

Overview of Laser Refractive Surgery

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Since approval of the use of the excimer laser in 1995 to reshape the cornea, significant developments in the correction of refractive errors such as myopia, hyperopia, and astigmatism have been achieved. Combined with other advanced ophthalmological instruments (e.g. anterior segment imaging systems, the femtosecond laser, wavefront-guided customized ablation) and the knowledge accumulated concerning the basic science of refractive errors (e.g. biomechanics and wound healing of the cornea, higher-order aberrations), laser refractive surgery has promisingly outshone other conventional techniques (e.g. radial keratotomy [RK], automated lamellar keratectomy [ALK]) in terms of both safety and efficacy. Photorefractive keratectomy (PRK) produces stable and predictable results with a safe profile. Similarly, laser in situ keratomileusis (LASIK) is also safe and efficacious with the additional advantages of rapid visual recovery and minimal postoperative pain. The choice between the two methods is made only after thoughtful discussion between the surgeon and the patient. Despite these advances, certain limitations and complications do exist. There are also specific and controversial circumstances for which studies should be conducted to make further breakthroughs and avoid annoying complications. In this review, the basic knowledge, surgical issues, and clinical outcomes, of laser refractive surgery, as well as complex cases, will be presented. (*Chang Gung Med J* 2008;31:237-52)



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Corneal refractive surgery, by definition, modifies corneal curvature. Procedures include ablative (photorefractive keratectomy [PRK], laser in situ keratomileusis [LASIK]), additive (intracorneal ring segments [ICRS], corneal inlays), incisional (astigmatic keratotomy [AK], radial keratotomy [RK]), and thermal (laser thermokeratoplasty [LTK], conductive keratoplasty [CK]) methods. With the advent of the excimer laser as an instrument for use in reshaping the corneal stroma, refractive surgery has

undergone significant progress and evolution during the past two decades. Given the fact that other methods are either limited in their indications, do not yield long-term stable results, or are still in the experimental or clinical trial stage, this review will focus on mainstream excimer laser refractive surgical options. These include PRK (representative of surface ablation, i.e. laser subepithelial keratomileusis [LASEK] with a manual epithelial lift or epi-LASIK with a mechanical lift) and LASIK (lamellar

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ablation). Basic knowledge, surgical issues, clinical outcomes, and complex cases will be presented.

Basic knowledge

Refraction

Refraction is the bending of light rays as they pass from one transparent medium to another of a different density. It is measured in diopters (D). The refractive power at the central cornea is about +43D, providing about 2/3 of the total refractive power of the eye (+58D).⁽¹⁾ The ideal refractive procedure would be simple, effective, minimally invasive, safe, and applicable in all patients desiring vision correction. Taken together, the cornea is supposed to be the main target for laser application in refractive surgery.

Anatomy of the cornea

The cornea is a transparent avascular tissue with a smooth, convex surface and concave inner surface, of which the main function is optical. The axial thickness of the cornea ranges from 0.50 mm to 0.52 mm, with 5 histological layers.⁽²⁻⁴⁾ The epithelium, the outermost layer, provides a smooth refractive surface and serves as a barrier against microorganisms. Bowman's layer is a narrow, acellular, homogeneous zone with uncertain functions. The resistance of the cornea is due to the collagenous components of the stroma, accounting for 90% of the corneal thickness.^(1,5,6) The endothelium and its basement membrane (Descemet's membrane, the 4th layer) are responsible for the relative dehydration necessary for corneal clarity via an active sodium potassium - adenosine triphosphatase pump.⁽⁷⁾

The excimer laser

The excimer laser is used to reshape the surface of the cornea by removing anterior stromal tissue. The excimer laser was introduced by Trokel et al in 1983⁽⁸⁾ and first used on a human subject by McDonald et al in 1991.^(9,10) The 193 nm ultraviolet light from the argon fluoride laser, which has the least corneal transmission, causes less adjacent tissue damage and creates a smoother ablation than longer wavelength lasers.⁽¹¹⁾ At a wavelength of 193 nm, high-energy photons break organic molecular bonds of the superficial corneal tissue in a process called ablative photodecomposition.^(12,13) Ejection of material from the cornea begins on a time scale of nanoseconds and continues for 5 to 15 microseconds follow-

ing the excimer pulse.⁽¹⁴⁾ Other important properties of the laser, including optimum irradiance levels and repetition rates,⁽¹⁵⁾ and optical principles for the laser correction of ametropia were also explored and developed.⁽¹⁶⁾ Thereafter, the US Food and Drug Administration (FDA) first approved the excimer laser in October 1995 for correcting mild to moderate nearsightedness.⁽¹⁷⁾ Currently, the excimer laser has been approved for use in PRK, and, since November 1998, for LASIK.⁽¹⁸⁾ Further improvement in lasers occurs with eye-tracking systems that allow precise corneal ablation during eye movement.⁽¹⁹⁾ For an optimal excimer laser beam the fundamental information needed is the corneal ablation behavior, i.e. the relationship between the per-pulse tissue ablation depth and the fluence (energy per area) of the incident laser radiation.⁽²⁰⁾ The ablation efficiency is the amount of tissue vaporized per unit of laser pulse energy, which maximizes for a peak fluence between 380 and 600 mJ/cm² (the absolute maximum occurs at approximately 440 mJ/cm²).⁽²⁰⁾

The femtosecond laser

Since FDA approval of an ultrafast laser in 2000, the femtosecond laser has revolutionized the creation of flaps for LASIK.⁽²¹⁻²⁴⁾ The pulse duration of the femtosecond laser is in the 10⁻¹⁵ second range. The 1053 nm wavelength of light used by the laser, unlike argon fluoride excimer pulses, is not absorbed by optically transparent tissues. The laser can be focused anywhere within the cornea where the energy can be raised to a threshold such that a plasma is generated.⁽²⁵⁾ During the laser-induced optical breakdown process, termed photodisruption, a plasma, shockwave, cavitation, and a gas (CO₂ and H₂O) bubble are produced. By decreasing the pulse duration, the fluence threshold for breakdown can be reduced, thus minimizing the collateral shock wave effects and bubble size.^(25,26)

Supervision through customized ablation?

Similar to stem cells in ocular surface reconstruction or neuroprotection in optic neuropathy, the pursuit of 20/10 or even 30/10 supervision is something like the "Holy Grail" in the field of laser refractive surgery. After being used in astronomy for nearly half century, adaptive optics with a Hartmann-Shack wavefront sensor were introduced to identify and correct low and high order aberrations in the

human eye.⁽²⁷⁾ Correction of optical aberrations of the eye is targeted to increase retinal image resolution for superior clinical outcomes. While Meriam-Webster's Online Dictionary defines customize as: "to build, fit, or alter according to individual specifications and needs,"⁽²⁸⁾ customized ablation attempts to optimize the eye's optical system using a variety of spherical, cylindrical, aspheric, and asymmetrical treatments based on an individual eye's functional, anatomical, and optical aspects,⁽²⁹⁾ as well as patient needs and preferences.

A large proportion of refractive surgeons have wavefront analyzers in their practice and routinely perform wavefront-guided ablation.⁽³⁰⁾ Studies report that wavefront-customized ablation is promising with minimal complications.⁽³¹⁻³⁵⁾ However, there are a number of challenges that need to be addressed regarding the future of customized ablation (Table 1).⁽³⁶⁾ In spite of the developing alternative strategies designed to reduce high-order aberrations of the eye, such as contact lenses^(37,38) and intraocular lens (IOL),^(39,40) the road to achieve the "Holy Grail" of supervision seems long.

Surgical issues

Preoperative screening

As with any other ophthalmic surgical procedure, a complete history (including past and present medical and ophthalmic history, family history, medications, and social and occupational history), a thorough examination, and specialized testing are indispensable for a successful outcome.

Not every patient is a candidate for vision correction using the excimer laser. Age, a high refractive error, and ocular or medical disease may preclude a patient from obtaining a satisfactory outcome.⁽⁵⁰⁾ Table 2 reviews patient selection criteria for PRK and LASIK procedures.

In general rigid contact lenses should be removed for a minimum of 3 weeks and soft lenses for at least one week before assessment.⁽⁵¹⁾ Even with these guidelines, several examples of abnormal corneal topography were observed up to 5 months after rigid lenses were removed.⁽⁵²⁾

Pre-operative pupil size measurement is also very important, although the role of pupil size in LASIK outcome and patient satisfaction remains controversial. Large pupils tend to increase the exposure of corneal aberrations, which can reduce visual acuity in untreated patients and LASIK patients,⁽⁵³⁾ and vice versa for small pupils in patients after refractive surgery and in untreated patients.^(53,54) However, there are reports showing that pupil size

Table 2. Patient Selection Criteria for LASIK and PRK

Age 18 years or older
Stable refraction of at least one year's duration
Myopia ≤ -12.00 diopters
Astigmatism ≤ 5.00 diopters
Hyperopia $\leq +6.00$ diopters
Absence of ocular contraindications:
Keratoconus
Herpetic keratitis
Corneal dystrophy or degeneration
Cataract
Glaucoma
Any other preexisting pathology of the cornea or anterior segment, including scarring, lagophthalmos, dry eye, blepharitis, and uveitis.
Absence of medical contraindications:
Diabetes mellitus
History of keloids
Pregnancy or lactation
Autoimmune disease
Immunosuppression or immunocompromised status

Table 1. Limiting Factors in Wavefront-guided Corneal Ablation

Limiting factor	Rationale
Accommodation	The pattern of HOAs depends on accommodation. ^(41,42)
Aging effect	HOAs of the eye increase with age. ⁽⁴³⁻⁴⁵⁾
Biochemical effect	Ablation-induced steepening and thickening in the midperiphery of the cornea may increase HOA. ⁽⁴⁶⁾
Neuroplasticity	Benefits of customized ablation might be undone by neural compensation for old aberrations. ⁽⁴⁷⁾
Pupil diameter	HOAs increase markedly in patients with large pupil sizes, especially under mesopic conditions. ^(48,49)

Abbreviation: HOA: higher order aberration.

may not play a role in night vision symptoms.^(55,56)

It is imperative to measure corneal thickness before refractive surgery. Despite controversy concerning a definitive minimal safe stromal bed thickness, a widely accepted 250 μm or even 275 or 300 μm should be reserved as the residual thickness.^(51,52) The residual corneal stromal bed thickness should be taken into account for enhancement after PRK or LASIK. The depth of ablation is determined by the Munnerlyn formula:⁽¹⁶⁾

$$\text{Ablation depth in } \mu\text{m} = [(\text{Dioptic correction})/3] \\ * (\text{Ablation diameter in mm}^2)$$

The main uses of corneal topography include pre-operative evaluation to rule out certain corneal abnormalities and post-operative evaluation to monitor the surgeon's and laser's performance. Moreover, corneal topographic analysis has become the standard of care in the pre-operative evaluation of all refractive surgical patients because of its ability to diagnose subclinical ectatic disorders.⁽⁵⁷⁻⁵⁹⁾

Surgical techniques

PRK: The surgical techniques and procedures for PRK are similar to those for LASIK, except for epithelial removal in PRK is replaced by flap creation in LASIK. The original technique of epithelial removal was mechanical scraping using either a blunt or scalpel blade.⁽⁶⁰⁾ An 18% to 20% ethanol solution can be applied to allow easy debridement with a spatula or microspunge.^(61,62) LASEK is an extension of this technique. A corneal marker is used to trephine through the epithelium and warm 18%⁽⁶³⁾ to 20%⁽⁶⁴⁾ alcohol is applied for 25 to 35 seconds to loosen the epithelium. An epithelial flap is then raised, and hinged at the 2 to 3 o'clock⁽⁶³⁾ or 12 o'clock⁽⁶⁴⁾ meridian. Recently, Pallikaris et al described an Epi-LASIK technique in which suction pressure, the blunt blade's oscillation frequency, and head-advance speed were optimized to separate the epithelial layer without disrupting the corneal stroma.^(65,66)

LASIK: LASIK is a lamellar laser refractive surgery in which excimer laser ablation is done under a partial-thickness lamellar corneal flap. After a suction ring has been properly positioned, suction is activated. Intraocular pressure should be raised to over 65 mmHg. A microkeratome, which works like a carpenter's plane, is used to create a corneal flap

about the size of a contact lens. Hinge positions, nasal or superior, depend on the design of the microkeratome, and are at the surgeon's discretion. There are no differences in refractive outcome;⁽⁶⁷⁾ however, it should be noted that loss of corneal sensation and dry eye syndrome occur more often with a superior-hinge flap than with a nasal-hinge flap.^(68,69) The flap thickness, which averages 130 μm to 160 μm , is folded back to expose the underlying stroma. The excimer laser system is then focused and centered over the pupil and the patient is asked to look at the fixation light. After the ablation is complete, the flap is replaced onto the stromal bed. If a significant epithelial defect is present, a bandage contact lens should be placed. Most surgeons place a drop of antibiotics and steroids over the eye at the conclusion of the procedure followed by placement of a clear shield. The flap is optionally rechecked at least one hour later to be sure that it has remained in proper alignment.

Recently, surgeons have been able to customize the thickness and diameter of the corneal flap utilizing a femtosecond laser. Unlike the microkeratome used in conventional LASIK, irregular flap thickness and epithelial injury are minimized.^(70,71) In addition, there are also biomechanical⁽²²⁾ and histopathological⁽⁷²⁾ advantages in femtosecond corneal flaps. In LASIK, a larger flap up to 9 mm or 10 mm in diameter is favored to compensate for any decentration. With the femtosecond laser, a smaller flap is possible if properly centered over the optical zone. It is therefore critical that the suction ring is centered on the monitor screen prior to beginning flap creation.⁽⁷³⁾

Postoperative management

Patients are placed on topical prophylactic antibiotics and topical steroids four times per day for 4 to 10 days, and they are generally seen 1 day, 1 week, 1 month, 3 months, 6 months, and 12 months post-operatively. Preservative-free lubricating drops are helpful for most patients for the first month and frequent use should be encouraged.

On the first post-operative day, careful inspection of the corneal flap of LASIK patients should be performed with a slit lamp. The patient may resume most activities if the post-operative evaluation is normal. Patients are particularly instructed not to rub their eyes or swim during the first month to prevent flap displacement or infectious keratitis.

Most surgeons prefer the use of a therapeutic soft contact lens to promote reepithelialization, decrease pain, and increase mobility.⁽⁷⁴⁾ The lens should be kept in place until complete reepithelialization occurs; however, sterile infiltrates and an increased risk of infectious keratitis must be kept in mind and treated meticulously. Medications and treatments vary in different laser refractive surgeries, and are summarized in Table 3.

Refractive stabilization may require up to 3 months in myopia and is usually longer for hyperopia, depending on the amount of treatment.⁽⁷⁷⁻⁸⁰⁾ Repeat surgery, which is often called enhancement, can be performed once the refraction is stable for at least 1 month, but is generally not performed until 3 months after the first surgery.⁽⁸¹⁾

Clinical outcomes

Safety and efficacy

Safety is defined as the number and percentage of eyes losing two or more lines of best spectacle-corrected visual acuity (BSCVA).⁽⁷⁷⁻⁸⁰⁾ Efficacy is defined as the percentage of eyes with an uncorrected visual acuity (UCVA) of 20/20, or 20/40 or better.⁽⁷⁷⁻⁸⁰⁾ We will review randomized controlled trials, comparative case series and prospective, noncomparative cases series, focusing on safety and efficacy in PRK and LASIK.

PRK: For low to moderate myopia (-1 to -6 diopters), studies showed that safety ranged from 0% to 7%, while efficacy ranged from 97% to 100% for a UCVA of 20/40 and from 36% to 70% for a UCVA of 20/20.^(77,78,82,83) For moderate to high myopia (-6 to

-15 diopters), safety ranged from 0% to 11.8%, while efficacy ranged from 59% to 93% for a UCVA of 20/40 and from 19% to 47% for a UCVA of 20/20.^(79,80,83-85)

LASIK: For low to moderate myopia (-1 to -6 diopters), safety ranged from 0% to 7%, while efficacy ranged from 95% to 100% for a UCVA of 20/40 and from 45% to 79% for a UCVA of 20/20.^(77,78,85,86) For moderate to high myopia (-6 to -12 diopters), safety ranged from 0% to 3.2%, while efficacy ranged from 55% to 94% for a UCVA of 20/40 and from 10% to 36% for a UCVA of 20/20.^(79,80,85,87)

Complications

The number of intraoperative complications has been reduced due to improved technology in laser refractive surgery, better microkeratomes and scanning excimer lasers, and the dramatically increased experience of surgeons. An increased awareness of the contraindications has also resulted in fewer post-operative complications. Most PRK or LASIK complications can be corrected so that no long-term problems persist.⁽⁸⁸⁾ However, serious complications leading to significant visual loss, such as infections⁽⁸⁹⁻⁹¹⁾ and corneal ectasia,⁽⁹²⁻⁹⁵⁾ probably occur rarely in PRK or LASIK procedures. In contrast, bothersome side effects such as dry eyes⁽⁹⁶⁻⁹⁸⁾ and night vision disturbance^(99,100) occur relatively frequently.

Intraoperative complications

Although previously common, eccentric ablations and decentrations are now a rare intraoperative complication, especially with refinements in patient

Table 3. Post-operative Management following Various Laser Refractive Surgeries

Management	PRK	LASIK	LASEK	Epi-LASIK
Topical broad-spectrum antibiotics	Until epithelium heals	First week	First week	First 2 weeks
Topical corticosteroids	First 3 months	First 2 to 4 weeks	First 2 to 4 weeks	First 3 months
Topical NSAID	First 24 to 48 hours	Optional	Optional	First 24 to 72 hours
Non-preserved artificial tears	First 3 to 6 months	First 1 to 2 month	First 1 to 2 months	First 2 to 3 months
Therapeutic soft contact lens	Until epithelium heals	Optional	First 1 to 3 days	First 3 to 4 days
Punctual plugs	Optional	Optional	Optional	Optional
Oral analgesics	First 48 to 72 hours	Optional	Optional	First 24 to 48 hours

Measures or dosages should be adjusted according to surgeon's clinical judgement.

References: 63, 74, 75, 76

Abbreviations: NSAID: non-steroid anti-inflammatory drug; PRK: photorefractive keratectomy; LASIK: laser epithelial kertomileusis; LASEK: laser in situ keratomileusis; Epi-LASIK: epipolis laser in situ keratomileusis.

fixation targets and autocentration eye trackers. Topography-guided laser treatment with a flying spot laser⁽¹⁰¹⁾ and wavefront-guided laser treatment with a small spot size⁽¹⁰²⁾ should prove to be the best treatments for this complication. With the LASIK procedure, intraoperative flap complications that occur with the use of microkeratomers include buttonholes, irregular flaps, incomplete flaps, and free cap flaps.⁽¹⁰³⁻¹¹⁹⁾ The incidence and management of flap-related complications are summarized in Table 4.

Early postoperative complications

Early postoperative PRK complications include pain secondary to an epithelial defect and/or delayed epithelial healing, which may increase the risk of infection.⁽¹²⁰⁾ With LASIK procedures, early postoperative complications include flap striae,^(108-111,117,118) dislodged flaps,^(107-111,116) and diffuse lamellar keratitis (DLK).⁽¹²¹⁾ Staging of DLK is shown in Table 5.

Treatment consists of potent topical steroids hourly. In stage 3 or deterioration of stage 2, irrigation of the interface should be performed immediately. In contrast, scarring may be even more prominent due to tissue loss during lifting and irrigation if stromal melting is already present.⁽¹²²⁾ Infections rarely occur after LASIK, but a recent review of the literature⁽⁹¹⁾ found that 83 cases have been reported to date and the incidence can vary widely (0% to 1.5%). Management of infection following LASIK is similar to that of infectious keratitis, except that the flap is usually lifted and the stromal bed irrigated with antibiotics. In cases of resistant bacterial infection, flap removal and intensive medical therapy has been found useful.⁽¹²³⁾

Late postoperative complications

Late postoperative PRK complications include undercorrections,^(79,124,125) overcorrections,⁽⁷⁷⁻⁷⁹⁾ haze,

Table 4. Flap-related Complications

Complication	Incidence	Management or prevention
Incomplete flap	0.049% to 0.5% ⁽¹⁰³⁻¹⁰⁶⁾	Reduce the optic zone of ablation. ⁽¹¹²⁾ Reposition the flap and postpone laser ablation.
Free cap	0.049% to 4.9% ⁽¹⁰³⁻¹⁰⁶⁾	Routine use of double-circle markings with different sized circles to aid in realignment in case a free cap occurs. ⁽¹¹³⁾
Thin flap and buttonholes	0.041% to 0.13% ⁽¹⁰³⁻¹⁰⁶⁾	With a full thickness hole, the ablation should be deferred. ⁽¹¹⁴⁾ An alternate approach is “transepithelial keratectomy.” ⁽¹¹⁵⁾
Dislodged flaps	0.07 to 2.0% ⁽¹⁰⁷⁻¹¹⁰⁾	Reposition and apply contact lens. In a completely detached flap, suturing of the flap may be needed. ⁽¹¹⁶⁾
Flap striae	1.1% to 3.5% ^(109,111)	Lifting the flap, hydration, stroking, smoothing, suturing, heating, use of contact lens, and discarding the flap. ^(108-111,117,118)
Corneal epithelial defect	0.041% to 9.7% ⁽¹⁰³⁻¹⁰⁶⁾	Preservative-free lubricants with antibiotics if the epithelial defect is less than 3 mm. Use of bandage soft contact lens in eyes with epithelial defect of more than 3 mm. ⁽¹¹⁹⁾

Table 5. Staging of Diffuse Lamellar Keratitis (DLK)

Stage	Description
1	Infiltrates in the periphery of the flap without involvement of the central cornea. This stage most commonly presents the day after surgery.
2	White granular cells involving the visual axis. This is more frequently seen on day 2 or 3 and is the result of central migration of cells. It leads to the “Sands of Sahara” syndrome.
3	Usually appears 48 to 72 hours after surgery with a 1- or 2-line loss of visual acuity. Stage 3 has been referred to as “threshold” DLK because permanent scarring could occur if not appropriately treated.
4	Severe lamellar keratitis. Stromal melting and permanent scarring is the likely result.

Adapted from Linebarger EJ, et al.⁽¹²¹⁾

scarring, and regression.⁽¹²⁶⁾ Undercorrections are generally treated between 6 weeks and 3 months after the primary procedure, and treatment is usually concentrated on the stromal bed.^(124,125) Non-contact thermokeratoplasty using a Ho:YAG laser⁽¹²⁷⁾ and hyperopia LASIK^(128,129) are suggested treatment modalities for overcorrected myopic LASIK. Late postoperative complications of LASIK include epithelial ingrowth,⁽¹³⁰⁻¹³²⁾ corneal ectasia,⁽⁹²⁻⁹⁴⁾ night vision disturbances,^(99,100) and dry eyes.^(96,97) The incidence and management are summarized in Table 6.

There is a large body of knowledge on the management and prognosis of complications after laser refractive surgery, and detailed descriptions are beyond the scope of this article. Readers who are interested in these details may refer to the more comprehensive references listed below.^(117,118,133)

Complex cases

LASIK or PRK in children

Although there have been no prospective randomized studies investigating the safety and efficacy of laser refractive surgery in children, some practitioners advocate its use in cases in which traditional treatments have failed.⁽¹³⁶⁾ PRK has been successfully performed on infants as young as 1 or 2 years of age,⁽¹³⁷⁾ and LASIK has been performed on children as young as 5 years of age.⁽¹³⁸⁾ LASEK has also been performed in young children.⁽¹³⁹⁾ As in other surgical issues related to the pediatric population, caution needs to be taken with regarding anesthesiological and physiological factors.

LASIK in glaucoma

To date, there has been no definitive report

proving the safety of LASIK in patients with glaucoma. It is well-known that the intraocular pressure (IOP) may be elevated to the range of 60 to 90 mmHg during the maximum vacuum phase of the microkeratome pass.^(140,141) Several studies have been conducted to determine whether this short but intense IOP increase results in damage to the retinal nerve fiber layer (RNFL).^(142,143) Although the results suggest that LASIK performed by experienced surgeons does not result in injury to the RNFL in normal individuals, there is still no large published series on patients with preexisting glaucoma subjected to LASIK.

The accuracy of IOP measurement is another important consideration for LASIK in glaucoma patients. Several studies have confirmed that the central corneal thickness (CCT) affects the applanation pressure measurement.⁽¹⁴⁴⁻¹⁴⁷⁾ The influence of corneal curvature on the IOP is less clear than that of the CCT. One study failed to find a statistical correlation between the CCT and IOP,⁽¹⁴⁸⁾ whereas others found that measurement in patients with a flatter cornea underestimated IOP.^(149,150)

LASIK or PRK after previous refractive surgery

According to the Prospective Evaluation of Radial Keratotomy (PERK) study, 25-43% of patients who had undergone incisional RK became hyperopic.⁽¹⁵¹⁾ Secondary myopia was also not uncommon because surgeons had a tendency to undercorrect myopia for fear of a possible hyperopic shift. Several studies have proven that LASIK is safe and effective in the treatment of residual myopia and RK-induced hyperopia.⁽¹⁵²⁻¹⁵⁴⁾

There is a risk of further regression, increased

Table 6. Late Post-operative LASIK Complications

Complication	Incidence	Management or prevention
Epithelial ingrowth	0.9% in primary LASIK; 1.7% in enhancements ⁽¹³⁰⁾	Treat if ingrowth > 2 mm from the flap edge. ⁽¹³⁰⁾ Flap lifted and scraped with sponge, a dull blade, alcohol, ⁽¹³¹⁾ or PTK. ⁽¹³²⁾
Corneal ectasia	0.66% ⁽⁹³⁾	Patients with keratoconus or suspected case identified on topography should avoid LASIK. ^(92,93) At least 250 µm of posterior stroma should be preserved. ⁽¹³⁴⁾
Night vision disturbances	25.6% at 1 month 4.7% at 12 months ⁽¹⁰⁰⁾	Patients are reassured that these symptoms generally abate over 3 to 6 months. ^(99,100) 0.125% pilocarpine or Brimonidine drops to reduce pupillary dilation at night. ⁽¹³⁵⁾
Dry eye	12.5% at 6 months (NH) 35.3% at 6 months (SH) ⁽⁹⁸⁾	Frequent lubrication, punctual plug, or topical steroids after LASIK procedure. ⁽⁹⁶⁾ Use a nasal hinge flap for patients with dry eye to avoid neurotrophic keratopathy. ⁽⁹⁸⁾

Abbreviations: PTK: phototherapeutic keratectomy; NH: nasal-hinge; SH: superior-hinge.

haze, and loss of visual acuity in PRK retreatment for undercorrection.^(155,156) LASIK appears to be a safe, effective, and predictable procedure for treating eyes with no or low haze after PRK.⁽¹⁵⁷⁾ On the other hand, when flap or interface complications such as flap striae and epithelial ingrowth are encountered in patients with previous LASIK, PRK may be a safe and effective method of improving visual acuity and reducing visual symptoms.⁽¹⁵⁸⁻¹⁶⁰⁾

LASIK or PRK after penetrating keratoplasty (PK)

Laser refractive surgery should be considered as a therapeutic option in post-PK patients when conventional optical methods of correction have failed. Prior to attempting PRK or LASIK after PK, the surgeon must be sure there is pertinent tectonic, refractive, and immunologic stability.

PRK has been used to treat residual refractive errors after PK,⁽¹⁶¹⁻¹⁶³⁾ however it has been associated with haze. The use of LASIK after PK was first reported in 1997,⁽¹⁶⁴⁾ and there were several reports of successful outcomes thereafter.⁽¹⁶⁵⁻¹⁶⁷⁾ LASIK offers several advantages over PRK in the issue of refractive errors after PK, including rapid visual rehabilitation, decreased stromal scarring, less irregular astigmatism, minimal regression, and the ability to treat a greater range of refractive errors.

Indications or Guidelines and contraindications for LASIK after PK are listed in Table 7. Uncorrected^(165,166,174,176) and spectacle-corrected^(166,174,176) visual acuity improved in patients in numerous reports. The stability of refraction ranged from 1 to 3 months,^(165,166,174) to 6 months⁽¹⁷⁷⁾ after LASIK. The mean percentage of endothelial cell loss was reported to be 8.67%⁽¹⁷³⁾ and 5.7%⁽¹⁶⁷⁾ at 6 months, and it increased to 8.67%⁽¹⁶⁵⁾ and 5.7%⁽¹⁶⁷⁾. On the contrary, endothelial counts were not found to be significantly altered in other studies.^(164,166,178)

Cataract surgery after laser refractive surgery

Difficulty in calculating IOL power in eyes undergoing cataract surgery may be one of the untoward consequences of previous corneal refractive surgery.⁽¹⁷⁹⁻¹⁸¹⁾ Calculations of IOL power in cataract surgery are based on the measurement of corneal power (radius of curvature), axial length, and estimation of the postoperative anterior chamber depth (effective lens position).⁽¹⁸²⁾ The main reason for underestimation of IOL power after corneal refractive surgery should be attributed to the inaccurate determination of keratometric power.⁽¹⁸³⁾ To accurately estimate the IOL power, several methods have been proposed⁽¹⁸⁴⁻¹⁹⁶⁾ as shown in Table 8. Due to personal experience and practical considerations, the

Table 7. Indications or Guidelines and Contraindications for LASIK after PK

Indications	Contraindications
Large refractive errors, anisometropia, not successfully corrected with spectacles, or cases of contact lens intolerance ^(170,171)	Prominent peripheral corneal neovascularization
Keratoconus as the underlying disorder for PK ^(164-167,172)	Wound ectasia
Safety interval between PK and LASIK: 8 months ⁽¹⁶⁵⁾ to 3 years ^(164,173)	Wound malposition ⁽¹⁷⁵⁾
Suture removal prior to LASIK: 3 ⁽¹³⁴⁾ to 6 ^(167,174) months	Minimum CCT of less than 500 μm ⁽¹⁷⁶⁾

Abbreviations: LASIK: laser in situ keratomileusis; PK: penetrating keratoplasty; CCT: central corneal thickness.

Table 8. Methods to Improve Intraocular Lens Calculation after Refractive Surgery (RS)

Developer and Year	Method	Disadvantages
Holladay, ⁽¹⁸⁴⁾ 1989	Clinical history	Changed corneal effective refractive index ^(185,186)
Holladay, ⁽¹⁸⁴⁾ 1989	Contact lens overrefraction	Unreliable refraction in patients with cataracts ⁽¹⁸⁷⁾
Feiz, ^(188,197) 2001	Nomogram-based correction	Pre-RS refraction data required ^(195,196)
Odenthal, ⁽¹⁸⁹⁾ 2002	Intra-operative autorefraction	Poor correlation between objective and subjective refraction. ^(190,191)
Hamed, ⁽¹⁹²⁾ 2004	Gaussian optics formula	Changed ratio of antero-posterior corneal curvature after RS ^(193,194)
Sonego-Krone, ⁽¹⁹³⁾ 2004	Direct corneal power measurement	Purely theoretical and not tested in large series ^(195,196)

nomogram-based correction is recommended,⁽¹⁸⁸⁻¹⁹⁷⁾ (Box 1). Readers who are interested in other methods may refer to the excellent review articles on these issues.⁽¹⁸⁵⁻¹⁹⁶⁾ Since there is no perfect method, data on keratometric power and refraction status should be obtained as accurately as possible before refractive surgery. Not only should patients remind their cataract surgeon of prior refractive surgery, but surgeons should also inform patients who are candidates for cataract surgery following refractive surgery that current methods of IOL calculation are not ideally perfect.

Box 1. Nomogram-based Intraocular Lens (IOL) Calculation after Refractive Surgery.

For post-myopic LASIK eyes:

$$IOL_{adj} = IOL_k - 0.231 + (0.595 \times SE_{RX})$$

For post-hyperopic LASIK eyes:

$$IOL_{adj} = IOL_k - 0.751 + (0.862 \times SE_{RX})$$

IOL_{adj} : adjusted IOL power to implant for emmetropia

IOL_k : IOL power using standard keratometry of post-LASIK cornea and SRK formula

SE_{RX} : absolute value of spherical equivalent change induced by LASIK (the sign should be positive in myopic cases and negative in hyperopic cases)

LASIK: laser in situ keratomileusis

SRK: Sanders, Retzlaff, and Kraff

CONCLUSIONS

PRK, including the surface ablation procedures LASEK and epi-LASIK, and LASIK are relatively effective and predictable surgical procedures for the correction of myopia and hyperopia with or without low-to-moderate astigmatism. However, data from prospective clinical trials directly comparing LASIK with PRK are insufficient. For low-to-moderate myopia (–6.0 diopters) with astigmatism, surface ablation procedures remain good alternatives to LASIK and have similar long-term results.⁽¹⁹⁸⁻²⁰⁰⁾ Despite the significant advantages of LASIK, such as faster visual recovery, less postoperative discomfort and better stability in high myopia groups, it can result in several rare but disastrous complications.⁽²⁰¹⁾

Advances in laser refractive surgery will continue to be driven by emerging technology, but the outcomes are not always so accurate. Meticulous

screening for suitable candidates and comprehensive informed consent should be done preoperatively. The best results are obtained by surgeons who check the instruments and laser before surgery and maintain excellent surgical technique. Additionally, the importance of well-organized postoperative care cannot be overemphasized. If surgical complications or untoward effects arise, the doctor should be available for both medical and emotional support.

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雷射屈光手術概述

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自從 1995 年引進雷射光以重塑眼角膜，針對近視、遠視，以及散光等屈光不正的矯正方法已有長足的進步。由於先進眼科儀器的發展，加上對屈光不正的基礎科學知識的累積，雷射屈光手術不論在手術結果的安全性或有效性均有實質性的進展。雷射屈光角膜切除術 (PRK) 的結果穩定、可預期，且過程相當安全。類似於 PRK，準分子雷射光原位角膜塑型術 (LASIK) 亦是安全且有效的，並有視力迅速恢復與極少術後疼痛等額外優點。儘管先進，雷射屈光手術仍存在一定的限制及併發症；仍有一些特殊或具爭議性的情況尚待深入研究以求突破，並避免惱人的併發症。在本篇綜論中，我們將介紹雷射屈光手術的基礎知識、手術議題、臨床結果，以及特殊個案。(長庚醫誌 2008;31:237-52)

關鍵詞：準分子雷射光原位角膜塑型術 (LASIK)，雷射屈光角膜切除術 (PRK)

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