diffuse lamellar keratitis (DLK) often resembles microbial keratitis and it is important to differentiate between the two. DLK is characterized by pain, photophobia, lacrimation, foreign body sensation, and decreased vision in the first few days after LASIK surgery. Unlike microbial keratitis, DLK is a self-limited noninfectious inflammatory reaction in which the infiltrates are confined to the interface extending neither anteriorly into the flap nor posteriorly into the stroma. The infiltrates are usually multiple and diffuse in nature, scattered over a large area, and are more concentrated around surgical debris. (Fig. 11.7) There is usually little or no anterior chamber reaction, no epithelial defect, and the conjunctiva is relatively uninflamed<sup>1</sup>. It has been referred to as the “Sands of Sahara” syndrome alluding to the white, granular appearance of the infiltrates.<sup>13,17</sup> It usually occurs in the first postoperative week but thorough slit lamp biomicroscopy can detect the cellular reaction on the first postoperative day. DLK may resolve spontaneously or progress to severe corneal scarring and an adverse visual

outcome. A multifactorial etiology has been proposed as no single agent is presumed to be responsible for this condition<sup>1,17</sup>. DLK is best managed by identifying granular white cells in the lamellar interface on the first postoperative day, staging their location and severity (4 Stages<sup>1</sup>), and intervening at the appropriate time. Intervention comprises starting intensive topical corticosteroids on the first postoperative day (Stage 1 and 2), reexamining the patient in 24 to 48 hours, and lifting the flap promptly by the second or third postoperative day if the condition has progressed to “threshold” or Stage 3<sup>17</sup>. (Fig. 11.8) Despite the certainty of the diagnosis, cultures should be performed for bacteria and fungus while scraping and irrigating the flap and stromal bed. Prompt surgical intervention at Stage 3 serves to debulk the inflammatory reaction in the lamellar interface and prevents progression to stromal necrosis, permanent scarring, and irregular astigmatism (Stage 4).<sup>17</sup>

### Subsequent Visits

Further evaluation should be performed at subsequent visits; i.e., 1 week, 3–5 weeks, 3 months,



**Figure 11.7.** Diffuse lamellar keratitis post-operative day 1 after LASIK

6 months, and 1 year after surgery. At each office visit, a complete ophthalmic examination is performed that generally includes measurement of the uncorrected and best corrected visual acuity for both distance and near vision, manifest refraction, measurement of the intraocular pressure, and slit lamp biomicroscopy. A detailed anterior segment evaluation should include grading corneal haze if present. A dilated fundus examination should be performed at least once, usually on the first week or first month office visit, to exclude a retinal detachment and to ensure that no retinal tears or breaks are present<sup>1</sup>. When indicated corneal topography, computerized corneal videokeratography pachymetry endothelial cell count, and/or contrast sensitivity can be performed. If any flap abnormality is detected, a schematic diagram and/or a photograph should be taken to be included as part of the patient’s history for future reference.

These examinations can assess the amount of overcorrection, undercorrection, regression, and/or regular astigmatism that has occurred. The higher the level of correction, the more likely regression due to wound healing will occur. If any residual refractive error is demonstrated, enhancement surgery may be considered depending on the type and amount. Enhancement surgery is usually delayed for three months or longer after the initial

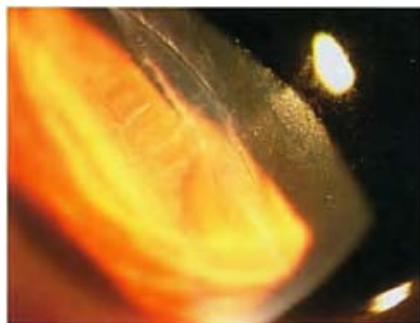


**Figure 11.8.** Same patient as in figure 11.7 responded on topical steroids (post operative day 4)

surgery. If simple under-correction has occurred, enhancement surgery may be considered no earlier than one month after the initial surgery.

Corneal LASIK flaps are prone to mechanical dislocation as late as two months postoperatively<sup>18</sup> (Fig. 11.9). This is consistent with reports of the ease by which a flap may be lifted up to 18 months after the initial procedure<sup>3,12,19</sup>. If a flap is found to be dislocated, immediate management is recommended. This is best performed by refloating the flap, scraping and irrigating the underlying stromal bed, repositioning the flap, and securing the flap in place with the use of a therapeutic soft contact lens<sup>18</sup>. Complete detachment of the flap requires careful positioning to achieve the proper orientation.<sup>1</sup> In rare cases, sutures are needed to anchor a free cap that is easily displaced or will not otherwise adhere.<sup>1</sup> If a flap is lost the epithelium is simply allowed to heal which may induce a hyperopic shift. Some surgeons have reported managing this complication by obtaining a new cap from a donor eye.<sup>1</sup>

Surgically induced surface irregularities include central islands or peninsulas, treatment decentration, irregular or multiple flap cuts, corneal ectasia (Fig. 11.10), and other forms of irregular astigmatism. These topographic abnormalities may adversely affect visual acuity and image quality. Computerized corneal videokeratography is helpful



**Figure 11.9.** Dislodged flap

in the diagnosis and management of these complications. Contact lenses may be used in these cases to decrease patient complaints and to increase best correct visual acuity. Irregular astigmatism tends to decrease over time. Therefore, before attempting any surgical intervention for these problems, it may be valuable to monitor the patient for three to six months to rule out any ectasia and to determine whether regression or progression has occurred. If a true central island or peninsula does not regress with time, surgical intervention may be necessary.<sup>1,7</sup> Corneal ectasia should always be considered in cases of irregular astigmatism and pachymetry and/or scanning slit corneal topography should be performed.<sup>20</sup> An initial preoperative corneal thickness of more than 500  $\mu\text{m}$  and a residual postoperative corneal stromal bed of more than 250  $\mu\text{m}$  is generally assumed to prevent corneal ectasia.<sup>1</sup> However, several cases of ectasia have been reported with stromal beds measuring more than this lower limit.<sup>7</sup>

### Medication

Routine postoperative management after conventional LASIK surgery will include topical broad-spectrum antibiotics and corticosteroids. The choice of which specific medications are utilized will vary from surgeon to surgeon and institution to institu



**Figure 11.10.** Post-LASIK keratectasia

tion. These are typically administered four times a day for three to ten days. Antibiotic selection usually consists of chloramphenicol (0.5%), tobramycin (0.3%), or a fluoroquinolone (0.3%; ciprofloxacin or ofloxacin). Corticosteroid selection usually consists of fluorometholone (0.1%) or prednisolone (1%). Some surgeons prefer the use of an antibiotic-corticosteroid combination preparation.

Also, many surgeons include a topical non-steroidal anti-inflammatory medication such as diclofenac (0.1%) or ketorolac (0.5%) as part of their routine management. Some patients require oral analgesics for the first few days after surgery but only in rare cases are narcotic analgesics required. Although controversial some surgeons may use a therapeutic soft contact lens or an occlusive eye patch under certain circumstances; i.e., epithelial defect, pain, flap dislocation, or flap striae.<sup>1,8</sup>

Dry eye and other ocular surface disorders are frequent following LASIK surgery. For this reason preservative free lubricants and wetting agents are utilized to ensure tear film stability and hasten corneal re-epithelialization in the early postoperative period. Lubrication is especially important if a superior hinge was performed, as the corneal nerves from the nasal and temporal limbus were transected intraoperatively.<sup>21</sup> Regeneration of corneal nerves after LASIK usually occurs within six to eight months.<sup>1,12</sup>

### **Patient Instructions**

It is important to counsel patients preoperatively as to what to expect in terms of discomfort and vision in the postoperative period. The patient should also be informed of potential complications that may occur. The possibility of a subconjunctival hemorrhage should be explained and that this is a self-limited condition.

The patient with presbyopia or approaching the age of presbyopia should be informed about the need for reading glasses postoperatively. Monovision LASIK is a valuable and viable option for the management of presbyopia and at present is the best surgical option.<sup>22</sup> However, monovision requires careful patient selection and the benefit is reduced when one considers depth perception and the patient's occupational and/or recreational needs. Monovision LASIK is not recommended for certain occupations (law enforcement officers, airline pilots, and taxi or truck drivers) and it may be less desirable for those patients who participate in sports (baseball, basketball, tennis, or golf). Patients choosing full distance correction are more likely to wear reading glasses after surgery but they report the advantage of no glasses for distance and equal focus. Conversely, patients choosing monovision correction are more likely to wear distance glasses occasionally but they report the advantage of freedom from glasses for both distance and near. They report their distance vision is not ideal and glasses are often required while driving at night. They also report it takes time to adjust to monovision as each eye has a different focus although only a slight reduction in stereoaucuity is observed.<sup>22</sup>

After the surgery the patient should be instructed to go home and rest. Emphasis should be on lid closure as this facilitates rapid re-epithelialization of the peripheral gutter created by the lamellar dissection. Mild pain, lacrimation, and a foreign body sensation may persist up to 24 hours following LASIK surgery. Fluctuations in vision in the first few weeks are normal and significant variability of the response between the two eyes may occur.

Oral and written instructions should be given to the patient for their care and ocular hygiene once they return home. The following precautions should be taken for a period of two weeks after the surgery

1. Absolute prohibition of rubbing or touching the eyes.
2. Wear a transparent protective eye shield fulltime for the first 24 hours and then while sleeping to prevent inadvertent touching of the operative eye.
3. Wear protective sunglasses any time while outdoors, especially for those patients that live in sunny areas.
4. Do not wash eyes with tap water.
5. Wash face and hair carefully and take caution to avoid getting any water into the eyes.
6. Wash hands thoroughly before administering any drops to the eyes.
7. Do not apply eye make-up.
8. Do not swim and after two weeks if swimming is resumed it is important to wear eye goggles.
9. Avoid holding an infant, participating in sports, or other activities that could lead to flap displacement by a finger or other object.
10. Avoid the use of hot tubs.
11. Avoid driving until otherwise instructed by a physician.
12. Normal everyday activities and work schedule may be resumed on the first postoperative day. Wear safety glasses in any environment in which they could be struck in the eye.
13. Prompt consultation with the treating physician should occur if any of the following symptoms occur:
  - a. Pain that is severe or that persists for more than 24 hours.
  - b. Redness associated with increased lacrimation, photophobia, or decreased vision.
  - c. Any significant visual disturbance; i.e., decreased vision, glare, blurring, ghosting, halos, monocular diplopia or multiplopia, or flashes and floaters.

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## **Section 4**

# **Results and Complications**



## 12

### ***Results of LASIK Surgery***

**Alka Rani, Balasubramanya R, Elankumaran S, Rasik B Vajpayee**

Laser assisted in situ keratomileusis (LASIK) has been performed world-wide for the primary correction of myopia, hyperopia and astigmatism and also for residual refractive errors following ocular surgery.

The results of LASIK like any other procedure are determined on the basis of certain parameters that include efficacy, safety, predictability, stability and patient satisfaction. The results that have been highlighted here are tabulated from the various published articles as well as abstracts.

#### **Efficacy**

The efficacy of LASIK surgery is determined by the postoperative uncorrected visual acuity (UCVA) attained by the patient. Most studies have quantified the results as the attainment of UCVA 20/40 or better, although attainment of a UCVA of 20/20 or better is a more qualified index.

#### **Safety**

The safety of a refractive procedure is reflected by the percentage of the patients who retain their best corrected visual acuity (BCVA) within 2 lines of their preoperative level.

#### **Predictability**

Although in the older studies predictability was defined in terms of within  $\pm 1.00\text{D}$ , in the more recent studies the limits have been decreased to within  $\pm 0.5\text{D}$  of correction postoperatively

#### **Stability**

In most studies refraction stabilizes by 3 to 6 months after LASIK surgery. It is inversely proportional to the amount of regression. Regression is defined as a change of refraction within  $\pm 0.5\text{D}$  over a period of time following LASIK.

## Myopia

For low to moderate myopia, results from studies in the literature have shown that LASIK is effective and predictable in terms of obtaining good to excellent UCVA postoperatively. For moderate to high myopia, the results are more variable.

### Low Myopia

Results of LASIK surgery in low myopia of less than 4D have demonstrated the highest predictability and minimum complications (Table 12.1).

**Table 12.1: Results of LASIK low to moderate myopia (-1 to -10D)**

Author/Year of study	No. of eyes	Follow-up months (% Completed)	Range of myopia (D)	% within $\pm 0.5D/1.0D$	Post-op UCVA =20/20 (%)	Post-op UCVA =20/40 (%)	Loss of $\geq 2$ Lines
El Danasoury <sup>3</sup> /1999	26	12 (92.3%)	-2 to -5.5	83.3/100	79.2	100	0
El Maghraby <sup>4</sup> /1993–1994	33	12 (91)	-2.5 to -8	73/90	61	NR	7
Casebeer <sup>5</sup> /1996–1997	911	3 (100)	-1 to -4 -4 to -7	75/90 52/73	NR NR	92 86	9 9
Mrochen <sup>6</sup> /2001	35	3(88)	-1 to -9.5	68/93.5	93.5	100	9

NR=Not reported

In a study by Salah<sup>1</sup>, et al 93% of eyes had refraction within  $\pm 1.00D$  in a group of patients with myopia of 2.0 to 6.0D at a mean follow-up of 5.2 months.

Similar results for low myopia have been reported by Bas and Onnis<sup>2</sup>. At the final follow-up (range; 6 to 25 months), 89% patients of low myopia group (3 to 6D) had achieved a UCVA of 20/40 or better and 30% eyes obtained a visual acuity of 20/ 20 or better. In the first month, 82% of eyes were within  $\pm 1D$ . At the final check-up, the mean spectacle corrected refraction was  $-0.42 \pm 0.98D$ .

### Moderate to High Myopia

The results of LASIK surgery for moderate and high myopia have not been as good as in low myopes (Table 12.2). Knorz et al<sup>7</sup> reported the results of a study in which myopia was divided into three categories: -5 to -9.90D; -10 to -14.9D; and -15 to -29.0D. An UCVA of 20/40 or better was obtained in 87.5% in the first category; 77.8% in the second category and 33.3% in the third category. Also, in this group (-15 to -29D) only 38.9% of the operated eyes were within  $\pm 1D$  as compared to 60% in-group 2 and 100%

in group 1. The authors concluded that the accuracy of the surgery and the patient satisfaction were sufficiently poor to advise against LASIK in myopia of more than 15D.

Waring et al<sup>8</sup> published the data for simultaneous LASIK in 378 eyes with myopia ranging from -2 to -22.5D. The predictability of obtaining a refractive error of  $\pm 1$ D was 84.5% and 88.9% of eyes achieved a UCVA of more than 20/40.

Hersh et al<sup>9</sup> performed LASIK on 115 eyes with a myopia ranging from -6 to -15D. 55 % of the eyes achieved an UCVA of 20/40 or better.

Perez-Santonja<sup>10</sup> performed LASIK in 143 eyes with myopia ranging from -8 to -20D, at the end of 6 months follow-up only 46.4% of eyes could achieve a UCVA of 20/40 or better. From the study group, 1.4% eyes demonstrated a loss of 2 or more lines of best corrected Snellen's acuity.

Gimbel<sup>11</sup> reported the results of LASIK in his first 1000 consecutive cases in myopia ranging from -1 to -23D. At the end of 6 months, a follow-up was available in 906 eyes, which had no intraoperative or postoperative complications. Seven hundred and ninety-six (87.8%) of these eyes were within  $\pm 1$ D of targeted spherical equivalent and 557 eyes (61.5%) were within  $\pm 0.5$ D.

In a study reported by Guell<sup>12</sup>, 71.4% of eyes gained a UCVA of 20/40 or better after LASIK, performed to correct myopia ranging from -7.0 to -12.0D. However, such an achievement was possible in only 45% of eyes having preoperative myopia of >12.0D.

At the end of 12 months follow-up, Helmy<sup>13</sup> reported a predictability of  $\pm 1$ D in 85.7% of eyes that had undergone LASIK for myopia ranging from -6 to -10D. The same study reported a UCVA of 20/40 or better in 75% of operated eyes.

Andrew Lyle et al<sup>14</sup> performed a prospective study, which included 332 eyes having myopia over -10D. The eyes were divided into 3 groups according to the amount of preoperative refraction: i.e. -10 to -11.90D, -12 to -14D, -14.1 to -18D. The mean follow up was 12 $\pm$ 5.6 months. At the last visit, 84% of eyes

**Table 12.2: Results of LASIK for moderate to high myopia (-6 to -25D)**

Author/Year of study	No. of eyes	Follow-up of months (Completed)	Range of myopia (D)	% within $\pm 0.5$ D/1.0D	Post-op UCVA $\geq$ 20/20 (%)	Post-op UCVA $\geq$ 20/40 (%)	Loss of $\geq 2$ Lines
Hersh <sup>9</sup> /1998	115	6(58)	-6 to -15	27.7/40.7	26.2	55.7	3.2
Steinert <sup>16</sup> /1998	76	12 (68)	-6 to -12	23/54	36	85	2
Casebee <sup>5</sup> /1996-1997	911	3 (100)	-7 to -10	40/54	NR	68	0
Perez-Santonja <sup>10</sup> /1997	143	6(NR)	Total groups -8 to -20 sub groups	NR/60 NR/72.4 NR/46 NR/50	NR	46.4 NR	1.4 NR

			-8 to -12 -12 to 46 -16 to -20				
Pallikaris 17/1994	20	12(100)	-8.8 to 49	NR/66.6	NR	NR	0
Kawesch <sup>18</sup> /1996-1998	290	9 (67.6)	-9 to -22	NR/75.9	NR	85.1	3.6

NR=Not reported

were within  $\pm 1$ D of emmetropia and 96.4% were within The UCVA was 20/20 or better in 45.8% of eyes and 20/40 or better in 89.5%. Six eyes (1.8%) lost 2 or more lines of BCVA. Retreatment was done in 37.0% of the eyes at a mean of  $6.3 \pm 5.3$  months after the initial treatment. At the last examination, 86% of eyes with myopia ranging from -10.0D to -14.0D and 70.0% in group with myopia ranging from -14.1D to -18.0D were within  $\pm 1$ D of emmetropia. The authors concluded that the efficacy, predictability, and safety were significantly less in eyes with myopia greater than -14D.

Merchea M et al<sup>15</sup> compared LASIK outcomes with the Nidek EC-5000 and Meditec Mel 70 excimer laser. They evaluated 5700 eyes treated for myopia and myopic astigmatism with the preoperative sphere ranged from -0.25 to -15.50D and cylinder ranged from -0.75 to -5.50D. They found that eyes treated for myopia and astigmatism with either of these lasers showed early refractive stability and similar efficacy.

### Astigmatism

Laser in situ keratomileusis (LASIK) has been employed to treat astigmatism, either as a component of myopia, hyperopia or existing as a entity itself. However, astigmatic corrections by LASIK have not demonstrated an optimal success.

Chayet et al<sup>19</sup> attempted to correct simple myopic, mixed and simple hyperopic astigmatism with manifest cylinder ranging from 2.00 to 6.50D at the end of 3 month follow-up, UCVA was 20/40 or better in 85% of the eyes. 95% of the corrected eyes were within +1.00D of the attempted correction.

Salchow et al<sup>20</sup> used LASIK to correct myopic astigmatism ranging from 0.00 to 3.00D, as a simultaneous procedure while correcting myopia. At the end of 6 months of follow-up 96.8% of the eyes were within +1.00D of attempted cylindrical correction and UCVA of 20/40 or better was achieved in 82.5% of eyes.

Argento et al<sup>21</sup> in a prospective non-randomized clinical trial used LASIK to treat simple hyperopic astigmatism ( $3.37 \pm 1.62$ D), compound hyperopic astigmatism ( $3.34 \pm 1.39$ D) and mixed astigmatism ( $3.45 \pm 2.15$ D). Six months after the procedure, refractive cylinder was reduced to  $+0.58 \pm 1.22$ D in simple hyperopic astigmatism,  $+0.12 \pm 1.23$ D in compound hyperopic astigmatism and  $-0.11 \pm 1.28$ D in mixed

astigmatism. UCVA were 20/20 or 20/25 in 66.7%; 60.4% and 76.5% of the three groups respectively.

Lui MM et al<sup>22</sup> evaluated LASIK performed with the Nidek EC-5000 excimer laser in 66 astigmatic eyes with cylinder from 4 to 8D. They achieved a UCVA of 20/40 or better in 89% of eyes with no loss of BCVA.

### Hyperopia

Although LASIK surgery has been increasingly used to treat hyperopia, the unsatisfactory predictability remains a major concern (Table 12.3). Argento et al<sup>23</sup> reported good success with LASIK to treat low (<2.00D), moderate (2–3 D) and high (>3D) of hyperopia. At the end of 6 months follow-up, 100% of eyes in the low group, 95.3% eyes in the moderate group and 71% of the eyes in the high hyperopia group were within  $\pm 1$ D of emmetropia.

In a study reported by Goker et al,<sup>24</sup> of 54 eyes treated for hyperopia ranging from +4.25D to +8D, 76% of eyes were within  $\pm 1$ D of intended correction at the end of 18 months follow-up. UCVA of 20/40 or better was achieved in 66.6% of eyes.

Ibrahim<sup>25</sup> reported a mean cycloplegic refraction of +2.25D, 6 months after LASIK surgery undertaken to correct hyperopia ranging from +1 to +6D in 58 eyes.

Buzard et al<sup>26</sup> used LASIK to treat hyperopia in 14 eyes. The mean preoperative spherical equivalent was +1.33D  $\pm$  0.50D. At the end of mean follow-up of 8 months, the mean spherical equivalent was  $-0.15D \pm 0.60D$ . Uncorrected visual acuity of 20/40 or better was achieved in 93% of the operated eyes. In a recent study Lian J et al<sup>27</sup> evaluated 44 hyperopic eyes with a spherical equivalent refraction between +1D and +6D, who were followed for at least 12 months following LASIK. 83.3% of eyes were in the range of  $\pm 1$ D and 61.1% of eyes were within  $\pm 0.5$ D of emmetropia at the end of 12 months. 92.6% of the eyes had UCVA of 20/40 or better and 63% of eyes had 20/20 or better. The authors concluded that LASIK could be used to treat hyperopia from +1 to +6D with good predictability and safety.

These studies indicate that though the procedure is safe for correction of hyperopia, its predictability and long-term stability need further improvement.

### Contrast Sensitivity Function After LASIK

Although LASIK offers good results in low to moderate myopia, light scattering from the interface or from the flap edge can decrease the visual acuity, increase glare, reduce vision at night or decreased object contrast. Visual acuity measured using standard clinical tests is useful but is an incomplete description of visual ability. In order to determine how well one can function in a complex environment, it is necessary to measure sensitivity to contrast as a function of spatial frequency.

**Table 12.3: Results of LASIK for hyperopia**

Author/Year of study	No of eyes	Range of Hyperopia (D)	Follow-up (Months)	Posttop VA $\geq 20/40$ (%)	% within $\pm 1.0D$
Argento <sup>23</sup> /1998	679	<2	6	94.1	100

		2–3		100	95.5
		>3		87.8	71.4
Ditzen <sup>28</sup> /1998	43	1–4		86.2	NR
		4.25–8	12	74.6	NR
Goker <sup>24</sup> /1998	54	4.25–8	19	66.6	75.9
Buzard <sup>26</sup> /1999	14	0.5–1.88	8	93	85
Tabbara <sup>29</sup> /2001	80	0.5–11.5	6	97.5	84
Salz <sup>30</sup> /2002	360	Upto 6D	12	93.4	87.4
Lian <sup>27</sup> /2002	44	1–6	12	92.6	83.3

NR—Not reported

Perez-Santonja et al<sup>31</sup> evaluated the effect on contrast sensitivity function of LASIK in myopia. Fourteen eyes had LASIK to correct myopia ranging from 6 to 19.50D. They found that although LASIK decreased contrast sensitivity values at low and intermediate spatial frequencies at 1 month after surgery, these values rapidly returned to preoperative values at three months. Their study also suggested that LASIK can improve the quality of vision in eyes with moderate and high myopia.

Yan Z et al<sup>32</sup> evaluated near contrast sensitivity function in 93 eyes before, 1 month and 6 months after LASIK. They found that there was a general reduction in near contrast sensitivity at all spatial frequencies at postoperative 1 month. By the end of 6 months, all eyes showed a recovery of static contrast sensitivity function. Eyes with myopia of  $\geq -6.00$ D had higher decrease rate of contrast sensitivity compared with that of myopia  $< -6.00$ D. Their study suggested that the near contrast sensitivity in post-LASIK patients at early stage is reduced despite normal visual acuities and this can affect the quality of vision.

Chan JW et al<sup>33</sup> in a similar study found a general depression in the contrast sensitivity function after LASIK; 1.5cpd and 3.4cpd being the most affected frequencies. However, contrast sensitivity function recovered at the end of 6 months and the reduction in contrast sensitivity was greater for higher amounts of myopia.

Tsai YY et al<sup>34</sup> evaluated the effect of LASIK on colour vision. Twenty-nine eyes were enrolled in the study with a normal colour vision test preoperatively, tested using Farnsworth-Munsell 100-hue test. They found that LASIK did not affect the colour vision.

**Table 12.4: Results of retreatment after LASIK**

Autho r/year	No of eyes	Retra tment rate (%)	Mean preop (D)	Mean postop (D)	Within $\pm 0.5D$	Within $\pm 1.00D$ (%)	$\geq 20/40$ (%)	$\geq 20/20$ (%)	Follow- up (months)
Martines and John	14	5.0	$-4.5 \pm 2.6$	-0.47	42.8	79	50.0	14.3	6

1996<sup>35</sup>

Probst and Machet 1998 <sup>36</sup>	209	NR	$-1.95 \pm 0.78$	$-0.67 \pm 0.90$	77.8	77.8	NR	NR	12
Zadok 1999 <sup>38</sup>	53	5.5	$-1.7 \pm 1.1$	$-0.09 \pm 0.29$	90.6	100	96.2	39.6	6
Perez Santonja 1999 <sup>39</sup>	59	17.5	$-2.92 \pm 1.22$	$-0.61 \pm 0.82$	NR	81.8	62	NR	12
Durrie 1999 <sup>40</sup>	12	NR	-2.24	-0.12	50.0	92.0	92	58 ( $\geq 20/25$ )	3
Rashad 2000 <sup>41</sup>	35	-	$-2.17 \pm 0.82$	$-0.23 \pm 0.28$	91.5		91.4	31.4	12
Febbraro 2000 <sup>42</sup>	52	7.3	$-0.77 \pm 0.94$	$-0.13 \pm 0.33$ D	100	100	100	100	NR
Lyle 2000 <sup>43</sup>	157	7.8	-1.28	-0.23	82	97	98	68.8	15
Brahms 2001 <sup>44</sup>	24	22	$-3.02 \pm 2.17$	$+0.18 \pm 0.42$	62	100	96	33	$12.8 \pm 5.1$

NR=Not reported

## Results of Re-LASIK Surgery

Overall, LASIK re-treatment by lifting the flap is an effective and safe procedure (Table 12.4). Overall improvement is seen in the uncorrected visual acuities, postoperative spherical equivalent, spherical equivalent within  $\pm 0.5$ D and  $\pm 1.00$ D and uncorrected visual acuities better than 20/20 and 20/40.

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# 13

## *Refractive Surgery and Strabismus*

**Lionel M Kowal, Ravindra R Battu**

This chapter will give the readers a knowledge of factors likely to lead to strabismic complications so that they may protect patients (and doctors) from these complications without depriving patients of the benefits of refractive surgery.

We will discuss the various strabismogenic mechanisms involved with illustrative case reports. Guidelines are given at the end of the chapter on risk stratification and the appropriate screening tests that one should employ.

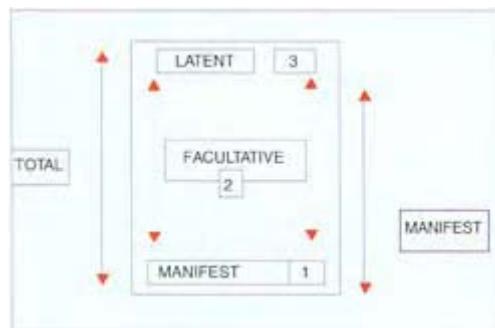
### **Hyperopia**

Some refractive surgeons believe hyperopia to be the mirror image of myopia. This is not the case. The myopic laser prescription is the same as the cyclopentolate refraction; clinical success and patient's satisfaction correlates highly with the technical results of corneal reshaping. Hyperopia is different. The optical defect interacts with monocular and binocular accommodation and convergence. The laser target is less well defined and is indeed a moving target, depending both on age and the total hyperopia. Early success depends on all of corneal reshaping, residual accommodative amplitude and binocular status. Late success depends on all of these and also the presence and magnitude of latent hyperopia. Further, the population of hyperopes is far more likely to have amblyopia, and are predisposed to esodeviations.<sup>1</sup>

Predisposition to post-surgical strabismus is related to the amount and components of the patient's corrected and uncorrected hyperopia as well as the underlying motor fusional status. It is important to understand the different components of hyperopia which are:

1. *Absolute hyperopia* This is the proportion of hyperopia not compensated by the patient's natural accommodation. It is measured as the minimum dioptric power required to bring the patient to threshold distance acuity.
2. *Facultative hyperopia* This is the proportion of hyperopia which the patient can compensate for by accommodating and which can be relaxed. It is measured as the difference between the maximum dioptric power required to keep the patient at threshold distance acuity and the absolute hyperopia.

3. *Latent hyperopia* This is the proportion of hyperopia compensated by ciliary body tone, which cannot be relaxed except by cycloplegics. It is measured as the extra hyperopia



**Figure 13.1.** Clinical components of hyperopia

demonstrable after appropriate cycloplegia (or the cycloplegic refraction minus the full manifest refraction).

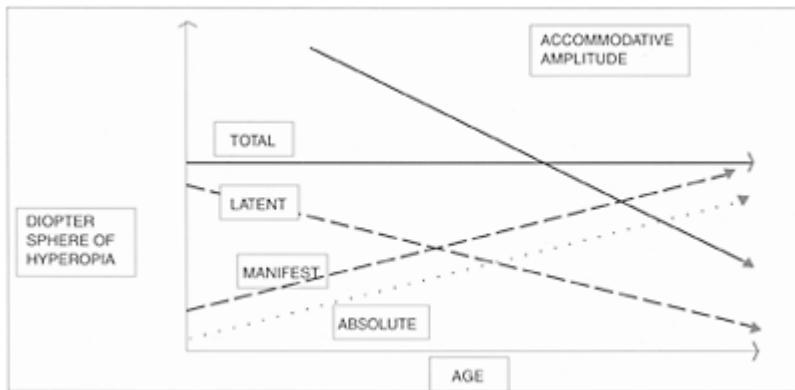
Facultative hyperopia, (mentioned above) reflects that component easily compensated for by active accommodation. Manifest hyperopia includes (1) plus (2). Total hyperopia on cycloplegia includes (1) plus (2) plus (3) (Fig. 13.1).

The total hyperopia probably remains constant throughout life. Variability in the expression of the components of hyperopia relates to ciliary body tone and accommodative amplitude. Facultative hyperopia is 'elastic' in the sense that it allows for large variations in hyperopic correction of the same patient, whilst maintaining threshold distance visual acuity (dotted arrows in Fig. 13.1). With time (measureable in years), latent hyperopia gradually decreases to become manifest and more of the facultative hyperopia becomes absolute as accommodative amplitude diminishes with age (Fig. 13.2).

*Example 1:* A patient with a vision of 6/12 requires +1.0D to achieve 6/6. This is his absolute hyperopia. He accepts an additional +1.0D while maintaining 6/6 vision; additional plus blurs. His manifest refraction is therefore +2.0D. Cyclopentolate refraction yields a figure of +2.75D. His latent hyperopia is, therefore, +0.75D.

*Example 2:* A 30 years old patient with uncorrected vision of 6/6 accepts +1.5D while maintaining vision at 6/6. Additional plus lenses blur. His absolute hyperopia is piano (zero). His manifest refraction is therefore +1.5D. Cyclopentolate refraction yields a figure of 3.0D. His latent hyperopia is therefore +1.5D. Ten years later, we may find that his manifest refraction is +2.5D, a Dioptrē of latent hyperopia having become manifest!

*Accommodative amplitude (AA) is initially 25–30 D and slowly decreases with age. As AA decreases, Absolute hyperopia and manifest hyperopia slowly increase. Latent hyperopia gradually decreases and becomes manifest.*



**Figure 13.2.** Change in hyperopia components with age

Short-term visual success of hyperopia surgery depends upon treating the absolute hyperopia. Clearly, correction of just absolute hyperopia is inadequate in maintaining overall patient satisfaction in the medium and long-term. As the facultative hyperopia becomes absolute and the latent hyperopia becomes manifest, the patient seems to have recurrent hyperopia.

The strabismogenic potential of hyperopia surgery relates to the underlying binocular status, particularly any esotropic tendency with the manifest hyperopic correction in place. This can be implied by the patient's motor fusional range which should be measured in these patients.

Motor fusion refers to the ability to align the eyes in such a manner that sensory fusion can be maintained.<sup>2</sup> The motor fusional range is measured with prisms of increasing strength placed before the eye in a way that stresses both sensory and motor fusion, yet maintains binocular single vision. The fusional range is also referred to as fusional amplitude (or fusional reserve).

*Assessing motor fusional amplitudes* To measure motor fusion, ask a 6/6 patient to look at a 6/12 letter.<sup>3</sup> Run a horizontal prism bar Base In from one pd upwards, until the patient experiences diplopia that cannot be resolved within a few seconds. Do the same with Base Out prism. Repeat for near vision using a 'paddle' with a miniaturised letter chart. Values greater than 10 pd for each measurement are safe. Patients should be considered high risk if values of less than five pd are obtained and also if diplopia cannot be obtained (there may be a suppression scotoma, which needs to be quantitated).

It is probably safe to operate on these patients if horizontal fusion range is more than five pd in either direction, unless the latent hyperopia exceeds two D. A significant latent hyperopia will become manifest with time and a previously safe motor fusion range of five pd may now become insufficient to maintain orthotropia.

Hyperopic LASIK is potentially effective in eliminating the hyperopic corrections in patients with accommodative esotropia, thus maintaining alignment without the need for glasses.<sup>4,5</sup>

Correction of only the absolute hyperopia is safe if a patient has large fusional reserves to keep the residual hyperopia from inducing an esotropia. It is usually preferable to correct all the manifest hyperopia. An important exception is the patient who has an underlying exodeviation which is being controlled by accommodative convergence. This patient will have poor Base out (convergence) fusional reserves with the manifest refraction in place.

**Case report:** A 32-year-old woman had a previously well controlled accommodative esotropia when wearing her cycloplegic refractive correction of OD+3.50 DS/+2.50 x 115 and OS+3.50 DS/ +3.50x60.<sup>6</sup> After undergoing bilateral LASIK surgery, she had a cycloplegic refraction of OD+1.75 DS/+1.50x115 and OS+1.25 DS /+1.75x60. Uncorrected visual acuity in each eye was 6/7.5 (20/25) despite the residual astigmatism. Consequently, she did not wear optical correction after surgery and developed a 15 pd esotropia and had constant diplopia when esotropic.

**Comment:** Despite the change of more than + 1.5D, her esotropia decompensated, which would indicate that she required a correction more than her absolute hyperopia to keep her esotropia under control. If her fusional amplitudes had been measured, it is likely that she would have had poor fusional amplitudes to begin with, or would have required a higher hyperopic correction than her absolute hyperopia for safe fusion range.

**Case report:** A 24-year-old woman had accommodative esotropia with a highAC/Aratio.<sup>6</sup> Her strabismus was well controlled with progressive additional lenses (PAL). The refractive surgeon was unaware that her spectacle contained a near add. After LASIK surgery, she manifested an esotropia and diplopia for near viewing.

**Comment:** Although AC/A ratio usually decreases with age, this patient's clearly hadn't. All patients undergoing refractive surgery should have their spectacles tested on the vertometer with the pupillary positions marked to check for prisms. It is also necessary to check the glasses for PALs in the occasional pre-presbyope who requires it for a high AC/A esotropia. The patient could have been forewarned about this problem that she would face if she did not wear a near add in the postoperative period.

### *Myopia*

Myopia surgery corrects the least minus required to reach distance threshold. Habitually overcorrected myopia is seen occasionally in the intermittent exotrope, who has been overminused to encourage accommodative convergence. Such a habitually overcorrected myope may experience a breakdown of fusion and subsequent exodeviation, once the correct degree of myopia is corrected. A useful test would be to appropriately correct or undercorrect the myopia with spectacles, or contact lenses and assess the deviation and motor fusional reserves before the refractive procedure.

**Case report:** The patient had intermittent exotropia which was controlled by an intentional overcorrection of the myopia.<sup>6</sup> Refractive surgery targeted and corrected the cycloplegic refraction, but did not take into account the fact that the patient had been intentionally prescribed an overcorrection. The intermittent exotropia deteriorated after surgery.

**Comment:** This stresses the importance of doing cycloplegic retinoscopy even in myopes and comparing this with the power of the optical correction being worn.

Accommodative convergence induced by overminusing the patient compensates for poor fusional convergence.

### Anisomyopia

Several mechanisms could play a role in strabismogenesis or the development of diplopia in these patients. The anisometropia per se is not strabismogenic, but the associated aniseikonia is. Aniseikonia is difficult to understand and the necessary aniseikonia quantitation is infrequently done. We recommend the Away a New Aniseikonia testbook. We do not have experience with space eikonometers or synoptophores. Aniseikonia as little as three percent can result in abnormalities of fusion, which in turn can contribute to symptomatic strabismus.<sup>7</sup>

Knapp hypothesised that axial ametropia corrected with a spectacle lens at a distance of the anterior focal plane of the eye results in a *normal* sized retinal image, and therefore no aniseikonia results. In practice, however, in high myopia, retinal concentration of photoreceptor elements is less and this more than compensates for Knapp's Law. The result is an actual minification of image as demonstrable on an Eikonometer. In fact, contact lenses diminish the degree of image minification and return subjective image size appearances towards normal.<sup>8,9</sup>

A patient with anisomyopia corrected with contact lenses and who has a safe demonstrable range of motor fusion can be safely corrected with refractive surgery, as surgery would reproduce the contact lens situation. However, the anisomyope corrected with glasses, and who has fusion, is at risk of aniseikonia with diplopia if the anisometropia is corrected by corneal surgery (see case report). Therefore, subject to the particular details of the optics of any one patient, anisometropia may be more or less aniseikonogenic, depending upon whether the correction is in the spectacle plane or at the cornea. It is not possible to reliably predict this effect for a particular patient without doing a contact lens trial because, for example, there may be abnormal sensorial adaptations to preexisting aniseikonia. A case could be made for placing all anisomyopes into contact lenses before refractive surgery to assess the subjective aniseikonic response.

**Case report:** A patient had OD -2.0D and OS - 8.0D with good fusion.<sup>6</sup> He had 60" of stereopsis before refractive surgery. After undergoing refractive surgery which left him with a negligible refractive error in both eyes, he had intractable diplopia due to aniseikonia which measured seven percent.

**Comment:** Changing the anisometric correction from the spectacle plane to the corneal plane has created this problem as predicted by Knapp. Contact lens 'simulation' of the post surgical vision would have probably predicted the emergence of aniseikonic diplopia in this patient. This type of diplopia is impossible to correct with strabismus surgery and the patient would need some other forms of optical correction (aniseikonic glasses, etc.).

### Astigmatism

Refractive surgery can result in an undercorrection or a rotation of the axis of the astigmatism by one or more of several mechanisms.

1. *Refractive surgery* is done under monocular fixation. The eye can undergo significant cyclorotation when changing from binocular to monocular fixation, and topography done with monocular fixation can show an axis shift when compared to topography done with binocular fixation.<sup>10</sup> Patients more likely to demonstrate this difference are those with cyclovertical disturbances (compensated 4th nerve palsy, DVD, latent nystagmus, cyclophoria, high myopes with a highAC/Aratio etc.).<sup>10</sup> Rotational change has also been demonstrated while changing from sitting to the supine position, such as from the refraction or topography position to the surgical position.<sup>10,11</sup> The combination of monocular fixation and position induced torsion change could significantly alter the axis and amount of ablation resulting in undercorrection of astigmatism or induction of a new cylinder. As well as a poor visual result, this could make the fusion mechanism quite tenuous due to blur.
2. *Another phenomenon* that occurs is subjective torsion due to induced astigmatism. A failure of cyclofusion of these images results in diplopia (Kushner B and Guyton D personal communication).

**Case report:** A 34-year-old male had a preoperative cycloplegic refraction in his left eye of  $-5.0\text{D}/+2.50\text{D}\times85$ .<sup>6</sup> After RK in his left eye, he was left with a refractive error of  $-2.0\text{D}/+3.25\text{D}\times55$ . This 30 degree rotation in his axis of astigmatism resulted in an optically-induced Excyclotropia of seven degrees of the operated eye, as measured subjectively with the Maddox Rod test. Although he was orthotropic, and had no objective fundus torsion, he remained symptomatic. He was able to fuse the tormented image and had fusional amplitudes on the synoptophore with the torsional misalignment optically corrected on the synoptophore.

**Comment:** An adaptation to cylindrical correction in one axis may result in inability to adapt to the induced cylinder after an imperfect keratorefractive procedure. The absence of torsion on orthoptic evaluation and absence of fundus torsion, indicated that the change in cylinder-induced torsional diplopia, which the patient could not fuse. The keratorefractive surgeon is encouraged to check topography using both binocular and monocular fixation techniques and be wary if there is a significant difference.

**Case report:** That more than one mechanism could contribute is seen in the following example. A 40-year-old female had a preoperative refractive error of  $-4.0\text{D}/+4.0\times90$  in her right eye.<sup>6</sup> Due to a mathematical error, the refractive error that was programmed into the computer placed the cylinder axis 90° from its correct location. After surgery she had a final refractive error of  $-8.0\text{D}/+8.5\text{D}\times170$ , which resulted in binocular diplopia. Although she was orthophoric, she could not fuse the images due to a combination of aniseikonia of nine percent and image distortion.

3. *Acquired astigmatism:* Uncorrected astigmatism can cause accommodative spasm, as can a new acquired astigmatism.<sup>12</sup> This could be a cause for asthenopic symptoms in a patient whose astigmatism has been imperfectly corrected, or has been changed, and does not wish to wear the correction. It can also predispose to symptomatic exodeviation.

## Planned Monovision

When one plans mono vision, one typically plans to leave the patient piano in one eye and  $-1.5$  DS in the other eye. Potential problems occur because:

1. The amblyopic eye is now dominant for some tasks and
2. Anisometropia lessens motor fusion. One can pre-test this with contact lens simulation (though the positive predictive value of this test has never been evaluated).

In the ISA meeting 2002, Fawcett reported 118 refractive surgery patients of whom 48 had planned monovision. Of these 48, eleven had symptoms of abnormal binocular vision (intermittent or persistent diplopia, visual confusion, and/or binocular perceptual blur requiring occlusion to focus comfortably). Of the 70 patients who did not have monovision, only two had symptoms of abnormal binocular vision. Of the 13 patients of both the groups who had abnormal binocular vision, the average ametropia was 1.9 DS. The other 105 patients with normal binocular vision had an average anisometropia of 0.5 DS.<sup>1</sup>

Fawcett also showed that surgical monovision can produce an uncorrectable deficiency of high grade stereopsis and foveal fusion.<sup>13</sup> This is quite different to patients who have contact lens monovision who spend some time without monovision and whose sensory status appears to be unchanged by intermittent monovision. Sheraf et al has shown that patients with longstanding asymmetrical keratoconus experience a similar breakdown of binocular visual function.<sup>14</sup>

Three mechanisms of diplopia have been proposed by Kushner:<sup>6</sup>

1. Intermittent strabismus, or a phoria with poor reserves could decompensate into a constant tropia due to the degradation of high grade stereopsis and foveal fusion as demonstrated by Fawcett.<sup>13</sup>
2. Fixation switch is a potential cause of diplopia in monovision patients. In some circumstances the amblyopic eye (with the scotoma) becomes the fixing eye. The habitually fixing eye is now the deviating eye; there is no transfer of scotoma facultatively, and diplopia may ensue.

**Case report:** A 52-year-old patient with OD  $-6.0$  DS  $-6/6$  and OS  $-6.0$  DS/  $-1.0$  D $\times$ 95–6/8. RE is corrected for distance and LE for near.<sup>3</sup> If the LE is mildly amblyopic and the RE the habitually fixing eye, then the three pd microesotropia may be missed and is not important. However, if the LE is forced to be the dominant (fixing) eye for near vision, the RE does not have any sensory adaptation to a 3 pd microesotropia and diplopia ensues whenever the patient reads.

3. Fixation switch diplopia could occur by another mechanism. In a well compensated 4th Nerve palsy, if the paretic eye is forced to preferentially fix for any direction (distance or near), then secondary deviation would result in a larger tropia (Hering's law). This could exceed the previously established fusional amplitudes and result in a deterioration of control of the ocular misalignment.<sup>6</sup>

Unplanned temporary surgical monovision was seen routinely in the early days of refractive surgery when there was typically a 3 month delay between treatment of the eyes. Of 50 patients reported by White, 1/50 had fusional convergence decrease from 35 pd to five pd. All patients were asymptomatic.<sup>15</sup> Temporary

surgical monovision seems not to have the same morbidity as permanent surgical monovision.

### Angle Kappa and Decentration

Many hyperopes have a positive angle kappa. This could theoretically result in flap decentration nasally, and a nasally decentred treatment zone. A significant horizontal prismatic effect could be created by this resultant decentration.

Similarly many high myopes have a negative angle kappa, which may result in significant decentration and creation of a horizontal prism.

The prismatic effects of such decentration are typically within the range of horizontal motor fusion. A patient with a poor fusional range is at risk of developing strabismus and diplopia in this situation.

Vertical fusional ranges are normally very poor ( $+/-3$  pd in either direction). A small vertical decentration is more likely to cause diplopia in this situation as the following case report demonstrates.

**Case report:** Adult male with 27.0D myopia (spherical equivalent), developed postoperative binocular diplopia after undergoing LASIK which attempted to correct 23D of myopia.<sup>16</sup> He had difficulty in maintaining fixation during the procedure and the treatment zone was inadvertently decentred upwards. This induced a vertical prism effect which resulted in 16 pd of hypertropia. An overlap of two different sizes images could be demonstrated with a hard contact lens or a prism.

**Comment:** This situation is rarely encountered nowadays. The vertical motor fusional range is too small ( $=/-3$  pd) to compensate for the large prismatic deviation involved. Vertical angle kappa, which could result in inadvertent treatment zone decentration is a rarely seen situation (1 in 5000 in a strabismus practice).

### Refractive Surgery in Patients with Manifest Strabismus

One needs to answer two main questions in this difficult group of patients:

**Question 1.** What is the risk of spontaneous deterioration, following successful refractive surgery, or following imperfect refractive surgery?

If the strabismus deteriorates, it is likely that deterioration will be blamed on refractive surgery. Spontaneous deterioration is more likely to happen if:

1. A version or a duction deficit is already present, or,
2. A cyclovertical disturbance (e.g. inferior oblique overaction, DVD, etc.) or an alphabet pattern is already present.

An imperfect refractive result may cause worsening of the strabismus, e.g. if the dominant  $-2.0$ D eye of a patient with a small esotropia ends up with  $+0.75$ D, it is likely that the esotropia will deteriorate because of the increased accommodative convergence induced by the dominant eye.

**Question 2.** What is the risk of diplopia developing spontaneously, following successful refractive surgery, or following imperfect refractive surgery?

The patient who has amblyopia with a tropia presenting for refractive surgery is not the usual strabismus patient. The amblyopic eye is going to be 6/9, or better. It is thus

important to assess the ‘depth’ and ‘size’ of the scotoma, and it is likely that a small shallow scotoma is more diplopiogenic than a large deep one.

To assess the depth of a suppression scotoma, we use a Bagolini filter bar.<sup>17</sup> This produces a quantitative measure of how much retinal rivalry is required to successfully overcome a suppression scotoma. A value of ‘1’ or ‘2’ is indicative of a shallow scotoma. A value of at least ‘5’ is indicative of a deeper and probably ‘safe’ scotoma.

The size of the suppression scotoma can be measured in a number of ways, and our favourite is the polarised four dot test developed by Arthur.<sup>18</sup> This uses circularly polarised stimuli of the same colour viewed through the appropriate translucent glasses. There is no retinal rivalry (the images are of the same colour) and there is minimal dissociation (the polarised glasses are as dissociating as a pair of sunglasses). The size of the suppression scotoma can be mapped from a fraction of a degree to five degrees. A large scotoma probably predicts a tolerance for a change of strabismic angle with time whereas a small one suggests lesser tolerance.

### ***Minimum Recommended Screening Test***

1. **History:** Prior strabismus, diplopia, prism in spectacles, bifocals in a pre-presbyope, eye exercises.
2. Check current glasses for prism and progressive additional lenses.
3. Cover Uncover and Alternate Cover Test for distance and near, while the patient is wearing the habitual and the targeted optical correction.
4. Refraction
  - a. **Manifest:** For myopes, least minus required for threshold acuity  
For hyperopes, least plus for threshold=absolute  
Most plus for threshold=manifest

For near, use a threshold card, not commercial throwaway ones. Threshold cards typically recognise N3+ (M 0.3 or 0.4) as threshold. It helps to explain the occasional hyperope with N5 vision who complains of near blur.

- b. **Cycloplegic:** Difference between cycloplegic and manifest hyperopia is latent hyperopia

### ***Additional Tests***

5. **Fusional divergence and convergence amplitudes:** To be performed in all hyperopes, and if there is a history or finding of diplopia, strabismus, prism in spectacles, or a moderate-sized phoria.
6. Trial with neutralising prism (if the patient habitually wears prisms).
7. Astigmatic axis viewing monocularly and binocularly: If substantially different, measure again on the operation table.
8. Trial of mono vision contact lenses, if mono vision is the desired outcome and the patient has substantial phoria, prisms in glasses, or poor motor fusion.

## Risk Stratification

### ***No Risk Group***

These are patients who have all of:

1. Myopia with less than 4.0D of anisometropia
2. No history of strabismus or diplopia
3. No prism in their glasses,
4. No more than a minimal phoria on an alternate cover test, and
5. The current spectacles, manifest refraction and cycloplegic refraction, are all within 0.5D of each other.

Patients with accommodative esotropia with good fusional reserves (>10pd) while wearing their absolute hyperopic correction, are also at low risk. So also are patients who have undergone strabismus surgery and have a good range of fusion while wearing their correction.

### ***Moderate Risk Group***

Patients not satisfying the above criteria are to be considered at least at moderate risk. One should test for motor fusion in these patients.

*Astigmatic surgery:* Patients undergoing surgery to correct a substantial astigmatic error, and who have a considerable difference between the axis of astigmatism under binocular and monocular fixing conditions are at risk of inadequate, or inappropriate correction of their astigmatism. Patients who have subtle strabismus with cyclovertical disturbance are at particular risk of this problem.

In accommodative esotropes with poor fusional reserve (<5 pd), the risks of strabismus exist. So also is the presence of 2D or more of latent hyperopia as this may result in late decompensation to strabismus.

Patients may be wearing spectacles with prisms incorporated. A trial of spectacles with the prism neutralised (stuck on prism or Fresnel prisms) would be sufficient to predict the risk of postoperative diplopia.

### ***High Risk Group***

This group includes the following:

1. Monovision patients who develop diplopia while on a monovision trial with contact lenses are at risk of developing postoperative diplopia.
2. An accommodative esotrope requiring substantially more plus correction than their absolute hyperopia to control their deviation. Patients with more than 4.0D of anisometropia with good fusion are high risk candidates for postoperative diplopia (possibility of aniseikonia).
3. Patients with manifest strabismus.

Finally, it has to be stressed that a patient who falls into a high risk group could still undergo refractive surgery, if all the risks are evaluated and the patient accepts the

possibility of undergoing strabismus surgery if required later. If refractive surgery has to be done on a patient with strabismus, it is preferable to do the refractive surgery first. If strabismus surgery is decided upon initially, then a fornix based approach is preferable to a limbal approach to allow for microkeratome suction.

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## 14

### *Intraoperative Complications*

Gerard L Sutton, Namrata Sharma, Rasik B Vajpayee

Laser in situ keratomileusis (LASIK) is a widely performed refractive surgery with an estimated 1.5 million annual procedures being performed worldwide.<sup>1</sup>

Some of the complications of LASIK surgery are well known and established; newer complications are also emerging as untoward events may be encountered since patients with yet unidentified contraindications undergo surgery.<sup>2</sup>

The complications of LASIK surgery as suggested by Gimbel may be divided into intraoperative or postoperative based on the time of occurrence as preventive strategies, presentation and management will differ.<sup>3</sup> Gulani has given a three-level classification based on the level at which the complication may occur, i.e. corneal level, interface level and at the ablation bed (Fig. 14.1).<sup>4</sup>

The corneal section comprises of the corneal flap and the hinge complications. The flap complications include full flap, small flap, large flap, incomplete flap, buttonhole, epithelial tear, thin flap, full thickness anterior chamber penetration, wrinkled flap, edematous flap, irregular flap and shrunken flap.

There is a definite learning curve which is associated with the occurrence of those complications. Lin RT et al<sup>11</sup> studied 1019 eyes of which 490 eyes underwent myopic keratomileusis in situ and 529 eyes underwent laser in situ keratomileusis using the automated corneal shaper.<sup>5</sup> They reported that 88 (8.6%) of 1019 eyes had flap related complications. They also reported that there was a decreasing rate of flap complications as the surgeon gained more experience. A significant learning curve in the use of microkeratome was also noted by Tham and Maloney in their series of 3998 eyes undergoing LASIK.

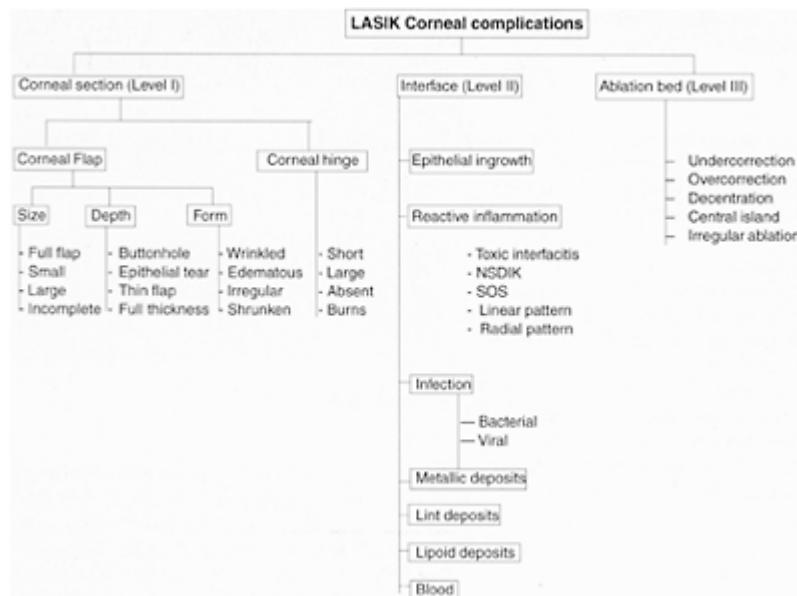
The creation of a regular lamellar flap of uniform thickness is the most important step in the LASIK surgical procedure (Fig.14.2).

#### **Avoiding Intraoperative Complications**

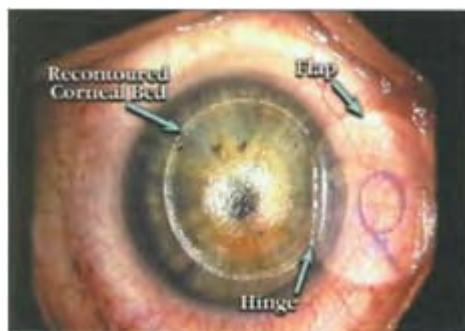
A general approach to avoiding intraoperative complications includes three key steps; **Exposure, Suction and Patience/Precision**. Using this “**ESP**” approach is very useful in avoiding complications.

## Exposure

It is essential that the microkeratome has a clear path to traverse the eye, and that the excursion of the microkeratome is not impaired by the speculum, lashes, drape or conjunctiva. A3M steridrape cut in



**Figure 14.1.** Gulani three-level classification<sup>4</sup>



**Figure 14.2.** The LASIK flap

half should be used to hold back the eyelashes. It is also important to have various specula available to fit different sized orbits.

The second most important aspect of exposure is the footplate diameter of the keratome. At least 20 mm or ideally a 19 mm diameter is important for smaller Asian eyes. 19 mm specula are available with various microkeratomates, including the Alcon SKBM, the Moria, the AMO Amadeus and the BD microkeratome. It may be difficult to obtain adequate exposure especially in small Asian eyes where the suction ring microkeratome assembly may not fit.

We have described a technique for eyes with narrow palpebral aperture.<sup>7</sup> We advocate removal of the lid speculum and placement of the 8.5 mm suction ring after opening the eyes with the index finger and the thumb, in cases of inadequate exposure. The Hansatome (Bausch and Lomb Surgical, Claremont, CA) is then placed on the suction ring and the flap may be created. The absence of lid speculum increases the potential space in the fornices. This technique requires caution and should only be undertaken by experienced surgeons.

### ***Suction***

Inadequate suction can result in a partial or thin flap. The signs of adequate suction include pupillary dilatation, and the patient's inability to see anything. The amount of suction obtained varies with different types of microkeratomates. For example the Alcon SKBM has a low suction on the eye with its 20 mm and 21 mm foot plates because of multiple suction holes on the under surface. The Moria M2 on the other hand, has higher suction, which allows easier maneuverability of the eye.

Novice surgeons should always check the intraocular pressure with a tonometer prior to engaging the microkeratome blade. With experience the "feel" of the eye, digital applanation and the sign of pupillary dilatation may be utilized to ensure that suction is adequate.

### ***Patience and Precision***

Creation of a LASIK flap requires both patience and precision. If suction cannot be achieved, patience is necessary. If a flap is incomplete or a buttonhole occurs and prevents adequate ablation of the stroma, the surgery should be deferred and patience is required. With flap positioning at the end of the surgery, especially if a free flap has resulted, precision is crucial to ensuring optimal visual outcome.

The "ESP" approach to LASIK emphasizes the important safety aspects of this surgery.

### ***Intraoperative Complications***

The incidence and type of complications that can occur in LASIK can vary from the innocuous, such as interface debris and mild epithelial defects, to severe sight threatening complications such as buttonholes, and even anterior chamber penetration.

We will address each of the intraoperative complications that can be encountered and discuss the causes, prevention and treatment of each complication (Tables 14.1 and 14.2).

**Table 14.1: Incidence of complications**

Primary LASIK in 13,300 consecutive eyes (1995–2000) n=144 (1.08%)

<i>Complication</i>	<i>n</i>	<i>%</i>
Buttonhole	13	0.10
Incomplete pass	38	0.29
Full pass	14	0.10
Thin flap	12	0.09
Loss of suction	33	0.25
Epithelial ingrowth	18	0.14
DLK	3	0.02
Loose epithelium	9	0.07
Flap slippage	35	0.26
Keratectasia	2	0.02

**Interface Debris*****Etiology***

Interface debris can come from a number of different origins.<sup>8</sup> These include metal fragments from blade shattering (Fig. 14.3)<sup>9</sup> during the insertion of the flap, oil material from the microkeratome, meibomian, gland secretions (Fig. 14.4), powder from gloves, sponge debris (Fig. 14.5), fibres and lint (Fig. 14.6), or even eyelashes. Although small amounts of debris are visually insignificant, larger debris may be associated with fibrosis and could be associated with an increased incidence of diffuse lamellar keratitis.



**Figure 14.3.** Metallic particles in the interface



**Figure 14.4.** Meibomian gland secretions in the interface

### ***Management***

Interface debris, if significant, is treated by lifting the flap and cleaning of the interface by copious irrigation. We examine patients routinely at 30 minutes after the procedure and undertake early flap lifting and irrigation if significant axial debris or fibers are noted. This is not necessary with small amounts of non-axial interface debris, which is usually insignificant. In fact unnecessary manipulation of the flap is contraindicated and as this may lead to the formation of striae.

### ***Prevention***

The eyelids should be cleaned preoperatively and any blepharitis or anterior segment inflammation addressed prior to surgery. Some surgeons advocate the washing out of the conjunctival sac preoperatively, although this is not our routine practice. Lint fibers may be minimized by the use of lint free gowns and drapes. Other measures include use of powder free gloves,<sup>10</sup> draping the lashes and applying a draining sponge around the limbus, which prevents the regurgitation of surrounding secretions.

We recommend the use of an aspirating speculum when irrigating the interface. A reasonable amount of fluid (2 mm to 4 mm of BSS) may be used to irrigate the stromal bed and the flap, and in the



**Figure 14.5.** Sponges in the interface

presence of an aspirating speculum this does not regurgitate from the conjunctival fornix, but instead is aspirated by the speculum. If in doubt, a coaxial light that is available on many lasers, is useful in identifying debris. Examination postoperatively at the slit lamp can also identify any significant interface debris. With superior hinges, debris can even be removed at this point by irrigation at the slit lamp.

### **Epithelial Defect**

The incidence of epithelial defects with LASIK varies from 1.6 to 5 percent.<sup>11</sup> Epithelial damage during the passage of the microkeratome, can vary from mild punctate epithelial changes to total dehiscence of the epithelial surface. Some microkeratomes appear to have a greater increased risk of epithelial defects than others. The initial rotating microkeratomes, such as the early versions of the Hansatome (Bausch & Lomb surgical, Claremont C A) were associated with varying levels of epithelial defects. The further development of non compression heads (Hansatome) and dual motors to drive oscillation and translation, have resulted in reduced incidence of epithelial defects. Larger epithelial defects are more dangerous, especially, those with connection to the flap edge (Fig. 14.7). There are increased chances of epithelial ingrowth and diffuse



**Figure 14.6.** Lint in the interface

lamellar keratitis with the presence of epithelial defects.<sup>2,12,13</sup>

### ***Etiology***

Epithelial basement membrane dystrophy is the major cause of significant epithelial loss. This condition is an absolute contraindication to LASIK surgery, and all patients should be screened for this prior to the operation.

Epithelial toxicity subsequent to topical medications may also predispose to intraoperative or postoperative epithelial defects. Anesthetic drops preoperatively should be limited to one or two drops only. They can also occur due to dehydration and drying of the flap or minor trauma by forceps and spatules.

### ***Management***

With minor epithelial defects the epithelium can be repositioned and a contact lens placed in situ. Pain relief may be required for twenty-four hours until the epithelium has healed. Epithelial defect increases the risk of epithelial ingrowth, and this needs to be monitored very closely in the postoperative period. There is a theoretical increase in the risk of infection, which fortunately is extremely rare in LASIK surgery.



**Figure 14.7.** Large epithelial defect during LASIK

### ***Prevention***

A thorough slit lamp examination is mandatory to rule out anterior basement membrane dystrophy. The corneal epithelium should be touched with a microsponge applicator in patients with suspected loose epithelium and if moveable, LASIK should not be done.

All patients with epithelial basement membrane dystrophy should be excluded from LASIK surgery.<sup>14</sup> The use of topical lubricants such as Cellufresh, which has been shown to reduce the viscosity with the passage of a microkeratome, are extremely important in preventing epithelial defects. A low pressure microkeratome, may be useful in preventing

epithelial defects. Limiting eye drops preoperatively is essential in reducing the incidence of epithelial defect.

### Incomplete Flap

#### *Etiology*

An incomplete flap is caused by the failure of the microkeratome to traverse adequately (Fig. 14.8).<sup>15,16</sup> This may occur if the microkeratome is caught on the eyelid, lashes, speculum, loose epithelium or precipitated salts from irrigating solutions or there is a malfunction of the motor or gears. The



**Figure 14.8.** Incomplete flap

incidence of this complication ranges from 0.3 to 1.2 percent.<sup>2</sup>

Another very significant cause of incomplete pass can be suction loss, resulting in complete or incomplete detachment of the suction ring. Other causes of failure of microkeratome to form a complete flap include, electrical failure, blockage of foot pedal or accidental interruption of its motion, damage in handling or transport, improper assembly or cleaning, and mineral deposits lodged in the housing or on the blade carrier that result in more than tolerable friction during the pass of the microkeratome through the suction ring slots.

Eyes with scleral buckling surgery and dense conjunctival scarring are at high risk of not being able to develop a sufficient suction and IOP elevation for the creation of a good flap with the microkeratome.

It is important to run the microkeratome through a complete cycle prior to use in each eye of a patient, to ensure proper functioning.

#### *Prevention*

Exposure is the key to preventing an incomplete flap. Various maneuvers can be used to ensure that there is adequate exposure. The use of various specula to accommodate different eye shapes is essential. With good suction it is also possible to elevate the eye,

or maneuver the eye to obtain clearance of the eyelids. In severe cases a lateral canthotomy can be used, but is rarely required in experienced hands. A 19 mm foot-plate is useful in ensuring clear travel. A check of IOP is mandatory to rule out inadvertent loss of suction pressure when lifting the globe. Microkeratome jamming should be minimized by meticulous cleaning of its components and by inspection of its electrical connections.

### ***Management***

In cases with incomplete flap during LASIK, management depends on the extent of uncut flap and location of the hinge of the reflected flap. It has been suggested that if the reflected flap hinge is at the periphery of the planned treatment zone, one can proceed with laser and the flap hinge can be shielded with a moist sponge during ablation.<sup>17,18</sup>

However, this approach can result in flattening and irregular astigmatism adjacent to the hinge. This is probably due to a tethering effect of the hinge on the adjacent cornea. Reducing the optic zone of ablation may also be considered to fit this smaller treatment area, but if the patient's scotopic pupil size is larger than the ablation zone, the result is not gratifying.<sup>19</sup>

If there is inadequate stroma exposed to accommodate the ablation, the case should be aborted. The flap is then repositioned accurately and further surgery is performed in three months' time. Any attempt to deliver the ablation where there is inadequate stroma will result in irregular astigmatism.

If the created hinge is beyond the visual axis, some surgeons prefer to manually dissect the flap taking care to maintain the same lamellar dissection in plane, so that it is completed and attempt laser ablation. The ablation should be performed with the originally planned optic zone or one that is slightly smaller. However, caution is mandatory as the manual dissection may lead to an irregular bed and hence can irregular astigmatism postoperatively. In cases where retreatment is planned after 3 months, a deeper and a more peripheral cut should be planned to encompass the original area.

Various studies have been done regarding the timing of retreatment after a partial flap and most suggest a 2–3 month delay before.<sup>5,9,16,19,20</sup> However, there is little information regarding a definite optimal time for retreatment in such cases. Durrie et al did a study on LASIK enhancement and found that the corneal flap can be relifted after up to 9 months following initial procedure.<sup>21</sup> This suggests that complete healing is not possible within a period of 2–3 months. A longer delay might increase the safety of retreatment, however, it may not be acceptable to the patient, particularly when the other eye has received LASIK resulting in anisometropia.

Rao et al studied the timing of retreatment after a partial flap and suggested that it can be safely performed as early as one month after the initial procedure, provided slit lamp biomicroscopy reveals a well healed corneal flap and the refraction is stable.<sup>18</sup> A thicker corneal flap is intended during retreatment. However, they also suggested that in patients with a thin cornea and/or high myopia, in whom an 180 µm flap is not appropriate, it is wiser to wait for a longer time.

### Buttonhole/Partial/Thin Flap

The incidence of thin flaps after LASIK varies from 0.3 to 0.75 percent.<sup>2</sup> A thin flap or flap is defined as a flap when the keratome cuts within or above 12 µm thick Bowman's layer.<sup>2</sup> A flap which is < 60 µm is suspicious as the thickness of the corneal epithelium is 50 µm. Buttonholes may be partial thickness if they transect the Bowman's layer or full thickness if they exit through the epithelium. The incidence of buttonholes varies from 0.2 to 0.56 percent.<sup>2</sup> A buttonhole is one of the most feared

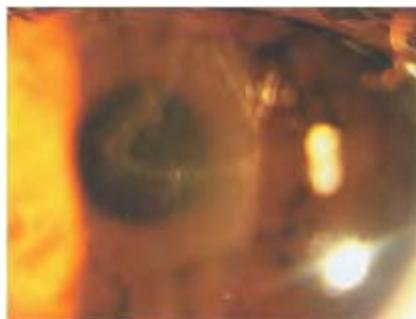


**Figure 14.9a.** Button hole flap

complications of LASIK surgery, because it can result in irregular astigmatism, epithelial ingrowth and significant visual loss (Figs 14.9a and 14.9b).

### *Etiology*

Buttonholes are associated with steeper corneas, and it has been postulated this occurs due to buckling of the cornea due to increased keratometric steepness.<sup>14</sup> The other possible mechanism is that a "potato peeler" effect occurs when the blade is elevated within the mechanism of the microkeratome.<sup>18</sup> Another mechanism of flap buttonhole has also been hypothesized.<sup>22</sup> The microkeratome provides two mechanism actions, a driving force that moves the microkeratome forward and a cutting force provided by the oscillating blade. The smooth incisional interface of the stroma is provided by the continuous slicing action of the oscillating blade. With repeated use, like any other mechanical equipment, the power of the microkeratome is gradually reduced but still sufficient to produce a good flap with a desired thickness in most cases. However, in cases where resistance is increased either due to blunted blade or poor oscillation, the blade can be trapped within the stroma and forced to advance without an adequate synchronized oscillatory slicing action. The blade may well be lifted up within the limited space available inside the microkeratome. Subsequently, the blade breaks through the flap, and the central cornea slips under



**Figure 14.9b.** Button hole flap

the blade, resulting in a perforated flap. It is the poor slicing action that results in a ragged edge. As, now the resistance is released, oscillation becomes effective again and can re-enter the stroma, leaving a clean sharp edge on the nasal side and complete the flap incision. The whole process is similar to potato skin peeling when one leaves a central island of intact skin after overcoming a point of friction. Even if the flap is not perforated, the resulting flap is likely to be thin. This complication is more common on the second eye and this can be explained by the blunting effect on the blade edge after the first incision and the collection of microcrystals and debris after the use of balanced salt solution in the first eye.

Leung et al postulate that a lack of synchronization between the translational flap keratome movement and oscillatory blade movement results in forward displacement of the tissue and hence may cause stepped, thin irregular or buttonholed flaps.<sup>23</sup>

Irregular flaps may also result from damaged microkeratome blades, irregular oscillation speeds or poor suction. The poor suction is likely to be present in deep set eyes or small diameter corneas with a less than optimal suction ring placement or conjunctival incarceration in the suction part generating a pseudosuction.<sup>11,24</sup> The integrity of the blade is crucial to the occurrence of irregular flaps and the blade damage may occur either during manufacture or handling.<sup>20</sup> The occurrence of previous ocular surgery is also a possible risk factor for occurrence of buttonholes.<sup>20</sup>

### *Prevention*

It is essential that the keratome chosen has a low incidence of buttonhole, and it is in good working condition. Extra care is taken with patients with steep corneas. It is imperative to ensure adequate suction by checking the intraocular pressure which should be  $>65$  mmHg in order to create optimal flaps. Conjunctival incarceration due to repeated suction ring application may lead to a disparity between the intraocular pressure and the actual suction pressure.

In flat corneas, the use of larger suction rings is advocated to prevent the occurrence of small flaps and in steep corneas, an utmost care should be taken to prevent buttonholes.

The microkeratome blade should be inspected under the operating microscope prior to its placement for evidence of any damage of the blade.

### ***Treatment***

In cases of buttonhole, the complication should be recognized early, and excess manipulation of the flap is avoided. A “key and keyhole” approach is used to ensure that the corneal surface is as close to its virginal state as possible. Sufficient time is given for corneal drying and a bandage contact lens is placed in situ. This may need to be left for twenty four to forty-eight hours. No attempt is made to perform laser treatment. The patient is then followed closely over a three month period to ensure that irregular astigmatism, haze or epithelial ingrowth does not occur. Three months later repeat surgery can be performed, planning a larger and deeper cut. Alternatively, some surgeons advocate photo-refractive keratectomy especially if the refractive error permits.<sup>24-26</sup>

### ***Free Cap***

A free cap occurs when there is unintended complete dissection of the flap. This occurs more commonly in flat corneas and was more common with the earlier microkeratomates (4.9%)<sup>27</sup> as compared to the newer models (0.01 to 1%).<sup>2</sup>

### ***Etiology***

The factors responsible for free cap are similar to those of thin flaps. Failure of microkeratome reversal coupled with an inadvertent or intended release of suction may cause the occurrence of a free flap. Another important cause of creation of free cap is that the stop mechanism of the microkeratome has not been fitted properly (automated corneal shaper). Other reasons resulting in such situation can be reduced intraoperative IOP and also due to lifting of the suction ring with the dehydrated flap adherent to it, with subsequent detachment.

### ***Management***

If the flap cannot be retrieved, the laser ablation is aborted and the epithelium is allowed to regenerate to cover the denuded area. No lamellar keratoplasty techniques are advocated.<sup>2</sup>

If the flap is retrievable, preplaced corneal markings should be used as a guide to correctly orient and place the flap/flap in position. Laser ablation may continue while the free flap is placed in the closed antidesiccation chamber with the epithelial side down, on a drop of balanced salt solution. The free cap is then carefully replaced with the use of Barraquer perforated spatula using the reference marks to guide its relocation with the stromal side down.

A bandage contact lens should be placed after the procedure and alternatively, some surgeons have also applied sutures. Gimbel et al<sup>19</sup> advocate the routine use of double-circle markings with different size circles to aid in the alignment if a free cap occurs. Free flaps usually fit well if carefully handled and the waiting time after cap replacement should be increased to 5 minutes to ensure an adequate adherence. However, the patient should be monitored for 2 hours before being discharged. Rarely do they need to be sutured and if at all needed, a continuous 8- bite antitorque nylon suture should be placed

or an external compression type suture may be needed. If the flap is lost, the epithelium is simply allowed to heal, however, it may lead to a significant hyperopic shift.

### ***Prevention***

Same measures as for thin flaps should be taken.

### **Flap Striae**

Flap Striae can either be minor and visually inconsequential, or severe and cause significant irregular astigmatism and loss of best corrected visual acuity, especially if visual axis is involved<sup>2,29</sup> (Fig. 14.10).

The flap striae or folds are of two types—*macrofolds* and *microfolds*. Macrofolds are easily visualized on slit lamp and appear as multiple parallel straight lines on retroillumination and are a result of flap slipping. These striae can cause visual deterioration and cause a full thickness flap tenting in a linear manner.<sup>2</sup>

Microfolds on the other hand are within the flap itself and are in the form of wrinkles in the Bowman's layer or in epithelial basement membrane.<sup>29</sup> These folds are best visualized on retroillumination in the slit lamp and are related to flap setting, not flap slipping. These are often not visually significant. The results of a survey, presented at the refractive surgery interest group at the American Academy of Ophthalmology Meeting 1999, found a mean percentage of occurrence of flap striae to be 1.3 percent.<sup>30</sup> The incidence of visually significant striae causing decreased best corrected visual acuity was 0.6% in a series of 1000 patients by Gimbel et al,<sup>16</sup> 6 months following LASIK.

Rabinowitz and Rasheed<sup>31</sup> described the detection of striae, with the use of fluorescein, in cases of sub optimal visual acuity who do not have visible striae on retroillumination. They reported that fluorescein is instilled in the cul de sac and the patient examined on slit lamp biomicroscope. The striae, if present, will be visible in 1 to 2 seconds after the blink. *Horizontal folds are more commonly seen with nasally hinged flaps, while vertical folds are more seen with superior hinged flaps.*



**Figure 14.10.** Flap striae

All folds/striae in the flap/flap do not require surgical intervention as the patients may not be symptomatic. The incidence of folds requiring reflootation of the flap varies from 0.2 to 1.5 percent.<sup>29</sup>

### ***Etiology***

Various etiological factors have been suggested regarding the formation of flap striae. These include flap desiccation and contraction during laser ablation, flap wrinkling during stretching, flap tenting after large ablations, and flap misalignment.<sup>32</sup> When the flap is reflected back for laser ablation of the stromal bed, there is risk of it getting dried resulting in flap wrinkles. Gimbel et al<sup>16</sup> have reported that flap stretching can occur with excessive manipulation of the flap as it is being repositioned. Movement of the properly positioned flap can occur in removing the drapes and eyelid speculum or if a patient rubs the eye after the procedure leading to misalignment. The striae can be best detected by the method of retroillumination on a slit lamp biomicroscopies.<sup>35</sup> There is an increased incidence of striae with thin flaps and with flaps having a small hinge. There are more chances of striae/folds in cases of high myopes and hyperopes as due to a greater ablation and peripheral ablation respectively, more redundant hydrated flap have to cover the corneal convexity<sup>33,34</sup>

### ***Prevention***

Ensuring that the flap is well positioned at the end of the surgery is essential in the prevention of striae. The gutter should be checked to ensure that it is equal throughout the circumference of the flap, and excess hydration of the corneal flap should be avoided. This can result in fine microstriae. Some surgeons recommend applying pressure distal to the flap edge to ensure that there is apposition. Pannu et al<sup>37</sup> have reported that to prevent wrinkles, the excess fluid should be squeezed out from under the flap using the irrigating cannula. This is followed by placement of a bandage soft contact lens on the cornea without waiting for the flap to adhere. The contact lens is removed after 30 minutes. However, Buratto et al<sup>36</sup> claimed that the additional manipulation and tearing caused by the contact lens may actually induce wrinkles as opposed to preventing them.

### ***Management***

Peripheral striae that do not cause diminution of visual acuity do not necessarily require treatment. Probst and Machat<sup>34</sup> suggested that central striae or any striae that affect visual acuity or quality of vision or cause irregular astigmatism should be treated appropriately. If the flap striae are identified within 24 hours of the procedure, the flap can be lifted, refloated and repositioned.

The drying time should be 3–4 minutes and the patient should be re-examined on the slit lamp biomicroscope after 1 to 2 hours. Those striae that do not smoothen with this technique, or those that are detected after more than 24 hours of the procedure require additional techniques. Probst and Machat<sup>21</sup> suggested that a careful identification of the extent and direction of the striae should be done. The flap edge is marked to ensure that the flap, when realigned is not in the same position as prior to repositioning. The flap is

dissected free of the stromal bed, and the undersurface of the flap is hydrated with balanced salt solution. The flap is floated back into position and allowed to adhere for 3 to 5 minutes. The striae is stretched by the side of a blunt forceps in a direction perpendicular to the striae, with a downward and outward movement, using the Machat stretch and smooth technique.<sup>37</sup> This is carried out for several minutes and done on both sides of the striae. The eye is then taped shut and the cornea is examined after 20 minutes.

Pannu<sup>38</sup> used a caro iron to smoothen the striae. After reflecting the flap, he does not hydrate it; he advocates the use of caro iron to smoothen it, and then floats it back into position. A bandage soft contact lens is placed and the eye is not taped shut. The contact lens is removed after 24 hours.

Gimbel et al<sup>16</sup> have described suturing the flap in place and leaving the sutures in place until adequate flap stroma adhesions has occurred.

Steinert<sup>39</sup> does not routinely lift the flap to remove striae. Sterile, distilled water is placed over the cornea and the epithelium over the striae is wiped off with a meroceel sponge, 30 to 60 seconds after application of distilled water. More distilled water is applied over the denuded areas of the cornea until the resolution of the striae occur. If it does not work, forceps can be used to break the fibrosis in the Bowman's membrane by applying the force across the striae. Flap needs to be lifted occasionally to break the fibrosis.

### Corneal Perforation

The most ominous intraoperative complication in LASIK surgery is anterior chamber penetration (Fig. 14.11).

#### Etiology

Anterior chamber penetration is totally microkeratome dependent.<sup>40,41</sup> It has been described with the Chiron ACS microkeratome and is theoretically

**Table 14.2: Intraoperative complications of LASIK: Etiology and management**

<i>Complication</i>	<i>Probable cause</i>	<i>Management</i>
1. Incomplete flap	Interference with the pass of the microkeratome Suction loss Motor failure	Flap hinge in periphery- proceed with ablation-Reduce optic zone Mid-periphery- Manual dissection Recut after 2-3 months if hinge is central
2. Free cap	Flat cornea (<41D) Improper stop mechanism of microkeratome Reduced intraoperative IOP Lifting of suction ring with adherent dehydrated flap	Flap kept in antidesiccation chamber Ablation performed and flap repositioned Increased drying time (5 minutes) Suture may be required

3. Thin flap and button hole	Steep cornea Inadequate suction Poor blade quality	Flap reposited Recut after 3 months
4. Flap subluxation	Patient squeezing eyes while drapes and speculum being removed Eye rubbing Trauma	Flap relifted Undersurface cleared of debris Flap reposited (guided by pre-placed marks if present) Prolonged drying time
5. Flap striae	Flap desiccation Flap misalignment	Flap relifted and repositioned Prolonged drying time Stretch and smooth technique Ironing Sutures No treatment if peripheral/visually non-significant
6. Corneal epithelial defect	Overuse of topical anaesthetic Trauma by instruments Desiccation of flap	Intensive lubricants Prophylactic antibiotic
7. Corneal perforation	Improper seating of thickness plate Corneal ectatic disorders	Depends on severity: Bandage soft contact lens Suturing of corneal perforation Anterior chamber reconstruction Lensectomy/Vitrectomy



**Figure 14.11.** Perforation of eye by microkeratome

possible with the Nidek microkeratome if assembly is incorrect. The microkeratome blade without the restraint of the thickness plate, can perforate the cornea during the pass and the intraocular contents, including lens and vitreous can be expulsed, as during the surgery, the IOP is kept very high. It can also be seen in corneal ectatic disorder. This may also occur during laser ablation.<sup>42,43</sup>

### ***Prevention***

Once the perforation occurs the suction should be completely turned off and the procedure terminated. There is a low risk of intraocular penetration with the newer microkeratomes. It is essential to ensure that the microkeratome is put together correctly and checked by the surgeon.

### ***Management***

Once the perforation occurs the suction should be completely turned off and the procedure terminated. The management of anterior chamber penetration involves immediate primary repair, and may involve cataract extraction, lens implant, iris restructuring, vitrectomy and even retinal detachment repair if it occurs.

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# 15

## *Postoperative LASIK Complications*

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LASIK is a relatively new surgical procedure presenting with a set of previously unknown complications. As the number of procedures performed increases exponentially, preventing and managing LASIK complications has become a challenging task for the ophthalmic surgeon.<sup>1</sup> The current chapter will address the various complications encountered in the postoperative LASIK course and discuss current management strategies.

### **ANATOMIC COMPLICATIONS**

One of the most feared complications with LASIK is a poor quality corneal flap. Jacobs et al showed an incidence of microkeratome related flap complications in 84711 eyes operated by 640 surgeons in 28 national laser centers to be at 0.302 percent.<sup>2</sup> There were 0.099 percent partial flaps, 0.087 percent thin or irregular flaps, 0.074 percent buttonholes, 0.012 percent free flaps. Similarly, Stulting et al<sup>3</sup> reported 1062 cases of patients undergoing LASIK and identified 27 intraoperative and 40 postoperative complications, all directly related to the flap with the exception of 2 cases of keratitis. Gimbel et al<sup>4</sup> in a review of 1000 consecutive cases of LASIK identified 32 intraoperative and 18 postoperative complications, most of which could be attributed to the flap. The incidence of microkeratomes related complications showed a steep learning curve, with 4.5 percent during the first 100 cases and 0.5 percent during the rest of the cases in the Gimbel study.

#### **Thin/Irregular/Buttonholed Flap**

The incidence of thin flaps after LASIK has been reported to vary between 0.3 percent and 0.75 percent.<sup>1</sup> Lamellar flap creation in LASIK should be deeper than Bowman's layer sparing it from laser ablation. A flap is considered "thin" when the keratome cuts within or above the 10  $\mu\text{m}$ -thick Bowman's layer. This is recognized by a shiny reflex on the stromal surface. The use of pachymetry before and after lifting the flap may also be helpful in recognizing this occurrence. A measurement of flap thickness below 60  $\mu\text{m}$  is suspicious as the thickness of the corneal epithelium is approximately 50  $\mu\text{m}$ .

The definition of an irregular flap varies according to the study. It can refer to a bi-leveled flap, a bisected flap or a flap with a notch. Its incidence is lower than that of thin flaps. This can usually lead to scarring and irregular astigmatism.

A buttonholed flap occurs when the microkeratomes blade travels more superficial than intended and enters the epithelium/Bowman's complex. This can provide a channel for epithelial cells to infiltrate the flap-stroma interface. Buttonholes may be partial-thickness if they transect Bowman's layer or may be full-thickness if they exit through the epithelium. The incidence is reported to range between 0.2 percent and 0.56 percent. This was the most common complication resulting in loss of BC VA among 1062 eyes studied by Stulting et al.<sup>3</sup> A flap buttonhole is more likely to occur when performing LASIK on eyes with previous incisional keratotomy.

### ***Etiology***

Steep corneas have been compared to tennis balls that would buckle centrally upon applanating pressure. This results in a central dimple missed by the blade leading to a buttonhole. Another theory is that higher keratometric values offer increased resistance to cutting when applanated, leading to upwards movement of the blade. Leung et al<sup>5</sup> reported 6 cases of buttonholed flaps with a mean keratometric value of 44.20D. Instead of high keratometric values, they believe that a lack of synchronization between translational keratome movement and oscillatory blade movement results in forward displacement of corneal tissue and a stepped, thinned, or buttonholed flaps. Flat corneas may result in a thin and/or small flap as they could be below the adequate cutting plane in certain locations.

Irregular flaps (abnormal shape/diameter) or buttonholes with or without abnormal thickness may result from damaged microkeratomes blades, irregular oscillation speed or poor suction. The latter is more likely to occur in the setting of deep set eyes/ small diameter corneas with inadequate suction ring placement or conjunctival incarceration in the suction port. Blade positioning in the microkeratomes and the preset space for the blade in the microkeratomes may affect flap thickness in the absence of irregular flap shape. Blade damage may happen either during manufacturing or at the time of usage. Another possible risk factor for flap buttonhole occurrence may be previous ocular surgery as suggested by Stulting et al.<sup>3</sup> However, this did not reach statistical significance (P=0.09).

### ***Management***

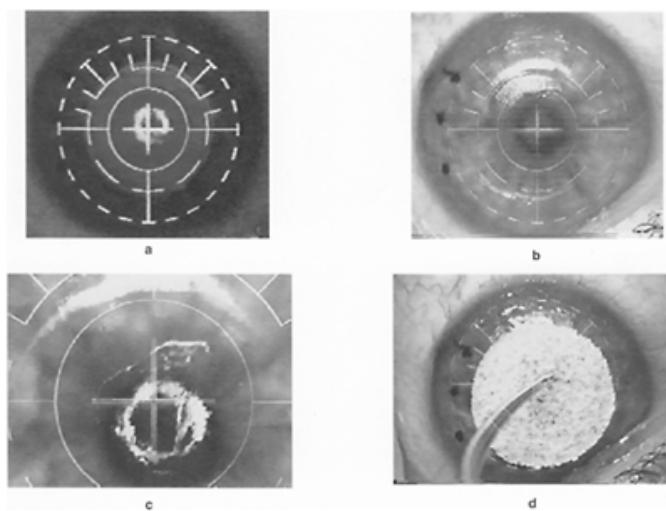
When a thin, irregular or buttonholed flap is encountered, the safest way to proceed is to reposition the flap and abort the procedure. While some advocate proceeding with the ablation after scraping the epithelium, many surgeons have reported a high incidence of corneal scarring, haze, irregular astigmatism and loss of BCVA.

Many strategies have been devised to address buttonhole formation after LASIK. Although some surgeons advocate recutting a deeper flap, we believe that surface ablation (PRK) is a safer approach as it would avoid the risk of buttonhole recurrence and/or intersecting flaps. PRK ablation can be performed either after alcohol-assisted epithelial removal or through a transepithelial PTK approach (Fig. 15.1). Using alcohol to

remove the epithelium is preferred when the epithelial surface is irregular by slit lamp exam. If the surface is smooth, PTK epithelial removal allows using the epithelium as a masking agent when ablating the underlying buttonhole scar. Kapadia and Wilson advocate using transepithelial PRK within 2 weeks of the initial irregular cut to prevent irregular astigmatism formation from the uneven ablation profile resulting from any late scar formation.<sup>6</sup> We prefer to wait approximately 3 months after buttonhole occurrence to allow the overlying epithelium to provide a smoother corneal contour to act as a masking agent as explained above. Earlier intervention to prevent central stromal melting and irregular astigmatism would be warranted if epithelial ingrowth is noted at the edges of the buttonhole. We typically use 0.02 percent mitomycin as a single application for 2 minutes as described by Majmudar et al<sup>7</sup> when we perform any type of surface ablation after LASIK to minimize the risk of haze formation (Fig. 15.1C).

### ***Prevention***

The incidence of thin, irregular and perforated flaps may be reduced if the surgeon ensures adequate suction, inspects the blades, adjusts the plate thickness according to corneal curvature and pays attention to the following guidelines:



**Figure 15.1.** Laser treatment after LASIK Flap Buttonhole. A transepithelial approach using combined PRK and PTK varies based on the laser system used. Epithelium is ablated with PTK mode. Two hundred pulses or 50 micron of large area (6.0 to 6.5 mm diameter) is used to ablate

the epithelium. The illumination of the microscope is set at a low level, allowing adequate visualization of the treatment area. Epithelial treatment is performed, monitoring the blue epithelial fluorescence (**a**), and is halted once a dark area of stromal ablation is noted. Following ablation of the epithelium, PRK stromal ablation is started (**b**). The latter treatment approach will ablate the boundaries of the buttonhole, hence enlarging it and receding its edges away from the visual axis (**c**). Mitomycin C is applied on a sponge at the end of the treatment (**d**).

- a. Avoid cutting the flap if the intraocular pressure (IOP) is low due to low suction. A pressure above 80 mm Hg may be essential for safest flap creation. Measurement is probably most valuable with a pneumotonometer as other means may provide imprecise readings at times. Care should be taken to avoid pseudosuction often caused by conjunctival clogging of the suction port which could lead to discrepancy between the intraocular pressure and the suction pressure recorded on the microkeratomes vacuum console.
- b. Set the microkeratomes to a deeper cutting depth if keratometry readings show evidence of a steep cornea assuming that the amount of intended myopic correction to be treated allows such modification. Most refractive surgeons follow such an approach setting the cut-off point at 47–48D, although no definitive supportive study exists in the literature. PRK or LASEK may be safer in such situations.
- c. Use larger suction rings in flat corneas to prevent small flaps.
- d. Inspect the microkeratomes blade under the operating microscope before engaging it in the suction ring in order to rule out manufacturing or other preoperative damage to the blade. Keep the microkeratomes away from hard surfaces after assembly to avoid subsequent blade damage.
- e. Inspect previous keratotomy incisions to ensure adequate healing and lack of epithelial plugs prior to proceeding with LASIK. This can prevent intraoperative separation of incisions.

### Incomplete Flap

Incomplete flaps are created when the microkeratomes blade comes to a halt prior to reaching the intended location of the hinge. Visual aberrations are more likely to occur when the created hinge results in scarring in proximity to the visual axis. The incidence of this complication reported in large series ranges between 0.3 percent and 1.2 percent.<sup>1</sup>

### ***Etiology***

Microkeratomes jamming due to either electrical failure or mechanical obstacles may be the most common etiology of incomplete flaps. Lashes, drape, loose epithelium, precipitated salt from the irrigating solution have been recognized as possible impediments to smooth keratome head progression.

Incomplete flaps also occur when the gear advancement mechanism jams or is inadequate. Loss of adequate suction in some microkeratomes may lead to automatic abortion of the dissection or force the surgeon to premature arrest of the microkeratomes head.

### ***Management***

Unless enough space exists for ablation, incomplete flaps are best managed by immediate repositioning and postponing the procedure. Resuming forward cutting after stoppage may result in an irregular stromal bed and irregular astigmatism. Retreatment can be achieved by either recutting a new flap or through surface ablation, usually 3 months after the initial procedure. If a recut is chosen, It is advisable to achieve a deeper and more peripheral entry point. We prefer PRK over a partial flap, to avoid intersecting flaps that may lead to irregular astigmatism and loss of BCVA.

If the created hinge is beyond the visual axis, some surgeons may instinctively consider to manually extend the dissection with a blade. Caution is advised when attempting such a maneuver due to the risks of uneven bed creation and flap buttonhole formation. When the laser ablation is performed, the flap should be protected from laser exposure. This may be more important in hyperopic treatments given the larger diameter ablations.

### ***Prevention***

Microkeratomes jamming can be minimized by meticulous cleaning of its components and by inspection of its electrical connections. The manufacturer's recommendations for cleaning procedures and solutions may differ over time as more is learned about a particular machine. A clear cutting path for the microkeratomes can be achieved through adequate draping (to prevent lashes from getting into the cutting field), adjustable eye speculae (to provide as wide of an interpalpebral opening as tolerated by the patient) and by gentle lifting of the globe after vacuum activation (to provide better exposure and unhindered gear progression). In addition, variable tilting of the suction ring and eye can be utilized to obtain a clear cutting path. This should be followed by the IOP measurement step to rule out inadvertent loss of suction pressure when lifting the globe.

Deep orbits may represent a challenge as some keratome heads may not fit and may be stopped by the eyelid speculum. We believe that the risks and discomfort associated with more invasive techniques such as retrobulbar saline injections and lateral canthotomies may not be justified given the elective nature of the procedure.

Poor or loss of suction can be prevented through measures discussed previously.

### **Dislodged Flap**

A dislodged flap (Fig. 15.2) is an emergency. It should be repositioned as soon as possible to prevent infection, fixed folds and epithelial ingrowth.<sup>8</sup> This displacement can occur as late as many months after the procedure. The incidence of perioperative flap dislocation has been reported to vary between 1.1 percent and 2.0 percent in recent LASIK literature reports. The relative high rate of dislodged flaps after LASIK in earlier publications has prompted many investigators to refine their techniques of flap repositioning with resultant positive impact on lowering the incidence of this complication.

#### ***Etiology***

LASIK corneal flaps can be lifted for retreatment many years after the primary procedure. This is an indication that complete healing is almost never achieved rendering the flap vulnerable to traumatic displacement. This is consistent with histological studies showing minimal healing at the stromal interface after LASIK. Ultrastructural studies using scanning and transmission electron microscopy of a corneal button recovered 6 months after LASIK showed no detectable wound repair at the stromal interface.<sup>9</sup>

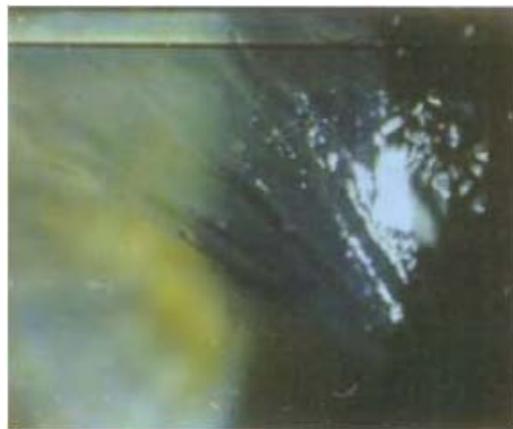
Mechanical movement by lid action can result in flap displacement in the early period especially if the ocular surface is dry. Larger diameter and thinner flaps are more prone to be displaced especially if the hinge is small. Trauma events such as air bag injury, finger to eye trauma, vitrectomy surgery and removing a contact lens have all been reported to cause LASIK flap dislocation.

#### ***Management***

The flap should first be reflected and the interface (stromal bed and stromal aspect of the flap) carefully examined for epithelial cells or other debris. They should be aggressively scraped prior to repositioning the flap. A contact lens can be applied to provide added protection from further displacement and to protect the flap from eyelid movement. Techniques described below to flatten any associated folds should be used. This is important to prevent epithelial cell migration from the healing periphery towards the flap interface under the tented folds.

#### ***Prevention***

Prevention of dislodged flaps rests mainly on using protective measures such as the superiorly-hinged flaps which were designed to circumvent upper flap



**Figure 15.2.** Dislocation of a corneal flap 3-weeks post-LASIK secondary to trauma by finger to the eye (Courtesy of Nada S. Jabbur MD)

edge displacement through blinking. It is not clear yet whether they have achieved their intended purpose. Other preventive steps include applying a contact lens after the procedure, lid taping and encouraging eyelid closure in the first few hours following surgery. We advise our patients not to apply eyedrops soon after surgery to avoid any early mechanical disturbances.

Wearing a protective shield when sleeping for 1–3 weeks after the procedure can also minimize traumatic displacement through unintentional rubbing or mechanical pressure on the eyelids. Patients involved in contact sports and similar activities should be thoroughly counseled about the added risk of late flap displacement with LASIK. PRK might be a better alternative, if judged feasible, in these situations.

### **Free Cap**

A free cap results from unintended complete dissection of the corneal flap. Flat corneas ( $K <40D$ ) are more prone to this complication. The cumulative mean incidence from early studies is reported to be about 5 percent. More recent studies report an incidence between 0.01 percent and 1 percent.<sup>1</sup> If the cap cannot be recovered, the epithelium is allowed to grow centrally in a manner similar to that after other “superficial” keratectomy procedures, but this may be associated with a significant hyperopic shift and/or irregular astigmatism.

### ***Etiology***

Often a free cap has also a reduced thickness than intended. In fact, intraoperative factors leading to a free cap are, for the most part, similar to those leading to a thin flap. Other

factors include malposition and maladjustment of the thickness footplate or the “stop” mechanism during assembly of early models of horizontal microkeratomies (e.g. Bausch and Lomb’s ACS keratome).

In certain instances, the microkeratomies can jam preventing microkeratome head reversal to free the cap. This might prompt the surgeon to release the suction thus lifting the instrument with an incarcerated flap resulting in a free cap.

### ***Management***

Pre-placed fiducial corneal marks used for proper orientation and careful attention during retrieval of the cap from the microkeratomies head allow for favorable management of a free cap. If the diameter of the exposed stroma is equal to or larger than the intended optical zone, laser treatment can proceed while conserving the cap in an anti-desiccation chamber. It can then be repositioned using the preplaced marks to allow proper orientation. A bandage contact lens is helpful to tamponade the cap and protect it from displacement by palpebral friction. Suturing is rarely necessary.

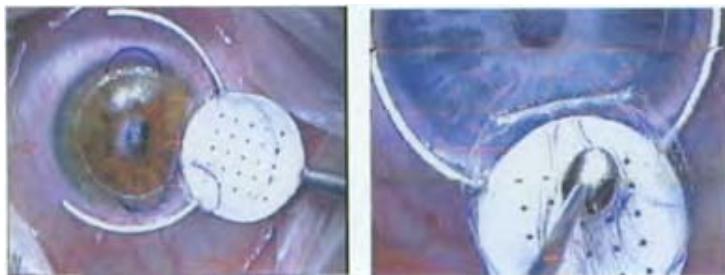
If the cap cannot be retrieved, attempts at fashioning a lamellar flap from a donor cap should not be attempted as a primary procedure. The corneal epithelium is allowed to heal as in PRK with possibly a more profound central appplanation effect. The excimer laser treatment should be aborted and retreatment deferred until refractive stability is achieved.

### ***Prevention***

The same measures described to prevent thin and small flaps also will help avoid this complication. We believe that pre-surgical fiducial marking may facilitate proper flap orientation during cap repositioning and avoid induced irregular astigmatism.

### **Flap Folds**

Flap folds can induce irregular astigmatism with optical aberrations and loss of BCVA especially if they involve the visual axis. ‘**Macrofolds**’ are easily seen by slitlamp exam and represent full thickness flap tenting in a linear fashion. On the other hand, ‘**microfolds**’ within the flap itself may represent wrinkles in Bowman’s layer or in the epithelial basement membrane. They are easily visualized as negative staining lines with sodium fluorescein. While confocal microscopy reveals microfolds at the Bowman’s layer in 97 percent of cases, the incidence of folds requiring intervention ranges between 0.2 percent and 1.5 percent.<sup>1</sup> It is not clear why some



**Figure 15.3.** The Melki LASIK flap Stabilizer allows suction-immobilization of the flap for fold ironing, epithelial ingrowth scraping or laser treatment to the flap underside, (a) The flap is flattened on the suction platform and laser enhancement or PTK treatment for residual epithelial ingrowth is then performed. (b) Similarly, instruments such as the Pineda flap iron can be used to flatten flap folds by applying pressure to both sides of the flap

folds may adversely affect vision while others with similar appearance may be asymptomatic.

### *Etiology*

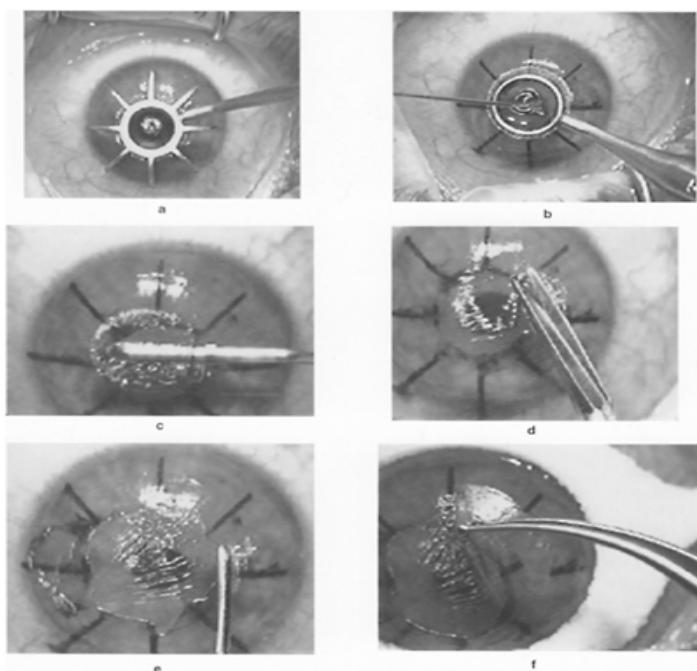
Flap folds result from uneven alignment of the flap edge and the peripheral epithelial ring. Thinner and larger flaps tend to shift more readily with resultant surface wrinkling. Uneven sponge smoothing can result in radial (with centrifugal movement) or circumferential folds (with centripetal movement). A higher incidence of flap folds is usually found in higher myopes and hyperopes and is sometimes unavoidable. This is due to the altered central convexity and stromal support resulting in flap redundancy that may be quite difficult to flatten.

### *Management*

The management of flap folds ranges from stroking the flap with a moist microsponge at the slit-lamp to simple lifting and refloating of the flap and to placement of sutures to stretch a recalcitrant flap in position. It is likely that the earlier a flap is attended to, the higher the chances of quick resolution. Fixed folds probably occur when epithelial hyperplasia has time to form in the crevices formed by the folds. Flattening should aim

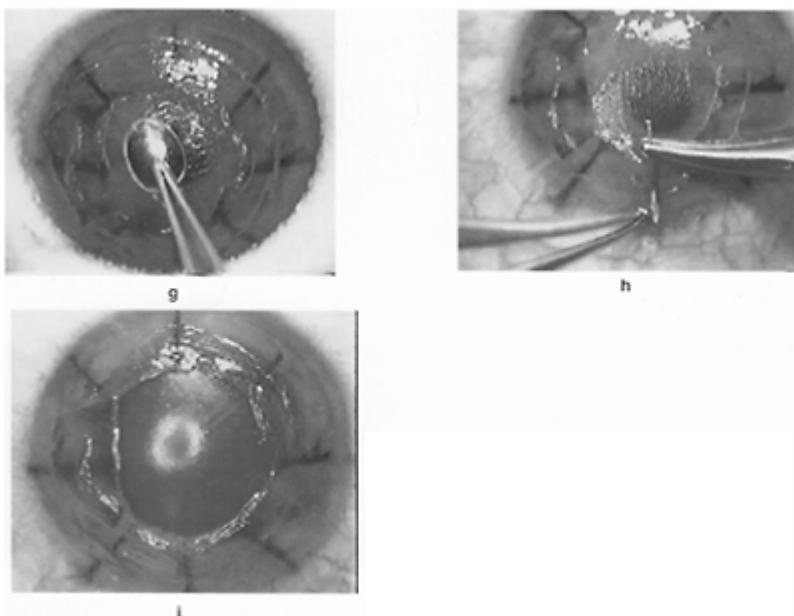
towards an even distribution of forces applied to the flap. This can be performed with methylcellulose sponges or their equivalent. Instruments such as the Pineda LASIK Flap Iron (Asico, Westmont IL) can also be used to flatten isolated flaps at the slit lamp or under the operating microscope by gently pressing on them. Ironing the underside of the flap using a hard surface for support may also be helpful. The Melki Flap Stabilizer (Rhein Medical, tampa, FL) may be used for that purpose (Fig. 15.3). It allows flattening of the flap using a suction platform connected to the microkeratomes vacuum pump.

Recalcitrant folds may respond well to placement of interrupted or running antitorque sutures at the flap edge. However, this may result in significant astigmatism and should be performed meticulously. Additional strategies involve debridement of the epithelium over the wrinkled area or removing it as sheet as performed with LASEK (Fig. 15.4). This may relieve contractures that occur secondary to epithelial hyperplasia in longer standing folds. Probst et al described a technique using the red reflex as a way to better detect mild irregularities.<sup>10</sup> Other reported strategies include hydrating the flap with hypotonic saline (60–80%) or deionized water which may facilitate flattening. In extreme cases, removal of the corneal cap may be the most successful course of action. We have noted few instances where mere flap ironing will result in refractive error shift of at least one diopter.



**Figures 15.4a to f.** Combined sutures and LASEK technique to repair LASIK recalcitrant flap folds, (a) The cornea is marked for possible radial

suture placement, (b) 20 percent ethyl alcohol is applied for 30 seconds within a 5 mm well. (c) The epithelium is dissected with a LASIK cannula. (d) Vannas scissors are used to cut the epithelial flap. (e) Severe flap folds more apparent after epithelial flap lifting. (f) The LASIK flap is lifted



**Figures 15.4g to i.** Combined sutures and LASEK technique to repair LASIK recalcitrant flap folds. (g) Flattening of flap folds with a Pineda iron. (h) Placement of radial interrupted 10-0 nylon sutures. (i) Resolution of all folds. The sutures are progressively removed 2–3 weeks after the procedure.

#### *Prevention*

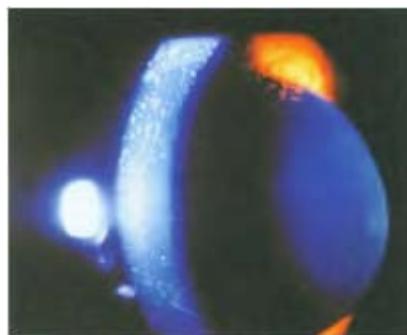
Pre-placed surgical landmarks straddling the flap edge permit accurate repositioning of the flap in the immediate operative and postoperative period. Examination at the slit lamp 20 minutes after the procedure is useful to ensure adequate flap positioning. Care should be taken to ensure even distribution of the gap ('gutter') between the flap edge and the peripheral epithelial ring. This is noted after the procedure and usually disappears by the first postoperative day. This gap is probably due to biomechanical retraction of the collagen lamellae or to flap dehydration and subsequent retraction. The dehydration

effect alone may not explain the gutter formation as the gutter can be seen immediately after the cut where dehydration may not have yet occurred. Contraction of intercellular adhesion complexes secondary to mechanical trauma might also contribute to the retraction of the flap. There has been no histologic confirmation of these theories.

Placing a wet microsponge on the stromal aspect of the flap during long ablations might minimize the dehydration effect. However, this may introduce fibrils and debris in the interface. We currently favor spreading 1–2 drops of fluid on the stromal aspect of the reflected flap after lifting. Other surgeons prefer folding the flap while performing the laser ablation.

### Epithelial Implantation and Ingrowth

Implantation of epithelial cells in the interface occurs either due to seeding during surgery or migration under the flap (Fig. 15.5). Connection to the outside epithelium might be conspicuous or undetectable at the slit lamp. Most isolated nests of cells will disappear without consequences. More concerning is epithelial ingrowth that is contiguous with the flap edge. This can progress to involve the visual axis with irregular astigmatism and possible overlying flap melting. The epithelial cells at the



**Figure 15.5.** Epithelial ingrowth under the LASIK flap

interface may block aqueous diffusion which may compromise the nutrition of the flap and result in corneal melting. The migrating epithelial cells may also produce proteolytic enzymes that may further contribute to stromal melting of the flap. Epithelial growth at the interface may be more common after enhancement procedures as the lifting of the flap can induce adjacent epithelial abrasions with increased cell proliferation.

### Etiology

Helena<sup>11</sup> described four mechanisms by which epithelial cells could reach the lamellar interface. These include: Mechanical dragging by the keratome blade during keratectomy backflow during irrigation carrying floating epithelial cells, outgrowth from epithelial plugs in eyes with previous incisional keratotomy and ingrowth at the junction of the

epithelium and keratotomy. The latter is believed to be the most frequent cause of epithelial ingrowth.

*Other mechanisms include:*

- Implantation of epithelial cells when the interface is manipulated with instruments that touch the surrounding epithelium.
- Cell migration under a fold extending to the flap edge. This is more likely to occur if an epithelial defect is induced at the edge of the flap during the procedure leading to greater mitotic activity.
- Buttonholed flaps are also vulnerable to epithelial infiltration at the edges of the perforation.

Wang et al<sup>12</sup> reported an incidence of 0.92 percent in a cohort of 3,786 eyes that underwent primary LASIK. The incidence after enhancement was 1.7 percent (480 eyes). The authors hypothesize that epithelial ingrowth is secondary to postoperative invasion under the flap by surface epithelial cells rather than intraoperative implantation of epithelial cells.

### ***Management***

Epithelial cells under the LASIK flap should be managed aggressively if they progress towards the visual axis or induce stromal melting. The flap is lifted, the stromal bed and the flap undersurface are thoroughly irrigated and scraped, and the flap is repositioned. Epithelial cells debridement can be achieved mechanically with a #15 Bard-Parker blade or with dedicated instruments such as the Yaghouti LASIK Polisher (Asico, Westmont IL), or by using excimer laser bursts in Phototherapeutic Keratectomy (PTK) mode. The latter epithelial removal techniques should also be applied to the underside of the flap. The Melki LASIK flap stabilizer (Rhein medical, Tampa EL) can be used to provide a platform for easier scraping or for PTK application to the underside of the flap (Fig.15.3). Non-progressive isolated epithelial cells should be monitored. Hyperopic shift is an early indicator of possible underlying stromal melt. This may result in irregular astigmatism and loss of BCVA.

### ***Prevention***

Close inspection for epithelial ingrowth is essential for patients with surgically-induced epithelial defects, especially when adjacent to the flap edge. Considering PRK rather than LASIK in patients with a history of poorly adherent epithelium (e.g. history of recurrent erosions) may help reduce epithelial defect formation. Other preventive measures include dedicating instruments for interface manipulation that do not come in contact with the surrounding epithelium. Similarly, meticulous attention to avoid flap folds especially those extending towards the periphery providing a conduit for cell infiltration. In our experience, the introduction of epithelial cells in the interface during LASIK enhancement may be significantly minimized by lifting the flap edge with a dedicated forceps rather than extensive edge dissection around the flap circumference. Alternatively, the gutter can be dissected with a Sinskey hook prior to separating the stromal lamellae. This may prevent large epithelial tears.

## Interface Debris

Interface debris should be distinguished from inflammatory or infectious reactions. This distinction may be difficult at times. An in-vivo confocal microscopy study revealed corneal flap interface debris in 100 percent of 62 eyes who had undergone myopic LASIK. As a rule, debris are usually inert with no progression or deleterious effects on vision unless present in large quantities. Nevertheless, it must be kept in mind that some patients might be more susceptible than others and may present with an inflammatory response to a variety of debris.

### *Etiology*

Several possible sources of debris have been identified at the LASIK flap interface. These include metallic fragments from blade shattering during the dissection, oil material from the microkeratomes, meibomian glands secretions, powder from gloves, air bubbles, central interface opacification of unknown etiology and lint fibers. Lint fibers settle on the stromal bed prior to flap repositioning. They can be released from clothes, eye patches used to cover the unoperated eye and gauze close to the operative field.

### *Management*

If an inflammatory reaction is suspected secondary to interface debris, the flap should be lifted and copious irrigation applied. We examine all of our patients 20 minutes after the procedure and proceed to early flap lifting and irrigation if debris or fibers are noted.

### *Prevention*

Lint fibers may be minimized by the use of scrub suits by the surgical team and having the patient wear a scrub-like cover to their clothes to minimize floating fibers in the atmosphere. Moistening any gauze material in the surgical field will also achieve a similar result. Other measures include using powder-free gloves, draping the lashes, and applying a fibrocellulose ring (LASIK Eye Drain [Chayet], Visitec, FL) around the limbus to provide a barrier from surrounding ocular secretions. Oblique illumination under the operating microscope can reveal very small fibrils and other debris in the interface after flap repositioning, which can be removed with generous interface irrigation.

## Epithelial Defects

On postoperative day #1, dilute sodium fluorescein is applied to detect epithelial defects that might have occurred during or after the procedure. Many patients will demonstrate mild staining at the edge of the flap. Larger defects are more worrisome, especially those with a connection to the flap edge. The incidence of epithelial defects with LASIK was reported to vary between 5 percent and 9.7 percent. As mentioned above, the proliferating epithelial cells might migrate under the flap edge. Associated inflammation can also lead to melting of the surrounding flap tissue. Furthermore, there is an increased risk of diffuse lamellar keratitis in patients with epithelial defects.

### ***Etiology***

Epithelial defects occur when the shearing forces from the microkeratomes pass overcome the adhesive forces between the epithelium and its basement membrane. Patients with a history of recurrent erosions and/or anterior basement membrane dystrophy (ABMD) are at higher risk of developing epithelial abrasions especially with LASIK and would probably be better PRK candidates. In fact, surface excimer laser ablation is used to treat patients with recurrent erosion syndrome. Tekwani et al<sup>13</sup> have also reported an increase in iatrogenic epithelial defects with older patients, thicker preoperative corneal thickness, maintenance of suction ring during the reverse pass and preoperative topical proparacaine use. We do not recommend releasing suction ring on the reverse pass as it can result in transection of the flap due to unexpected patient head movement.

### ***Management***

If an epithelial defect is noted intraoperatively, a higher index of suspicion for epithelial ingrowth should be maintained. An attempt at repositioning the loose epithelium should be performed. Alternatively, the epithelium can be gently debrided and a contact lens applied. These measures help in pain control as well as improving flap adherence and preventing epithelial cell infiltration. Topical non-steroidal anti-inflammatory drugs (NSAIDs) may also be useful to ease the associated discomfort but may be associated with the induction of sterile infiltrates.

### ***Prevention***

Candidates for LASIK surgery should be questioned for prior history or symptoms of recurrent erosion syndrome. Slit lamp examination should include careful inspection of the epithelial surface for signs of ABMD. Even when the corneal surface appears clear, negative or asymmetric fluorescein staining should alert the observer to an abnormality in corneal surface integrity. Some investigators recommend touching the corneal epithelium at the slitlamp with a microsponge applicator in patients with suspected loose epithelium. If movable epithelium is noted, PRK may be a more appropriate procedure. Minimizing the use of preoperative proparacaine and delaying it till immediately prior to the procedure may also decrease the incidence of epithelial defects. In patients undergoing bilateral LASIK procedures the second eye procedure should be postponed if the first eye develops a significant epithelial defect. PRK may be considered for the fellow eye.

### ***Corneal Perforation***

This devastating complication occurs mainly as a result of faulty microkeratomes assembly. A handful of studies in the literature report cases of anterior chamber penetration during lamellar dissection or through laser ablation. The original ACS microkeratomes (Bausch & Lomb Surgical, Rochester NY) keratome models require the placement of a thickness footplate to determine the depth of dissection. If left out, a full thickness corneal incision with serious damage to anterior segment structures could ensue. This should be managed as any traumatic ruptured globe situation. Meticulous

adherence to the instructions of keratome assembly cannot be emphasized enough to prevent this catastrophic event. In one published case, a thin preexisting keratoconic cornea was suspected as the etiology for the full thickness laser ablation.

### Corneal Ectasia

Corneal ectasia is one of the most feared and insidious long-term complication of refractive surgery, as it induces a keratoconus-like condition with all its attendant complications. Only a relatively small number of cases have been reported in the literature to date. The true incidence of this iatrogenic complication might not emerge till longer-term follow-up studies are conducted.

The safe limit of residual stromal bed thickness after refractive surgery remains subject to speculation. The current consensus is a minimum of 250  $\mu\text{m}$ , while Barraquer has recommended a minimal thickness of 300  $\mu\text{m}$  of stress-bearing corneal stroma. However, in a recent study it has been shown that a residual stromal bed thickness of 250 microns does not preclude the development of keratectasia after LASIK.<sup>14</sup> Other features that may predispose patients to ectasia after LASIK include forme fruste keratoconus, preoperative corneal thickness less than 500  $\mu\text{m}$  and a high refractive error. Geggel showed no underlying inflammation in an excised ectatic corneal button after LASIK suggesting biomechanical corneal weakening as the cause of the ectasia.<sup>15</sup> A combination of clinical and topographic criteria is currently used at the Massachusetts Eye and Ear Infirmary, which serves as the basis for diagnosing keratoconus and keratoconus suspects (Fig. 15.6).

Calculations should be made prior to surgery to determine if a safe corneal bed thickness can be achieved. It must be stressed that there can be considerable variation in the actual flap thickness compared to the expected one (based on microkeratomates manufacturer's specifications). In high refractive error cases, pachymetry should be performed on the stromal bed after lifting the flap. By factoring the amount of tissue removed by the laser, a more accurate assessment of residual bed thickness can be made. This can guide the surgeon later if enhancement is necessary. Establishing a registry of corneal ectasia cases could help collect much needed information on this concerning aspect of LASIK and prevent a late discovery of a potentially disastrous long-term outcome of the procedure.

Suspicion should arise when a patient develops unstable vision in association with regression of corrected refractive error and irregular astigmatism. Ectasia can also masquerade as a videokeratographic central island. More typically, progressive inferior steepening on topography confirms the diagnosis. Orbscan technology (Orbtek Inc., Salt Lake City, UT) can image posterior corneal curvature and total corneal pachymetry which may also be useful in following these patients after LASIK. Slitlamp findings similar to those found in keratoconus patients can also be seen.

Management of patients with progressive ectasia after LASIK is similar to patients with native corneal disorders. Conservative management with hard contact lenses is usually followed by penetrating keratoplasty. Recent attempts at stabilizing the ectasia with intracorneal ring placement have been met with encouraging success.

## MEEI Keratoconus Classification

Name \_\_\_\_\_

Patient ID # \_\_\_\_\_

		Score	Score			
Kod-Kos	≤1.9	0		0	≤1.9	Kos-Kod
	>1.9	1		1	>1.9	
Kod	<47.2	0		0	<47.2	Kod
	47.2-48.7	1		1	47.2-48.7	
	>48.7	2		2	>48.7	
ISod	<1.4	0		0	<1.4	ISod
	1.4-1.9	1		1	1.4-1.9	
	>1.9	2		2	>1.9	
≥2 Findings on hx (atopy, down), FH and exam (Fleisher, Vogt, Munson, nerves, scarring)	No	0		0	No	≥2 Findings on hx hx (atopy, down), FH and exam (Fleisher, Vogt, Munson, nerves, scarring)
	Yes	2		2	Yes	
Corneal Hydrops (by exam or hx) OD	No	0		0	No	Corneal hydrops (by exam or hx) OS
	Yes	2		2	Yes	
		Total score	OD	OS	Total score	

SCORE	DIAGNOSIS
(Zero)	Normal
(1-3)	Suspect
(4-5)	Early KC
(6-9)	Advanced KC

Diagnosis: \_\_\_\_\_ OD      Diagnosis: \_\_\_\_\_ OS

**Figure 15.6.** The Massachusetts Eye and Ear Infirmary KC classification

## REFRACTIVE COMPLICATIONS

### Central Islands

Patients with topographic central islands often report visual fluctuations, ghost images and monocular diplopia. Both, uncorrected and bestcorrected vision may be affected. Wilson suspected that the incidence of central islands after LASIK is higher than that after PRK but no data has been reported. Laser manufacturers have modified their software to allow additional central pulses, which appears to have minimized the incidence of this complication. Other factors such as pattern of laser ablation and surgical technique may also influence the development of central islands.

### ***Etiology***

No consensus exists about the true etiology of central islands after PRK or LASIK. They are thought to result from shielding of the central stroma by pulverized tissue plume or central collection of fluid as the ablation is performed. Degradation of the laser optics has also been implicated in causing central islands.

### ***Management***

Central islands in LASIK have less of a tendency to spontaneously resolve than in PRK. This is probably due to minimal epithelial remodeling after LASIK. Central island treatment is usually based on the last topography performed as described by Rachid et al.<sup>16</sup> Manche et al<sup>17</sup> also described a technique to treat central islands after refractive surgery but cautioned against associated hyperopic shifts. Successful treatment protocols after PRK may not apply to LASIK patients.

Custom-ablations solely based on videokeratography data might erroneously treat areas of overlying epithelial hyperplasia over areas of stromal depression not achieving the intended stromal smoothness. In recalcitrant cases, hard contact lenses may be the only currently-available means of regaining lost visual acuity and relieving visual aberrations.

### ***Prevention***

Some laser companies developed anti-island software for additional central ablation. There is growing evidence of minimal occurrence of this complication with scanning-slit beam and flying spot lasers. Some surgeons believe that corneal fluid collects on the surface of the central stroma and suggest wiping the bed surface with a sponge or spatula every 40 to 50 laser bursts. Others only dry the surface when moisture is visible. To date, there are no studies to evaluate the benefit of these techniques.

### ***Decentration***

Corneal surgical procedures should always be centered over the pupil. Astigmatism due to decentration of the ablation is probably the most difficult problem to correct. Although patient fixation might be more difficult under a dissected flap, Pallikaris et al<sup>18</sup> reported similar centration between their LASIK and PRK groups. Decentration results in an uneven ablation area with the flatter treatment zone shifted peripherally, leaving the central area of the ablation zone with a higher corneal surface power difference. Consequently, the area of greatest flattening of tangential curvature is shifted away from the center of the ablation zone, resulting in uneven and undercorrected corneal surface over the pupillary axis. Decentration that involves laser application to the stromal side of the flap results in significant asymmetric flattening. This is translated into irregular astigmatism causing glare, monocular diplopia and halos. Decentration is best measured with tangential topography. Decentration not exceeding 0.3 mm is rarely visually significant.

### ***Etiology***

Decentration of excimer laser ablation may occur secondary to either treatment displacement (shift) or intraoperative drift. Shift refers to a decentered treatment throughout the ablation. This can occur due to poor fixation or surgeon's error. Drift occurs when the eye moves involuntarily during treatment or when the surgeon attempts to correct apparent decentration during treatment. Azar and Yeh<sup>19</sup> have shown that the visual outcomes of patients with treatment displacement were better than those with intraoperative drift.

### ***Management***

Theoretically, the flap can be lifted, and the patient retreated with decentration of the treatment in the opposite direction to the previous ablation, using a wide optical zone. This is easier performed with decentered PRK after transepithelial PTK using the epithelium as a masking agent over the already ablated area. Such a technique yields quite satisfactory results. It is not clear whether other masking agents at the LASIK interface would be as effective. Currently developed modalities such as wavefront or topography-guided ablations may yield more accurate results.

Miotics can be tried to constrict the pupillary axis to the central smooth ablation and minimize optical aberrations. This might be more useful if both the decentration and the pupil shift with pharmacological miosis are superonasal. A hard contact lens can alleviate the symptoms by neutralizing optical aberrations resulting from irregular astigmatism.

### ***Prevention***

The risk of decentration can be minimized by performing the ablation under the lowest illumination possible to improve the patient fixation. Meticulous attention should be directed towards adequate centration from the onset of ablation. Recentration should be avoided when possible, in view of the drift effect on visual outcome. When recentration is attempted early in the procedure, the drift effect might not be as significant as compared to that in the late stages of the ablation. Continuous verbal encouragement can help patients maintain fixation especially during deep ablations.

Lasers with a pupillary-tracking ability are designed to prevent decentered ablations (drift). The effects of the microsaccades of the eye may be abolished, in principle, with these lasers. Miotics or high illumination are preferably avoided. They can shift the pupil superonasally resulting in decentered ablations that are only apparent after surgery.

### ***Over and Under-Correction***

Variations in corneal healing, atmospheric pressure, humidity and ambient temperature are among the many factors that contribute to the relative unpredictability of refractive surgical procedures. Some patients develop unintentional refractive over- or under-corrections following LASIK, often affecting uncorrected visual acuity (UCVA). Myopic patients with a hyperopic result can suffer from quite unsatisfactory UCVA both at near and distance especially if they belong to the presbyopic age group.

### ***Etiology***

Surgical procedures based on an inaccurate refractions could result in significant residual or induced postoperative refractive errors. This includes erroneous refraction, relying on non-cycloplegic refraction in an accommodating patient and wrong information input into the laser secondary to human error.

Failing to reexamine a contact lens wearer until a stable and reproducible refraction is obtained may result in unexpected refractive outcomes. In the case of rigid or gas permeable contact lens, it can take 5 weeks to achieve preoperative refractive stability.

Plano-cylindrical corrections have been associated with a higher incidence of over-correction with certain lasers. This is probably due to the fact that flattening of the intended steep meridian is accompanied by the unintentional flattening of the flat meridian (but to a lesser degree).

### ***Management***

Over- or under-correction can be corrected by lifting the flap (even months after the surgery) and applying additional laser ablation. Multiple procedures have been developed to correct hyperopia, whether induced or native. The FDA-approved treatments in the USA at the time of this publication are hyperopic PRK, laser thermokeratoplasty (LTK) and conductive keratoplasty (CK). The latter two are only approved for the temporary reduction of low levels of hyperopia. As mentioned above, a high level of suspicion for keratectasia disguised as “myopic regression” is vital especially in patients with higher levels of initial corneal ablation.

### ***Prevention***

Accurate preoperative manifest and cycloplegic refractions are essential for reliable assessment of the patient’s refractive error. Re-examination of patients with fluctuating or unstable refractions prior to performing primary or secondary treatments may help avoid unexpected outcomes. We advocate a conservative approach in treating planocylindrical errors, erring on the side of undercorrection.

### ***Residual/ Induced Astigmatism***

Correction of preoperative astigmatism can result in incomplete resolution, worsening and/or shift in axis. Spherical corrections can also lead to postoperative cylindrical refractive errors.

### ***Etiology***

Inaccurate refraction, contact lens induced corneal warpage can easily lead to unexpected cylindrical residual or induced errors. Similar errors may occur following rotational ocular shift or drift during laser ablation. A 15-degree axis error results in loss of 50 percent of the cylindrical correction, while a 30-degree axis error results in no change of the magnitude of the cylinder (but with a rotation in the axis of astigmatism).

### ***Management***

Depending on the amount of residual refractive error, an enhancement procedure can be contemplated. Some currently available software programs do not allow treatment of piano-cylindrical errors. Maneuvers to bypass the built-in software could lead to unexpected over-correction.

### ***Prevention***

As noted above, meticulous refractions and ensuring refractive stability improve the predictability of refractive outcomes. Marking of the cardinal meridians at the slitlamp prior to the procedure and constant monitoring during the ablation to ensure proper globe orientation may help reduce the effect of ocular rotation.

### ***Regression***

Regression seems to be reported with higher frequency after high myopia correction and after hyperopic LASIK. Often the underlying stromal bed is too thin to permit additional laser ablation. Regression may be differentiated from natural progression of refractive error by analyzing difference maps by corneal topography. Hyperopic treatment has been plagued by regression due to peripheral epithelial hyperplasia counteracting the laser-induced corneal steepness. It must be noted that, in principle, an over-corrected myopic treatment may require less peripheral and hyperopic ablation for a specific desired long-term outcome than primary hyperopic treatments. This is because of the associated amelioration of the steep zone at the junction of the treated and untreated areas.

### ***Etiology***

Postoperative epithelial or subepithelial and stromal hyperplasia leading to postoperative corneal steepening have been implicated in the etiology of postoperative refractive regression. It is not clear yet which layer plays a more prominent role in this postoperative complication. Occasionally, patients whose refractive error is erroneously believed to have reached the plateau stage prior to the surgery will exhibit progressive refractive change even months after the procedure. This is more likely to occur in younger patients.

### ***Management***

It is not clear if regression after LASIK is as amenable to pharmacological manipulation as in PRK. There is no data to confirm the benefits of topical steroids for corneal steepening secondary to the healing response. Additional laser ablation must be guided by careful and conservative calculations of residual stromal bed thickness. The temptation of not disappointing a demanding patient should be tempered by the increased risk of excessive corneal thinning. Sophisticated instruments such as the very high frequency ultrasound might be able to accurately measure residual stromal thickness and better guide the surgeon in his deciding whether or not to perform additional surgery.

### ***Prevention***

Development of surgeon-specific nomograms might allow better tailoring of ablations for higher correction. The variety of factors that influence the outcome (age, corneal hydration, ambient temperature) makes this task relatively imprecise.

### ***Halos and Glare***

Visual aberrations have plagued most refractive procedures sometimes permanently affecting the quality of vision.<sup>20</sup> It is not clear to what extent pupil size plays a role in the pathogenesis of glare and halos. Generally these symptoms abate over time. It is not clear if this is due to resolution of an underlying anatomic irregularity or to patient's adaptation. A small subset of patients report no significant improvement and can be substantially incapacitated under various lighting situations such as night driving.

### ***Etiology***

There is growing evidence that the main reasons for higher order aberrations resulting in glare and halos are subclinical decentration (less than 1.0 mm).<sup>21</sup> Similarly, when pupils dilate to a diameter larger than the optical treatment zone, rays of light refracted by the untreated peripheral cornea are not focused at the same position as the central rays and result in blur circles (negative clearance phenomenon). These symptoms are more pronounced after treatment of cylindrical errors due to the oval shape of laser treatment with inherently smaller optical zone in the steep meridian. In addition, correction of higher refractive errors is associated with increased aberrations possibly due to the larger refractive differential between the ablated and the intact cornea. Irregular astigmatism due to flap folds, topographic abnormalities or simply residual myopia can also result in these symptoms. Other contributing factors include dry eyes and irregular epithelial surface.

### ***Management***

Optical aberrations after refractive surgery may be significantly reduced through enlargement of the ablation zone by means of the currently developed wavefront- or topography guided lasers. Currently, conservative management such as mild miotics are prescribed which can help for night activities especially driving. Leaving the car dome's light on when driving at night has also been reported to improve symptoms through pupillary constriction. Anecdotal evidence suggests a reduction in mesopic pupillary dilation with topical brimonidine (Alphagan, Allergan Irvine CA). Tinted contact lenses with artificial pupils and yellow-tinted eyeglasses might occasionally provide significant relief. Ocular surface lubrication with artificial tears or punctal plugs can occasionally result in dramatic improvement of symptoms related to ocular surface dryness.

Other strategies include prescribing correcting spectacles which can sometimes be the easiest solution to relieve poor night vision if due to residual myopia. Similarly a well-centered hard contact lens will enlarge the optical zone and could be helpful in select situations.

### ***Prevention***

Pupil size can be gauged using a Rosenbaum near card scale or an infrared Colvard infrared pupillometer. Room lights should be dimmed in both situations to replicate mesopic conditions encountered by the patient at night. Patients with pupil diameter of more than 6.0 mm should be informed of the significant risk of night vision disturbances after LASIK. Larger ablation zone diameters have been associated with decreased incidence of night glare. The development of software allowing effective larger ablation diameter with adequate preservation of stromal tissue could help lower the incidence of this problem. Measures discussed above to prevent decentration and central islands may also help diminish the incidence of these symptoms.

Several investigators encourage their patients to look for symptoms of glare, halos and starburst effects at night, prior to surgery. This may help reduce the possibility of attributing pre-existing visual aberrations to the surgical procedure.

### **Loss of Contrast Sensitivity**

Holladay et al<sup>22</sup> showed worsening in functional vision as the target contrast diminishes and the pupil size increases. They concluded that the oblate shape of the cornea following LASIK is the predominant factor in the functional vision decrease. On the other hand, Perez-Santonja<sup>23</sup> reported improvement in contrast sensitivity at certain frequencies 6 months after LASIK in eyes with moderate to high myopia. It is difficult to compare studies measuring contrast sensitivity due to the different methods used. It is unclear to what extent loss of contrast sensitivity overlaps with patients' complaints of other optical disturbances such as glare and halos.

### **Loss of Best Spectacle Corrected Visual Acuity (BSCVA)**

The incidence of loss of 2 or more lines of BCVA after LASIK is reported to be about 4.8 percent. It is more frequent with correction of larger refractive errors and with correction of compound astigmatism compared to spherical corrections. Comparing various studies could prove difficult as some report BCVA while others only measure spectaclecorrected visual acuity. Lin et al reported less than 2 lines of loss of BSCVA which were secondary to flap complications in lamellar surgery but did not mention other types of complications. Davidorf reported higher loss of BSCVA with hyperopic treatment.<sup>24</sup> Most complications described in this chapter could potentially affect BSCVA either temporarily or permanently. Early recognition and heightened levels of suspicion are valuable for the prevention of unnecessary loss of vision in an otherwise healthy eye.

### **Dry Eyes**

A majority of patients experience temporary dry eye symptoms after LASIK. Patients with pre-existing dry eye condition may be affected more severely and permanently.

Patients with dry eyes often seek laser vision correction due to contact lens intolerance. Todo et al<sup>25</sup> showed that 35.2 percent and 41.2 percent of patients undergoing LASIK were diagnosed with definite dry eyes and probable dry eyes respectively preoperatively. Tear function and ocular surface condition determined by

results of the Schirmer test, tear BUT, rose bengal and fluorescein stainings may be useful tests to detect preoperative dry eye condition. A recent study reported thirty-five (42.2%) of 83 eyes displayed a distinctive brown-colored corneal iron line of variable density in a ring or patch configuration near the margin of the ablated zone in the overlying corneal flap epithelium after LASIK. The appearance of this iron line correlated positively with time after surgery (>3 months) and preoperative spherical equivalent (>-4.5 diopters).<sup>26</sup> This probably reflects an alteration in the surface tear dynamics due to the central corneal flattening. Similarly, an iron ring is usually noted after hyperopic excimer ablation.

### ***Etiology***

The dry eye condition after LASIK may be due to decreased corneal sensation resulting from severing of corneal nerves with subsequent decreased blinking rate. Wilson et al<sup>27</sup> have suggested the term LASIK induced neurotrophic epitheliopathy for superficial punctate keratopathy and rose bengal staining of the cornea after LASIK. Kim and Kim<sup>28</sup> have reported that the greater the ablation of the stroma, the greater the reduction in the corneal sensitivity. Another theory implicates suction ring damage to the keratolimbal area with subsequent damage to goblet cells.

### ***Management***

Most patients will notice an improvement in their symptoms few weeks after the procedure. Meanwhile, surface lubrication will dampen the sensation of ocular irritation. A recent report showed better results with carmellose-based artificial tears as compared to balanced salt solution. Temporary collagen plugs or longer lasting silicone lacrimal punctal plugs are also valuable to provide symptomatic relief in the postoperative period after LASIK.

### ***Prevention***

Prophylactic placement of temporary lacrimal punctal plugs at the end of the procedure has been used by some surgeons to enhance the tear lake in the early postoperative period. A slow taper of the postoperative topical steroids may also provide relief from dry eye symptoms in the early postoperative period.

## **INFECTIOUS KERATITIS AND STERILE INFILTRATES**

Infectious keratitis after LASIK is considered to be uncommon. Infections can be from bacteria, fungi and non-tuberous mycobacterium. Most of these organism are generally uncommon, slow growing and opportunistic. Early diagnosis and treatment is very important as any delay can have disastrous consequences. Bilateral corneal infections and cases of endophthalmitis have been reported. The incidence of bacterial keratitis after LASIK is reported to be 0.1 percent by Lin et al.<sup>29</sup> The low rate of infection may have encouraged some surgeons to abandon sterile techniques while performing the procedure.

It is not known whether this has resulted in a higher rate of infection. Nevertheless, this approach is inherently risky from the medical and legal standpoints.

Similarly, cases of fungal infection from cultures taken from post-LASIK eyes have been reported. Occasionally, sterile infiltrates may be seen at the edge of the flap. Blepharitis with or without Rosacea, dry eyes, the use of topical NSAIDs and undiagnosed connective tissue diseases may predispose to the formation of such infiltrates. These cannot be reliably differentiated solely by their appearance from infectious infiltrates; a high level of suspicion should be maintained.

### ***Etiology***

Sources of contamination include the ocular flora, any instruments or sponges used to manipulate the eye, the surgeon's hands or *air-borne*. *Mycobacterium szulgai*, a non-tuberculous mycobacterium, was isolated from the ice used to chill syringes for saline lavage in a cluster of 5 patients occurring at a laser center.

A recent report by Jarade et al<sup>30</sup> showed performing LASIK in 3 eyes with inactive herpes keratitis under prophylactic use of oral antivirals with no virus reactivation in a six-month follow-up. However, there is current consensus among refractive surgeons on the absolute contraindication of performing LASIK in eyes with herpes simplex virus, due to the risk of virus reactivation.

### ***Management***

Treatment should be initiated promptly after corneal cultures are obtained whenever possible. Cultures should be obtained for bacterial, fungal and mycobacterium.

Unique features to post-LASIK infectious keratitis include the possibility of lifting the flap and culturing/irrigating the interface if deemed useful. In addition, the flap can be disinserted and excised in extreme cases of a non-responsive infections leading to severe flap melting or even penetrating keratoplasty

### ***Prevention***

- Treatment of blepharitis preoperatively.
- Maintain strict sterility of the instruments.
- Using one microkeratomes blade per eye in cases of simultaneous bilateral LASIK.
- Use fresh sterile distilled water for cleaning instruments.
- Use prophylactic antibiotics postoperatively

### ***Diffuse Lamellar Keratitis***

This is a recently described syndrome characterized by proliferation of presumably inflammatory cells at the LASIK interface (Fig. 15.7). It occurs in approximately 0.2–3.2 percent of cases and can lead to stromal corneal melting with induced hyperopia or hyperopic astigmatism. Additional symptoms include loss of BCVA with optical aberrations secondary to irregular astigmatism.



**Figure 15.7.** Diffuse lamellar keratitis

In their initial report about DLK, Smith and Maloney<sup>31</sup> noted several characteristics defining the infiltrate associated with this new syndrome. Since then, others and we have noted major differences as compared to the criteria described by Smith et al. (in *italics* thereafter). Our patients include cases where the patients presented with DLK as early as the first postoperative day (*day 2*), asymptomatic (*pain/photophobia*), extending beyond the interface (*confined to the interface*), localized (*diffuse and scattered*), more prevalent with epithelial defects (*no overlying epithelial defect*), and associated with an inflamed conjunctiva (*no ciliary flush*). It has been anecdotally reported to happen sporadically or in clusters with primary procedures or in cases of LASIK enhancement. It is still unclear if it is an infectious or an inflammatory process. No single agent has been demonstrated to be responsible for this relatively rare but potentially serious complication.

*Burkholderia pickettii* was isolated from the sterilizer reservoir in a cluster of cases a reported by Holland et al.<sup>32</sup> The live bacteria were killed by the sterilization process, however the cellular particles of the gram-negative bacterial cell wall, acting as an antigenic endotoxin are potentially responsible for initiating a severe neutrophilic reaction. These lipopolysaccharide subunits and possibly peptidoglycans from gram-positive bacteria could accumulate on the surgical instruments during sterilization and be deposited under the corneal flap at the time of LASIK surgery. Biofilm treated sterilizing reservoirs reduced the incidence of this type of cluster outbreak.

Irrespective of the etiology, when polymorphonuclear (PMN) leukocytes migrate to the stromal interface of the LASIK incision they release destructive collagenases. This may lead to central stromal melting and scarring. Management consists of intensive topical corticosteroid eyedrops and close observation for any signs of central stromal melting. The latter could be detected by a hyperopic shift on refraction or flattening on corneal topography. Our current protocol involves flap lift, scraping and irrigation by the fourth postoperative day at the latest if the inflammation is judged to progress despite hourly topical prednisolone acetate 1 percent with broad-spectrum topical antibiotics coverage. On occasion, oral corticosteroids are also indicated to quell the inflammation. Any signs of stromal melting should prompt earlier surgical intervention. We have used intensive peri-operative topical steroids when retreating at least 5 patients after an episode of diffuse lamellar keratitis (DLK) with no recurrence (unpublished

observations). Peters et al propose using topical intrastromal steroid during LASIK to reduce the incidence and severity of DKL.<sup>33</sup>

Linebarger et al<sup>34</sup> have divided the stages and treatment modalities as shown in Table 15.1.

## INTERFACE FLUID AND GLAUCOMA

Interface fluid and its association with glaucoma has been recently recognized as a potentially blinding complication after LASIK.<sup>35</sup> The lamellar space may accumulate fluid as the underlying cornea deturgesces in response to increased intraocular pressure. Pressure elevation is usually due to topical steroid use to treat inflammatory conditions such as diffuse lamellar keratitis. The lamellar fluid may masquerade as chronic DKL leading the surgeon to increase the steroid treatment with further elevation in intraocular pressure. The latter may go undetected if tonometry is performed over the central cornea resulting in significant loss of visual field function. Tonopen (Medtronic Solan) measurements at the edges of the cornea may be more accurate reflection of the true intraocular pressure. Once recognized, management involves appropriate intraocular pressure reduction medications along with a taper of the steroids.

### Vitreoretinal Complications

A large study of 29,916 eyes that have undergone LASIK by Arevalo<sup>36</sup> showed a low incidence of vitreoretinal pathology (0.06%) confirming earlier reports of infrequent serious retinal complications.

**Table 15.1: Stages and treatment of diffuse lamellar keratitis**

<i>Time</i>	<i>Incidence</i>	<i>Clinical presentation and outcome</i>	<i>Treatment</i>
Stage 1	Day 1	1 in 25 to 50 cases	Fine, white, granular cells in the periphery. No decrease in BCVA, Self-limiting.
			Prednisone acetate 1% every 1 hr. Topical flouroquinolone TID. Follow-up 24–48 hrs.
Stage 2	Day 2 or 3 Occasionally Day 1	1 in 200 cases	Fine, white, granular cells migrate from periphery to the center. Some cells still in periphery. Involves central visual axis, Shifting Sands. No decrease in BCVA.
			Prednisone acetate 1% every 1 hr. Topical flouroquinolone TID. Follow-up 24–48 hrs.
Stage 3	Day 2 or 3	1 in 500 cases	Increased density of clumped inflammatory cells in the center. Involves central visual axis, Subjective haze felt by the patient.
			Prednisone acetate 1% every 1 hr. Topical flouroquinolone TID.

			to 2 lines decrease in BCVA. Threshold DLK	Lift flap, irrigate bed and flap with BSS. Wipe gently with moistened sponge. Follow-up in 24–48 hrs.
Stage 4	Follows stage 3	1 in 5000 cases	Increased collagenase activity. Fluid collection, bullae formation. Stromal melting Corneal scarring BCVA decreased Irregular astigmatism Hyperopic shift	Prednisone acetate 1% every 1 hr Topical flouroquinolone TID. Lift flap, irrigate bed and flap with BSS. Wipe gently with moistened sponge. Follow-up in 24–48 hrs. AVOID at Stage 3,

### Other Complications

These include reports of increased risk of cataract formation, effect on endothelial cell count, unilateral or bilateral macular hemorrhage, difficulty in contact lens fitting, and difficulties in IOL power calculations in patients undergoing cataract extraction.

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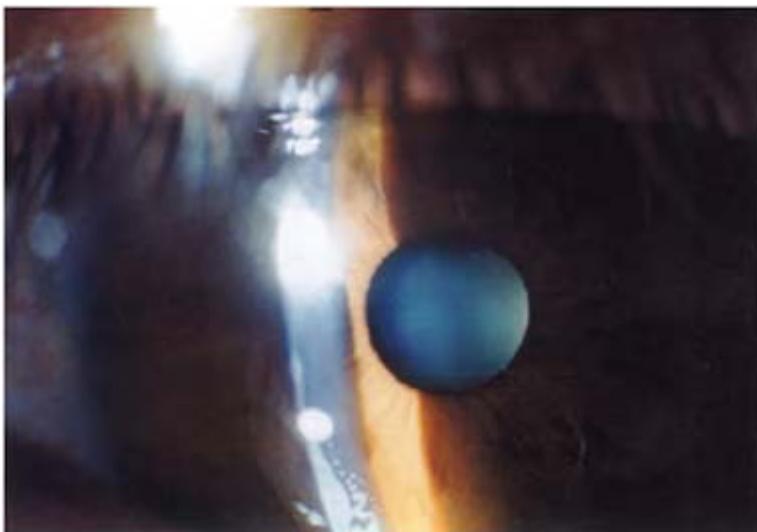
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## **Section 5**

# **Retreatment after LASIK**



# 16

## *Retreatment of Residual Refractive Errors after LASIK*

**Howard V Gimbel, EE Anderson Penno**

The need for enhancement following LASIK has been reported to be between 11.3 percent and 59 percent.<sup>1,2</sup> Hyperopic and astigmatic corrections carry a higher likelihood that an enhancement will be required to achieve the best possible uncorrected visual acuity.

There are a variety of factors that may result in the variable responses to the excimer laser including tissue and healing response, ambient humidity and surgical techniques.<sup>3</sup> In the majority of cases the retreatment for residual refractive errors following LASIK involves the straightforward approach of lifting the existing flap to expose the stromal bed for additional excimer laser ablation.<sup>4</sup>

While retreatment for residual refractive error following LASIK is common, it carries a small but real risk for complications. The most common concerns would be the risks of epithelial ingrowth, inflammation (diffuse lamellar keratitis), and infection.<sup>1,2,4,5</sup> These risks are small, however for patients with satisfactory visual acuity and small amounts of residual refractive error the risks may outweigh the benefits of enhancement. Furthermore, just as primary LASIK patients are counseled as to the risks and benefits of proceeding with this elective surgery so should patients presenting for enhancement.

In this chapter criteria and techniques for performing both straightforward enhancements as well as more complex cases will be discussed. In addition, the principles of minimizing the need for enhancement and minimizing the risks of enhancements will be covered.

### **Minimizing the Need for Retreatment after LASIK**

The most powerful tools for reducing the rate of retreatment following LASIK are accurate preoperative testing including cycloplegic refractions where appropriate, consistent surgical technique, careful attention to data entry and laser calibration, consistent laser suite conditions, and outcomes analysis for algorithm refinement (Table 16.1).

A variety of factors must be considered when determining if LASIK is appropriate for a given

### Table 16.1: Minimizing the need for retreatment after LASIK

- Accurate preoperative testing
- Cycloplegic refractions where appropriate
- Consistent surgical technique
- Careful attention to data entry
- Proper laser calibration
- Outcomes analysis for algorithm refinement

patient. Appropriate patient selection and preoperative assessment has been discussed previously in the literature.<sup>1-5</sup> Verification of refractive stability for two years and the use of cycloplegic refractions in younger patients are essential to avoid over or under corrections. To avoid enhancements for monovision reversal, a contact lens trial or demonstration with trial frames should be performed.

During primary LASIK, careful fluid management is key. It is important to avoid over hydration or dehydration of the stromal bed prior to ablation. In addition, it is essential to properly calibrate the laser according to the manufacturer's recommendations. Checking the mirrors between eyes will prevent the rare case of irregular astigmatism which can result from water droplets interfering with laser ablation. Ambient conditions may affect the outcome of laser ablation, so attention to consistent laser suite conditions will likely lead to more predictable outcomes.<sup>3</sup>

A routine of checks should be implemented such that the correct patient, correct eye, and correct refraction is entered for each case. For astigmatic corrections it is helpful to cross reference with the corneal topography to avoid axis errors. Finally, outcomes analysis is essential for algorithm refinement. Attention to detail throughout the preoperative testing and primary LASIK surgery will reduce the likelihood of refractive errors following LASIK.

#### Selection Criteria for Simple LASIK Enhancement

Each case is considered individually using the following guidelines (Table 16.2). The refraction

### Table 16.2: Selection criteria for simple LASIK enhancement

- Refraction stable for at least one month
- Corneal thickness verified
- 0.50 diopters residual refractive error
- Visual symptoms present
- Monovision patients advised to wait three months prior to monovision reversal

- Corrective lenses recommended, if concerns only for specific activities

must be stable for at least one month; in some cases enhancement should be delayed due to fluctuations in refraction. For example, a significantly dry eye following primary LASIK may lead to fluctuating visual acuity, and enhancement would not be recommended until the dry eye is stabilized. Regression is less common following LASIK than it is following PRK.<sup>1,2,4,5</sup> Therefore if patients present with a large shift in the refraction, particularly if this occurs many months after primary LASIK, other causes such as cataracts or diabetes should be considered prior to considering an enhancement. In some cases cycloplegic refraction might be recommended. Vertex distances and repeat mapping are performed for all enhancement cases. Corneal thickness is always verified to ensure that there is sufficient residual bed thickness to perform additional treatment. Optical methods may read falsely low following LASIK, therefore ultrasound pachymetry may be needed.<sup>6</sup>

Only patients with 0.50 diopters or more residual refractive error who have vision complaints are considered for enhancement. Patients with residual refractive error who have no complaints or patients with a small amount of residual refractive error who have concerns only under monocular conditions are generally not considered for enhancement. It is important to counsel patients to work with both eyes together and avoid continuous checking of one eye at a time as this will highlight even small differences between the two eyes. This is particularly important for monovision patients. Monovision patients are also advised to wait at least three months prior to reversal of monovision, and if there are concerns only for specific activities such as night driving then corrective lenses are recommended for part time use rather than surgical enhancement.

Presbyopic patients often present with particular post-operative concerns. In some cases a mild myopic residual correction in one eye can become an asset for the presbyopic patient and may not need to be enhanced. Older patients who did not wear contact lenses prior to surgery may have concerns about the mid-range visual acuity, in these cases a small hyperopic residual correction may be enhanced to relieve these specific difficulties. The decision to enhance or not to enhance is made on an individual basis, taking into consideration the residual refractive error, visual concerns, and patient age.

### **Surgical Technique for Simple LASIK Enhancement**

The technique used for straightforward retreatment of residual refractive errors following LASIK has also been described elsewhere.<sup>1,2,4,5</sup> Soft contact lenses are discontinued at least 48 hours prior to enhancement, and for gas permeable lenses the patient is asked to discontinue lenses two weeks prior to retreatment. The patient is given one drop of topical anesthetic in the operative eye or eyes. The edge of the flap is visualized at the slit lamp and marked by making a small scratch with a 25 gauge needle. At this time marking the eye at the slit lamp preoperatively for axis may help improve accuracy of laser ablation. It may not be necessary to mark a flap that is well delineated by fibrosis at the edge. However in many cases marking will facilitate finding the edge intraoperatively which can be more difficult to visualize with the operating microscope which may not have the benefit of a fully moveable slit beam.

The eye is draped in the standard sterile manner and a wire lid speculum is inserted. Additional topical anesthetic drops are given. The flap edge is marked in the standard manner using gentian violet. A Lewicky or Sinskey instrument is used to delineate the flap edge. The tip of the instrument is inserted gently into the gutter using the scratch as a guide. If the flap edge is hard to visualize, indenting the cornea with a dry sponge may highlight the previous flap edge when the corneal epithelium is dry. If one still cannot find the edge the tip can be dragged from the periphery towards the flap edge with slight downward pressure; the tip will generally pop into the gutter when the edge is reached. This approach should be used sparingly since repeated attempts to find the flap edge, in this manner may result in peripheral corneal abrasions. Prior marking of the edge at the slit lamp can avoid this situation.

The tip of the instrument can be used to delineate the entire circumference of the flap. One side of a curved non-toothed forceps is then inserted under the flap oriented tangentially to the cornea. Using a gentle sweeping motion starting at the hinge and working towards the opposite edge, the flap is loosened entirely from the stromal bed. Some cases will require more force than others to release the flap. If it has been over a year from the primary surgery and the adhesions are substantial, a recut may be required. The surgeon may make the choice to halt the procedure at this point if there is a risk of damage to the flap due to the strength of flap adherence. This will be discussed in more detail below.

In the majority of cases the flap will be relatively easy to loosen from the stromal bed. The forceps are then used to sweep the flap back to expose the bed for ablation. A Chayet sponge is used to lay the flap on and to absorb any excess fluid. With the bed exposed, a spatula is used to clear the epithelium from the flap edge. Techniques for removing epithelial ingrowth will be discussed in detail below. The stromal bed should be clear of any debris or epithelial tags prior to ablation. If it is necessary to remove any debris from the stromal bed, a dry technique using the forceps or spatula is recommended to avoid hydration of the tissue which could decrease the effect of ablation and result in an undercorrection of the residual refractive error.

Laser ablation is performed in the standard manner. When an expanded zone is used on a smaller diameter flap, the edges are shielded with the Chayet sponge to avoid spillover of the ablation onto the epithelium. Spillover of the ablation onto the epithelium may pose a risk for subsequent epithelial ingrowth.<sup>2,5</sup> Before repositioning the flap, the edges are inspected and any epithelial tags are cleared from the gutter prior to reflecting the flap back onto the stromal bed.

Flap repositioning using balanced salt is performed in the same manner as in primary LASIK cases. The same attention to thorough inspection after repositioning is required to avoid the epithelial edge or debris trapped in the interface or microstriae. The same post-operative medications and precautions are used. A combination steroid and antibiotic drop is prescribed and the use of protective eye shields is recommended when sleeping for the first week. Patients are examined one day and then one month postoperatively for straightforward cases.

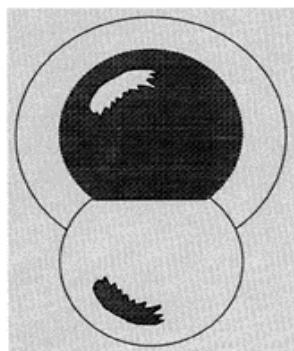
## Surgical Techniques for Complicated LASIK Enhancement

### *Late Enhancement of Residual Refractive Error after LASIK*

Primary LASIK patients are counseled that if an enhancement is needed it is preferable to do it within 12 to 18 months after primary surgery. While it is possible in most cases to lift the flap even three or five years following LASIK, the adherence of the flap to the stromal bed will generally increase over time. In rare cases, patients may present for enhancement within a year of primary surgery, and the flap may be too adherent to lift using the standard simple enhancement technique; this seems to occur more often in cases where a very thin flap was created during the primary LASIK surgery.

In our experience a simple lift of the existing flap is likely to be a lower risk than attempting a recut. Others have reported that lifting the flap may show better long-term stability of refractive error and uncorrected acuity as compared to recutting the flap for enhancements.<sup>4</sup> For these reasons, even for patients who present late for retreatment of residual refractive error a simple enhancement is usually attempted first. The surgeon must determine during the simple enhancement attempt if the flap is at risk of damage due to increased adherence to the stromal bed. In these cases the portion of the flap that was lifted is repositioned with careful attention to clearing the interface and gutter of any epithelial debris or tags to avoid epithelial ingrowth. The patient is given post-operative antibiotic and steroid drops, and a recut can be considered in approximately one month.

For some patients with minimal refractive error, the decision may be that a recut is more risky than is appropriate, given the amount of correction needed. For patients undergoing a recut the surgical technique is identical to that of primary LASIK. The surgeon must be prepared for the rare case in which the new cut may transect the existing flap. In rare cases a small stromal crescent may be created at the edge of the new flap (Fig. 16.1) These cases require meticulous attention to flap reposition and clearing of any epithelial debris or tags to avoid ingrowth or irregular astigmatism. In the majority of cases the recut for late enhancement of residual refractive



**Figure 16.1.** Recut of the flap for enhancement may result in a small

## stromal crescent on the flap undersurface or on the stromal bed

errors following LASIK will provide an excellent outcome.

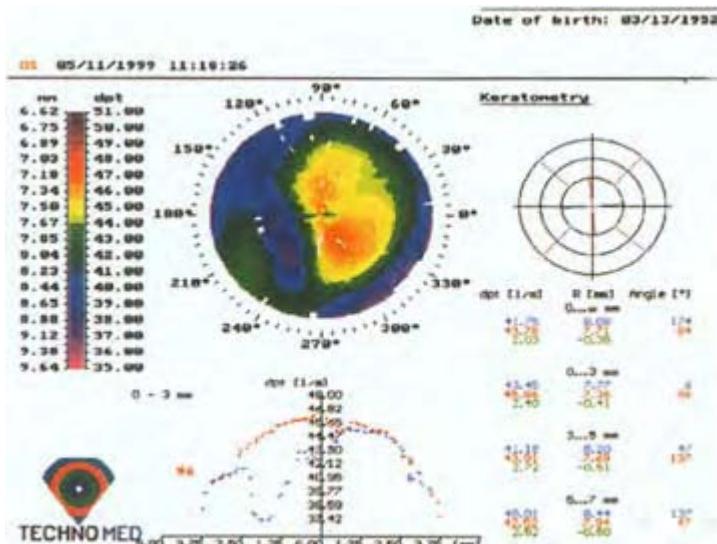
### *Residual Refractive Error and Epithelial Ingrowth*

In some cases residual refractive error and epithelial ingrowth may co-exist. If the amount of epithelial ingrowth is small and well outside the treatment zone, ingrowth removal and correction of residual refractive error can be performed in a single procedure. In these cases the epithelial ingrowth should be cleared from the stromal bed with a spatula prior to laser ablation. To avoid dragging epithelial fragments further into the center of the stromal bed, the surgical assistant should wipe the spatula with a clean sponge between each pass over the ingrowth area.<sup>5</sup> The undersurface of the flap should be inspected and cleaned following laser ablation; this avoids desiccation of the bed which may occur if the flap remains reflected for a long period of time while the flap is cleaned. Desiccation of the bed may lead to unexpected ablation results.

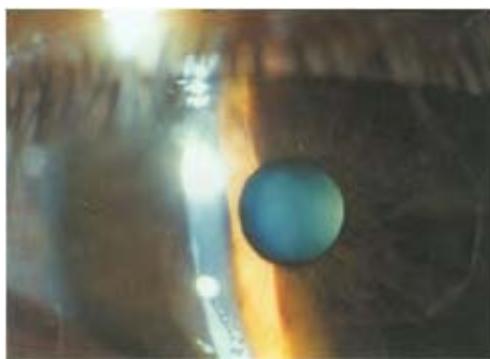
If there is a substantial area of epithelial ingrowth, irregular astigmatism, or flap melting, it may be advisable to attend to the ingrowth first and attempt correction of the residual refractive error at a later date (Figs 16.2a and b). For example, hyperopic cylinder may result from epithelial ingrowth. In some cases, removal of a large area of ingrowth which extends into the treatment zone may cause a refractive change. To attain optimal results it may be best to let the refraction stabilize following ingrowth removal before attempting refractive correction.

### **Irregular Astigmatism and Residual Refractive Error**

In cases where irregular astigmatism is present the following techniques may be considered. In select cases with minimal refractive error, a light transepithelial PTK may improve the quality of vision. Caution should be used with this approach as surface ablation over a LASIK flap may pose an increased risk of haze following retreatment. Alternatively the flap may be lifted, and PTK on the stromal bed using sodium hyaluronate 0.25 percent (Laservis®) smoothing fluid to shield low areas may be effective. Fluid containing carboxymethylcellulose, such as Celluvisc®, should not be applied to the stromal bed as this has been shown to induce diffuse lamellar keratitis.<sup>7</sup> The smoothing fluid will leave the high points exposed to allow PTK to ablate only those areas. This approach has been effective in the rare cases where water droplets on the laser mirror resulted in irregular astigmatism following primary LASIK. With the advent of wavefront mapping and custom ablation, cases of irregular astigmatism may undergo enhancement with good results using these techniques.



**Figure 16.2a.** Epithelial ingrowth occurred 10 months postoperatively following primary hyperopic LASIK



**Figure 16.2b.** Irregular astigmatism reduced BCVA to 20/40 (refraction +1.75/-2.00x30)

## CONCLUSION

In most cases a simple enhancement technique will lead to excellent results. Some enhancements may be avoided with careful counseling, and others may not be recommended due to corneal thickness or refractive instability. With the approaches

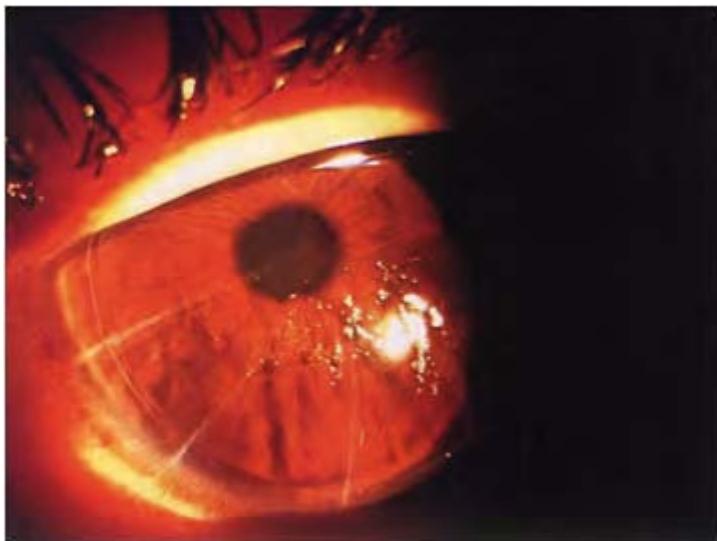
discussed above, even complex enhancements can be treated to provide improved visual acuity.

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# **Section 6**

## **LASIK in Special situations**



# 17

## *Hyperopic LASIK*

**Mittanamalli S Sridh**

The treatment of hyperopia has lagged behind that of myopia primarily because of issues related to efficacy and safety.<sup>1</sup> Although the amount of research effort and published material is now much larger, it is still less than myopia. It is easier to flatten the cornea permanently than to steepen it centrally for hyperopia. The variety of approaches attempted for the surgical correction of hyperopia reflect the lack of availability of a single approach to deliver safe, effective and predictable results consistently. Attempts to steepen the cornea for correction of hyperopic refractive error using techniques such as hexagonal keratotomy, automated lamellar keratoplasty and laser thermokeratoplasty have met with varying degree of success.<sup>2</sup> Irregular astigmatism and wearing off of the hyperopic affect with initial procedures were responsible for the initial lack of enthusiasm of refractive surgery in the treatment of hyperopia.<sup>3</sup>

### **Refractive Surgeries for Hyperopia**

Refractive hyperopia operations can be classified into three categories.<sup>4</sup> First, is collagen shrinkage procedure, which would be Holmium and radiofrequency waves. Their drawback is that there is an initial overshoot where the patient becomes quite myopic and then gradually ends up at the target.

The second category comprises corneal implants and inlays or phakic intraocular lenses. These procedures have the potential for reversibility or exchangeability.

The third category encompasses the excimer laser procedures, which allows reshaping the corneal surface to submicron precision. Hyperopic ablations are designed to be annular in nature to steepen the central cornea, thus achieving the desired refractive effect. Currently, the procedure of choice for correction of hyperopia is based on the level of hyperopia. For hyperopia <2D, LASIK/PRK/intracorneal ring is recommended, for hyperopia between 2–6D, LASIK/PRK is the preferred surgery, for 5–15D of hyperopia, phakic intraocular lens and for hyperopia between 7–20D, clear lens extraction with intraocular lens is the recommended procedure.<sup>5</sup>

For the last two decades, photorefractive keratectomy (PRK) and laser in situ keratomileusis (LASIK) have emerged as effective procedures for the surgical correction of myopia. The main advantage of LASIK is a presumably attenuated wound healing response compared with PRK as a result of preservation of the corneal epithelium and Bowman's membrane.<sup>4</sup> The clinical advantages of LASIK include rapid rehabilitation, less postoperative pain, a reduced need for continuous steroid therapy, more stable and

predictable refraction, absence of epithelial defect, minimal distortion of Bowman's layer and epithelium and elimination of stromal haze.<sup>6</sup>

In the last several years, the explosive growth of LASIK has led to more intensive interest in the treatment of hyperopia and astigmatism. The early reports of hyperopic LASIK (H-LASIK) showed unsatisfactory results with significant regression and high incidence of loss of best corrected visual acuity (BCVA).<sup>6</sup> These poor results were primarily caused by small outer zone ablations. Even though, H-PRK studies showed that larger optical zones were important for improved visual outcomes, the optical zones of initial hyperopic LASIK studies were limited by smaller flaps created by automated corneal shaper (ACS) microkeratome and early undefined excimer laser algorithms. The development of new microkeratomes such as Hansatome, Moria LSK, Moria Carriazo-Barraquer, and Summit Kruemich-Barraquer have enabled the creation of larger flaps. These large diameter flaps are more stable and permit the application of wider ablation zones. As microkeratomes have improved, so have excimer lasers which are capable of larger outer zone ablations. Furthermore, better algorithms and nomograms are being developed based on earlier and increased experience in treatment of hyperopia with excimer lasers.<sup>6,7</sup>

### **Preoperative Considerations**

Typically, LASIK has been successfully used to correct low to moderate levels of hyperopia (+1.0 to +5.0 diopters). Just like in myopic LASIK, patients should be older than 21 years of age, and should have stable refractive error for at least last one year. A complete history taking and ocular examination is a must. This includes a manifest refraction, cycloplegic refraction, corneal topography, slit lamp examination, pachymetry and dilated fundus evaluation.

The identification of the peripheral corneal vascularization is a must as larger flaps are advocated in these eyes to accommodate larger hyperopic annular photo ablation.

Cycloplegic refraction is essential in these eyes as this unmasks latent hyperopia in eyes with vigorous accommodative ability.

The central keratometry as well as videokeratography is essential in these eyes as less keratometry readings are associated with smaller diameter flaps, which may not accommodate larger peripheral ablations, which are required in these eyes. Eyes with keratometry >50 diopters may suffer from suboptimal visual acuity postoperatively due to increased steepness of the cornea postoperatively.

### **Surgical Technique**

The basic surgical technique for hyperopia is similar to that for myopia with additional precautions. Following topical anesthesia with proparacaine the lids and lashes are draped and the cornea is marked with gentian violet. Careful positioning of the suction ring is mandatory in hyperopic LASIK. A larger suction ring should be used in such eye, preferably 9.5 mm to accommodate a larger-and a more peripheral hyperopic ablation profile. Decentration of the suction ring should be avoided, as even a slight amount of decentration may not accommodate a larger hyperopic profile. One might decentre the suction ring slightly towards the hinge so that the hinge remains out of the field of

hyperopic ablation. Additionally, a hinge protector or a moist methylcellulose sponge may be used to protect the hinge from photo ablation.

The optical zone in the center is 6.0 mm and the area of the mid-peripheral and peripheral zone, which is the area of stromal ablation begins after this and extends upto 9.0 mm. Centration of the photo ablation is therefore critical as the relatively small optic zone due to the hyperopic LASIK is less forgiving than the larger optical zone of a comparative myopic LASIK.

## Results

### *Primary Hyperopia*

There are few published reports on the visual and refractive outcome of H-LASIK with adequate follow-up. Table 17.1 is a brief review of the literature on the outcome of hyperopic LASIK.<sup>1,4,8-12</sup> These studies have been carried out using different excimer lasers, beam profiles, ablation-zone parameters,

**Table 17.1 Summary of major studies of hyperopia LASIK**

Author	Machine	No. of eyes	Mean of SE	Range of SE	SE within 1D	SE within 0.5D	UCVA $\geq 20/40$ (%)	BCVA with loss $\geq$ of 2 lines/(> 20%)	Mean follow-up (months)
Ditzen et al 1998 <sup>8</sup>	MEL 60	20	$+2.5 \pm 1.7$	+1.00 to +4.00	85	ND	95	5	12
		23	$+5.3 \pm 1.9$	+4.25 to +8.00	58	ND	90	4.3	12
Goker et al (1998) <sup>9</sup>	Keracor 116	54	$+6.5 \pm 1.3$	+4.25 to +8.0	75.9	ND	66.6	6.8	19
Ibrahim (1998) <sup>10</sup>	Nidek EC-5000	58	+3.75	+1 to +6	ND	(Mean SE at 6 months +2)	ND	ND	6
Argento et al (1998) <sup>11</sup>	Keracor 116/117	138		+1 to +5	100	ND	941	2	6
		153		+3 to +5.1	95.3	ND	100		
		170		+3.1 to +9	71.4	ND	83.8		

Arbelaez et al (1999) <sup>12</sup>	Keracor 117C	24 20 16	+1 to +3 +3.1 to +5 +5.1 to +9	55% 44% 38%	95 93 50	13	12
Zadok et al(2000) <sup>4</sup>	Nidek EC-5000	45 27	+2 ±0.5 +3.8±0.5	+1 to +3 +3 to +5	88.9 51.8	95.6 77.8	0 1.4
Choi et al (2001) <sup>1</sup>	Visx S2	32	+4±4.5	+1.5 to +8.5	53	66	3
Salz (2002) <sup>19</sup>	LADARVision	88 29		+0.88 to +2.99 +3 to +6	93.2 85.7	97.2 88.8	45 12

SE: Spherical equivalent, UCVA—Uncorrected visual acuity, BCVA—Best corrected visual acuity

**Table 17.2 Lindstrom's nomogram for hyperopia**

Age (Yrs)	Primary hyperopia			Secondary hyperopia	
	Preoperative manifest SE			After	After
0–2D	2–4D	4–6D	RK		LASIK
20–29	0%	+10%	+20%	-4%	-14%
30–39	+10%	+18%	+25%	82%	-10%
40–49	+17%	+23%	+28%	-1%	-4%
50–59	+30%	+30%	+30%	0%	+4%
60–69	+35%	+32%	+31%	+2%	+8%

levels of hyperopia and likely different treatment nomograms. A careful review of literature suggests that LASIK gives good results in patients with mild to moderate hyperopia. Most of the studies have a follow up in the range of 6–12 months, except for the study by Goker et al which has a follow up of about 19 months.<sup>9</sup> The spherical equivalent within 1 diopter was seen in 90 percent in patients with low and moderate hyperopia. The study by Argento et al showed that 100 percent of the patients were within 1 diopter at 6 months follow-up in low hyperopia.<sup>11</sup> Similarly the uncorrected visual acuity of 20/40 or better ranges from 90–95 percent in low to moderate hyperopia, and it drops down when the surgery is performed for high hyperopia.

Loss of best corrected visual acuity has been reported even in low hyperopia, but in patients with high hyperopia it has been reported to be as high as 13 percent.<sup>12</sup> The results

of various studies show that several excimer laser systems are capable of adequately treating hyperopia with or without astigmatism upto a spherical equivalent of upto +5 D. Above that amount, efficacy as determined by uncorrected visual acuity (UCVA) proximity to emmetropia falls off dramatically.

A useful nomogram has been given by Lindstrom et al, which can be followed for patients with primary hyperopia and secondary hyperopia (Table 17.2).<sup>6</sup>

Since small optic zones are more susceptible to glare, halo effects and poor quality from decentered ablations, better results are obtained from a large optic zone of 6 mm and a transition zone upto 9 mm. A large flap is desired so that the ablation does not involve the flap margin or the hinge. Corneal diameter and width of the flap appears to be important factors in the feasibility of LASIK in hyperopic eyes.<sup>13</sup>

### ***Hyperopia and Mixed Astigmatism***

The correction of hyperopic astigmatism and mixed astigmatism has also been tried with LASIK. In general uncorrected visual acuity has been reported to be better in the spherical group than in the toric group. In both the groups, efficacy was acceptable in low and moderate hyperopia but poor in high hyperopia. There are several ablation patterns possible for correcting hyperopic astigmatism. The flat axis can be steepened, the steep axis can be flattened or a combination of both may be undertaken.<sup>6</sup> To minimize the amount of tissue ablated, the best method appears to be the cross cylinder method where there is flattening of the steep meridian and steepening of the flat meridian.

Ibrahim et al reported their experience of LASIK in hyperopic astigmatism.<sup>10</sup> The mean preoperative astigmatism was +2.75D (range 0 to +4D). The authors used a minus cylinder notation and began ablating the myopic ablation profile and this was followed by hyperopic ablation after adjusting for the coupling effect of the other astigmatic correction to the desired spherical hyperopic correction. According to their nomogram, to correct myopic astigmatism they added 20 percent to desired correction and to correct hyperopic sphere, they added 50 percent of cylinder to correction.

*Example* +2.00 Dsph./+2.00 Dcyl. X 180°. This is converted into minus cylinder+4.00 Dsph./-2.00 Dcyl. X 90°. To correct myopic cylinder: -2.00 + (20%) = -2.40 Dcyl x 90°. To correct hyperopic sphere +4.00 + (1.00) = +5.00D. The mean postoperative astigmatism was +1.25D (range 0 to 2.75D). There was loss of astigmatic correction in the early post-operative periods, the mean astigmatism increased from +0.50D (range 0 to +2.25D) at one week to +1.00D (range 0 to +3.00D) at one month, and remained stable thereafter until the last follow up.

Barraquer and Gutierrez reported the results of LASIK in hyperopic compound astigmatism.<sup>14</sup> In a large series of 111 eyes, 90 percent of the eyes achieved cylinder correction within  $\pm 1.00$ D of emmetropia. Uncorrected visual acuity was 20/40 or better in 71.0 percent of eyes, 6 months after surgery. Loss of BCVA is reported to be as high as 15 percent in high toric hyperopia. Overall outcomes of LASIK for hyperopic astigmatism suggest that the results are satisfactory for +2 to +5D of astigmatism and as the astigmatism increases, the percentage of eyes with less than 20/40 vision increased. Loss of best corrected visual acuity reported varied from 3.8 percent to 5.5 percent.

### ***LASIK for Residual Hyperopia following Other Surgical Procedures***

Hyperopic LASIK has been used to treat hyperopic overcorrections after radial keratotomy(RK)<sup>15,16</sup> and laser thermokeratoplasty.<sup>17</sup> The results are generally satisfactory but there is a risk of epithelial ingrowth at the site of the LASIK flap and at the site of gaping radial keratotomy incision. Lipshitz et al reported the results of LASIK to correct hyperopic shift after RK.<sup>15</sup> The mean spherical equivalent refraction was corrected from  $+3.08 \pm 1.02$ D to  $-0.16 \pm 0.73$ D after LASIK at a mean follow-up was 7.3 months. At the last follow-up, 80 percent of the eyes had a refractive error within  $\pm 1.00$ D of emmetropia and an uncorrected visual acuity of 20/40 or better. No wound dehiscence, epithelial ingrowth or significant complication developed in any eye. Authors believe that hyperopic LASIK may be a better option in treating overcorrected RK or PRK, because the irregular epithelium and poor stromal healing along the RK incisions may predispose to haze development with the PRK procedure.

Hence there are risks of performing LASIK in post RK eyes. Because the RK incision goes as deep as 90 percent of corneal thickness, there is a risk that the incisions will split open with LASIK flap creation. The presence of epithelial inclusions and crossing incisions indicate areas of poor wound adhesion which are more prone to splitting open when a flap is created with the microkeratome. The more the number of incisions present, the greater the likelihood of split incision over previous RK. Therefore, each eye needs to be carefully examined and the risks and benefits of additional surgery evaluated.

Lindstrom et al reported that LASIK is safe and effective for secondary hyperopia and hyperopic astigmatism after LASIK, photorefractive keratectomy, automated lamellar keratoplasty or radial keratotomy.<sup>6</sup> In their study, mean manifest spherical equivalent was  $+1.73 \pm 0.79$ D before surgery,  $-0.13 \pm 1.00$ D at 6 months after surgery, and  $-0.18 \pm 1.08$ D at 1 year after surgery. At 1 year, 85 percent had UCVA of 20/40 or better and 85 percent were within  $\pm 1$ D of emmetropia. The surgical correction was initially set to 80 percent of the manifest sphere, but early experience showed that this nomogram resulted in residual hyperopia in many patients. The spherical correction subsequently increased by 10 to 20 percent.

Attia et al reported the results of LASIK for regression following laser thermoplasty for hyperopia.<sup>17</sup> Mean spherical equivalent refraction improved from  $+2.92 \pm 1.60$  to  $0.36 \pm 1.48$ D. Forty two percent were within  $\pm 0.50$ D of intended correction, 60 percent were within  $\pm 1.0$ D and 76 percent were within  $\pm 2.00$ D. Confluent haze was seen between previous LTK spots was observed in most eyes, as LASIK ablation took place at the sites of the LTK spots.

### **Complications**

As in myopic LASIK, the complications of hyperopic LASIK are associated with the creation of the corneal flap.

#### ***Problems in Exposure***

Small size of hyperopic eyes and associated palpebral apertures give rise to problems in centering the suction ring.

We advocate the removal of the lid speculum and placement of the 8.5 mm suction ring after opening the eyes with the index finger and the thumb, in cases of inadequate exposure.<sup>18</sup> The Hansatome, with a 180- $\mu\text{m}$  thickness plate, is then placed on the suction ring and the LASIK flaps may then be created. The presence of the lid speculum decreases the potential space in the fornices, especially in eyes with narrow palpebral apertures. However, the use of the Hansatome without the speculum requires caution and should be only undertaken by experienced surgeons.

### ***Ablation of the Hinge***

Special precautions should be taken to protect the hinge with the help of a flap protector or use of a wet methylcellulose sponge as has been described earlier.

### ***Decentration***

Decentractions should be avoided as has been explained earlier.

### ***Intraoperative Bleeding***

Due to the creation of larger diameter flaps which have been advocated in these eyes, the chances of intraoperative hemorrhage are much more and due precautions must be taken when this occurs. Methyl-cellulose sponges may be used to drain away the hemorrhage. This is more critical in hyperopic laser as compared to myopic laser since the ablation is peripheral.

### ***Epithelial Ingrowth***

Earlier microkeratomes were capable of producing a flap diameter of about 8.5 mm. This was inadequate because of larger optical and transition zone needed. The encroachment of the periphery of the flap gives rise to epithelial ingrowth,<sup>8</sup> which have a higher incidence in hyperopic LASIK than in myopic LASIK. In the last few years, the availability of keratomes with a capability of creating 9.5mm flaps, such as the Hansatome, Nidek, Moria and others improved the hyperopic LASIK procedure in terms of safety and efficacy.

### ***Loss of BCVA***

A loss of BCVA has been reported in most studies. The small effective optic zone makes centration more critical. Even small levels of decentration result in irregular astigmatism and increased risk of subjective symptoms such as monocular diplopia or degraded visual acuity.

Improvement in trackers and surgical experience will help to reduce decentractions. The loss of spectacle corrected visual acuity observed in high hyperopic groups may be due to significant optical aberrations caused by the high amount of corneal steepening producing a degradation of image. This deterioration of image is not associated with final

keratometry but to the amount of hyperopia corrected. 4.5 to 5 percent loss of BCVA has been reported even in eyes with low hyperopia.<sup>8,19</sup>

### ***Regression***

Hyperopic LASIK is associated with more regression than myopic procedures and hence the need for retreatment. The mechanism of hyperopic LASIK regression is not clearly defined but epithelial hyperplasia may be one of the causes. Regression has been associated with the magnitude of hyperopia.<sup>19</sup> It is considerably greater in the high hyperopia group, though significant regression can occur even in lower degrees of hyperopia.<sup>4</sup>

In a study of 72 consecutive eyes reported by Zadok et al,<sup>4</sup> 18 eyes (25%) underwent retreatment, 9 eyes (20%) from the low hyperopia group and 9 eyes (33%) from the moderate hyperopia group. Eight eyes which were initially undercorrected later regressed, four in each group. Two eyes in the low hyperopia that were initially emmetropic, regressed at 4 months and required retreatment. Uncorrected visual acuity improved in all eyes after retreatment, and there was no decrease in BCVA.

In a large series, Arbelaez reported that 7 percent of eyes of spherical hyperopia and 15 percent of toric hyperopia required retreatment.<sup>12</sup> Choi and Wilson have shown that primary hyperopia showed small regression of treatment over time.<sup>1</sup> This change appears to be small between 1 to 3 months after surgery, with stability between 3 and 6 months. Other studies have also shown regression upto 6 months.

### ***Corneal Iron Ring***

An interesting complication of corneal ring after hyperopic LASIK has been reported where there is corneal iron ring located at the paracentral area.<sup>20,21</sup> The clinical significance of this iron ring is not known. Probably it occurs because of malapposition of the eyelids to the cornea and cause disturbances in the precorneal tear film. Iron from the tears may deposit in the corneal epithelium in the areas of tear pooling.

### ***Fluctuation of Vision***

Severe fluctuation of vision despite unchanged spectacle corrected visual acuity has been reported.<sup>12</sup>

### ***Limitations of Hyperopic LASIK***

There are certain limitations of hyperopic LASIK surgery. Using large-diameter ablation zones for H-LASIK is not optimal because they often exceed the flap size created by most currently available microkeratomes. Centration is critical to avert potential complications such as accidental ablation of the hinge of the flap or of epithelium surrounding the stromal bed.<sup>4</sup> Generally it is agreed that steepening the cornea to produce K readings beyond 49 to 50 is deleterious to the physiological optics of cornea.<sup>3</sup> Knorz et al found that the upper limit of hyperopic LASIK should be +5.00D, although others

suggest good results upto +8.00D. Besides this, regression is another problem, which occurs more frequently in these eyes.

### Prognosis

Studies have shown that the factor, which influenced the outcome of hyperopic LASIK negatively, was the degree of hyperopia. Relating the outcome to the corneal curvature have shown contradictory results. Ditzén et al found that preoperative corneal radius appears to be an important prognostic factor in eyes with high hyperopia,<sup>8</sup> with more undercorrections occurring in eyes with hyperopia greater than 6.0D plus a preoperative corneal radius of more than 8 mm whereas Cobo-Soriano et al found that preoperative keratometry did not significantly influence the postoperative results.<sup>22</sup>

To conclude, hyperopic-LASIK, is a safe, effective and predictable procedure for low to moderate hyperopia. Significant regression can occur upto about 6 months and this can occur even in low hyperopia. LASIK performed for high hyperopia can result in loss of best corrected visual acuity in a significant proportion of patients. Retreatment can be safely performed to improve visual acuity and refractive outcome. With further experience, the accuracy will improve with decline in the incidence of retreatment.

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## 18

# ***LASIK for Presbyopia***

**Amar Agarwal, Athiya Agarwal, Sunita Agarwal, Guillermo Avalos-Urzua**

Presbyopia, is the final frontier for an ophthalmologist. In the 21st century, the latest developments, which are taking place, are in the field of presbyopia. In presbyopia, the nearest point that can be focused gradually recedes, leading to the need for optical prosthesis for close work such as reading, and, eventually, even for focusing in the intermediate distance.

### **Previous Excimer Laser-Techniques**

Presbyopic photorefractive keratectomy (PRK) has been tried earlier. In this, using the excimer laser, a mask consisting of a mobile diaphragm formed by two blunt blades was used to ablate a 10–17 micron deep semilunar-shaped zone immediately below the pupillary center, steepening the corneal curvature in that area.

Monofocal vision with LASIK has also been tried to solve the problem of presbyopia. The goal in such cases is to make the patient anisotropic. In this, one eye is used for distance vision and the other for near vision. This is obviously not indicated in all subjects. The residual consequences are partial loss of stereopsis, asthenopia, headache, aniseikonia and decreased binocularly.

### **History**

Guillermo Avalos<sup>1,2</sup> started the idea of presbyopic LASIK. This is called the PARM technique, i.e. the Presbyopic—Avalos and Rosakis Method.

### **Principle**

The objective is to allow the patient to focus on near objects while retaining his ability to focus on far objects, taking into account the refractive error of the eye when the treatment is performed. With this LASIK technique the corneal curvature is modified, creating a bilateral multifocal cornea in the treated optical zone. A combination of hyperopic and myopic LASIK is done aiming to make a multifocal cornea. We determine if the eye is presbyopic piano, presbyopic with spherical hyperopia, or presbyopia with spherical

myopia. These may also have astigmatism, in which case the astigmatism is treated at the same time.

### Prolate and Oblate Cornea

It is important for us to understand a prolate and oblate cornea before we progress further on the technique of presbyopic LASIK. The shape of spheroid (a conoidal surface of revolution) is qualitatively prolate or oblate, depending on whether it is stretched or flattened in its axial dimension. In a prolate cornea the meridional curvature decreases from pole to equator and in an oblate cornea the meridional curvature continually increases. The optical surfaces of the normal human eye's both cornea and lens is prolate. This shape has an optical advantage in that spherical aberration can be avoided. Following LASIK the prolateness of the anterior cornea reduces, but is insufficient to eliminate its spherical aberration. Thus one should remember that normal cornea is prolate. When myopic LASIK is done the cornea becomes oblate. When hyperopic LASIK is done the cornea becomes prolate.

Every patient treated with an excimer laser is left with an oblate or prolate-shaped cornea depending upon the myopia or hyperopia of the patient. The approach to improve visual quality after LASIK is to apply geometric optics and use the patient's refraction, precise preoperative corneal height data, and optimal postoperative anterior corneal shape in order to have a customized prolate shape treatment.

### Technique

A superficial corneal flap is created first with the microkeratome. The corneal flap performed with the microkeratome must be between 8.5 and 9.5 mm in order to have an available corneal surface for treatment of at least eight mm. In this way, the laser beam does not touch the hinge of the flap. Once the flap has been created a hyperopic ablation in an optical zone of five mm is done (Fig. 18.1). The treated cornea now has a steeper section. The cornea



**Figure 18.1.** Hyperopic LASIK done on the cornea. Myopic prolate cornea produced

is thus myopic, prolate. This allows the eye to focus in a range that includes near vision but excludes far vision.

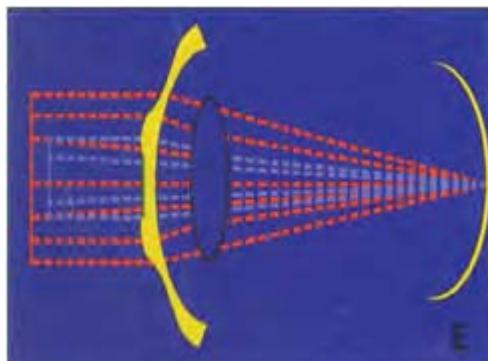
With this myopic-shaped cornea, one now selects a smaller area of the central cornea that is concentric with the previous worked area. The size of the area is a four mm optical zone. A myopic LASIK is now done with the 4 mm optical zone (Fig. 18.2). The resulting cornea now has a central area (oblate) that is configured for the eye to focus on far objects and a ring shaped area that allows the eye to focus on near objects (Fig.18.3). The flap is now irrigated and replaced back in position.

### Keratometry and Pachymetry

Pachymetry is not important for this procedure. The preoperative keratometry reading is extremely important. The postoperative keratometer reading should not exceed 48D. The keratometer reading should be taken from topography and not from a manual keratometer machine. For each hypermetropic dioptrre corrected, the corneal curvature increases in 0.89 keratometric dioptres as an average. It is recommended to treat patients with keratometry in the range between 41 and 43D to obtain postoperative curves under 48D. If the cornea is



**Figure 18.2.** Myopic LASIK done.  
Myopic ablation of 4 mm optical zone  
performed to create a central oblate  
cornea



**Figure 18.3.** Schematic diagram of a presbyopic cornea in which hyperopic and myopic LASIK have been done. The patient can thus focus for near and distance

more than 48D, it produces undesired optical alterations like glare, halos, decreased visual acuity and decreased contrast sensitivity. The preoperative and postoperative keratometer readings should be nearly the same for the patient to be comfortable.

### Astigmatism

If astigmatism is present, the recommended upper limit is 2.5D. One should also remember that there is an induced astigmatism of 0.5 to 0.75D, created by the corneal shape after the surgery, and this can decrease one or two lines of uncorrected visual acuity

### *Piano Examples*

Now let us look at treating presbyopic patients who are basically piano for distance.

*Examples 1* Let us take a patient who is piano for distance and is 20/20. For near, on addition of +2D the patient is J1. The preoperative keratometry let us say is 41D.

There are three steps in the presbyopic LASIK treatment.

*Step 1:* For distance- No treatment is required as the patient is piano 20/20

*Step 2:* For near- Hyperopic LASIK is done of +2 D. A 5 mm optical zone is taken. We have already mentioned that each dioptre of hyperopia corrected, changes the corneal curvature by 0.89D, which is approximately 1D. So the keratometry changes from 41 to 43D (approximately).

*Step 3:* Myopic LASIK of minus 1D with a 4 mm optical zone. So keratometry now becomes 42D.

Regression occurs for hyperopia treatment to about 1D, so we have done myopic ablation of minus 1 and not minus 2D. The preoperative keratometry reading was 41D and postoperative keratometry reading is 42D, which is nearly the same.

### ***Hyperopic Examples***

Now let us look at presbyopic LASIK being performed in a hyperopic eye.

#### ***Example 2***

Let us take a patient who is hyperopic for distance and is 20/20 with +1D. For near, on addition of +3 D the patient is J1. The preoperative keratometry let us say is 42D.

There are three steps in the presbyopic LASIK treatment.

*Step 1:* For distance- Hyperopic LASIK is done of +1D with a five mm optical zone. So keratometry changes from 42D to 43D.

*Step 2:* For near- Hyperopic LASIK is done of +3 D. A 5 mm optical zone is taken. We have already mentioned that each dioptre of hyperopia corrected changes the corneal curvature by 0.89D, which is approximately 1D. So the keratometry changes from 43 to 46D (approximately).

*Step 3:* Myopic LASIK of minus 2D with a 4 mm optical zone. So keratometry now becomes 44D. Regression occurs for hyperopia treatment to about 1D, so we have done myopic ablation of minus 2 and not minus 3D. The preoperative keratometer reading was 42D but after making the patient piano it is 43D. The postoperative keratometer reading is 44D, which is nearly the same.

Though we have to correct totally 4D for hypermetropia, we take it in two steps. One should not do it in one step, as that much hyperopia corrected in one step makes the central cornea too steep to perform the myopic ablation.

#### ***Example 3***

Let us take a patient who is hyperopic for distance and is 20/20 with +3D. For near, on addition of +3 D the patient is J1. The preoperative keratometry let us say is 44D.

The preoperative keratometer reading is 44D and we have to correct 3D for distance and 3D for near. So if we attempt presbyopic LASIK, we will make the keratometer reading 50D. Hence, one should not treat such patients with presbyopic LASIK.

### ***Myopic Example***

Now let us look at myopic patients.

#### ***Example 4***

Let us take a patient who is myopic for distance and is 20/20 with minus 2D. For near, on addition of + 2D the patient is J1. This means the patient is piano for near. The preoperative keratometry let us say is 43D.

There are three steps in the presbyopic LASIK treatment.

*Step 1:* For distance- Patient is myopic, so no treatment is required.

*Step 2:* For near- Hyperopic LASIK is done of +2 D. A 5 mm optical zone is taken. We have already mentioned that each dioptre of hyperopia corrected changes the corneal curvature by 0.89D, which is approximately 1D. So the keratometry changes from 43 to 45D (approximately).

*Step 3:* Myopic LASIK of minus 3D with a 4 mm optical zone. So keratometry now becomes 42D.

Regression occurs for hyperopia treatment to about 1D, so we have done myopic ablation of minus 3 and not minus 4D. The preoperative keratometer reading was 43D, but patient was myopic by 2D, so actually the keratometer reading should be 41D. The postoperative keratometer reading is 42 D, which is nearly the same.

We did myopic ablation of 3D, as patient is myopic by 2D and presbyopic by 2D. Regression factor taken is 1D.

## SUMMARY

This idea of presbyopic LASIK needs further improvisations to become the technique of choice for one and all.

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## 19

### *LASIK in Pediatric Eyes*

**Deepinder K Dhaliwal**

At first glance, the concept of pediatric refractive surgery seems quite aggressive and radical. However, when used as a therapeutic modality in children that have no other option to restore vision, pediatric LASIK may have a useful role. Several studies have reported on the use of LASIK in the treatment of anisomyopic amblyopia in children.<sup>1-5</sup> It is well known that uncorrected unilateral high myopia results in amblyopia in the pediatric age group.<sup>6</sup> Current standard therapy can be successful if there is early detection and compliant treatment with spectacles or contact lens combined with occlusion therapy.<sup>7-9</sup> However, some children are not successfully treated using these techniques. Difficulty with compliance is a common cause for failure<sup>10</sup> and can be secondary to psychological resistance to patching or heavy and unbalanced myopic glasses that are easily removed.<sup>11</sup> In addition, optical problems due to aniseikonia with contact lenses and spectacles<sup>12</sup> and induced prism anisophoria with spectacles contribute to dissimilar binocular imagery and may further promote the development of amblyopia and abnormal binocular integration.

In these children that have “failed” conventional amblyopia therapy for anisomyopic amblyopia, LASIK has been shown to be of some benefit in several small studies.<sup>1-5</sup> There are many special considerations in performing pediatric LASIK in regards to anesthesia, fixation, microkeratome selection, size of globe, and refractive endpoint that make the surgery different than adult LASIK. These points will be discussed in further detail.

#### **Anesthesia Selection**

The choice of anesthesia for pediatric LASIK depends on the maturity and cooperation of the child. General anesthesia has been used safely in small children undergoing LASIK; however, it is critical to minimize the leak of anesthetic gases into the laser environment otherwise the laser will malfunction.<sup>13</sup> This occurs because the wavelength of the argon fluoride excimer beam (193 nm) is within the absorption spectrum of anesthetic gases such as nitrous oxide. Therefore, if nitrous oxide escapes into the path of the excimer beam, attenuation of the beam will occur. The laser will attempt to increase voltage to maintain fluence, but if treatment time is prolonged, the laser will stop firing and an error

message such as “fluence out of range” will appear.<sup>13</sup> **Laryngeal mask airway is superior to using a face mask when delivering general**



**Figure 19.1.** Pediatric LASIK being performed

**anesthesia in pediatric LASIK because gas leak is minimized and unimpeded access to the globe is possible (Fig. 19.1).**

Intravenous sedation using ketamine or propofol with topical anesthesia and verbal encouragement has also been successfully used during pediatric refractive surgery.<sup>1,14</sup>

### Fixation/Centration Issues

In sedated children with or without general anesthesia, patient fixation is not possible. During our pediatric LASIK study at the University of Pittsburgh, we found the suction ring to be very helpful in aiding fixation and centration. The Moria microkeratome units (Antony, France) have the feature of a “low vacuum” setting for the suction ring. This enables the surgeon to maintain full control of the globe after the flap is created since suction is switched from high vacuum (used during creation of the corneal flap) to low vacuum, which is maintained until the excimer ablation is completed and the flap is repositioned. The intraocular pressure is raised to only ~40 mmHg so the retinal vasculature is not compromised during low vacuum application to the globe. Preoperative pilocarpine drops are necessary in children under general anesthesia with suction ring globe fixation to avoid excessive pupil dilation, which makes centration by the surgeon difficult. Assessment of angle kappa is made after pilocarpine drops are instilled and the laser ablation is centered closer to this point while staying within the pupil.

### Microkeratome Selection

Although there are three studies in which the Automated Corneal Shaper (ACS) (Bausch & Lomb, Claremont, CA) was used,<sup>1,3,4</sup> we could not achieve adequate suction on the globe of our first patient with the suction ring of our ACS unit. Therefore, we switched to the Carriazo-Barraquer microkeratome (Moria) and had no difficulty. Adequate suction was easily achieved on the first attempt and, as mentioned previously; we utilized the low vacuum setting to fixate the globe after flap creation. There is also one report of

successfully using the Hansatome (Bausch & Lomb Claremont, CA) for pediatric LASIK.<sup>5</sup> The only two intraoperative flap complications that occurred in the published studies of pediatric LASIK were free caps, and both occurred with the ACS.<sup>1</sup>

### Size of Globe

The diameter of the cornea and axial length of the eye reach 95 percent of full growth by age 2. Therefore, there is no difficulty encountered in performing LASIK in children in regards to corneal flap diameter or access to the globe through the palpebral fissures.

### Refractive Endpoint

Unlike adult LASIK where emmetropia is generally the goal, the refractive endpoint when performing pediatric LASIK for anisomyopic amblyopia should be balance with the fellow eye. The basic concept is that with an equalization of refractive errors and elimination of anisometropia, amblyopia should be more amenable to treatment with adequate occlusion therapy.

### Results of Pediatric LASIK

In reviewing the literature, the cumulative results of pediatric LASIK for anisomyopic amblyopia are overall encouraging. There was a reduction of anisometropia in all cases and an improvement in amblyopia in some cases.<sup>1-4</sup> Out of a total of 44 eyes in 4 studies, there was a gain of best spectacle corrected visual acuity (BSCVA) in 23 eyes (52%), no change in BSCVA in 19 eyes (43%), and a loss of BSCVA in 2 eyes (5%). The etiology of the loss of BSCVA (which was only one line in both cases) was diffuse interface haze with flap striae in one eye with a free cap that was sutured, and grade 2 interface haze in a patient with preoperative myopia of -23.00 diopters.<sup>1</sup>

Of note, there is no report of postoperative flap dislocation in the pediatric LASIK literature. This is often the feared complication due to the possibility that a child would rub his eye in the immediate post-operative period. In our series, one child was caught rubbing her eye within the first 24 hours after LASIK; however, there was no evidence of flap striae or dislocation. Perhaps corneal flaps in the pediatric population are more stable due to a stronger endothelial pump mechanism in the cornea.

In summary, pediatric LASIK seems to have a role in the treatment of anisomyopic amblyopia in selected cases. Special adjustments need to be made when performing LASIK in this population, and a multi-disciplinary approach including a refractive surgeon, pediatric ophthalmologist, and pediatric anesthesiologist is needed. Worldwide experience is somewhat limited. Larger series with long-term follow-up are necessary to more thoroughly evaluate this therapeutic modality.

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## 20

# ***LASIK after Radial Keratotomy***

**Tushar Agarwal, Namrata Sharma, Rasik B Vajpayee**

Introduced in 1972, Radial Keratotomy (RK) was perhaps the first refractive surgery to gain wide popularity among both patients and surgeons. It is estimated that between 1980 and 1990, approximately 1.2 million patients underwent incisional RK worldwide.<sup>1</sup> It was widely performed up to the late 1990s and as recently as 1996, about 39 percent of refractive surgeons in the United States of America were performing 1 to 5 RK procedures per month.<sup>2</sup> Ever since, its popularity has gone down substantially due to the advent of LASIK.

Ten-year data from the Prospective Evaluation of Radial Keratotomy (PERK) study indicated that 43 percent of the patients had a hyperopic shift of greater than 1.0 D. Further, 17 percent of the patients had a residual myopic error of greater than 1.0 D.<sup>3</sup> Hence, there exists a large pool of patients, with potentially treatable residual refractive errors after RK. LASIK has emerged as a viable treatment option for these cases.

*Hyperopia after RK:* Progressive hyperopia is a frequent complication following RK and has been attributed to a number of factors.<sup>4</sup> These include lack of preoperative cycloplegic refraction, extension of radial incisions to the limbus, multiple RK enhancement procedures, redeepening procedures, extended contact wear after RK and possibly postoperative ocular rubbing.

*Residual Myopia after Radial Keratotomy:* This has been attributed to factors like large optical zone, few or shallow incisions and varying healing response in different patients.<sup>5</sup>

### **Preoperative Assessment**

As for any refractive surgery, the first and foremost inclusion criterion is the patient's demand. It is documented that certain patients are satisfied with a particular refractive result and some others with even a better result are not so.<sup>6</sup> Thus, patients who are not satisfied with the outcome of the RK procedure should be considered for LASIK enhancement.

Although, after RK, the cornea never attains the preoperative strength, still there should be an interval of at least one year between the RK procedure and the intended LASIK enhancement. Timing is especially crucial with patients demonstrating regression after RK. Overactive healing is responsible for this regression, and its effect may

continue after LASIK, if it is performed too early. As in any routine LASIK, procedure the patient should have a stable refraction for over a six-month period. If



**Figure 20.1.** Radial keratotomy

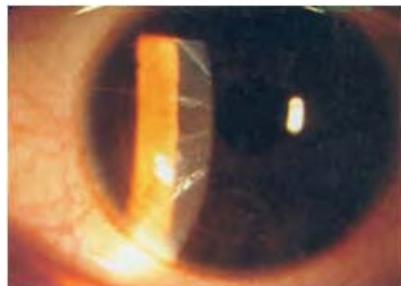
the patient has been wearing contact lenses, these should be taken off two weeks before the evaluation and actual LASIK procedure in case of soft contact lenses. This period is four weeks in cases of rigid gas permeable lenses. Patients wearing contact lenses may have deep vascularization, especially in the deeper incisions. In these eyes, the contact lenses should be discontinued for a longer period to allow for blood vessel regression. Topographic stability is adjudged by two similar topographic patterns obtained at a one-month interval.

The RK incisions should be examined in detail under high magnification of the slit lamp. The number of incisions and the size of the optical zone used for the RK procedure should be noted. There should be adequate healing of the incisions (Fig. 20.1). One should carefully search for the presence of any epithelial cysts in the incisions and presence of deep vascularization.

### Contraindications

While selecting patients for LASIK enhancement for post-RK eyes, there are certain absolute and some relative contraindications.

- 1. Thin Corneas:** The thickness of the cornea should allow for a minimum residual bed thickness of 300 microns after the ablation. As a greater flap thickness is desired in these eyes, this fact should be taken into consideration. In addition,



**Figure 20.2.** Contraindication for LASIK after RK—Epithelial inclusion cyst in RK incisions

the total corneal thickness should be at least 500 microns.

2. **History of Perforation During the Previous RK Procedure:** Any history of perforation during the previous RK procedure should be carefully looked into. Macroperforations are those which lead to a collapse of the anterior chamber compared to microperforations in which there is entry into the anterior chamber without its collapse. While there is consensus regarding a macroperforation being an absolute contraindication for a LASIK procedure, there is variable opinion regarding microperforations. Attia et al are of the view that history of microperforations also renders the eye unsuitable for LASIK enhancement procedure.<sup>7</sup> Others have said that only macroperforations should be considered as a contraindication and LASIK can be performed if, microperforation alone had occurred during the previous RK procedure.
3. **Epithelial Inclusion Cysts:** The RK incisions should be examined in detail under high magnification of the slit lamp. If there is evidence of epithelial inclusion cysts, LASIK should not be performed. (Fig. 20.2). These should be debrided and the cornea may be allowed to heal completely before LASIK is performed. This is a grave problem as the epithelium may be displaced under the flap, which may even cause flap melting.



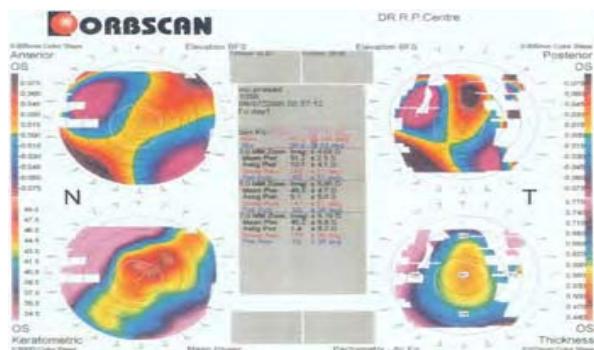
**Figure 20.3.** Contraindication for LASIK after RK -More than 8 incisions

- 4. More than Eight Incisions:** In the initial studies, LASIK enhancement was performed irrespective of the number of RK incisions. (Fig. 20.3) However, according to current opinion, LASIK enhancement should not be undertaken in eyes in which more than eight RK incisions have been given.
- 5. Small Optical Zone in the RK Procedure:** RK was performed with widely varying sizes of optical zone. If the optical zone is found to be less than 3 millimeters, LASIK should not be done.
- 6. Irregular Astigmatism:** LASIK enhancement should not be performed in cases with irregular astigmatism. (Fig. 20.4)
- 7. Flat Corneas:** These are more common in patients with overcorrections. They may cause a free flap. In addition, the diameter of the cut may not be large enough to perform hyperopic ablation.
- 8. Deep Vascularization:** It may be seen in contact lens users and is a relative contraindication.

### Surgical Technique

The basic surgical technique for performing LASIK enhancement in eyes having undergone RK is similar to the routine LASIK procedure; it is the flap management that differs.

- 1. Suction Ring:** A larger suction ring is preferred in such cases and a minimum diameter of 9.5 mm size should be used so that the RK incisions are encompassed in the ring.
- 2. Flap Thickness:** A thicker than normal flap is desired for performing LASIK in post-RK eyes. This helps in easier manipulation of the flap and prevents the gaping and opening of the incisions and consequently flap slippage. Thus, one should aim for a minimum flap thickness of 180



**Figure 20.4.** Contraindication for LASIK after RK—Irregular astigmatism



**Figure 20.5.** LASIK after RK

microns. It is desirable that the corneal epithelium should always be kept wet as this facilitates the pass of the microkeratome.

**3. Lifting of the Flap:** The cornea of a post-RK eye never regains the preoperative strength, as the keratotomy incisions never heal completely. This factor should always be kept in mind by the surgeon. The shearing forces applied on the flap edge while lifting can lead to opening of the RK incision sites or even the complete dehiscence of the flap. Keeping this fact in mind, the flap is handled with extreme care during the entire procedure. Various techniques have been suggested to successfully lift the flap in these eyes. The edge of the flap is teased open with a wide spatula and is lifted using the same. Use of forceps in these cases should be avoided to lift the flap as this causes unnecessary shearing force and may cause the splitting open of the incisions. Chung et al described a method of managing the flap in these cases.<sup>8</sup> In this method, a sinskey hook is first used to circumferentially inspect the flap periphery and identify any tears in the RK sites. Then, the hook is passed horizontally under the inferior aspect of the flap and the hook itself is used to lift the inferior quarter of the flap. Thus, the flap is completely supported during the lift, and no uneven forces are applied on the flap.



**Figure 20.6.** LASIK after RK

The process is repeated, so that the flap is folded on itself in quarters like a carpet. This technique was used in seven eyes of six patients, and no complications were reported during the lifting of the flap.<sup>8</sup>

4. Perfect fixation of the patient is necessary. If it is not maintained, eccentric correction and unpredictable astigmatism may result.
5. The ablation is performed in the routine manner. There is no special normogram for correction of residual refractive errors after RK. It has been proposed that an overcorrection of 0.50D should be applied to prevent regression of ablation effect.
6. A good flap apposition is mandatory after the ablation. If there are any areas of flap dehiscences, they should be carefully opposed during the repositioning of the flap. This helps to avoid seeding of the epithelial cells into the opened incisions.
7. Routine postoperative schedule is followed in these eyes. (Figs 20.5 and 20.6) However, the use of soft bandage contact lens is mandatory and should be applied in all the cases. It should be used for a minimum of four days or until complete epithelialization of the flap and incision edges, whichever is later.

**Table 20.1 Results of LASIK for residual refractive errors after RK**

Author/ Year	No of eyes	RKL Interval (years)	Mean FU (mo nths)	Preop SEQ	Preop Cyl	Postop SEQ	Pos top (D)	Pos top Cyl (D)	Postop UCVA*	Postop BCVA*	Post op BCV	±0.5D (%)	±1.0D (%)
Frances coni, 2002 <sup>1</sup>	69	9.4± 2.8	8.5± 2.4	3.4± 1.6	0.87± 0.92	0.32± 1.2	+0.76± 1.03	65.2	21.7	5.8	49.3	79.7	
Lipsh itz, 2001 <sup>11</sup>	15	10.4± 2.2	7.3	3.08± 1.02	1.20± 0.65	0.16± 0.73	0.0± 0.73	80.0	13.3	0	NA	80.0	
Yong, 2000 <sup>12</sup>	16	5.4	8.3	3.14± 3.04	NA	0.16± 0.68	NA	93.8	0	0	75.0	93.8	
Porte llinha, 2000 <sup>9</sup>	20	9±3	18±6	3.44± 1.25	0.78± 0.91	-0.66± 1.0	0.31± 0.58	NA	15.0	15.0	55.0	80.0	
Foresto, 1999 <sup>13</sup>	14	5.21± 3.32	12.64± 5.02	3.48± 3.52	2.75± 1.71	0.04± 0.87	0.70± 0.24	71.4	7.1	0	57.1	71.4	

FU=Follow-up, SEQ=Spherical equivalent, Cyl=Cylinder, NA=Not available, Preop=Preoperative, Postop=Postoperative

\* % of eyes having lost 1 line

\* \* % of eyes having lost 2 or more lines

### Complications

There are some complications that can occur while performing LASIK in post-RK eyes, which are unique to these eyes.

- 1. Opening of the RK incisions in the flap:** The shearing forces while lifting of the flap assume greater significance when done in post-RK eyes. The flap has been reported to open in “pie-like” pieces while being lifted. The opening of the RK incision specially occurs in cases of thin flaps and in those cases where the healing has not been proper following RK. To avoid this potentially serious complication, precautions for flap management have been discussed before. However, if it does occur, the pieces of the flap are repositioned carefully and LASIK is aborted. It should be performed at least one year later using a larger and a deeper cut.
- 2. Opening of the RK incisions in the stromal bed:** The RK incisions can also open up in the stromal bed rather than in the flap. If there is no loss of anterior chamber, then the incisions are aligned together and one can proceed with LASIK. However, if it leads to the loss of the anterior chamber, then the procedure has to be abandoned. These opened incisions would require sutures with 10–0 monofilament nylon.
- 3. Epithelial ingrowth:** These eyes are more prone to developing epithelial ingrowth due to the presence of multiple incisions. Careful repositioning of the flap and thorough irrigation of the interface can help in preventing this.

## Results

The aim of any refractive surgery is to give the best possible uncorrected visual acuity to the patient while avoiding any loss in the preoperative best corrected visual acuity.

Safety of any refractive surgery is assessed by comparing the postoperative best-corrected visual acuity to the preoperative levels. In the largest series of such surgeries reported till date, by Francesconi et al, 21.7 percent eyes lost 1 line of visual acuity and 5.8 percent lost two lines (Table 20.1).<sup>1</sup> Other smaller series have reported these rates in the range of 0 percent to 15 percent.<sup>9</sup> In the same series,<sup>1</sup> it was reported that 79.7 percent of patients were within 1D of emmetropia after LASIK.

A well-documented sequel of RK is diurnal fluctuation in visual acuity. In the Prospective Evaluation of Radial Keratotomy (PERK) study, 47 percent of patients with visual complaints who completed a questionnaire had fluctuating visual acuity at one year.<sup>3</sup> The mean diurnal change was  $-0.42 \text{ D} \pm 0.38 \text{ D}$ . Shah et al reported an unintended benefit of LASIK enhancement after previous RK.<sup>10</sup> They performed LASIK in 9 eyes of 6 patients having previously undergone RK. They found that after LASIK, there was a significant improvement in the diurnal fluctuation of visual acuity. The mean change in the manifest spherical equivalent from morning to evening was  $-0.143 \text{ D}$ .

## CONCLUSION

Only small series of LASIK enhancement after previous radial keratotomy have been reported. Most of them suggest that it is a safe and predictable procedure. Rigorous patient selection and careful flap handling is the key to a successful LASIK enhancement after previous radial keratotomy.

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## 21

# *LASIK after Penetrating Keratoplasty*

**Eric D Donnenfeld, Renée Solomon**

Over the past two decades dramatic improvements in microsurgical techniques have resulted in penetrating keratoplasty (PKP) becoming a more common and successful procedure, with over 40,000 surgeries performed annually.<sup>1</sup> Unfortunately, refractive errors postoperatively continue to challenge the visual rehabilitation of these patients. Most patients will not tolerate more than three diopters of anisometropia, due to image size disparity or astigmatism of greater than one and a half to three to 3 diopters.<sup>2-3</sup> Refractive unpredictability following penetrating keratoplasty is extremely common, due to the inherent imprecision of the operation with most series documenting mean cylinders of four to five diopters and significant anisometropia.<sup>4-10</sup> The residual refractive error may be due to surgical technique, wound healing and donor tissue variables, and is often further complicated by implantation of an intraocular lens. Refractive anisometropia and high postoperative astigmatism can compromise the patient's return to normal binocular function. Anisometropia may result in headache, photophobia, burning, tearing, diplopia, and blurred vision.<sup>2</sup> Binder reported in a series of patients following corneal transplant and cataract extraction that only 21 out of 43 eyes achieved refractive errors within two diopters of emmetropia.<sup>11</sup> Davis et al evaluated patients having combined cataract extraction with penetrating keratoplasty. Only 75 percent of patients fell between -4.00 and +2.00, when emmetropia was the goal.<sup>12</sup> Flowers, et al evaluated intraocular lens power calculation in combined corneal transplant and cataract extraction and reported that only 39 percent of patients had a refractive error within two diopters of emmetropia. The range of ametropia was from -9.75 to +12.88 diopters, with 65 percent of the patients having myopic errors.<sup>5</sup>

Many of these patients who cannot be rehabilitated with spectacle correction can be aided by contact lenses. Contact lenses are vital to the rehabilitation of the post-keratoplasty patient. Ten to 30 percent of patients who undergo penetrating keratoplasty wear contact lenses for visual rehabilitation. The incidence of contact lens wear following penetrating keratoplasty for keratoconus is 25 to 50 percent.<sup>13,14</sup> Both soft and gas-permeable contact lenses are extremely effective and remain the primary technique of visual rehabilitation following penetrating keratoplasty for patients who cannot tolerate spectacles.<sup>13-15</sup> Their use is successful in 80 to 90 percent of cases.<sup>13</sup> For myopia with low degrees of astigmatism, soft contact lenses are highly effective. Fitting with a gas-

permeable contact lens may be required for patients with greater levels of regular astigmatism and any level of irregular astigmatism.

Contact lens wear is not successful in many patients requiring visual correction following penetrating keratoplasty. The topographic abnormalities created by the penetrating keratoplasty wound can limit contact lens wear. In addition, contact lens intolerance may be caused by ocular, occupational, and systemic factors. Patients with dry eyes, blepharitis, lid abnormalities, and corneal neovascularization may not tolerate contact lenses. Occupational concerns include exposure to environmental factors such as wind, water, smoke, and poor sanitary conditions. Patients with poor manual dexterity, tremors, arthritis, or decreased visual acuity may be unable to manipulate a contact lens. Finally, unmotivated patients and patients unwilling or unable to practice good contact lens hygiene will be contact lens failures. In these patients, surgical alternatives may be the only option.

### **Surgical Alternatives to LASIK Following Penetrating Keratoplasty**

The surgical alternatives for correction of post-keratoplasty astigmatism include corneal relaxing incisions and wedge resections.<sup>16-18</sup> Kirkness et al reported a series of 201 corneal transplants for keratoconus and found that 18 percent of patients required refractive surgery for the correction of astigmatism.<sup>19</sup> These procedures can significantly decrease corneal cylinder and are highly effective procedures. However, they have minimal effect on spherical equivalent. In addition, they can be unpredictable and may destabilize the graft-host wound.

Radial keratotomy can decrease low to intermediate levels of myopia. In a large clinical trial, radial keratotomy has been shown to be effective but is associated with glare, significant inaccuracy, refractive instability, increased risk of traumatic ruptured globe, and progressive hyperopia.<sup>20</sup> Most series document poor visual rehabilitation with radial keratotomy for post-keratoplasty myopia, therefore radial keratotomy is not considered effective in its treatment.<sup>21</sup>

Pseudophakic patients with significant anisometropia can consider an intraocular lens exchange or a piggy-back intraocular lens. Unfortunately, these patients have already often undergone a significant number of intraocular procedures. This alternative requires an additional intraocular procedure, which increases the risk of endothelial decompensation, glaucoma, and may incite a graft rejection.<sup>22</sup>

### **Photorefractive Keratectomy Following Penetrating Keratoplasty**

Given the success of the excimer laser in treating myopia and astigmatism,<sup>23-25</sup> photorefractive keratectomy (PRK) has been studied and used to treat post-penetrating keratoplasty refractive errors.<sup>26-38</sup> However, the use of PRK in PKP patients is less predictable and less effective than for naturally occurring astigmatism and myopia.<sup>26,27,39</sup> A previously transplanted cornea may respond differently to PRK because corneal wound healing in a grafted cornea may differ from the normal wound-healing response of a patient's own cornea.<sup>26</sup> Post-penetrating keratoplasty PRK is also associated with increased incidence of irregular astigmatism,<sup>40,41</sup> significant regression, and late-developing corneal haze, which limit the effectiveness of PRK after PKP.<sup>26,29,30,37,42</sup>

Maloney, et al in a multicenter trial, reported a 29 percent rate of 2 lines or more visual acuity loss in patients treated with a photoreactive keratectomy following prior ocular surgery.<sup>33</sup> Two case-reports have documented allograft rejection following surface excimer laser photoablation.<sup>43,44</sup>

Recently, topography modulated PRK after PKP has been investigated to treat irregular astigmatism.<sup>45,46</sup> The software programme, corneal interactive programmed topographic ablation (LIGI, Taranto, Italy), has been shown to be extremely effective for the treatment of irregular astigmatism after PKP.<sup>45</sup> This software programme, which, by transferring programmed ablation from the corneal topography to a flying-spot excimer laser, is able to provide customized laser ablation to correct post-PKP astigmatism. There was improvement in uncorrected and best corrected visual acuity in all 10 eyes studied. During the mean follow-up of 8.4 months, no haze or regression was observed. The authors attribute their good results to the nature of the localized abnormality seen with irregular astigmatism. Ablating this localized abnormality requires less tissue removal than that required to correct a similar amount of regular astigmatism. Alessio et al believe that this sparing of corneal tissue allows treatment of high levels of irregular astigmatism, achieving at the same time a regular and smooth surface. Hjortdal and Ehlers have also studied astigmatism in post-keratoplasty eyes with customized laser ablation and have concluded that topography guided PRK of highly astigmatic corneal grafts can improve best corrected visual acuity and decrease corneal wavefront aberrations.<sup>46</sup>

While PRK is effective in reducing spherical equivalent to improve uncorrected and best corrected visual acuity as well as refractive and keratometric astigmatism, there is frequently a decrease in best spectacle corrected visual acuity (BSCVA) of at least one line. Visually significant haze, which develops from three to 12 months postoperatively, is the primary cause of the reduced BSCVA. More postoperative visually significant haze develops in PRK patients who have undergone prior keratoplasty, and a tendency for haze formation correlates positively with ablation depth.<sup>26,29,40</sup> In addition to reducing BSCVA, dense haze may also induce regression and irregular astigmatism, and cause visual symptoms including haloes, blurred vision, and glare. Many techniques have been tried that have had either little or no success in reducing postoperative haze or which produced severe side effects, including postoperative steroids,<sup>47,48</sup> corneal cooling and rehydration during PRK,<sup>49</sup> synthetic inhibitor of metalloproteinase and cyclosporin A,<sup>50</sup> and topical anti-transforming growth factor-beta and topical interferon alpha 2b.<sup>51,52</sup> More recently mitomycin C (MMC), an antibiotic with alkylating properties, has been shown to be effective in treating post-PRK haze by preventing the proliferation of keratocytes,<sup>53-56</sup> and MMC has been shown to decrease corneal light scattering after phototherapeutic keratectomy.<sup>57</sup> MMC inhibits DNA synthesis, preferentially affecting rapidly dividing cells, is fast-acting and demonstrates long-lasting suppression of keratocyte activity after only a single dose.<sup>56</sup> Typically only prolonged use of higher concentrations of MMC lead to significant complications.<sup>58,59</sup> Transient toxic side effects such as hyperemia, pain and blepharospasm have been reported with 0.02 percent MMC but resolved with cessation of the drug.<sup>53</sup> Majmudar et al.<sup>54</sup> used MMC in eight eyes of five patients who had undergone RK or PRK and demonstrated an improvement in corneal clarity and BSCVA in each eye the technique described by Majmudar<sup>54</sup> and Raviv<sup>60</sup> is as follows: A No. 64 Beaver blade was used to remove the patient's corneal epithelium and as much as fibrosis as possible. Then a 6 mm circular sponge soaked in MMC (0.02%) was applied to the central corneal

surface for two minutes. After removal of the sponge, the ocular surface was irrigated with 30 ml of balanced salt solution. The eye was then covered with antibiotic-steroid ointment and covered with a contact lens or patch. In one of the eight eyes described by Majmudar et al<sup>53</sup> they used MMC to treat central haze in a PRK patient post-PKP. A 44-year old patient, who underwent PRK post-PKP 18 years prior developed corneal haze, which limited his BSCVA to 20/30. The described procedure resulted in a clear cornea and BSCVA of 20/20. Azar and Jain<sup>61</sup> emphasize that based on the data by Majmudar et al<sup>54</sup> it may be justified to use MMC to treat pre-existing corneal scarring, however, they caution against the use of MMC for the prevention of corneal scarring. Azar and Jain propose, that if MMC is used prophylactically, the use of annular application may be more beneficial than use of MMC soaked discs.<sup>61,62</sup> They hypothesize that the beneficial effect of MMC may be due to the inhibition of keratocytes under the annular zone of application, thus decreasing the centripetal migration of activated keratocytes and subsequent collagen deposition. They also believe that the annular method may be beneficial in decreasing corneal toxicity and the contact of MMC with the central three mm of the cornea. We have applied 0.02 percent MMC for thirty seconds to nine patients undergoing PRK following PKP for keratoconus, with no loss of BSCVA, corneal haze, or adverse reactions to the corneal button. Further studies need to be performed to investigate the effectiveness of MMC in the prophylaxis of corneal haze after PRK. When applied as described by Majmudar et al<sup>54</sup> MMC appears to be a safe and effective method for treating postoperative haze following PRK and may improve the efficacy of PRK following PKP.

### **LASIK Following Penetrating Keratoplasty**

LASIK offers several advantages over PRK in the treatment of myopia and astigmatism. These advantages include, but are not limited to, rapid visual rehabilitation, decreased stromal scarring, less irregular astigmatism, minimal regression, and the ability to treat a greater range of refractive disorders.<sup>23,63-66</sup> The major disadvantage of LASIK is the risk of complications related to the creation of the lamellar flap. There have been several reports demonstrating efficacy and safety of LASIK following penetrating keratoplasty.<sup>67-79</sup>

### **Patient Selection and Preoperative Evaluation**

LASIK following penetrating keratoplasty is subject to the same constraints as conventional LASIK. Monocular patients or patients with limited visual potential in the fellow eye are not good candidates. In addition, patients with wound healing disorders, significant dry eye and collagen vascular disease should be offered other options. Finally, patients should have realistic expectations for their rehabilitation following LASIK for penetrating keratoplasty. The accuracy of the procedure is not as precise as conventional LASIK and patients should expect to require spectacles for residual refractive error. The goal of LASIK following penetrating keratoplasty is the return of spectacle corrected binocular vision.

## Time Interval between PKP and LASIK

The time frame between performing the penetrating keratoplasty and the LASIK procedure has not been firmly established. However, all corneal sutures must be removed prior to the LASIK as they will induce astigmatism. The time frame for suture removal varies greatly depending upon the variables of patient age, corneal vascularization, corticosteroid use, physical examination of the graft-wound interface, and surgeon preference. Following suture removal there are two variables, which dictate whether the eye is ready for LASIK: *a stable refraction* and *a well-healed wound*, which will withstand the increased intraocular pressure, created during the LASIK procedure. Conventional wisdom is that following gas-permeable contact lens wear, the lens should be removed for a month for every decade of contact lens wear. Following suture removal, the cornea should also be allowed to return to a stable configuration. Lam and colleagues<sup>80</sup> have recommended that the wound be examined for whitening and scarification, while the refraction and corneal topography should be stable on serial evaluation. Some authors recommend waiting for 2–3 years,<sup>68,71</sup> while others recommend for as little as eight months<sup>70</sup> to perform LASIK following the penetrating keratoplasty procedure. Of note, there have been no documented cases of wound dehiscence following LASIK for penetrating keratoplasty refractive errors. We therefore recommend waiting a minimum of three months following suture removal and until serial topographies are stable to perform LASIK following penetrating keratoplasty. We always perform monocular surgery.

## Preoperative Evaluation

The preoperative examination should be comprehensive and include a thorough retinal evaluation. The ocular surface should be carefully evaluated as patients following penetrating keratoplasty will have decreased corneal sensation and may have accompanying tear-film abnormalities. The anticipated LASIK procedure will often cause a neurotrophic keratitis and worsen the dry eye condition.<sup>81</sup> Patients with preoperative lid disease should be treated with lid hygiene, antibiotic and/or steroid application to the lid margin as indicated, and oral tetracycline family antibiotics as indicated. Patients with aqueous deficiency dry eye should be treated with tear supplementation, ointments, and punctal occlusion when needed. The corneal graft should be carefully evaluated. Any sign of allograft rejection or intraocular inflammation is a contraindication to the procedure and should be treated. Areas of pannus should be noted as they may cause significant bleeding during the LASIK procedure. In addition, the graft/host interface should be examined for adequate wound healing and particularly for signs of poor wound apposition. Patients with high astigmatism may have an unstable wound with override of the wound, which would increase the risk of wound dehiscence. Typically, patients with wound override will have marked hemimeridional flattening in the axis of the override. These patients should have their wound reapproximated in the aberrant region and then resutured prior to considering LASIK. The corneal clarity and pachymetry should be evaluated, and, when in doubt, specular microscopy should be performed. Patients with poor endothelial reserve may have an increased risk of flap slippage due to decreased endothelial pump function holding the flap in place. Donnenfeld et al described three cases of flap slippage in patients with PKP for endothelial decompensation with

peripheral corneal edema. Patients with a history of keratoconus should have their topography examined carefully for signs of recurrent disease. When the topography is equivocal or additional information is needed, new technology, such as the Orbscan (Orbtek, Inc. Salt Lake City Utah) or high frequency ultrasound may provide additional information regarding anterior corneal curvature, posterior corneal curvature, and corneal pachymetry. Patients with previous relaxing incisions should have the axis of the incisions carefully documented. The corneal hinge should be positioned away from the relaxing incision to decrease the incidence of free flaps. For example, a patient with a superior relaxing incision should have a nasal hinged flap.

The status of the lens should also be carefully evaluated. Following penetrating keratoplasty there is an increased incidence of cataract formation. LASIK is contraindicated in these patients who would most benefit from cataract extraction and intraocular lens implantation to help correct spherical refractive errors. In patients with a history of previous cataract extraction and intraocular lens implantation the status of the implant should be evaluated. In general patients with posterior chamber, lenses do very well with LASIK. On the other hand LASIK is usually contraindicated in patients with an anterior chamber intraocular lens, unless the anterior chamber is very deep. These patients are at risk for endothelial touch against the intraocular lens when the cornea is compressed during the microkeratome pass.

The most common indication in the United States for penetrating keratoplasty is pseudophakic bullous keratopathy.<sup>82-84</sup> There is a high incidence of macular pathology following penetrating keratoplasty for pseudophakic bullous keratopathy. Patients whose final visual rehabilitation is limited by macular pathology are often less motivated to wear contact lenses. Chronic cystoid macular edema is seen in 42 to 50 percent of cases of pseudophakic bullous keratopathy<sup>85,86</sup> and there is a six to 24 percent incidence of involutional macular degeneration following penetrating keratoplasty,<sup>87,88</sup> both of which can severely limit visual rehabilitation. These patients may have a best corrected visual acuity ranging from 20/25 to count fingers, with the majority having visual acuities of 20/40 or less.<sup>14</sup> Price reported that only 50 percent of patients with grafts for pseudophakic bullous keratopathy achieved a visual acuity of 20/40 or better,<sup>14</sup> while Zaidman<sup>89</sup> reported 31 percent and Speaker<sup>90</sup> a 22 percent incidence of visual acuity of 20/40 or better following penetrating keratoplasty for pseudophakic bullous keratopathy.

Pseudophakic bullous keratopathy occurs over-whelmingly in an elderly population. Assuming these patients have good visual acuity in their fellow eye, there may be little motivation for an elderly individual, with no possibility of visual rehabilitation to the level of the fellow eye, to wear a soft or gas-permeable contact lens. These patients have had previous cataract surgery, penetrating keratoplasty, approximately one year of postoperative visits prior to suture removal, and, often, a vitreoretinal consultation. When they are ready for their visual rehabilitation, they are told they cannot be improved with spectacles due to significant anisometropia. Even though their central visual acuity may be diminished, these patients would benefit greatly from the expanded peripheral visual field. These patients are excellent candidates for post-penetrating keratoplasty LASIK, which can offer permanent rehabilitation of their refractive error.

### ***Surgical Technique***

There are several alterations of our normal LASIK technique when treating myopia and/or astigmatism following penetrating keratoplasty.

As in all LASIK, preservation of the epithelium is extremely important to reduce the risk of flap slippage, epithelial ingrowth, and flap melts. Following a penetrating keratoplasty these concerns are even more important. The surgeon should optimize the ocular surface preoperatively as discussed earlier and at the time of surgery minimize the use of topical anesthetics with the first drop of topical anesthesia given immediately prior to the surgical procedure. The ocular surface should be irrigated immediately following surface marking with gentian violet to reduce toxicity but maintain the marking in the event of a free flap. Perioperatively, toxic medications such as the aminoglycoside antibiotics should be avoided, and if a non-steroidal anti-inflammatory is employed, we prefer non-preserved ketorolac tromethamine (Acular, Allergan, Irvine, CA). Intraoperatively, following flap repositioning, we place a drop of carboxymethylcellulose 1 percent (Celluvisc, Allergan, Irvine C A) directly on the center of the flap after approximately 30 seconds to lubricate and protect the ocular surface.<sup>91</sup> After repositioning of the corneal flap, we generally wait two minutes for the flap to adhere to the underlying stromal bed in conventional LASIK. In LASIK after penetrating keratoplasty, we wait five minutes for flap adherence before removing the speculum. We carefully perform a striae test for flap adherence and if the flap is not tightly apposed to the stromal bed or if there is an epithelial defect, we place a bandage contact lens. Immediately after exiting the surgical suite the patient is asked to gently keep their eyes closed for 30 minutes and the flap is re-evaluated carefully by slit lamp biomicroscopy. Any flap irregularity is dealt with and we do not allow the patient to leave until we are fully satisfied that the flap is in good position. The patients are then asked to return home and keep their eyes closed for 2–3 hours. The patient uses non-preserved tears transiently or for a week and wears a shield for a week as well. We are also more liberal with our use of postoperative corticosteroids than in our normal LASIK patients. In LASIK following penetrating keratoplasty, we use prednisolone acetate 1 percent four times daily for one week tapering to once daily for two weeks. We feel the additional use of corticosteroids is indicated due to the potential risk of graft rejection following any surgical procedure on a penetrating keratoplasty. For antibiotic prophylaxis we use ofloxacin 0.3 percent four times a day beginning the day prior to surgery and continuing 5 days postoperatively.

We also alter our perioperative management for specific indications. Patients with corneal neovascularization are given one drop of 1 percent epinephrine 30 seconds prior to the microkeratome pass to reduce intraoperative bleeding. Patients with a history of *herpes simplex* or *herpes zoster* should be evaluated carefully for corneal sensation. Patients with a history of *herpes simplex* are treated preoperatively with oral antiviral therapy, which is then continued for a minimum of 10 days postoperatively to reduce the risk of recurrent viral disease induced by surgical trauma.

The LASIK surgeon must maintain a high degree of concern for the possibility of flap instability and slippage in any post-keratoplasty eye, especially during the perioperative period. Donnenfeld et al<sup>92</sup> presented three cases of flap slippage in post-keratoplasty LASIK eyes. The main risk for flap slippage was corneal edema. All three patients had pseudophakic bullous keratopathy as the indication for penetrating keratoplasty, and all had peripheral corneal edema at the time of flap slippage, which occurred at a mean of

seven days postoperatively (range, 3 to 10 days). The final results of treatment for flap slippage were mixed. One patient had a lift and smooth procedure with a one-line improvement in BSCVA to 20/40; one patient had a two-line loss of BSCVA and underwent removal of the surgical flap, with uncorrected visual acuity (UCVA) of 20/50 and no loss of BSCVA of 20/30. The third patient had a three-line loss of BSCVA following a lift and smooth procedure, and underwent a repeat penetrating keratoplasty for irregular astigmatism. This small case series highlights the importance of the endothelial pump function in maintaining the adherence of the LASIK flap. Any sign of corneal edema is an indication that the endothelial pump function has been overwhelmed, and that the flap is at increased risk for slippage.

Corneal grafts are at higher risk for corneal edema because of their lower numbers of endothelial cells. The mean human endothelial cell density starts at around 4000 cells/mm<sup>2</sup> in the first decade of life, declining gradually to a plateau of around 2600 cells/mm<sup>2</sup> by age 40.<sup>93</sup> While the average cell density of donor corneas is around 2,665 cells/mm<sup>2</sup>,<sup>94</sup> grafts undergo a more rapid and continual decline in endothelial cell count than do normal corneas, with cell loss of 7.8 percent per year for the first five postoperative years, followed by a 4.7 percent annual decline for years 5–10, according to a Mayo clinic study.<sup>95</sup> This compares to a 0.5 percent per year decline in normal controls.<sup>96</sup>

Even if a graft is clear and non-edematous before LASIK, the surgeon must decide whether there is a possibility of endothelial compromise from LASIK itself. On the one hand, current studies have found no long-term endothelial effects of LASIK Jones et al found no effect on the endothelium in 98 eyes which were followed up to 12 weeks postoperatively,<sup>97</sup> and Perez-Santonja et al, who followed patients up to six months, found that endothelial parameters in contact lens wearers actually improved after LASIK because of the discontinuation of contact lens wear.<sup>98</sup> One study of four patients who underwent LASIK after penetrating keratoplasty and were followed for 12 months found no change in the endothelium.<sup>99</sup> On the other hand, changes in endothelial cell morphology, probably related to transient corneal edema, were noted at 15 minutes postoperatively by Kim et al.<sup>100</sup> Although these changes resolved by the first post-operative day, they could compromise endothelial pump function in post-keratoplasty eyes.

As part of the LASIK evaluation in post-keratoplasty eyes, we recommend a careful examination of the corneal graft for evidence of corneal edema. Pachymetry should be reviewed not only for adequate post-LASIK bed thickness, but also for evidence of edema. Specular microscopy may be performed if there is clinical suspicion of low endothelial cell density.

In most cases of LASIK, especially in patients with a history of a dry eye, we recommend a nasal-hinged flap, which helps to retain corneal sensation. We maintain this recommendation in post-keratoplasty eyes, because maintaining corneal sensation is vital to long-term success of a corneal graft. However, in the case of LASIK performed on a post-keratoplasty eye with Fuchs' dystrophy or pseudophakic bullous keratopathy, or any post-keratoplasty eye in which the endothelial function may be marginal, we instead recommend an 8.5 mm diameter superior hinge flap, particularly when the peripheral host bed has frank edema. If the peripheral cornea is edematous and the pump function of the endothelium is decreased, it is more likely the peripheral flap will elevate and dislocate

following a blink, compared to a superior-hinged flap. The smaller diameter flap has less tissue overlying the edematous peripheral bed and is also less likely to elevate. We also recommend that patients with endothelial compromise who undergo LASIK wear protective shields for a longer than normal period, and be followed closely to reduce the risk of flap slippage.

At the time of surgery we use our standard LASIK procedure altered only to avoid initiating the incision at the corneal transplant graft-host interface. The patients donor corneas generally range in size from 7.75 to 8.5 mm in diameter. The flap diameter created by most microkeratomes is approximately 8.5 to 9.5 mm. Therefore, the flap is almost exactly the same size as the donor cornea. We avoid initiating the flap temporally or inferiorly at the graft-host interface, while attempting to center the flap over the pupil. This allows the flap to drape over the wound. We believe this creates better wound apposition of the flap to the recipient bed. The corneal scar tissue at the penetrating keratoplasty wound tends to be less pliable than normal corneal tissue. In addition, initiating the LASIK incision away from the wound prevents applying additional pressure directly to the corneal transplant incision and may decrease the risk of wound dehiscence. We also avoid placing the hinge over corneal relaxing incisions.

### **One Step Versus Two Step LASIK Following Penetrating Keratoplasty**

When planning to perform LASIK on an eye with a previous corneal transplant, the surgeon must address the issue of whether to perform LASIK as a one-step or a two-step procedure. In the two-step procedure, as described by Vajpayee and Dada,<sup>101</sup> the surgeon cuts and replaces the flap, and then follows the corneal topography, keratometry, and refraction for a variable span of time (weeks to months). Once the measurements have stabilized, the flap is lifted and ablation is performed to correct any residual refractive error.

The main argument for performing a two-step procedure is that some corneal remodeling may occur following the creation of the microkeratome cut alone. This cut may change the biomechanics of the posttransplant cornea, which depends to a great extent on the dynamics at the host-graft interface. Changes in corneal shape following the creation of a flap, and prior to laser ablation, has been noted by Roberts.<sup>102</sup> Anecdotally, Vajpayee and Dada reported treating several of their patients successfully with the two-step procedure. Busin et al<sup>103</sup> sought to take advantage of the change in astigmatic power and/or axis that occurs following the creation of a lamellar cut. In a series of nine eyes, all of which were at least 22 months post-transplant, creation of lamellar flaps alone resulted in a mean reduction of 1.6D of cylindrical error and 1.0D mean reduction of myopia three months postoperatively, without laser ablation.

There are a few arguments for performing a onestep LASIK procedure in a post-keratoplasty eye. First, it is likely that most of the instability of the refractive error following flap formation (with or without stromal ablation) is due to a change in flap position rather than to changes in corneal biomechanics. Good flap position may be difficult to obtain even in normal corneas, and flap instability is especially problematic in post-keratoplasty eyes, in part because of the compromised pump function of the graft endothelium, and in part because of the irregularity of the bed and the graft-host junction.

It is possible that the changes in refraction and topography, seen over the weeks to months following the creation of a corneal flap in a post-keratoplasty eye, are due to continued slippage of the flap. If this is the case, then performing a two-step procedure simply increases the uncertainty about the final flap position, because the flap must be laid down twice. In addition, performing a two-step procedure gives rise to an additional episode of possible flap complications, including infection and allograft rejection. The adherence of the flap over some areas of the graft-host interface can be much more tenacious than is seen in normal corneas, making it more difficult for the surgeon to relift the flap without complications. Epithelial ingrowth becomes a higher likelihood with the irregular flap border that can occur in these situations.

Although the refraction in post-keratoplasty eyes seems to fluctuate more than in normal eyes, the results of the one-step procedure produce a considerable and immediate improvement in visual function that will be delayed with the two-step procedure, and that is not achieved with the creation of a lamellar flap alone. Nirankari produced a 74 percent reduction in myopia with the one-step method, and Donnenfeld et al achieved a 90 percent reduction in myopia in 22 patients (with an average improvement of 6.8D at three months).<sup>92</sup> In contrast, Busin et al saw a reduction of myopia of 19 percent in eyes treated with a lamellar cut alone.<sup>103</sup> The cylindrical correction was also better with the one-step



**Figure 21.1.** Epithelial ingrowth following LASIK in a patient with previous PKP



**Figure 21.2.** Flap melt in a patient with epithelial ingrowth following

## LASIK after PKP for residual refractive error.

method (a 65% reduction in cylinder documented by Nirankari, and 59% by Donnenfeld et al<sup>92</sup>) compared to the lamellar flap only method (32% reduction in cylinder).<sup>103</sup>

### Complications of LASIK after Penetrating Keratoplasty

Any complication reported following LASIK for visual rehabilitation of myopia, hyperopia, or astigmatism may occur following LASIK for post keratoplasty refractive error. The complications cited in the literature include intraoperative paracentral flap perforation,<sup>71</sup> flap dislocations requiring placement of a suture,<sup>71,73</sup> buttonhole flap,<sup>74</sup> hemorrhage



**Figure 21.3.** Protecting the flap with carboxymethylcellulose immediately following LASIK in a patient with a prior PKP



**Figure 21.4.** Relaxing incision post LASIK residual myopia and astigmatism following PKP

in the stromal bed,<sup>67</sup> obstruction of the microkeratome path by graft sutures,<sup>67</sup> consecutive irregular astigmatism,<sup>69</sup> photoablation decentration,<sup>96</sup> corneal perforation concurrent with astigmatic keratotomy performed under the flap,<sup>72</sup> peripheral interface epithelial ingrowth not requiring treatment,<sup>77</sup> one case of severe epithelial ingrowth treated without success for six months at which time eye had irregular astigmatism and moderate stromal melt,<sup>78</sup> and three cases of diffuse lamellar keratitis, one of which caused a decrease in BSCVA.<sup>79</sup> We have additionally seen flap striae, epithelial ingrowth, and flap melts following LASIK in patients with previous penetrating keratoplasties (Figs 21.1 to 21.4).

In LASIK the intraocular pressure is elevated to over 65 mmHg, and there is a very small but very real risk of wound dehiscence. We recommend LASIK following penetrating keratoplasty be performed by experienced LASIK surgeons who can minimize the suction time needed during surgery. A careful slit lamp examination on the day of surgery is extremely important as improper wound alignment may lead to wound dehiscence, epithelial ingrowth, poor flap adherence, and ectasia.<sup>73</sup>

If the placement of a flap on an eye post-PKP needs to be adjusted, it is extremely important to carefully debride that epithelium which rapidly grows over the exposed stromal bed. Flap stabilization with 10–0 nylon interrupted sutures should be considered if the flap does not properly adhere. It is important to bury the knots outside the flap to prevent epithelial defects on the flap and epithelial seeding at the stromal interface. Furthermore, burying the knots under the peripheral epithelium helps to prevent flap dislocation from suture tension caused by the resistance to sliding of the knot through the flap at the time of surgical removal.<sup>73</sup>

### Clinical Results

The first case reports by Arenas and Maglione,<sup>67</sup> Arenas and Garcia,<sup>76</sup> Zaldivar and associates,<sup>68</sup> as well as Parisi<sup>70</sup> in 1997 documented the efficacy of LASIK following penetrating keratoplasty. In these case-reports all the patients were treated for residual myopia or myopic astigmatism following penetrating keratoplasty for keratoconus.

The first large series of LASIK following penetrating keratoplasty was presented by Donnenfeld and associates at the American Academy of Ophthalmology in 1998 and published in 1999 (Table 21.1).<sup>69</sup> The most common indication for the penetrating keratoplasty was keratoconus (13 eyes), followed by pseudophakic bullous keratopathy (5 eyes), Fuchs' endothelial dystrophy with combined cataract extraction (3 eyes), *herpes simplex* keratitis (1 eye), and *herpes zoster* keratitis (1 eye). Fifteen eyes were phakic and eight eyes were pseudophakic. Three patients had undergone corneal relaxing incisions for high cylinder following penetrating keratoplasty and antecedent to their LASIK surgery. Two patients underwent enhancements. Sixteen eyes were followed for six months, and seven eyes were followed for 12 months. The mean spherical equivalent preoperatively was  $-7.58 \pm 4.42$  diopters, which was reduced to  $-1.09 \pm 2.01$  diopters,  $-0.79 \pm 1.84$  diopters,  $-0.77 \pm 1.25$  diopters, and  $-1.57 \pm 1.20$  diopters respectively one, three, six and 12 months following LASIK. The mean cylinder preoperatively was  $3.64 \pm 1.72$  diopters, which was reduced to  $1.98 \pm 1.15$  diopters,  $1.64 \pm 1.14$ ,  $1.48 \pm 0.92$  diopters, and  $1.29 \pm 1.04$  diopters respectively at one, three, six and 12 months following LASIK. Spherical equivalent anisometropia was reduced from a mean of  $6.88 \pm 4.4$

diopters to  $1.42 \pm 1.05$  diopters at the final exam. Best corrected visual acuity remained the same or improved in 21 of 23 eyes, and decreased by one line in a patient who developed a nuclear sclerotic cataract and three lines in a patient who

**Table 21.1: Summary of clinical results of LASIK after penetrating keratoplasty**

Study	No. of Eyes	Change in Spherical Equivalent (%)	Change in Cylinder (%)	Patients with UCVA $\geq 20/40$ after LASIK (%)
Donnenfeld et al.	23	79.28–89.84	45.60–59.34	36
Preschel et al.	25	79.79	65.07	31.81
Webber et al.*	25	74.80	66.32	28
Forseto et al.	22	85.27	57.78	54.5
Malecha et al	19	80.0	69.9	73.7

LASIK=laser in situ keratomileusis, UCVA=uncorrected visual acuity, \*14 patients also received arcuate keratotomies in the stromal bed at the time of surgery

developed irregular astigmatism. Endothelial cell counts measured in nine patients preoperatively and at three months postoperatively demonstrated no statistically significant loss. There were no surgical flap or corneal transplant complications.

### Results and Visual Outcome

There have been several other studies of comparably large series examining LASIK after penetrating keratoplasty whose results are summarized in Table 21.1. Preschel and colleagues<sup>73</sup> examined 25 eyes treated with LASIK for astigmatism and myopia following penetrating keratoplasty. Two eyes were enhanced with additional LASIK, but the authors did not include these post enhancement results in their analysis. Fifteen patients were followed for at least six months and five of those were followed for one year. The mean follow-up time was 5.52 months with a range of one day to 12 months. The mean preoperative spherical equivalent of  $-4.70 \pm 2.98$  diopters was decreased to  $-0.95 \pm 1.45$  diopters post-operatively. The mean cylinder preoperatively was  $-4.58 \pm 2.12$  diopters, which was reduced post-operatively to  $1.60 \pm 1.19$  diopters. For this series, the UCVA was available in only 16 eyes at the last examination. Prior to LASIK, the uncorrected visual acuity was worse than 20/40 in all the eyes. After LASIK 31.81 percent of the eyes demonstrated an UCVA of equal to or better than 20/40. Best spectacle corrected visual acuity remained the same or improved in 16 of 23 eyes. Four eyes lost one line of BSCVA and three eyes lost two lines of BSCVA, one of which only had one day of post-LASIK follow-up. Another one of these eyes had a dislocated flap one the first postoperative day and had a BSCVA of 20/30 but gained 4 lines of UCVA. A third eye of this group had a postoperative BSCVA of 20/40 but gained eight lines of UCVA from 20/800 to 20/50. The complications in this series were two displaced flaps

that were treated with 10-0 nylon interrupted sutures to stabilize the flaps after repositioning.

Guell and coworkers<sup>77</sup> performed LASIK in 87 eyes of which 20 had undergone prior PKP. The authors presented a pooled analysis or the results of LASIK after PKP and after other surgical procedures including RK, PRK, and cataract surgery. A distinct analysis of post-PKP results was not offered. They did note that the predictability in treating astigmatism in post-PKP eyes was comparable to that for eyes with no prior surgery. The authors reported that when examining stability of post-LASIK refraction for the entire group, a change of  $\pm 0.5$  diopters was observed for 94.3 percent of patients. They point out that an important exception was one case of LASIK after a penetrating keratoplasty, which regressed 2.00 diopters of cylinder. Guell et al also noted that for 45 percent of the eyes (9 out of 20 eyes) that were treated with LASIK post-PKP, enhancements were necessary to treat under-corrections. Although not included in the studied series, Guell and coworkers mentioned that they perform relaxing incisions in post-PKP eyes with more than six diopters of cylinder and wait until the refraction is stable to treat the residual error with LASIK.

Webber and associates<sup>72</sup> studied 26 eyes and reported results of LASIK in 25 eyes with post-PKP ametropia. One eye was excluded from the analysis as it sustained a corneal perforation. The most common indication for penetrating keratoplasty in the Webber et al study was keratoconus (23 eyes). The three other grafts were performed for pseudophakic bullous keratopathy, childhood trauma, and *Acanthamoeba* keratitis. Four eyes had a history of ocular surgery after the PKP. One eye underwent a cataract extraction with intraocular lens implantation, one eye had a resuture of the graft host junction, and two eyes had incisional refractive keratectomies. Fourteen eyes received arcuate cuts in the stromal bed at the time of surgery. Eighteen eyes were followed for six months or more and seven eyes were followed for 12 months. The mean preoperative spherical equivalent of  $-5.20 \pm 2.31$  diopters was reduced to  $-1.31 \pm 1.63$  diopters at the final follow-up. The mean cylinder preoperatively was  $-8.67 \pm 3.22$  diopters, which was decreased postoperatively to  $2.92 \pm 1.71$  diopters. The patients who received arcuate cuts concurrent with the LASIK demonstrated greater target-induced astigmatism, surgically induced astigmatism, and astigmatism correction index than those eyes, which did not. Three eyes showed a decreased BSCVA by one line and all eyes were unchanged or showed improvement in up to six lines of UCVA.

In their case series, Forseto and colleagues<sup>71</sup> studied the efficacy of LASIK in 22 eyes post-keratoplasty. Eighteen eyes had a history of prior PKP, while four eyes underwent lamellar keratoplasty. The most common indication for penetrating keratoplasty in the Forseto et al study was keratoconus (20 eyes). The two other grafts were performed for leukoma from herpes and irregular astigmatism after LASIK. The eyes were followed for an average of 10.09 months with 11 patients being followed for one year. Spherical equivalent demonstrated a mean reduction from  $-4.55 \pm 3.66$  diopters preoperatively to  $-0.67 \pm 1.24$  diopters postoperatively. Cylinder demonstrated a mean reduction from  $-4.24 \pm 2.29$  diopters preoperatively to  $-1.79 \pm 1.12$  diopters postoperatively. In 17 eyes the BSCVA was unchanged or improved. Of the five eyes not showing improvement, two lost two lines and three showed a decrease in one line of BSCVA. Stability of the refractive results was noticed between one to six months post-LASIK. At their final examination, 16 eyes (72.7%) demonstrated a refractive error within  $\pm 1.00$  diopter of

emmetropia. In 11 eyes it was determined that the mean endothelial cell count did not show any statistically significant loss. There were complications in two eyes, one eye had an intraoperative paracentral flap perforation and the other eye had a flap dislocation, which required stabilization with sutures.

In a series of 27 cases, Lima and colleagues<sup>78</sup> reported results of LASIK to correct ametropia after PKP for keratoconus for 26 of the eyes. One eye was excluded from the analysis because of an inability to obtain an exact postoperative refraction. The patient was treated for severe epithelial ingrowth for 6 months at which point he developed irregular astigmatism and moderate stromal melt. The average length of follow-up was 9.52 months for 23 myopic eyes and 5.75 months for 4 hyperopic eyes. Prior to LASIK the mean refractive spherical equivalent in the myopic eyes was  $-5.27 \pm 1.91$  diopters and  $-0.45 \pm 1.68$  diopters at the final follow-up. Mean spherical equivalent for hyperopic eyes decreased from  $+5.18 \pm 1.46$  diopters to  $+1.18 \pm 0.94$  diopters post-LASIK. In all of the hyperopic eyes and 18 (78%) myopic eyes postoperative uncorrected visual acuity was 20/40 or better. Postoperative BSCVA was better than 20/25 in all of the hyperopic eyes and 22 (95.7%) of the myopic eyes. One eye lost one line of BSCVA. The significant complication was that one eye lost six lines secondary to refractory epithelial ingrowth which resulted in irregular astigmatism and stromal melt.

Malecha and Holland<sup>79</sup> examined LASIK in 20 eyes following PKP. One eye was excluded from the analysis because of a severe traumatic injury post-LASIK. In the majority of eyes (73.7%) keratoconus was the indication for PKP. Other causes included corneal scar secondary to injury (2 eyes), corneal scar secondary to HSV keratitis (1 eye) and corneal thinning (1 eye). One eye received an arcuate incision in the graft to reduce astigmatism. The average length of post-LASIK follow-up was five months (range 1–14 months). UCVA was 20/400 or worse in 73.7 percent of eyes before LASIK and improved to 20/40 or better post LASIK in 73.7 percent of eyes. The mean preoperative refractive spherical equivalent was reduced by 3.39 diopters (80.0%) from  $4.24 \pm 2.81$  diopters preoperatively to  $0.85 \pm 0.84$  diopters at the final follow-up. The mean cylinder was reduced by 2.83 diopters (69.9%) from  $4.05 \pm 1.71$  diopters to  $1.22 \pm 1.14$  D. Seventeen of the nineteen eyes achieved a BSCVA of 30/40 or better. Myopic degeneration was responsible for the decreased BSCVA in one eye with BSCVA of 20/50 and DLK was noted in one eye with a BSCVA of 20/150. A total of three eyes developed DLK and were treated with steroids. Two of the cases resolved promptly with no decrease in BSCVA. In the third case, grade 2 DLK persisted, causing stromal haze and decreased BSCVA in a patient with a history of systemic lupus erythematosus.

## CONCLUSION

The goal of therapeutic LASIK for visual rehabilitation following penetrating keratoplasty is not necessarily the same as LASIK for the correction of myopia and/or astigmatism. The primary goal of LASIK following penetrating keratoplasty is resolution of sufficient myopia and astigmatism to allow spectacle correction of the residual refractive error. Uncorrected visual acuity remains a secondary goal with LASIK following penetrating keratoplasty, whereas uncorrected visual acuity is clearly the primary objective of cosmetic LASIK. For this reason, return to binocularity and

optimized best-corrected visual acuity with spectacles is the true end-point for success with LASIK following penetrating keratoplasty.

Unfortunately, irregular as well as regular astigmatism is a common finding after penetrating keratoplasty. A potential advantage of LASIK is that there is evidence that the flap in LASIK creates a more regular ocular surface than occurs in PRK.<sup>23</sup> While irregular astigmatism can be a significant problem following LASIK for visual rehabilitation following penetrating keratoplasty, we feel there is less irregular astigmatism as compared to PRK.

Many patients following penetrating keratoplasty will have irregular astigmatism, which although not amenable to spectacle correction, can be rehabilitated with a gas-permeable contact lens. We discourage these patients, if they are at all contact lens tolerant, from having LASIK performed, as the excimer laser is currently not successful in treating irregular astigmatism. We anticipate that the development of customized corneal ablations guided by corneal topography or wavefront analysis will successfully treat some forms of irregular astigmatism in the next several years. This will allow even more accurate treatment of post-penetrating keratoplasty refractive errors. While we only treated myopia and myopic astigmatism, LASIK may also be effective in the treatment of hyperopia and hyperopic astigmatism, although their larger peripheral ablations may impact directly on the corneal transplant wound.

In conclusion, LASIK is successful in treating post-keratoplasty myopia and astigmatism in most patients. Patients are overwhelmingly able to resolve their anisometropia and achieve binocular function. LASIK following PKP is more effective in treating residual myopia than astigmatism. We advocate a conservative approach to treating refractive errors following penetrating keratoplasty with LASIK. Contact lenses remain the standard of care and are to be encouraged whenever feasible. When contact lens use is not possible, we suggest slightly under-correcting the myopia, especially when the fellow eye is myopic. In addition, LASIK offers the advantage of allowing enhancements at a later date for residual refractive errors. LASIK offers the corneal surgeon an exciting new tool in the visual rehabilitation of the corneal transplant patient.

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## 22

# ***LASIK for Residual Errors after Previous Surgery***

**Namrata Sharma, Rakesh Ahuja, Rajesh Sinha, Rasik B Vajpayee**

Management of residual or induced refractive errors is an uncommon but significant use of LASIK surgery. LASIK may be used both as a refractive modality as well as a therapeutic modality in cases where refractive abnormalities occur in cases of previous ocular surgery or aberrations and irregular astigmatism, which have been induced by previous surgeries.

LASIK may be performed after astigmatic keratotomy (AK), photorefractive keratectomy (PRK), penetrating keratoplasty (PK), radial keratotomy (RK) and phacoemulsification with intraocular lens implantation or retinal detachment surgery.<sup>1</sup> LASIK after RK and PK has been dealt in details elsewhere.

### **LASIK after AK**

Astigmatic keratotomy flattens the steep cylinder axis and steepens the flatter axis by the process of coupling.<sup>2</sup> The coupling ratio (flattening/strengthening ratio) depends on the location, length and depth of incisions (Fig. 22.1).

Following uncomplicated AK, the anatomical structure of the cornea does not show significant alteration either in the superficial layers or in the deep stroma. Alio et al recommend that a LASIK flap can be cut through the astigmatic keratotomy incisions and LASIK procedure is possible without any special intraoperative precautions.<sup>3</sup>

### ***Preoperative Evaluation***

LASIK procedure should be undertaken after waiting for at least 3 months after AK. The treatment is usually based on the manifest refraction for axis correction. However, if there is a disparity of greater than 10° between the refractive axis and the topo-



**Figure 22.1. Astigmatic keratotomy**

graphic axis, one should preferably use the topographic axis. LASIK surgery should only be performed for myopia, hyperopia or regular astigmatism. In cases of irregular astigmatism, conventional LASIK is contraindicated and these cases are better dealt with topography assisted lasers.

#### *Intraoperative and Postoperative Considerations*

The LASIK surgery should be performed as is done routinely. A precise centration is crucial to the successful outcome especially in cases of astigmatic correction. Postoperative follow-up and treatment is similar to routine LASIK surgery.

#### *Results*

Ten patients with mixed astigmatism were treated after AK with LASIK.<sup>3</sup> The mean spherical equivalent preoperatively was  $+0.57 \pm 2.8$ D ( $-1.5$  to  $+6.0$ D) and the mean astigmatic value was  $-1.50$ D  $\pm 0.60$  ( $-0.5$  to  $-2.5$ D). Postoperatively, the UCVA was  $+0.60 \pm 0.31$ D and the mean UCVA improved from  $0.5 \pm 0.16$  to  $0.74 \pm 0.18$  with the cylinder's vector corrected change of  $1.61 \pm 0.71$ D. No untoward intraoperative complications were reported.

### **LASIK AFTER PRK**

LASIK has now been safely and successfully performed for residual refractive errors after PRK.<sup>3-5</sup>

#### *Preoperative Evaluations*

The two most important complications that may occur following PRK are regression and corneal haze. Since one of the indications for LASIK after PRK is regression, it is

mandatory to perform LASIK when the refraction becomes stable for at least one year after PRK. This should be documented on two occasions at least one month apart.

The corneal haze following PRK should also be assessed. If the corneal haze is greater than grade 2, regression in the immediate postoperative period should be expected.

### ***Intraoperative Considerations***

The depth of the microkeratome cut is a key issue in performing LASIK after PRK. These corneas have variable consistency in different areas due to previous PRK treatment in central cornea, which has become more tough. As the microkeratome has to pass through, both peripheral normal clear cornea and the central more tough area, the flap should be as thick as possible.<sup>3</sup> In spite of this precaution, the consistency of the cut may not be uniform throughout. Additionally, due to incomplete or complete dissolution of the Bowman's membrane consequent to PRK, there are more chances of presence of wrinkles and folds in the flap in the post-operative period.

### ***Postoperative Treatment***

Postoperatively, a greater frequency of steroids over prolonged periods is required to decrease haze and regression.

### ***Results***

Alio et al have shown good results in cases in PRK following LASIK.<sup>3</sup> The mean UCVA improved from  $0.24 \pm 0.41$  to  $0.6 \pm 0.18$  at 6 months and 98 percent of the patients were within  $\pm 1.0$  D of intended refraction.

Comaish et al performed LASIK after PRK in 50 eyes. The preoperative spherical improvement decreased from  $-2.92$  diopters (D)  $\pm 1.57$  to  $-0.65 \pm 0.86$  D. They concluded that LASIK was a safe and predictable procedure for treating eyes with 0 to low haze with residual myopia after PRK; for eyes with severe haze, it was less predictable.<sup>4</sup> Artola reported 4 eyes of 3 patients who developed severe haze after LASIK treatment for residual myopia after PRK.<sup>6</sup>

### ***LASIK after Cataract Surgery***

LASIK may be performed in cases of phakic intraocular lens implantation to correct high refractive errors or may be undertaken to correct residual refractive errors after cataract extraction and intraocular lens implantation.

### ***Bioptics***

Bioptics is the term applied for different techniques, which share the refractive error in two planes. One of the advantages of this technique is the possibility of correction of the refractive errors completely. Initially this technique was described as a surgery in the phakic patients with posterior chamber phakic implantation (ICL) followed sometime later by laser in situ keratomileusis. Currently, bioptics has expanded and is applied when

combining techniques that use IOL implantation (in anterior or posterior chamber) in phakic or pseudophakic patients, followed by corneal refractive surgery (LASIK, PRK, Intracorneal rings, LASEK).

Velarde et al have reported optimal results in 22 eyes with high myopia, hyperopia and astigmatism when bioptics was undertaken.<sup>7</sup> In these eyes first lens phacoemulsification with intraocular lens implantation was done followed 3 months later by LASIK. The preoperative spherical equivalent decreased from -11.76D and +5.25D to +0.26D and a visual acuity of 20/40 or better was obtained in 81.8 percent eyes.

### **LASIK after Intraocular Lens Implantation**

LASIK has been undertaken for residual refractive surgery following cataract extraction and intraocular lens implantation. Ayala et al reported that LASIK is safe and predictable procedure for correcting residual myopia after cataract surgery.<sup>8</sup> No intraocular lens or cataract related complications occurred when LASIK was performed 3 months after phacoemulsification. 81.8 percent of the eyes (18 out of 22) had spherical equivalent which was within  $\pm 1.00$ D.

### **LASIK after Retinal Detachment Surgery**

Patients with myopia are at a higher risk of developing retinal detachment.<sup>9,10</sup> In addition, myopic changes may also be induced by retinal detachment surgery due to the changes in axial length, anterior chamber depth or position of the crystalline lens.<sup>11,12</sup> Thus many patients may desire a refractive correction after having undergone successful retinal detachment surgery. There is only one study in literature which has undertaken LASIK after retinal detachment surgery.<sup>13</sup> We at our center have also undertaken LASIK in 12 myopic eyes following retinal detachment surgery.<sup>14</sup>

### ***Preoperative Considerations***

It is imperative to obtain a detailed history about the *previous retinal surgery* including the time of the surgery and the exact intraoperative details such as the position of the buckle and encirclage. Information should also be sought whether any vitrectomy was done. There should be a minimum interval of at least 6 months between the retinal detachment surgery and the proposed LASIK surgery in order for the inflammation to subside and the refraction to become stable.

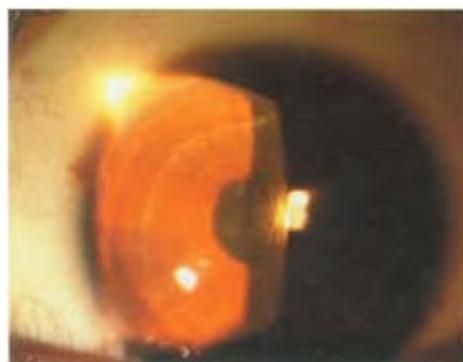
A careful slit lamp biomicroscopy is mandatory to detect any presence of conjunctival scarring due to previous retinal surgery. Apart from the routine investigations, an applanation tonometry is a must as intraocular pressures are usually on the lower side in such eyes and hence the built up of vacuum during the application of the suction ring may be difficult in such eyes.

Further, a comprehensive indirect ophthalmoscopy preoperatively should be undertaken preferably by a retina specialist to assess the status of the retina, which includes exclusion of any treatable peripheral retinal lesions or presence of any retinal detachment. If any additional interventions are required such as a prophylactic cryopexy or photocoagulation the surgery should be deferred for at least six weeks.

The surgeon must assess the visual potential and the patients should be appropriately informed, as it may not be possible to achieve a visual acuity of 20/20 in all eyes depending on the functional status of the retina.

### ***Intraoperative Considerations***

Due to the presence of conjunctival scarring an adequate suction may not be obtained so that the intraocular pressure generated is less than 65 mm Hg. An adequate grip on the ocular surface is not obtained and the surgery may have to be deferred (two out of twelve eyes in our study) in these eyes. This may also result in the creation of thin flaps (Fig. 22.2) while performing the microkeratome cut.



**Figure 22.2.** Thin flap in a case of LASIK following retinal detachment surgery

The intraocular pressure generated after the activation of the suction should be measured with the Barraquer tonometer. The flap should only be cut if on applanation of the cornea, the central mire is equal to or within the circular mark etched on the tonometer (indicating a pressure of equal to or more than 65 mm Hg).

A suction ring of 8.5 mm should be preferably used in such eyes especially if conjunctival scarring is detected, which provides a firmer grip in these eyes. The microkeratome head, which generates a thicker flap, should be used, as there is a propensity for creation of thinner flaps due to inadequate suction.

### ***Results***

There are two studies in literature, which have mentioned the use of photorefractive procedures (LASIK and PRK) for the management of refractive errors in 21 eyes following retinal detachment surgery.<sup>13,14</sup> In the study by Georgiev et al, all eyes had an improvement in the uncorrected visual acuity and there was no decrease in the best-corrected visual acuity in any of the cases. All eyes achieved a refractive error of within 1D of emmetropia and an uncorrected visual acuity of better than 20/60.

We have undertaken LASIK in twelve eyes of eleven patients after retinal detachment surgery.<sup>14</sup> The mean spherical equivalent of  $-5.75 \pm 2.3$ D (range: -3 to -11D) decreased to  $-0.05 \pm 0.6$ D at 6 months. Four eyes were within  $+0.5$ D of emmetropia and all 10 eyes were within  $+1$ D of emmetropia at 6 months after the surgery. Four eyes had a UCVA better than 6/12, while all eyes had a UCVA better than or equal to 6/18.

### ***Postoperative Considerations***

No cases of retinal detachment were noted either in the study by Georgiev et al<sup>13</sup> after 3 years follow up or by us after a follow-up of one year.<sup>14</sup> However, a regular screening of the retinal periphery with indirect ophthalmoscopy is a must in the post-operative period to detect any new retinal lesion or the presence of retinal detachment. Although there are studies, which have reported the occurrence of retinal detachment following LASIK surgery, especially in myopic eyes, no cause effect relationship has been determined conclusively.<sup>15,16</sup> Nevertheless, one should be cautious in these myopic eyes as they are inherently prone to retinal detachment.

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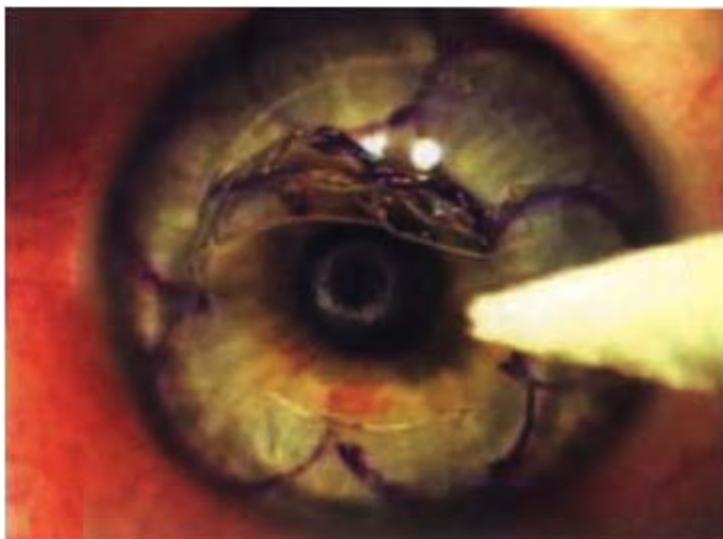
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# Section 7

## Recent Advances in LASIK



## 23

### ***Topography Assisted LASIK***

**Mayank S Pangtey, Namrata Sharma, Rasik B Vajpayee**

The concept of topography assisted customized ablations was first suggested by Seitz et al in 1998 in experimental studies. This was made possible due to the various topography based software and the technology of the flying spot excimer lasers (Fig. 23.1).

The surface aberrations from the cornea are first calculated from the corneal elevation data, which is derived from the various corneal topography measurements, and this is coupled with a standard refraction to generate customized ablation patterns through an excimer laser delivery system.

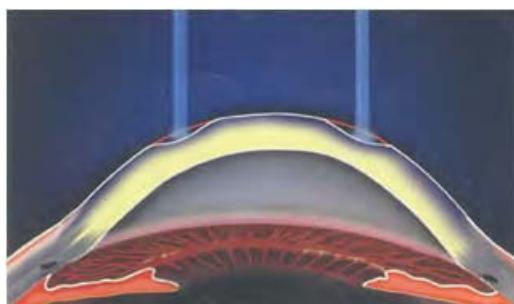
To begin with, this approach was initiated in the ‘repair procedures’, i.e. eyes who had undergone previous refractive surgeries and had corneal abnormalities. This was then done in the so-called normal eyes with the routine LASIK procedure.

#### **Basic Principle**

The basic formula for the topography-guided ablation is expressed in the following equation:

$$A(x, y) = C - (T[x, y] - T_{\text{target}}[x, y])$$

Where  $A(x, y)$  is the ablation pattern,  $T[x, y]$  is the actual corneal elevation topography,  $T_{\text{target}}[x, y]$  is



**Figure 23.1.** Topography assisted LASIK. Due to flying spot laser preferential aspheric treatment is

possible (red area denotes normal curvature)

the target corneal topography one wishes to achieve, and  $C$  is the smallest constant depth needed to keep  $A(x, y)$  from becoming negative anywhere. Ablation depth  $A(x, y)$  cannot take negative values because the ablation cannot add tissue to the cornea.  $C =$  the maximal value of  $(T[x, y] - T_{\text{target}}[x, y])$  over the optical zone.

A tricky step in topography guided ablation is the determination of the target topography  $T_{\text{target}}[x, y]$ . Theoretically,  $T_{\text{target}}[x, y]$  should be a parabolic surface with the right refractive power to achieve emmetropia or other postoperative refractive targets. In practice, the spherical equivalent power of the preoperative cornea and the spherical equivalent refraction of the preoperative eye may be difficult to determine in cases with severe aberrations and poor best corrected visual acuity.

### Indications

The indications of topography assisted customized ablation vary from the correction of the primary errors to the corrections of aberrations due to iatrogenic causes, following corneal trauma and keratitis (Table 23.1).

The results have been encouraging in regular astigmatism and decentered ablations but require refinement with irregular astigmatism. Though this

**Table 23.1: Indications of Topography assisted customized ablations**

*Primary*

*Secondary*

*Iatrogenic*

Previous refractive surgery

Decentration

Irregular ablations

Interface irregularities after DLK

Insufficient effective optical zone size

After other eye surgery like penetrating keratoplasty

After eye injury

After keratitis

technique is more challenging in patients with irregular astigmatism, they may benefit the most once the technique becomes more refined. This is especially true in cases of penetrating keratoplasty, and posttraumatic corneal scar with large irregular postoperative astigmatism.

## Prerequisites

1. The stability of the corneal curvature prior to surgery should be ascertained. One should wait for at least 1 year before performing topography assisted customized ablation following penetrating keratoplasty or in cases of larger corneal scars. For smaller corneal scars, this interval may be shortened provided the corneal topography is stable.
2. A high quality topography map should be generated, since it is the basis of customized ablation. A good image is one that is acquired with wideopen lids and regular tear film. The image should be well centered, and focused and there should be no dark spots on the map. The images should be taken repeatedly, unless optimal maps are acquired. It is best to obtain 3 different maps and the one featuring the least eye movement should be used.

## Topography Assisted Customized Ablations

A variety of software is available which link the topography systems to the excimer laser delivery systems in order to achieve the topography assisted customized ablation. These include the following:

### Topolink (Bausch and Lomb Surgical, St.Louis Mo)

The topography is obtained on Orbscan II analysis system (Bausch & Lomb Surgical, Orbtek, Salt Lake City, UT) the data are copied and ablation profile is calculated based on Topolink software. The software determines the target keratometric value by subtracting the manifest sphere from the keratometric value in the steep corneal meridian. The target keratometric value and a preset shape factor of  $-0.25$  is defined as the target asphere which one aims to achieve after LASIK.

The topolink software is not based on Munnerlyn's formula; instead, it calculates a certain "lenticule" of corneal tissue to be removed. The Topolink software compares the shape of the target asphere to the corneal shape actually measured. The target shape is fitted from beneath to the actual cornea for a given planned optical zone size. The difference between the target and actual shapes is then ablated.

### *Corneal Interactive Programmed Topographic Ablation*

The corneal interactive programmed topographic ablation (CIPTA) system is an interactive software programme that links the elevation data obtained with the Orbscan II corneal topography system (Bausch and Lomb Surgical, St. Louis, Mo) and a flying-spot excimer laser (LaserScan 2000, Laser Sight, Orlando, Fla) to develop a customized ablation pattern.

The normal cornea has an aspheric surface with a more pronounced curve in the central portion and a gradual flattening at the periphery. CIPTA software is based on the altimetric topography and compares the cornea with an aconic ellipsoid with an adjustable coefficient of asphericity to preserve the patient's physiological astigmatism and prolate shape.

To increase the precision, at least three measurements are performed and accuracy is assumed when the height difference in the central 5 mm differs by less than 3 microns. Cyclo-torsion of the eye during topography acquisition and ablation should be avoided because it can reduce the accuracy of the astigmatic correction. In addition, there is a learning curve for planning the ablation with CIPTA, as the software requires the user to select the center of the ablation, the size of the transition zone, and the index of asphericity.

### **Topographic Simulated Customized Ablation (TOSCA)**

In this technique the elevation maps of Technomed C-scan (Technomed GmbH, Baseweiler, Germany) and the Tomey TMS II or III (Tomey and Erlanger Tennenlohe, Germany) are used. The keratometric and the elevation maps are used to calculate the best fit sphere. A simulated ablation map is generated which is automatically transferred to the laser shot file, which is loaded onto the laser machine MEL70 Asclepion-Meditec uses a TSA (Tissue Saving Algorithm) module to TOSCA (Topography Supported Customized Ablations) software for carrying out topography-guided corrections.<sup>1</sup> This module automatically minimizes the tissue removal when calculating the correction program (Fig. 23.2).



**Figure 23.2.** Topographic simulated customized ablation (TOSCA)

### ***Custom Contoured Ablation Patterns (C-CAP)***

The custom contoured ablation patterns An elevation topography map is generated with the help of a placido disc shaped topographer (such as Humphrey) or a slit scan elevation topographer (such as Orbscan). The most elevated areas of the cornea are located on the horizontal and the vertical meridians using the grid pattern. The shape, size and depth of the most elevated areas and axis of ablation (cylindrical or elliptical) are defined and the elevation is related to the best fit curvature and the elevation in microns of the zones to be ablated is calculated. The treatment of the irregular astigmatism is fed into the Visx Star

system and the ablation performed. C-CAP method is basically used for decentered ablations.

### Results of Topography Assisted Corneal Ablations

Studies have been done to evaluate the role of topography guided corneal ablations using various machines and software.

Knorz et al treated 114 patients (eyes) with myopia of  $-1$  to  $6D$  and astigmatism of  $0$  to  $-4D$  (group 1), and 89 patients (eyes) with myopia of  $-6.1$  to  $-12D$  and astigmatism of  $0$  to  $-4D$  (group 2). They treated these patients on the basis of corneal topography measured with the Orbscan II system using a Keracor 217 excimer laser and the Hansatome microkeratome. In the low (high) myopia group, 96.1% (75.0%) were within  $0.50D$  of emmetropia, and uncorrected visual acuity was 20/20 or better in 82.4% (62.5%), 20/25 or better in 98.0% (70.0%), and 20/40 or better in 100% (95.0%).<sup>2,3</sup>

Tamayo et al performed topography guided custom ablation with LASIK on 5 eyes for irregular astigmatism secondary to penetrating keratoplasty for keratoconus, prior decentered laser in situ keratomileusis, or incisional refractive surgery.<sup>4</sup> The contoured ablation patterns (CAP) method (VISX, Inc.) was used to automatically decenter the ablation over the corneal elevation. The UCVA uncorrected visual acuity (UCVA) was better than 20/30 in all but one eye. The best corrected visual acuity (BCVA) was maintained or improved in all eyes.<sup>4</sup>

Alessio et al<sup>5</sup> evaluated the efficacy, predictability, stability, and safety of CIPTA. Forty-two eyes of 34 subjects had CIPTA were treated for hyperopic and myopic irregular astigmatism using a corneal topography guided PRK and LASIK At a mean follow-up of 13.2 months, 26 eyes (92.8%) in the hyperopic group and 12 eyes (85.7%) in the myopic group had an UCVA superior to 20/40. Twelve hyperopic eyes (42.8%) and five myopic eyes (35.7%) had a UCVA of 20/20.

### Comparison between Topography and Wavefront based Systems

As corneal topography can only measure the aberrations of the corneal surface, it cannot by itself eliminate all ocular aberrations. In comparison to wavefront technology, which measures only a few hundred points<sup>6,7</sup> corneal topography maps the surface based on several thousand points in a reflected ring pattern. In cases in which corneal aberration is predominant and contains small-scale irregularities as scar, dystrophies, ectasia, steep central islands, corneal topography may be able to map ocular aberration with higher resolution than current wavefront sensors.

Moreover wavefront sensing devices measure the entire refractive status of the eye and cannot differentiate measured aberrations caused from the cornea or by a combination of effects of the cornea and crystalline lens. Unlike corneal topographers, they give no direct information on the corneal status of the corneal surface. In addition, there are cases in which a wavefront sensor will not work well because wavefront sensing devices must be able to send and receive light from the retinal surface without significant interference from the ocular tissue. In corneal trauma, the cornea may be compromised to the extent that it is not possible for the incoming beam to form a reasonably well-focused spot on the retina. When this happens, the detected spots of light may be so badly

deformed that a good measurement of higher order aberrations is not possible. The corneal topographer has no such limitations, which can measure the corneal surface even in the presence of serious irregularity.

### Limitations of Topography based Systems

There are several limitations to the accuracy and completeness of corneal topography in practice. Placido ring based devices measure the local radial slope of the cornea at discrete sampling points. Slope data is converted to height topography by an integrated operation starting from the center outward. This integration introduces the error in a cumulative fashion; therefore, height estimates becomes less reliable further from the center. The coverage of the ring projections on the cornea can be the nose and the brow. The tear film is variable over time and often there are poorly wet areas on the cornea where measurement cannot be made. These patches of missing slope data can introduce large errors into height calculations. With all these limitations, Placido disc based technology is still the most successful technology so far.

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## 24

# ***Wavefront Guided LASIK***

**Laurence Sullivan, Namrata Sharma**

Wavefront guided customization is one of the most successful methods of corneal ablation. This essentially consists of the wavefront analysis, the coupling of the wavefront map to the excimer laser machine and consequently the excimer laser delivery in accordance with the wavefront profile.

The first wavefront guided LASIK was performed by Dr Theo Seiler in 1999.

### **Basic principle**

First, the information from the wavefront analysis is integrated into the excimer laser so that it utilizes the diagnostic information in therapeutic mode. The map is then used to generate the shot pattern. This information is written on the floppy disc placed inside the laser to drive the ablation.

### **Methods of Refraction Evaluation System** *Wavefront Analysis*

#### *Phoropter and Autorefractometer*

These are used for refraction, which incorporate both objective retinoscopy by a trained optometrist and subjective refinement by patient input. However, with either of these formats, only sphere, cylinder and axis of cylinder can be measured. Higher order aberrations cannot be evaluated. The minimal measurement by these methods is 0.12 diopters.

#### *Corneal Topography*

Corneal topography systems use images from the reflection of a Placido disc from the tear film based on which the corneal curvature and the refractive power is calculated. Although, it does not directly show true corneal shape, this can be calculated/ inferred from the above. It also does not address or measure the internal ocular optics, and may not correlate closely with the refractive data. These supply corneal curvature data with an accuracy of 0.25 diopters.

### ***Orbscan Topography***

The Orbscan (Orbtek, Bausch and Lomb) records video images of reflective surfaces by means of a scanning slit beam following which a computer performs reconstruction of approximately 40 slitscanning images which are acquired over 1.5 seconds. The four maps show anterior and posterior cornea elevation, corneal power (keratometry) and the corneal thickness in microns. Excessive ( $>75$  micron) posterior corneal bowing or asymmetric pachymetry map may be an indication of the forme fruste keratoconus (FFKCN) or indicate increased risk of postoperative keratectasia which may help exclude some patients from LASIK. However, Orbscan pachymetry is not reliable for estimating residual beds (ultrasound is the gold standard) and does not address or measure the internal ocular optics, and may not correlate closely with the refractive data.

### ***Wavefront Analysis***

Wavefront systems measure the entire ocular refractive path which includes the entire chain of refractive surfaces such as the tear film, anterior corneal surface, corneal stroma, posterior corneal surface, anterior crystalline lens surface, crystalline lens substance, posterior crystalline lens surface, vitreous and finally the retina. These systems approximate the “autorefractor map of the pupil”. They describe the refraction of the eye within 0.05 microns. This is five times more accurate than the excimer LASER beam and approximately 25–50 times more accurate than the phoropter, autorefractor and the topography based system.

These systems can also measure the higher order optical aberrations, e.g. Tilt, coma, spherical aberration, trefoil and quadrafoil apart from the lower order aberrations such as sphere and cylinder.

### ***Wavefront Analysis—underlying Principles***

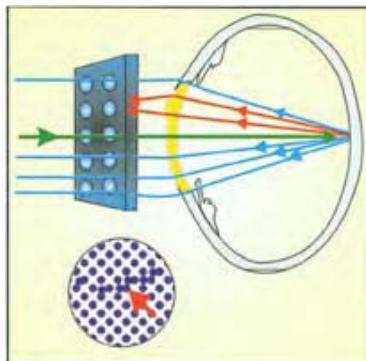
#### ***Type 1. Hartmann-Shack Method***

This is based on the concept of “outgoing reflective aberrometry”. A single laser beam is projected as a spot on the retina and the reflected bundle of rays passes through the optical system of the eye. It is then picked up by an array of small lenslets, which focus these rays into spots on an array of charge coupled device (CCD) cameras. Then this mosaic of spots is used to define the wavefront and analyze its deformation. The position, the pattern and the point-spread function of each spot are analyzed and the displacement of these images on the CCD camera from the calibrated position reveals the aberrations of the eye<sup>1</sup> (Fig. 24.1).

This is the method used in the *Bausch & Lomb aberrometer*, *Alcon LADARVision*, *VisX* and *Zeiss Meditec aberrometer s*.

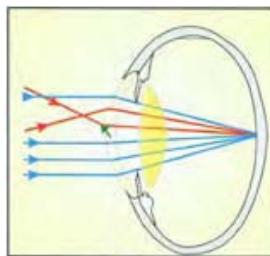
#### ***Type 2. Ray Tracing***

This is based on the concept of “ingoing adjustable aberrometry” (spatially resolved refractometer).



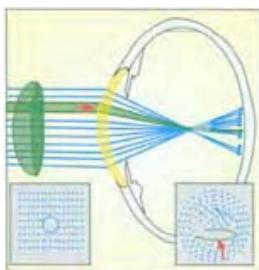
**Figure 24.1.** Hartmann-Shack Device. A laser beam (red line) is reflected from the fovea as a wavefront. A local defect in the cornea causes deviation of the beam (yellow line) which passes through lenslet array which describes the deviated wavefront of the focused spots

Ingoing adjustable aberrometry involves recording the ingoing rays of light which are manually guided by the patient to define the wavefront needed to cancel ocular aberrations (Fig. 24.2). Recording these deviations presents a wavefront pattern at the level



**Figure 24.2.** “Ingoing” adjustable aberrometry (Spatially Resolved Refractometer). The ingoing rays of light are manually directed by the patient to define wavefront needed to cancel aberrations. The patient subjectively redirects the light rays

(red line) compensating for the aberration so that the light strikes the fovea



**Figure 24.3.** “Ingoing” retinal imaging aberrometry (Tscherning Device). Laser light passes through aberroscope lens so that laser pattern is projected on fovea. Deviation from the optimal constitutes the aberration profile by ray tracing

of the cornea to custom treat each part of the cornea for a more optimal overall result. Here a point incident on the retina and the location of its conjugate focus is analyzed with reference to the ideal conjugate focus point. Many such points are measured to calculate a wavefront map.

The measured deviation is adjusted either manually by the patients depending on what they visualize or be recorded by retinoscopic principles. The latter is used in *Nidek OPDScan* and *Spatially Resolved Refractometer*.

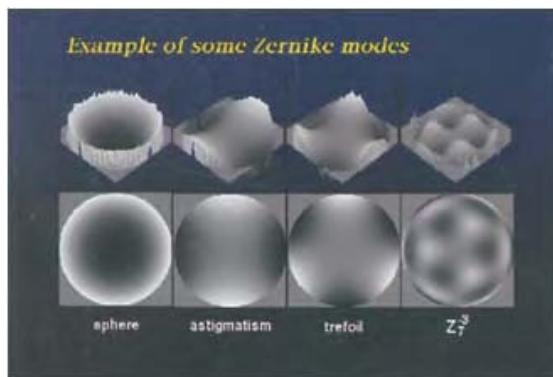
#### Type 3. Tscherning Aberroscope

This is based on the concept of “ingoining retinal imaging aberrometry”. A bundle of equidistant laser light as a grid passes through an aberroscope lens and the laser pattern is projected on the retina (Fig. 24.4 and 24.5). Any deviation from the ideal constitutes the aberration profile by ray tracing. In an aberration free eye, the retinal pattern consists of equidistant spots corresponding to the incident pattern. But in the normal eyes this pattern is distorted due to aberrations. If there is a localized aberration in the cornea, this causes a misdirection of the refraction of the laser light on to the retina so that the resulting deviation in the grid pattern is seen and recorded. A low light CCD camera linked to a computer measures the deviation of each spot from the ideal equidistant position.

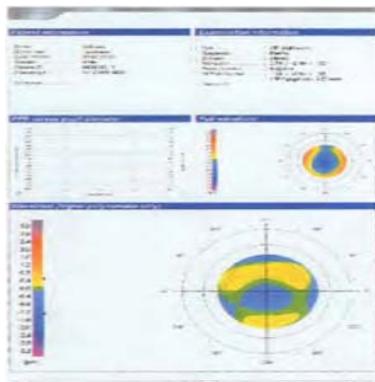
This forms the basis of *Dresden*, *Tracy technologies*, *Schwind* and *Wavelight Wavefront Analyzer*.

**Zernicke polynomials (ZP):** A mathematical way of grouping and describing optical aberrations is via Zernicke polynomials.

Data from the wavefront is explained mathematically in three dimensions with polynomial functions (Fig. 24.4 and 24.5). This can be done either by using the Zernicke's method or by using the



**Figure 24.4.** A graphical representation of commonly described optical aberrations.



**Figure 24.5.** An example of a wavefront analysis of the author. The lower graphic indicates the presence of trefoil, indicated by the three yellow “peaks” on the blue-green background. The magnitude of the wavefront deformation is shown on the scale at the left (arrowheads).

Taylor's method. The ray points as described by ZP are used to obtain a best fit toric to compensate for the refractive error of the eye. The coefficient for each of the Zernicke term reveals the term's relative contribution to the total root mean square (RMS) error.

The points are described in the X, Y and Z coordinates. ZP description for wavefront analysis vary from 1st to the 10th order of expression.

The most important and commonly used are the first 4 orders of ZP which are as follows (Fig. 24.4):

- 0-order ZP (piston)—Term ZT0
- 1st-order ZP (prism)—Term ZT1, 2 (tilt)—[describes the spherical error or power of the eye].
- 2nd-order ZP (spherocylinder)—Term ZT3, 5 (astigmatism), and ZT4 (defocus, sphere) [describes the regular astigmatic component with axis]
- 3rd-order ZP (coma)—Term 6, 9 (trefoil) and term ZT7, 8 (coma)
- 4th-order ZP—Term ZT10, 14 (quadrafoil) and term ZT 11, 12, 13 [spherical aberration]
- 5th-order ZP (secondary coma)—Terms ZT 15, 16, 17, 18, 19, 20 and so forth

Various aberrometers and machines based on wavefront guided ablation will now be described.

### LADAR Vision System

This system uses a 0.8 mm Gaussian flying small spot and a closed loop tracker which tracks at a frequency of 4000 Hz. In LADAR Wave Custom Cornea system (Fig. 24.6) approximately 240 spots are captured within a 7 mm pupillary area, which helps to obtain a detailed wavefront of a large zone size.

This system measures upto eighth-order aberrations and treats upto sixth order aberrations. It has a function of registration in which the wavefront image is oriented to the ablation profile. The tissue removal is at the rate of 11  $\mu\text{m}$  per diopter at a 6 mm zone and the spot placement is nonsequential so that the thermal effects are minimized. It can adjust and compensate for cyclotorsion, i.e. if an ink spot is placed at 3 and 9 O'clock position at the slit lamp the horizontal reference line can be re-adjusted for the correct



**Figure 24.6.** LADAR wave system



**Figure 24.7.** VISX 20/10 Perfect Vision™ wavefront technology

orientation. It also has virtual hinge protector software to prevent the ablation of the hinge.

### **VISX 20/10 Perfect Vision Wavefront Technology**

This works on the basis of a Hartmann-Shack principle in which the returning wavefront is converted into a color coded (Fig. 24.7). This is a 'Phase Map' or a 'Spatially Resolved Refractometer Map'. This map is a translation of 1000,000 data point numbers for a 6 mm pupil area.

The latest Star 3 system has a wavescan wavefront diagnostic hardware and a software package and the Prevue lens. It has an ActiveTrak three dimensional automated real-time eyetracking device to optimize centration. It is also developing a new eye tracking system which uses iris pattern recognition software to detect cyclorotational eye movement.

On the Prevue lens the patient gets a video preview of his future corrected vision and the ablation profiles may be modified accordingly

### **Zyoptix**

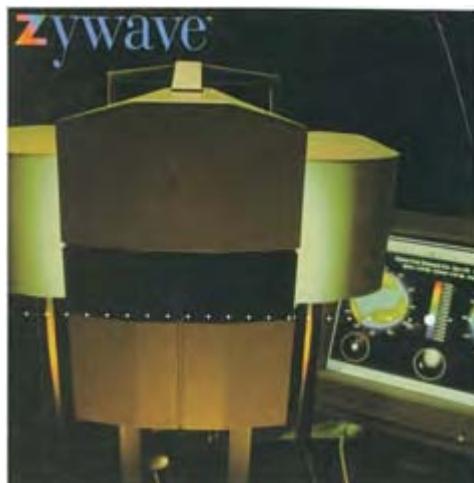
Zyoptix is a wavefront guided LASIK. The Bausch and Lomb Zyoptix system for Technolas 217z laser customises the LASIK for each patient. It has the following components:

*Orbscan IIz* is a multi-dimensional corneal diagnostic system, which collects 9000 data points in 1.5 seconds. This measures elevation and curvature of both the front and back surface of cornea (unlike other topography instruments which assess only the front

surface). It captures full corneal thickness data and generates comprehensive corneal maps essential for individualized vision correction.

*Zywave Aberrometer* This is developed on the basis of Hartmann-Shack wavefront sensor. The Zywave consists of a laser beam and a junction of lenses and some elements (Collimators, diaphragms, lights) that focus the light on the retina. On the emerging path, it has an array of spherical slits and a CCD camera (Fig. 24.8).

*Bausch & Lomb's Technolas 217z* has a 2 mm flying spot with a spot Laser beam quickly and effectively corrects the refractive error. The 1 mm spot creates an extremely smooth transition zone on the cornea. Utilizing the truncated Gaussian beam, less tissue is removed and larger optical zones may be treated. In the more recent models a 120 Hz eye-tracker is used.



**Figure 24.8.** Zywave aberrometer

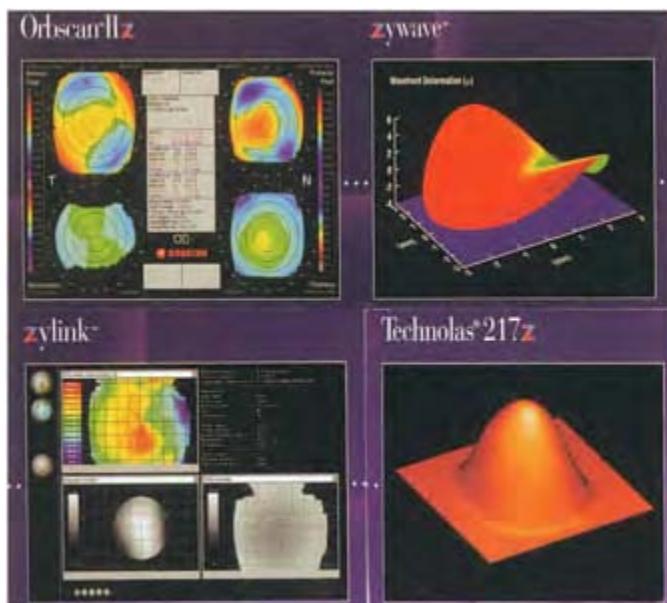
The truncated Gaussian beam shape combines the advantages of both the shapes, i.e. the flat top as well as the Gaussian beam. The advantage of the flat top is that the energy level is constant across the whole surface and superior to the minimum threshold value for cold ablation.; whereas the advantage of the Gaussian beam is that it gives a smooth surface.

In the phase 1, a multidimensional 3-D corneal mapping and wavefront analysis is done with the help of Orbscan Hz and Zywave respectively. With the help of Zylink, the optical correction module applies the correction and the tissue ablation profile is then obtained with the Technolas 217z (Fig. 24.9).

#### **Nidek NAVScan System**

This uses a combination of small spot and slit beam scanning. Small spots of 1-mm size are used for precise initial ablation of the higher order aberrations for customized surgery

and the slit beam is used for accurate ablation of the large amounts of corneal tissue for smoothness and faster ablation rates.



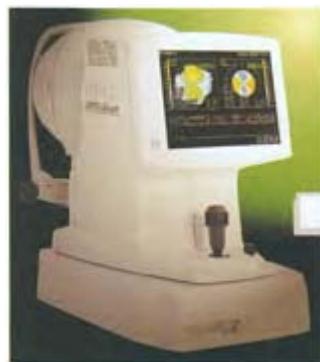
**Figure 24.9.** Principle of Zyoptix

It is said that due to the combination of small spots as well as slit beams there is a better control of tissue hydration, a faster ablation time with a lower number of pulses.

The multipoint ablation module divides the rectangular-shaped laser beam into six equal spots of 1 mm in diameter which are individually and simultaneously projected onto the cornea. The two consecutive spot beam centers are separated by 1.8 mm.

The eyetracking modality uses a high speed, digital video camera technology to follow the patient's eye in 3 dimensions that is, x, y and z axis.

The optical path difference scanning system or the OPD-Scan™ provides the surgeon with the information on refractometry, keratometry, corneal topography and the wavefront analysis<sup>2,3</sup> (Fig. 24.10). It measures the aberrations using dynamic



**Figure 24.10.** Nidek OPDscan™ Scan

skiascopy technology and placido disk corneal topography. By the combination of these two, the chances of misalignment are minimized.

A Final Fit™ software evaluates and converts the OPD-Scan™ refractive and topographic data into three different components: Sphere, cylinder and irregular (Fig. 24.11). These algorithms control the Multipoint™ ablation module which corrects the higher order optical aberrations, corneal irregularities and decentred ablations: the IRIS™ corrects the spherical ablation and the slit scan module corrects the cylindrical component. These combine to produce the customized ablation on the Nidek's EC-5000CX II excimer laser system.

### **Wavelight Allegretto**

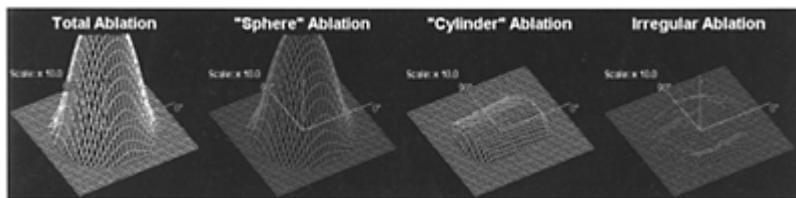
This system has a 0.95 mm flying spot at 200 Hz, which is projected in a non-sequential manner. (Fig. 24.12) It has a wavefront measuring device the ALLEGRETTO WAVE, which is based on a Tscherning aberrometer principle.

The video based eye tracker cameras have three individual illumination modules which sense the eye movements with a detection frequency of 250 Hz and a reaction time of 6 to 8 ms. Treatment times are short and it takes 4 seconds to correct one diopter.

It has a built-in slit lamp, which is useful especially if enhancements are required as the need to take the patient to a slit lamp and mark the flap is obviated. The system also has a large vacuum apparatus which evacuates the ablation plume.

### **WASCA Asclepion Mel 80**

The complete work station by Asclepion is called as **WASCA** or the Wavefront Aberration Supported



**Figure 24.11.** Final Fit™ software



**Figure 24.12.** Allegretto wave

Cornea Ablation (Fig. 24.13). It has both the corneal topography as well as the aberrometry systems incorporated in it. The Asclepion aberrometer or the Mel 80 scan uses a Hartmann-Shack sensor with a resolution of 210mm at the corneal plane and uses 1500 spots over the total sensor area and more than 800 spots within a 7mm pupil. The MEL 80 uses a Gaussian beam profile of 1.8mm diameter with a cone for controlled atmosphere technique (CCA), which allows the ablation products to be removed immediately without generating a drying air stream at the cornea.

A personalized visual acuity simulation is also present which allows the individual to perceive what his vision would be postoperatively.

#### ***Results of Wave front Guided Ablations***

Few studies are available which have published the reports of wavefront guided ablations.<sup>4</sup> The reports from the various clinical trials are as follows:

In the Alcon FDA trials, 98.6 percent of the eyes treated for myopia achieved an uncorrected visual



**Figure 24.13.** WASCA Wavefront Analyzer

acuity of 20/40 or better with 79.9 percent having a visual acuity of 20/20 or better. Improvements were also seen in contrast sensitivity and higher order aberrations.<sup>5</sup>

With Visx Star S3 excimer laser and wave scan system, in a multicentric trial all patients had a visual acuity of 20/20 with 73 percent having a visual acuity of 20/16 or better.<sup>5</sup>

In a study of wavefront-guided ablations in 340 myopic eyes, 91.5 percent had an uncorrected visual acuity of 20/20 or better with 70 percent achieving a visual acuity of 20/16 or better with Zyoptix.<sup>5</sup>

The results of wavefront guided ablations with Wavelight Allegretto excimer laser, showed that an uncorrected visual acuity of 20/20 was obtained by 91 percent eyes, 20/15 by 62 percent eyes and 20/10 by 31 percent eyes at the end of 3 months.<sup>6</sup>

Panagopoulou et al compared the results of Wavefront Aberration Supported Cornea Ablation (WASCA) PRK with LASIK and obtained better outcomes with PRK.<sup>8</sup> In the eyes that received WASCA correction with PRK or LASIK, at 3 months postoperative the high order aberrations averaged an increase of 1.3 times for PRK and 1.8 times for LASIK.

It was also found in the subsequent study that the flap formation during LASIK could modify the eye's existing natural higher-order aberrations (especially spherical and coma-like aberrations along the axis of the flap's hinge), while visual acuity and refractive error

remain unaffected. Flap creation only changed the higher order aberrations slightly, and caused a shift toward hyperopia.<sup>9</sup>

### The Future

The potential benefits of Wavefront Guided Custom LASIK are greater chances of achieving a visual acuity better than 20/20, better contrast sensitivity, night vision with less chances of night vision disturbances and glare.

It may be useful in treating patients for primary refractive error and also in patients who are having problems after previous refractive surgery such as photorefractive keratectomy and laser-in-situ keratomileusis. This may apply for cases that have higher order aberrations, decentered ablations or night vision problems.

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## 25

# ***Laser Sub-epithelial Keratomileusis (LASEK)***

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Excimer laser surface ablation has been used since 1987 to treat myopia. The original procedure was termed Photorefractive keratectomy (PRK) in which the epithelium is scraped prior to laser refractive surgical correction. After the introduction of laser in situ keratomileusis (LASIK), there was a movement away from surface ablation. The visual rehabilitation, after LASIK is rapid; its major limitations include ectasia, flap wrinkles, free caps, incomplete pass of the microkeratome, epithelial ingrowth, flap melt, interface debris, and diffuse lamellar keratitis.<sup>1,2</sup> PRK has no flap-related complications; its major limitations are subepithelial haze, postoperative pain, and slow visual rehabilitation.<sup>3-5</sup>

Laser subepithelial keratomileusis (LASEK) is a surgical procedure which may reduce the complications of LASIK and PRK. The early results seem promising especially for the potential applications in thin corneas and in wavefront-guided keratorefractive surgery. It is a surgical technique in which conventional photorefractive keratectomy (PRK) is modified to allow for the replacement of the corneal epithelium at the end of the procedure.<sup>6</sup> Alcohol is often used to facilitate removal of the corneal epithelium as a sheet. A hinged epithelial flap is created by peeling the loosened epithelium as a sheet using one of several recently developed surgical techniques. After laser ablation, the flap is repositioned over the ablated stroma.<sup>7</sup> This provides coverage of the lasered stromal bed, and reduces epithelial migration in those patients where the flap adheres to the stroma.

### **Indications**

There are several indications for LASEK surface ablation (Table 25.1). In patients with corneal pachymetry of 500 $\mu$ m or lower and in patients with asymmetric corneal curvature, the use of the AzarLu MEEI keratoconus classification<sup>2</sup> is helpful in identifying patients with keratoconus or who are keratoconus suspects (in whom LASIK surgery should be avoided) (See Fig. 15.6).

In patients with lifestyles or professions that predispose to flap trauma including contact sports athletes and military personnel, and patients with low myopia who are at a

lower risk for subepithelial haze, laser sub-epithelial keratomileusis (LASEK) may be a viable alternative.

### Preoperative Evaluation

Patients undergo routine preoperative evaluation in a manner similar to that for other refractive

### Table 25.1: LASEK indications and contraindications

*Indications:*

- Thin corneal pachymetry
- Epithelial irregularities (M/D/F changes)
- LASIK complications in the contralateral eye
- Predisposition to trauma
- Irregular astigmatism (Corneal topographical abnormalities not qualifying as keratoconus)
- Glaucoma suspects
- Dry eyes

*Contraindications:*

- Patient concern about postoperative pain
- Keratoconus
- Pregnancy
- Glaucoma (relative contraindication)
- Diabetes (relative contraindication)
- High myopia (relative contraindication)

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Modified from Reference #5, with permission

surgical procedures. These include uncorrected visual acuity (UCVA), best-corrected visual acuity (BCVA), manifest and cycloplegic refraction, ocular dominance, keratometry, tonometry, slit lamp examination, aberrometry and computerized videokeratography.

### Standard Surgical Techniques

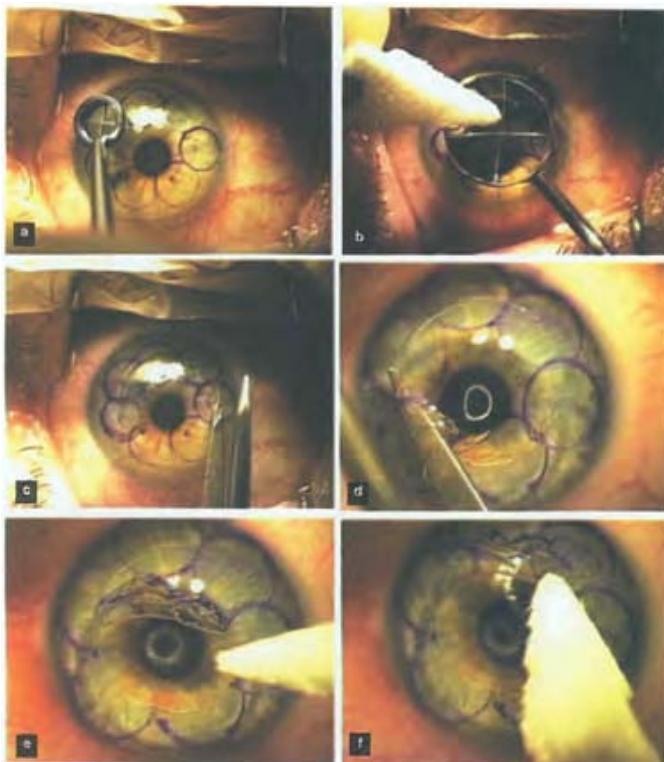
Several surgical techniques have been described including our original technique which is illustrated in Figures 25.1A to F.<sup>5</sup> Camellin,<sup>7</sup> Vinciguerra<sup>8</sup> McDonald, Rashid, Langerman, and Melki have described similar techniques with encouraging results.

Topical 0.5 percent proparacaine (Ophthetic; Allergan, Inc., Irvine, CA) and 4 percent tetracaine (formulated in the MEEI pharmacy) are instilled, a sterile drape is applied and

a lid speculum is inserted. We use multiple preplaced marks which are applied around the corneal periphery, simulating a floral pattern (Fig. 25.1A). Placement of these overlapping corneal marks is crucial in ensuring correct epithelial alignment and avoiding irregular epithelial placement and mismatch. An alcohol dispenser consisting of a customized 7- or 9-mm semi-sharp marker (ASICO, Westmont, IL) attached to a hollow metal handle serves as a reservoir for 18 percent alcohol. Firm pressure is exerted on the cornea and alcohol is released into the well of the marker. After 25–30 seconds, the ethanol is absorbed through a side-port or using a dry cellulose sponge (Weck Cell or Merocel; Xomed, Jacksonville, FL) (Fig. 25.1B). Camellin uses a sharp partial thickness trephine to cut the epithelium prior to alcohol application. He has also developed useful specialized instruments which are designed specifically for LASEK. A pre-incision is done using a Janach trephine (Como, Italy) and specialized microhoe, alcohol solution is instilled using a small silicone irrigator, and then the epithelium is detached using the short side of a hockey spatula and returned after laser ablation.<sup>7</sup> We however apply the alcohol first which is followed by epithelial elevation and dissection. From our experience, we have learned that in patients with weak epithelial adhesion, the technique may not require specialized instruments. However, several key steps are necessary for consistent epithelial flap creation and replacement.<sup>6</sup> Pretreatment with 4 percent tetracaine prior to alcohol exposure is helpful in loosening the epithelium and lessening intraoperative discomfort. A modified Vannas scissors or a microscissors with a blunt tip are inserted under the epithelium and traced around the delineated margin of the epithelium, leaving 2–3 clock hours of intact margin preferably at the 12 o'clock position.

The loosened epithelium is peeled as a single sheet using a specialized hoe and wire cheese cutter devices. In many patients, we observed that a Merocel sponge or the edge of the jewelers forceps may be adequate to create a flap of epithelium with the hinge still attached (Figs 25.1c to f).

After excimer laser ablation, an anterior chamber cannula is used to hydrate the stroma and epithelial flap with balanced salt solution (Fig. 25.1g). The epithelial flap is replaced on the stroma using the straight part of the cannula under intermittent irrigation (Figs 25.1h and i). In our technique, we realign the epithelial flap using the previous marks, which acts as a guide (Fig. 25.1j). The flap is then allowed to dry for 2–5 minutes, which is adequate



**Figure 25.1 a to f.** (a) Overlapping circular marks are preplaced on the cornea. (b) 18 percent ethanol is released into the marker well. Care is taken to avoid spillage by using dry sponge to absorb the overflowing ethanol. (c, d) A jeweler's forceps is used to delineate the flap edges and locate the dissecting plane, (e, f). A dry, non-fragmenting sponge is used to peel the epithelial flap

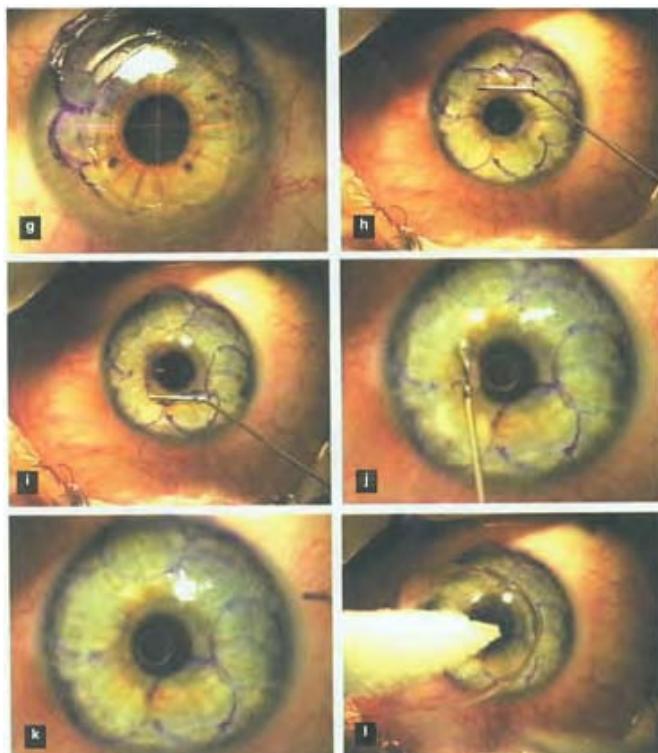
to allow adhesion of epithelial flap to stroma (Fig 25.1k). Camellin's approach however allows the flap epithelium to drape over the peripheral epithelium.

After the procedure, topical steroids and antibiotic medications are applied. A bandage contact lens (Soflens 66; Bausch and Lomb, Rochester, NY) is placed (Fig. 25.1l). Patients are prescribed oral analgesics, and instructed to take them only if needed. Postoperative regimen consisted of either tobramycin-dexamethasone ointment

(Tobradex; Alcon Laboratories, Inc.) four times a day for one week and prednisolone acetate 1 percent (Pred Forte 1%; Allergan, Inc., Irvine, CA) four times a day for two weeks. Artificial tears are also prescribed (on an as-needed basis). The bandage contact lens is removed after complete re-epithelialization (at postoperative days 3 and 4). Removal or manipulation of the contact lens in the first postoperative day risks peeling the epithelial flap with the contact lens.

### Alternative Surgical Techniques

Alternative surgical techniques include the classical Camellin technique,<sup>7</sup> in which a sharp partial thickness dissection of the epithelium is carried on



**Figures 25.1 g to i.** (g) Laser ablation is applied to the exposed Bowman's layer and stroma. (h, i) A 30-gauge Rycroft irrigating cannula is used to hydrate and reposition the epithelial flap, (j) Care is taken to realign the wound edges using the preplaced

marks as a guide, (k) Flap edges are aligned, and no epithelial defects are noted after flap repositioning and during the 5-minute waiting period. (l) A bandage soft contact lens is applied at the end of the procedure (from Reference #5, with permission)

prior to alcohol application, hydrodissection, viscodissection techniques (gel assisted LASEK) and the Vinciguerra butterfly technique (Table 25.2).<sup>8</sup>

The butterfly technique, performed after alcohol application, involves creating a linear cut of the epithelium. The sheet of epithelium is peeled sideways to allow exposure of the central cornea. This technique may have the potential theoretical advantage of maximizing the communication of the epithelial sheet with the limbal stem cell supply as well as the nerve supply to the anterior corneal layers. The initial epithelial scraping is often performed in a paracentral location. Often hydrodissection is used to balloon the epithelial sheets prior to scraping in a sideways direction. The scraped epithelium often results in a vertically oval area of stromal bed exposure. If the horizontal dimension is not wide enough to allow the full diameter of the laser treatment, adding horizontal incision will allow easy enlargement of the bare stromal bed. Melki's technique is based on dissection of the epithelium from Bowman's layer using a LASIK flap cannula. The cannula is inserted in the periphery of the alcohol-treated epithelium and slid across the cornea to reach the diametrically opposed location. The cannula is then moved in a

**Table 25.2: Modifications in LASEK technique**

<i>Technique</i>	<i>Modification</i>
<b>Camellin technique</b>	Partial thickness trephination prior to alcohol application
<b>Vinciguerra butterfly technique</b>	Cut made paracentrally in the epithelial flap so that limbal communication of epithelium is preserved
<b>Melki's technique</b>	Mechanical dissection with a LASIK cannula flap lifter) combined with the butterfly technique for flap elevation
<b>McDonald's technique</b>	Gel assisted LASEK, which uses viscoelastics for flap elevation
<b>Rashid and Langerman</b>	Hydrodissection for flap elevation

windshield-wiper fashion freeing the epithelial flap from its underlying adhesion complexes. A Vannas scissors are then used to cut across the outer 1/3<sup>rd</sup> of the flap converting to the butterfly technique.

The viscoelastic technique (gel assisted LASEK) was described by McDonald, in which the epithelium is lifted by viscoelastics instead of alcohol. A similar technique was described independently by Rashid and Langerman who used hydrodissection instead of

viscodissection. The epithelium is elevated with these methods after application of topical anesthetics. Alcohol is not used, and this may be a major advantage of this approach.

## BIOLOGICAL RESPONSE TO LASEK

There are differences in the wound healing patterns between LASIK and PRK. At the time of this writing, it is still not clear if LASEK, by protecting the ablated stromal bed with viable epithelial sheet,<sup>9,10</sup> provides environment that lead to a more advantageous wound healing than that which occurs after PRK.

Several complex cytokine-mediated interactions exist between epithelial cells and active and inactive keratocytes during the wound healing process after refractive surgery. Epithelial injury sustained in the creation of a LASIK flap and epithelial debridement and removal in PRK and LASEK release cytokines such as IL-1/IL-1 receptor and Fas/Fas ligand.<sup>11-13</sup> Wilson et al have demonstrated that IL-1 mediated production of Fas/Fas ligand can result in keratocyte apoptosis.

Keratocyte apoptosis occurs immediately after epithelial insult. Keratocytes, which do not undergo the apoptotic cascade, are transformed into fibroblasts or myofibroblasts, which move into the injured zone and release factors, which induce epithelial recovery, and proliferation.<sup>14</sup> Myofibroblast migration and action may be regulated by epithelial cells. These interactions between the epithelium and stroma, which modulate the reactionary response to injury, are responsible for the return to the normal corneal milieu.

In PRK, the apoptotic response is in the immediate vicinity of the epithelial injury. Myofibroblast migration and proliferation accompany its release of factors favoring epithelial cell proliferation which, may in turn result in an over-proliferation of epithelial cells.<sup>15</sup> It has been published that regression in PRK is in part due to epithelial hyperplasia and is caused by an abrupt change in the contour of the ablated area.<sup>16-18</sup> Epithelial proliferation and migration is mediated by epidermal growth factor (EGF), transforming growth factor (TGF- $\beta$ ) fibroblast growth factor (FGF), keratocyte growth factor (KGF), and hepatocyte growth factor (HGF).<sup>19</sup> The replacement of the basement membrane and its associated attachment complexes: hemidesmosomes, fibronectin, collagen type IV, and anchoring fibrils were demonstrated by immunolocalization three months after surgery.<sup>20,21</sup> These are all necessary for the maintenance of a normal regenerated epithelium.

We performed electron microscopy and cell culture studies on specimens obtained after conventional alcohol-assisted PRK.<sup>6,10</sup> We found that the epithelial cells are still viable immediately after exposure to alcohol and surgical peeling. In most specimens, the presence of the basement membrane attached to the basal epithelial cell layer indicates that the point of separation was likely to be between the basement membrane and Bowman's layer. The preservation of the hemidesmosomes in the basal epithelial layer may promote the adhesion of a viable epithelium to the ablated stroma.<sup>5</sup>

The epithelium is generally disrupted in LASIK only at the area where the microkeratome cuts through to create the flap. The over-proliferation of epithelial cells is less likely to be observed in LASIK. This may then be the substantiating evidence for the observation of less regression in patients who undergo LASIK versus those who are managed with PRK with the same order of myopic aberration.<sup>15</sup> However, an epithelial

ingrowth may sometimes result from hyperplastic epithelial plugs at the site of the microkeratome incision causing haze in the interface.<sup>21</sup> Type IV collagen has been localized at this region suggesting that basement membrane components may be responsible.<sup>22</sup> The proliferation of my fibroblasts after LASIK occurs further away from the epithelial layers separated by normal stroma. It has been recently described that there is an apparent loss of keratocytes in the most anterior portion of the cornea six months after LASIK. However, the implications of this finding have not been elucidated.<sup>23</sup>

Our LASEK technique involves alcohol-assisted epithelial removal. We used this technique to perform the first LASEK surgery in 1996.<sup>6</sup> Abad et al showed that alcohol-assisted epithelial removal was a simple and safe alternative to mechanical epithelial removal before PRK.<sup>23,24</sup> Applying 25 percent ethanol for 3 minutes, Stein et al were able to grasp, lift, pull apart, and split the corneal epithelium using two McPherson forceps.<sup>26</sup> Similarly, Shah et al exposed the epithelium using a dry sponge.<sup>27</sup> These early reports revealed that epithelial removal using 18–25 percent alcohol for 20–25 seconds was fast, easy, and safe to perform compared with mechanical debridement, that this concentration can produce sharp wound edges and clean, smooth Bowman's layer, and that the central epithelium can be translocated in part or *en toto*.<sup>26,27</sup>

Our initial involvement with epithelial sheet preparation was a continuation of Professor Gipson's *in vitro* studies.<sup>28</sup> We were subsequently able to recombine sheets of epithelium with stroma *in vitro*.<sup>27</sup>

Work in our laboratory has demonstrated the phenomenon of apoptosis occurring in the anterior portion of the treated stromal bed post LASEK in the avian model. The alcohol-assisted removal of the epithelial flap separated at the basement membrane, is then re-approximated to its original position. Questions pertaining to the aforementioned arise; would there be more apoptosis induced by repositioning a viable epithelial flap<sup>9,10</sup> onto a newly treated stromal bed or would the existence of viable tissue serve as a barrier to attenuate epithelial hyperplasia mediated by myofibroblastic activity.<sup>10</sup>

## SURGICAL RESULTS OF RECENT LASEK STUDIES

The surgical results following LASEK have been summarized in Table 25.3. Shahinian<sup>29</sup> reported his experience with 146 eyes of 83 consecutive patients treated with the classical Camellin technique, with a follow up of 1 to 12 months, a slightly gray epithelial flap under the bandage contact lens at day one, and examination with fluorescein dye at day one, when the contact lens was cleaned or exchanged, revealed a central area of fluorescein staining overlying a glassy smooth base with no laser stromal etching marks visible, which suggested that an intact epithelial basement membrane overlies the ablated stromal surface. Complete epithelium healing was achieved in 88 percent of eyes by day 4 and in 100 percent of eyes by day 6. The percentage of eyes with UCVA of 20/40 or better improved from 10 percent at day 1 to 78 percent at 1 week, and the UCVA was 20/40 or better in 95 percent to 96 percent of eyes at 3, 6, and 12 months respectively. At 3 months, the UCVA was 20/20 or better in 50 percent of eyes. This improved to 57 percent at 6 and 12 months. No significant regression was observed over time with a mean refraction close to zero from 1 to 12 months. The mean postoperative astigmatism was approximately one third of the preoperative value and remained stable from 1 to 12

months postoperatively. No eye lost more than 1 line of BSCVA. +0.5 haze at 1 and 3 months was significantly more common in eyes with higher preoperative myopia, and no eye was affected by the haze development at any time. Minor tear film changes near the superior limbus were observed in 33 percent of the eyes postoperatively. This change was transient and did not affect vision. Small flap

**Table 25.3: Results of LASEK**

Author/Year/No. of eyes	Refractive error	Study	Pre-op SEQ (Diopters)	UCVA
Lee 2001 (54)	Myopia	<b>LASEK vs PRK</b>	-3 to -6.5	$\geq 20/30$ LASEK PRK
				1 week 92% 78%
				3 months 100% 100%
Azar 2001 (20)	Myopia	<b>LASEK</b>	-1.0 to -14.0	>20/40 96%
				1 week 12 months 78%
Shahinian 2002 (146)	Myopia/Astig	<b>LASEK</b>	-1.2 to -14.0	>20/25 96%
				1 week 12 months 78%
Litwak 2002 (50)	Myopia	<b>LASEWK vs PRK</b>	-0.75 to -7.75	>20/25 LASEK PRK
				1 week 80% 76%
				48% 48%
Anderson 2002 (343)	Myopia	<b>LASEK</b>	-1.0 to -14.0	>20/40 90%
				1 week 6 months 98%
Claringbold 2002 (222)	Myopia/ Astig	<b>LASEK</b>	-1.25 to -11.25	>20/40 83.8%
				1 day 6 months 99.4%
Lee et al 2002 (84)	Myopia	<b>LASEK</b>	-3.25 to -7.0	>20/30 78.6%
				1 week 6 months 96.4%
Rouwewyha 2002 (58)	Myopia	<b>LASEK vs LASIK</b>	-1.5 to -14.75	>20/40 20/20 83% -
				1 week 6 months 97% 73%

tear at the time of surgery happened in 14 percent of cases without affecting the surgical outcome.

Azar et al<sup>6</sup> reported UCVA of 20/25 or better at 1 month after LASEK in 92 percent of eyes. At 1 year after surgery, the residual refractive error in all eyes was  $\pm 0.50$  diopter (spherical equivalent) of the desired refraction.

Lee et al<sup>30</sup> evaluated the results of LASEK in 84 myopic eyes of 48 patients; with a consecutive 6 months follow up period. The epithelial completely healed without

infection in 3 to 5 days in most cases. Successfully created epithelial flap without any epithelial tear was achieved in 70 percent of early cases, but the percentage increased to 96 percent after the initial learning curve. UCVA of 20/30 or better was achieved in 78.6 percent of eyes at 1 week and in 96.4 percent at 6 months after surgery. Only 2 eyes lost one Snellen's line of spectacle corrected visual acuity and no eyes lost more than one line. The postoperative pain scores were  $1.49 \pm 0.65$ ; 4 eyes (4.8%) had a +3 grade pain, and 3 eyes (3.6%) did not report any pain after surgery. Subepithelial corneal haze scores were  $0.56 \pm 0.34$  and  $0.16 \pm 0.25$  at 1 and 6 months respectively. Alcohol leakage occurred in 3 eyes, and incomplete epithelial detachment in 3 eyes preoperatively. Contact lens intolerance was reported in 5 eyes postoperatively, and corticosteroid induced ocular hypertension in one eye, which responded to  $\beta$ -blocker.

In a prospective study, Litwak et al<sup>31</sup> compared the results of LASEK and PRK in 50 eyes of 25 myopic patients who received LASEK in one eye and PRK in the contralateral eye. There was no difference in base line refraction between eyes assigned to PRK and LASEK. The epithelial defect was completely healed by the fourth day in PRK and LASEK eyes. At day one postoperatively, 72 percent reported more discomfort in the LASEK eye compared to 24 percent in PRK eye. At day 3, this difference increased to 80 percent LASEK eye and 4 percent in PRK eye. At 1 month, the UCVA similar in both groups; no eye had lost lines of BCVA or developed haze. Also, rapid visual recovery post-operatively, was observed in the PRK group. These results contradicted the conclusion of Lee et al<sup>32</sup> who compared the results of LASEK done in one eye with those of PRK done in the other eye in 27 patients. Three months after surgery there were no significant differences in uncorrected visual acuity (UCVA) and residual refractive error between LASEK and PRK. LASEK, however, resulted in lower postoperative pain scores and corneal haze scores than PRK. Seventeen patients (63%) preferred LASEK over PRK, because of its faster visual improvement, better final visual outcome, and a relatively pain-free recovery period.

Rouwelyha et al<sup>33</sup> compared retrospectively the results of 58 LASEK-treated eyes to a group of randomly selected LASIK-treated eyes treated during the same time period. After the initial healing period, LASEK appeared to be equivalent to LASIK with regard to refractive outcome, stability and safety. Neither group suffered any loss of BCVA. Scerrati<sup>34</sup> compared the postoperative results of LASIK patients with that of LASEK patients, and noted that long-term BCVA was better in LASEK patients. Results also indicated that LASEK patients had generally better corneal topographic contours and contrast sensitivities than did the LASIK patients.

Vinciguerra et al<sup>35</sup> reported better results with Butterfly technique of LASEK and 90 percent of patients reported greater comfort with Butterfly LASEK than with the conventional Camellin LASEK.

LASEK is still a recent evolving surgical technique, and early results vary according to the physician experiences. Large prospective, randomized clinical trials to examine the safety and efficacy of LASEK, especially in comparison with other refractive surgery procedures, will be helpful.

Long-term follow up data on LASEK is still pending. Two of our patients had LASEK performed six years ago.<sup>6</sup> They have not experienced recurrent epithelial defect or developed corneal haze.

## Complications of LASEK

There are various problems, which may be encountered during LASEK surgery. These include intraoperative alcohol leak, diffuse epithelial detachment (especially in young, contact lens wearers, and postmenopausal patients) incomplete epithelial detachment and tear in the flap. In the event of intraoperative loss of epithelium flap, the procedure may be converted to PRK.

The main disadvantages of LASEK remain to be the unpredictable postoperative pain and epithelial healing.<sup>5</sup> Even after ensuring that no epithelial defects were present at the end of each procedure, de-epithelialized areas are still observed in more than half the cases one day after surgery. This is accompanied by a similar number of reports of postoperative pain.

## CONCLUSION

LASEK offers the potential advantage of avoiding LASIK-related flap complications and decreasing epithelial healing time and postoperative pain associated with PRK. Surface ablation also avoids the possibility of flap induced higher order aberrations. This is an important consideration in wave front-guided customized corneal ablation. The main indications for LASEK are thin corneas relative to the intended amount of excimer laser ablation, and patients with predisposition to trauma such as contact sports athletes and military personnel.<sup>5-7</sup> Patients with low myopia who are at a lower risk for subepithelial haze may also benefit from LASEK.

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*Figs 5.7, 5.12a, b, 24.6*

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*Figs 6.8a-d*

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*Figs 23.2, 24.13*

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*Figs 4.3, 6.1, 6.2, 24.8, 24.9*

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*Figs 6.13a, b*

Benjamin F. Boyd, Highlights of Ophthalmology

*Figs 5.3 to 5.5*

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*The following figures have been redrawn—Figs. 7.4 to 7.6, 7.9 to 7.20, 7.22 to 7.29*

Lasersight Technologies

*Fig. 5.13*

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*Fig. 6.11*

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*Figs 6.12a, b*

Moria

*Figs 6.3 to 6.7*

Nidek

*Figs 5.10a, b, 6.9, 24.10, 24.11*

Schwind

*Figs 5.15, 6.10*

Visijet

*Fig. 6.14*

VISX

*Figs 5.9, 24.7*

Zeiss

*Fig. 5.11*

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*Note:* A *t* and *f* following a page number indicates tabular (*t*) and figure (*f*) matter.

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