Recent advances in refractive surgery

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Education

Éducation

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Abstract

REFRACTIVE ERRORS ARE SOME OF THE MOST COMMON ophthalmic abnormalities worldwide and are associated with significant morbidity. Tremendous advances in treating refractive errors have occurred over the past 20 years. The arrival of the excimer laser has allowed a level of accuracy in modifying the cornea that was unattainable before. Although refractive surgery is generally safe and effective, it does carry some risks. Careful patient selection, meticulous surgical technique and frequent follow-up can avoid most complications. The experience of a surgical team can also affect the outcome and the incidence of complications. The future should bring continued improvement in outcomes, fewer complications and exciting new options for treating refractive errors.

Refractive errors are some of the most common ophthalmic abnormalities worldwide and are associated with significant morbidity. In North America 20% of people have some degree of myopia and almost 50% have hyperopia.[1–4] Eyeglasses are the traditional mainstream treatment. However, for some patients, especially those with severe (high) myopia, hyperopia or astigmatism, they are unsatisfactory because of optical distortion, significant inconvenience or unacceptable social stigma. Contact lenses were introduced in 1960, but for some people they are troublesome to use, require manual dexterity and can be associated with sight-threatening complications such as corneal ulcers.

Refractive surgery is used to alter the refractive state of the eye. Thermal cautery was one of the first surgical techniques, used more than 100 years ago, to steepen the corneal curvature in people with hyperopia. In the last 50 years refractive surgery has evolved dramatically, with improving outcomes. Radial keratotomy became popular in the late 1970s and early 1980s for the treatment of myopia. This was followed by photorefractive keratectomy (PRK) using the excimer laser, introduced in 1987, and laser-assisted in situ keratomileusis (LASIK), introduced in 1990, whereby laser energy is applied in the stromal bed. The use of lasers to correct refractive errors has been rapidly gaining popularity in Canada. Surgical techniques that do not use lasers are also now available, including clear lens extraction, implantation of phakic refractive lens (intraocular contact lens for severe myopia and hyperopia), use of intracorneal rings for mild myopia and insertion of scleral implants to restore accommodation in presbyopia.

In this article we provide an overview of recent important advances in refractive surgery.

Refractive errors

In the normal eye, light is refracted first by the cornea and then by the lens to focus on the retina (Fig. 1). The cornea contributes 60% to 70% of the refractive power of the eye, the remaining 30% to 40% coming from the lens. Because the shape of the cornea affects the refractive state of the eye so profoundly, most forms of refractive surgery are designed to alter the cornea's curvature and thus the refractive power of the eye.

There are 4 types of refractive error: myopia, hyperopia, astigmatism and presbyopia. In myopia, the axial length of the eye is long, and thus the refractive power of the cornea is too strong for the eye and the image is focused in front of the retina (Fig. 2). Consequently, surgical treatment involves flattening the cornea to reduce its power. In nonsurgical treatment a "negative" (concave) lens is used to accomplish this. In general, myopia is classified as mild (low) (–1.00 to –6.00 dioptres [D]), moderate (> –6.00 to –10.00 D) or severe (high) (> –10.00 D), according to

Abbreviations in this article

BSCVA	Best spectacle-corrected visual acuity
D	Dioptre
H-PRK	Hyperopic photorefractive keratectomy
LASIK	Laser-assisted in situ keratomileusis
PARK	Photoastigmatic refractive keratectomy
PRK	Photorefractive keratectomy
PTK	Phototherapeutic keratectomy

the power of the refractive lens needed to correct the myopia.

In hyperopia, the axial length of the eye is short, the refractive power of the cornea is therefore insufficient, and the image is focused behind the retina (Fig. 3). As a result, surgical treatment involves steepening the cornea to increase its power. Nonsurgical treatment uses a "plus" (convex) lens to accomplish this.

Astigmatism results from variations in the curvature of the cornea in different meridians. This prevents a single clear image from focusing on the retina (Fig. 4). Astigmatism can be accompanied by myopia or hyperopia. Nonsurgical treatment includes the use of eyeglasses with spherocylindrical lenses or the use of hard and toric contact lenses.

Presbyopia occurs with aging. Accommodation (the eye's ability to focus) is gradually lost as the lens becomes less elastic. As a result, near objects are focused behind the retina. Presbyopia usually begins at age 40 to 50 and is present in everyone over 50. Correction requires the use of bifocal, multifocal or reading glasses, bifocal contact lenses or contact lenses with one eye corrected for reading (monovision).[5]

The basic science of the excimer laser

The excimer laser emits high-energy ultraviolet light at a wavelength of 193 nm. It was first developed in 1975 for the manufacture of integrated circuits. "Excimer" was shortened from "excited dimer," a phrase used by photochemists to describe the state of energized molecules composed of 2 identical elements.[6] Most excimer lasers use 2 different molecules — a rare gas (argon) and a halogen (fluoride) — so the term "excimer" is actually a misnomer.

The laser beam is produced by first pre-ionizing a mixture of the argon and fluoride with a set of electrodes. High-voltage electricity is then applied and causes unstable argon–fluoride molecules to form. These molecules rapidly dissociate, emitting ultraviolet light at a fixed wavelength of 193 nm.

The excimer laser has a unique interaction with biological tissue called photoablation.[7] The photons from the laser possess enough energy to break intramolecular bonds, which results in immediate material decomposition, with minimal thermal damage to surrounding tissue (Fig. 5). The excimer laser can thus be used to remove small portions of corneal tissue and effectively sculpt the cornea to a desired shape for precise refractive change.

Excimer lasers ablate the corneal stroma under computer control through an expanding diaphragm, an erodible mask, a scanning slit or a flying spot. The flying spot requires the use of an eye tracker to improve centration.

The biological response of the cornea to PRK is analogous to wound healing of the skin. Within the first 24 hours stromal wound healing is evident, with the presence of neutrophils from the tear film and a marked increase in the prostaglandin E_2 (PGE_2) level along with other mediators. It is believed that this high level of PGE_2 is responsible for the early postoperative pain. Because the PGE_2 level can be lowered with the topical use of NSAIDs, these drugs are commonly used to control pain after PRK. In the next 1 to 6 days after surgery epithelialization pro-

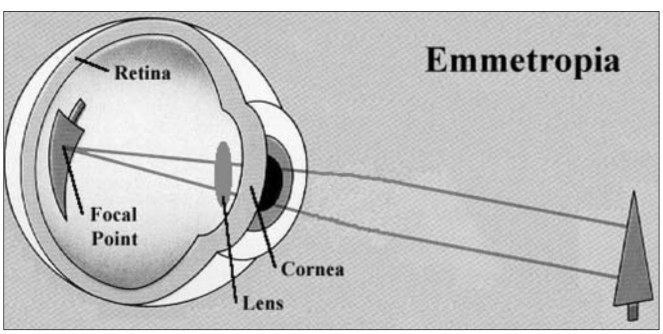

Fig. 1: In the normal eye (emmetropia) light is refracted first by the cornea and then by the lens to focus on the retina.

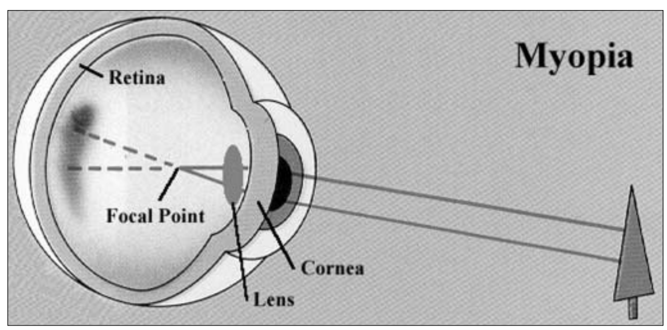

Fig. 2: In myopia (nearsightedness) the axial length of the eye is long. The refractive power of the cornea is therefore too strong, and the image is focused in front of the retina.

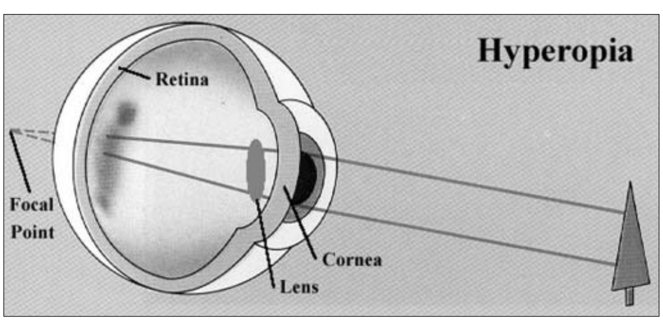

Fig. 3: In hyperopia (farsightedness) the axial length of the eye is short. The refractive power of the cornea is therefore insufficient, and the image is focused behind the retina.

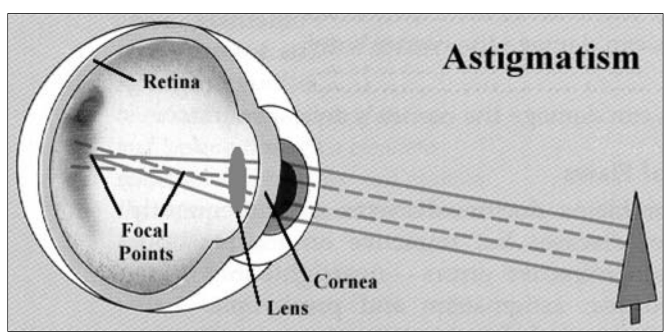

Fig. 4: Astigmatism results from variations in the curvature of the cornea in different meridians. This prevents a single clear image from focusing on the retina.

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gresses with deposition of collagen type IV and VII, which form basement membrane and normal anchoring complexes. Complete epithelialization is usually achieved in 5 days. In the stroma, keratocytes are markedly decreased during the first 3 days but later repopulate and increase to 3 times the normal density by the third week. These keratocytes produce subepithelial deposits consisting of collagen and new extracellular matrix proteoglycans, which are responsible for the formation of corneal haze and regression.[8] The wound healing response following LASIK is less intense because of the limited disruption of the epithelium and Bowman's membrane; there are few histologic changes observed in the corneal stroma, but some deposits can be seen in the interface.

Patient selection

Patient selection and evaluation are the most important aspects of elective refractive surgery. Patients should be at least 18 years of age and have a stable refractive error. As with any other evaluation for ophthalmologic surgery, detailed history taking (including past and present medical and ophthalmic history, family history, medications, social and occupational history, refractive stability and history of contact lens use), thorough examination and testing are important for a successful outcome.

Table 1 lists the contraindications to refractive surgery. Essentially any disease that interferes with normal epithelial and stromal healing is a contraindication. These include severe dry eyes, connective-tissue diseases, active or residual corneal disease and the use of medications such as amiodarone, isotretinoin and sumatriptan. Surgery during pregnancy and lactation is contraindicated because it can cause unstable refractive outcome owing to hormonal changes. Visually significant cataract is a contraindication because the refractive error can be corrected through intraocular lens implantation during cataract surgery. Relative exclusions include large pupils, diabetes mellitus, prior ocular surgery, and open-angle glaucoma if not well controlled medically.[6,9]

Patients should not only meet the medical and surgical criteria but also have realistic expectations. Their social and career history and their reasons for surgery need to be assessed carefully. Patients need to be aware that the refractive procedure may not completely eliminate the need for nonsurgical refractive correction. Patients with unrealistic expectations, even if they meet all the criteria for the procedure, should still be advised against elective refractive surgery.

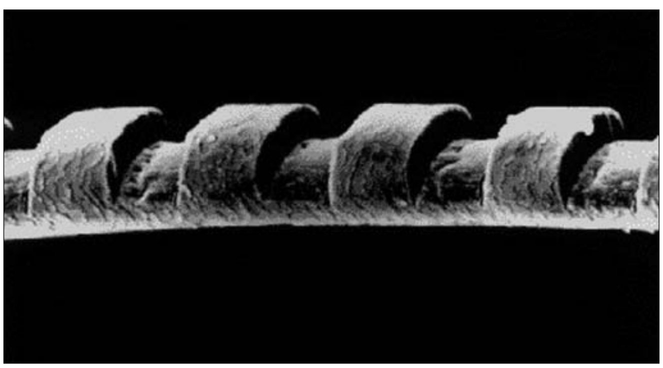

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Fig. 5: Notches cut in a strand of human hair by an excimer laser. Photons from the laser possess enough energy to break intramolecular bonds, which results in immediate material decomposition, but thermal damage to surrounding tissue is minimal.

Table 1: Contraindications to photorefractive keratectomy

Progressive myopia	Connective-tissue disease
Ocular surface disease	Rheumatoid arthritis
Dry eyes	Wegener's granulomatosis
Rosacea	Sjögren's syndrome
Atopic disease	Systemic lupus erythematosus
Neurotrophic keratitis	Ocular cicatricial pemphigoid
Exposure keratitis	Immunocompromised state (e.g., HIV infection)
Chemical burn	Pregnancy and lactation
Residual, recurrent or active ocular disease	Medication use
Iritis	Amiodarone
Herpetic keratitis	Isotretinoin
Corneal ectasia	Sumatriptan
Keratoconus	Corticosteroid
Keratoglobus	Oral contraceptive — relative
Visually significant cataract	Unrealistic expectations

Surgical techniques

Surgical techniques to correct refractive errors can be divided into 4 categories: incisional, thermal, lamellar and intraocular (Table 2). Common incisional surgery includes radial and astigmatic keratotomy (Fig. 6). For these procedures, a thin, ultra-sharp diamond knife is used to create partial-thickness incisions in the cornea to weaken it structurally, allowing the intraocular pressure and biomechanical forces to induce changes in its curvature.

With thermal techniques, heat is used to shrink collagen in the periphery of the cornea; this results in the formation of a bandlike constriction that steepens the centre of the cornea while flattening the periphery for hyperopia correc-

Table 2: Surgical techniques used to correct refractive errors

Incisional
Radial keratotomy
Astigmatic keratotomy
Thermal
Holmium:YAG laser
Lamellar
Photorefractive keratectomy
Photoastigmatic refractive keratectomy
Hyperopic photorefractive keratectomy
Presbyopic photorefractive keratectomy
Laser-assisted in situ keratomileusis
Intrastromal corneal ring
Intraocular
Clear lens extraction with intraocular lens implant
Intraocular phakic lens implant (intraocular contact lens or phakic refractive lens)

tion. Use of the noncontact holmium:YAG laser is currently the most common method of thermal delivery and can correct mild hyperopia without involving the corneal epithelium or the central visual axis.[10]

Lamellar procedures are the most widely used in refractive surgery. Common procedures include PRK for myopia, photoastigmatic refractive keratectomy (PARK), PRK for hyperopia (H-PRK) and LASIK. The intrastromal ring can be used to correct mild myopia with the insertion of 2 thin crescent-shaped polymethylmethacrylate segments into the periphery of the cornea. The segments flatten the centre of the cornea; the degree of correction is determined by the thickness of the segments. The segments leave the central optical zone untouched, which results in excellent quality of vision, and they can be removed if the refractive effect needs to be reversed. Early results indicate that the use of a scleral expansion band — whereby 4 crescent-shaped polymethylmethacrylate segments, each 4.5 mm long and 600 μm wide, are inserted in the sclera 2–2.5 mm from the limbus — can reverse the effects of presbyopia by restoring accommodation. The use of this scleral expansion band can be combined with corneal refractive surgery to correct other refractive errors.

Intraocular surgery can be used to correct severe myopia or hyperopia. The surgery is performed in the same way as cataract surgery if the natural lens is removed. If the natural lens is clear and the patient has accommodation, an intraocular implant (phakic refractive lens or implantable contact lens) can be positioned in the anterior chamber, fixed to the iris or placed in the posterior chamber behind the iris, in front of the patient's lens. The main advantages of intraocular procedures are rapid rehabilitation, better predictability of outcome and excellent quality of vision, especially in people with severe refractive errors. Disadvantages include loss of accommodation if the natural lens is removed and complications that are associated with any intraocular surgery (corneal decompensation, retinal detachment, especially in people with severe myopia, and postoperative endophthalmitis). The long-term risk of cataract formation after intraocular lens implantation is unknown.[11]

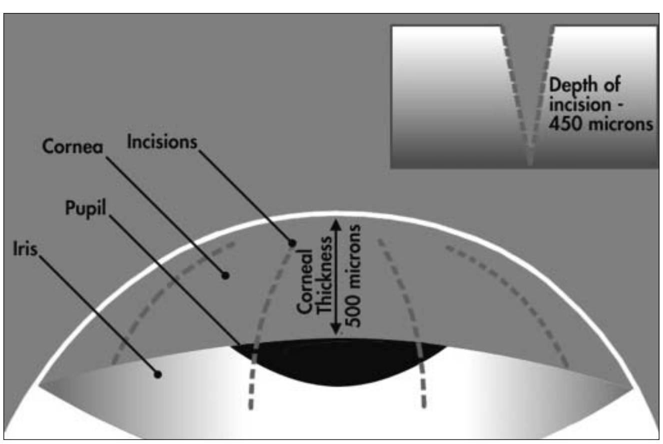

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Fig. 6: Radial keratotomy is a common incisional technique for correcting refractive errors. Partial-thickness incisions weaken the cornea structurally to induce changes in its curvature.

Surgical techniques for myopia

The 2 most common surgical techniques for the correction of myopia and myopic astigmatism are PRK and LASIK.

Photorefractive keratectomy

PRK was the first and is the simplest laser refractive surgical procedure performed in Canada. A lamellar procedure, it relies on the unique ability of the excimer laser to remove submicrometer amounts of tissue from the central region of the cornea through photoablation (Fig. 7). The cornea is thereby flattened and the refractive power of the eye decreased. The higher the degree of correction and the larger the treatment diameter, the more tissue that must be ablated. Astigmatism up to 6.00 D can be corrected by preferentially ablating the steepest meridian or by ablating an elliptical shape that will correct both the myopia and the astigmatism.[7]

Procedure

On the day of surgery, the patient is re-examined to ensure that the refractive error is stable. The patient is then placed in a supine position. A topical anesthetic is applied, and a lid speculum is used to open the eye being treated. The patient is instructed to fix on a target so that the laser beam can be directed at the centre of the pupil. Epithelium is then removed mechanically (with a spatula or rotating brush), chemically (with alcohol) or with the laser. After the epithelium is removed, ablation with the laser is performed while the patient fixes on a blinking light. With broad-beam lasers the ablation starts in the centre of the cornea and expands peripherally to produce central flattening of the cornea. With scanning and flying-spot lasers, the ablation is applied more randomly in an attempt to produce a smoother ablation profile.

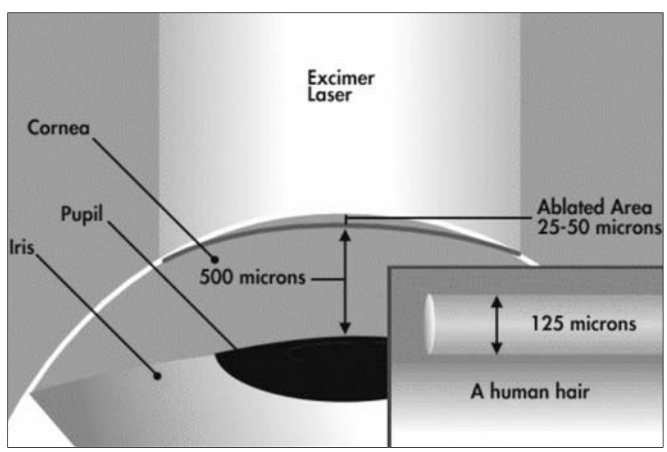


Fig. 7: Photorefractive keratectomy is a lamellar procedure used to correct myopia. The excimer laser removes submicrometer amounts of tissue from the centre of the cornea, thereby flattening the cornea and decreasing the refractive power of the eye.

Many surgeons treat both eyes during the same session. Some delay treatment of the second eye for a few days or weeks until they are assured of a good result in the first eye. The duration of treatment for each eye depends on the degree of correction required, but it usually lasts less than 60 seconds.

Postoperatively, a bandage contact lens or eye patch is applied, along with antibiotic and anti-inflammatory eye drops. The patient is monitored closely to assess the healing process and to detect infections early. Daily follow-up visits to the surgeon is mandatory until the epithelium is healed. Epithelium normally heals in 3–4 days for myopia and 4–5 days for hyperopia. Follow-up in the first few months, especially if topical steroids are used, is important and can be performed by the ophthalmologist or co-managed with an optometrist.

Outcomes

Results of PRK are generally excellent and are related to the degree of correction required and the preoperative visual acuity.[7] Recent data from the University of Ottawa Eye Institute[12] on 408 eyes treated with a broad-beam laser showed that, at 1 year postoperatively, 97% of the 286 eyes with mild myopia achieved an uncorrected visual acuity (the visual acuity measured when a person is not wearing any spectacles or contact lens [Appendix 1]) of 20/40 (metric 6/12), which is the legal vision requirement for driving, and 68% achieved an uncorrected visual acuity of 20/20 (6/6); 97% were within ±1.00 D of the intended correction. Haze was minimal in this group; 68% of the patients had no loss of BSCVA (best spectacle-corrected visual acuity [Appendix 1]), and no patient lost more than 1 line on the Snellen chart. Of the 122 eyes with moderate myopia 100% achieved an uncorrected visual acuity of 20/40 (6/12) and 58% an uncorrected visual acuity of 20/20 (6/6); 92% of the eyes were within ±1.00 D of the intended correction. Most (78%) of the patients had no loss of BSCVA, 21% lost 1 line on the Snellen chart, and 1% lost 2 lines. Follow-up at 2 years showed findings that were not significantly different from those at 1 year.

The most common causes of loss of BSCVA are irregular astigmatism and haze. Patients with severe myopia have had lower success rates and may require a second treatment to achieve the desired results. Some surgeons have had improved outcomes with a planned 2-stage approach,[13] where 8.00 to 10.00 D is corrected at the first session and the remaining refractive error corrected 1 to 2 months later.

Complications

Although PRK is very effective and most patients are pleased with the results, there are potential complications (Table 3).[6,7,9] The most common is the sensation of glare and haloes, especially at night, similar to that experienced by people who wear contact lenses. This complication is more common in patients with large pupils and a small ablation zone (less than 6 mm). The prevalence is about 1%–5% at 6 months after PRK, and it decreases with longer follow-up. Glare and haloes are caused primarily by the spherical aberration from the centrally flattened cornea. It worsens at night as the pupil dilates and more peripheral light enters the eye through the peripheral transition zone. Haloes and glare can also be associated with loss of contrast sensitivity when the person is looking at low-contrast objects in dim light. Fortunately, in most cases the symptoms disappear with time. If glare and haloes persist, however, retreatment with an ablation zone greater than 6.5 mm may resolve the problem.

Although the result of PRK is very predictable (over 90% of eyes will be within ±1.00 D of the intended correction), over- and undercorrection are still possible, especially in people with severe myopia. Overcorrection to hyperopia is not tolerated well by people who have myopia and presbyopia. Early overcorrection may occur in older patients with moderate or severe myopia. Sustained overcorrection is uncommon but can occur if there is minimal healing after PRK. Treatment of overcorrection involves stopping the use of corticosteroids, applying a bandage contact lens or scraping the epithelium to stimulate wound healing and using a topically applied NSAID for 1 month. If the patient remains symptomatic at 6–12 months, H-PRK or holmium: YAG laser surgery are the best treatment options and give good results.

Undercorrection is more common than overcorrection, occurring in 4%–10% of eyes with mild myopia and in 25% of those with severe myopia. If undercorrection occurs, patients who may be accustomed to being myopic will experience at least some improvement of vision; however, significant undercorrection is disappointing to patients. Unlike overcorrection, undercorrection is due to a more

Table 3: Complications of photorefractive keratectomy

Suboptimal refractive correction
Overcorrection
Undercorrection
Induced astigmatism
Regression
Altered vision
Glare
Haloes
Night-vision abnormality
Diplopia
Loss of lines of BSCVA
Haze/scarring
Irregular astigmatism
Topographic changes (central islands, decentration)
Rare but severe complications
Corneal infection
Endophthalmitis
Glaucoma (steroid induced)
Cataract (steroid induced)

Note: BSCVA = best spectacle-corrected visual acuity (see Appendix 1 for definition).

aggressive healing response, with refractive regression usually accompanied by corneal haze. For persistent undercorrection, with or without haze, retreatment with PRK is safe and effective in improving visual acuity without increasing haze.[14] Currently, there is controversy over whether retreatment should be done in the first few months after surgery or after at least 6 months.[15]

Myopic regression because of a lack of long-term refractive stability is possible after PRK. It usually occurs within the first 6 months but can present up to 18 months postoperatively. The risk factors for regression are correction of severe myopia, presence of regression and haze after treatment of the first eye, significant ultraviolet light exposure, sun tanning, pregnancy, viral infection and use of an oral contraceptive.[16] The incidence of regression is currently greatly reduced with newer ablation algorithms, and our experience with a broad-beam laser suggests that the average amount of regression at 2 years is only –0.30 D. If regression occurs, topical steroid therapy will be started in most cases and may have dramatic results in some patients.[17,18] For persistent regression, retreatment with PRK and avoidance of risk factors are usually satisfactory.[19]

Other complications of PRK include surgically induced astigmatism, decentration (off-centre ablation) and central islands (areas of undercorrection within the treatment centre). However, these are largely preventable and are currently very rare with new laser technology and experienced surgeons.[20,21]

Haze formation or scarring occur in 3%–17% of people with severe myopia and can cause decreased BSCVA.[22] Haze and its most severe form scarring result from an aggressive healing response, in which there is increased production of stromal extracellular matrix and collagen. Mild haze typically presents 2 to 4 weeks after PRK, peaks between 1 and 3 months and gradually resolves in 1 to 2 years. It frequently is associated with myopic regression. The risk factors for haze include correction of severe myopia, delayed healing of the epithelium, prior haze formation in the same or fellow eye, and unprotected exposure to ultraviolet light. As a precaution all patients should wear ultraviolet-protection sunglasses for at least 1 year postoperatively. For patients with marked haze within the first month after surgery, the use of topical steroids can help to reduce the level of haze and the associated myopic regression. If significant haze persists beyond 6–12 months, retreatment with PRK is successful in some patients, especially those with significant regression. However, these patients are prone to haze formation after retreatment and need to use topical steroids for a number of months after retreatment. If significant haze develops before the second eye is treated, other refractive surgery techniques such as LASIK may be considered.

Infectious keratitis is the most devastating complication of PRK, but fortunately it occurs in only 0.1%–0.2% of cases. It usually appears 24–48 hours after surgery. Significant corneal infection can cause scarring or perforation of the cornea, which requires corneal transplantation. It is essential to follow-up patients daily after PRK until epithelialization is complete. Other reported but rare complications include reactivation of herpetic keratitis, posterior subcapsular cataract formation and increased intraocular pressure owing to steroid use.[7]

Laser-assisted in situ keratomileusis

LASIK is a lamellar procedure that combines photoablation using the excimer laser and an intrastromal surgical technique that preserves the integrity of the outer layer of the cornea.[23] A microkeratome is a mechanical device that uses a high-vacuum suction ring to fix on the globe and a motorized blade to perform a partial-thickness cut in the cornea (Fig. 8). The depth of the cut is controlled by the microkeratome and is usually 130–160 µm, depending on the degree of correction required. After the corneal flap is made, the beam from the excimer laser is then applied to the stromal bed in a fashion similar to that in PRK to correct myopia, hyperopia or astigmatism. After the ablation, the corneal flap is replaced.

The main advantages of LASIK over PRK are the rapid recovery of vision (in 2–3 days compared with 5–14 days) and less discomfort. The amount of haze and regression is also less with LASIK, especially in people with severe myopia. As a result, LASIK is most commonly used to treat more severe myopia, but with experience it is being used to treat all degrees of myopia. The rapid recovery of vision has encouraged many people to have both eyes treated during the same session. The main disadvantages of LASIK are related to the intraoperative complications caused by the microkeratome. Flap-related problems include debris becoming trapped under the flap, epithelial ingrowth, misalignment, wrinkling of the flap and diffuse lamellar keratitis ("shifting sands of the Sahara").

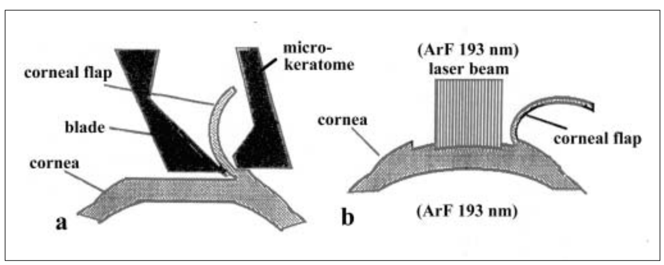


Fig. 8: Laser-assisted in situ keratomileusis, combines photoablation with the excimer laser and an intrastromal surgical technique that preserves the outer layer of the cornea. A device called a microkeratome uses a high-vacuum suction ring to fix on the globe and a motorized blade to perform a partial-thickness cut in the cornea (a). After the corneal flap is made, the laser beam is applied to the stromal bed to correct the refractive error (b). Once photoablation is complete, the corneal flap is replaced. (From Pallikaris IG, Papatzanaki ME, Stathi EZ, Frenschock O, Georgiadis A. Laser in situ keratomileusis. *Lasers Surg Med* 1990;10:463-8. ©1990 Wiley-Liss, Inc. Reproduced with permission of John Wiley & Sons, Inc.)

Outcomes

LASIK is a relatively new procedure, and most reported data are only for a mean follow-up of 6–12 months.[7] It was originally used in patients with moderate or severe myopia because LASIK is believed to cause less haze and regression. Published results with LASIK are generally comparable to those with PRK. In a recent study of PRK and LASIK 115 patients with moderate to severe myopia (–60.00 to –14.00 D) underwent LASIK.[24] At 6 months 41% of the eyes were within ±1.00 D of the intended correction, and 56% of the patients had a visual acuity of 20/40 (6/12) or better.[24] Only 3.2% of the eyes had decreased BSCVA and lost 2 or more lines on the Snellen chart. The results were similar for the 105 patients who underwent PRK; however, the PRK patients achieved improved visual acuity more slowly. A longer follow-up is necessary to address the issue of haze and regression.

Complications

Patients undergoing LASIK are susceptible to all the complications of PRK, as well as flap-related complications (Table 4).[7,25,26] Most complications associated with LASIK occur intraoperatively and are related to the microkeratome device. Intraoperative complications occur in up to 3% of cases, and the rate is significantly related to the surgeon's experience with using a microkeratome.[26] Incomplete flap creation or failure of the microkeratome to stop at the hinge results in a free, off-centre or irregularly shaped flap. Such complications should be detected before the laser beam is applied and should be managed by repositioning the flap and deferring laser treatment. In most cases, there will be no significant loss of BSCVA, and treatment can be undertaken within 3 months. The most devastating complication is intraocular penetration from a misassembled microkeratome. Damage to the iris and lens has been reported.[7]

Table 4: Complications of laser-assisted in situ keratomileusis

Microkeratome-related complications
Inadequate suction, gear, blade or calibration
Flap irregularity (partial cut, donut shape, thin, free, lost or irregular shape)
Damage to anterior segment
Damage to optic nerve because of elevated intraocular pressure

Flap-related complication
Displacement or loss of flap postoperatively
Wrinkling
Misalignment
Deposits within the lamellar surface
- Epithelial ingrowth
- Foreign material (mucus, oil, metal shavings)
- Diffuse lamellar keratitis ("shifting sands of the Sahara" syndrome)

Suboptimal refractive correction
Overcorrection
Undercorrection
Induced astigmatism, regular
Irregular astigmatism (central island, decentration, malposition of flap)
Regression

Rare but severe complications
Corneal infection
Corneal perforation

Postoperative flap-related complications are also possible. Loss of the corneal flap can result from incomplete adherence of the flap to the stromal bed. Eye rubbing may result in dislocation or loss of the flap. This severe complication usually results in significant haze formation that may require a corneal transplant. Other postoperative flap-related complications include epithelialization of the stromal bed, particulate matter becoming trapped between the stromal bed and the epithelium, diffuse lamellar keratitis ("shifting sands of the Sahara"),[27] epithelium ingrowth, flap dislocation and wrinkling of the flap. Flap-related complications can result in loss of BSCVA and may require lifting of the flap and débridement. Rarer complications of LASIK are listed in Table 4.

Postoperative complications seen with PRK such as decentration, central island, haze and regression can also happen with LASIK. However, short-term data (up to 1 year postoperatively) indicate that the incidence of haze and regression are lower with LASIK.[24]

Surgical techniques for hyperopia

There are currently 2 major techniques available to correct hyperopia: thermal keratoplasty with a holmium:YAG laser, and a lamellar procedure using H-PRK or LASIK. As mentioned earlier, long-term data indicate that thermal keratoplasty is associated with significant regression in patients with severe hyperopia and thus should be used only for patients with mild hyperopia (up to +3.00 D).[10] In contrast, H-PRK has recently been shown to yield excellent results and high refractive stability in patients with mild to moderate hyperopia (up to +6.00 or +8.00 D).[28,29] Promising results have also been obtained with the use of H-PRK to treat overcorrection of myopia from PRK and radial keratotomy (unpublished data).

Hyperopic photorefractive keratectomy

H-PRK is similar to PRK for myopia, wherein the excimer laser is used to remove small amounts of corneal stroma. Instead of flattening the central cornea, in H-PRK the excimer laser produces central steepening by ablating tissue in the periphery of the cornea, with a central zone of 5–6 mm and an overall treatment zone out to 9 mm (Fig. 9).

Patients who undergo H-PRK are generally older and more likely to have dry eyes, eyelid diseases and cataract than those who undergo myopic PRK. Presbyopia is also an important issue. Patients over 40 years need to understand that reading glasses may still be necessary despite a successful outcome. Re-epithelialization takes longer after H-PRK than after myopic PRK because of the larger ablation zone. Postoperative improvement in visual acuity and the return of BSCVA may take 3–6 months. Patient satisfaction is very high with H-PRK because of the improvement in both distance and near vision[28]

Outcomes

In a study of H-PRK to treat mild hyperopia[29] 80% of the eyes were within 0.50 D of the intended correction at 1 year postoperatively, and 98% were within 1.00 D; 70% achieved the preoperative BSCVA, with acuity not worse than 20/25 (6/8). The results were the same at 18 months. Regression tended to occur within the first 6 months after surgery, but refraction tended to stabilize between 6 and 12 months. At 18 months, 75% of the eyes had uncorrected visual acuity of 20/25 (6/8). There were no significant complications. The use of H-PRK to treat moderate hyperopia is also effective, but more initial overcorrection and regression is noted in the first 12 months.[28,30] Treatment of hyperopic astigmatism by steepening the flatter axis is currently being evaluated.[30]

The use of LASIK to treat hyperopia offers the potential of faster recovery of visual acuity and BSCVA, less discomfort and more stability than that achieved with H-PRK. Careful clinical studies are necessary to confirm these initial impressions.

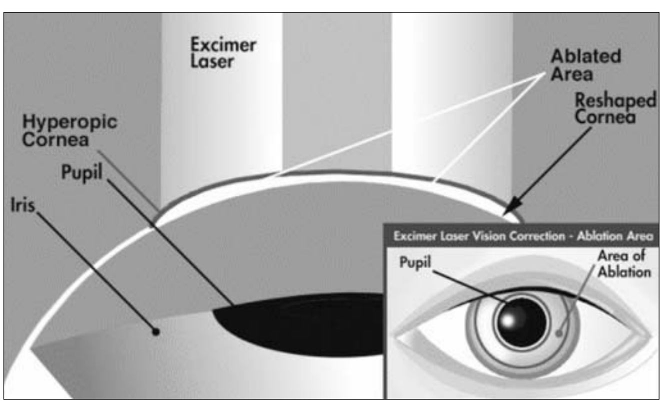
Complications

Possible complications from H-PRK are identical to those from PRK for myopia. However, central haze is much less likely to occur, because the deepest ablation zone is located in the periphery of the cornea. Peripheral haze may occur, but it usually does not decrease visual acuity.

Other uses of the excimer laser

Besides its usefulness in reshaping the cornea for refractive correction, the excimer laser is also effective in treating superficial corneal problems such as various types of corneal dystrophy,[31–38] stromal scarring from injury,[32] infection or surgery, elevated corneal lesions, keratoconus and irregular astigmatism (Table 5). The excimer laser's ability to remove corneal tissue precisely and in a relatively atraumatic manner makes it an ideal tool for treating these conditions. The objective of phototherapeutic keratectomy is to smooth the surface of the cornea to enable correction with eyeglasses or contact lenses, and in some cases to avoid or delay the need for corneal transplantation.

Relative contraindications include corneal abnormalities with a poor healing response such as neurotrophic keratitis, exposure keratitis and dry eyes. Haze with associated decreased visual acuity could develop if the patient has an overly aggressive healing response. Patients with a history of herpetic keratitis are at risk of recurrence. Other complications include induced hyperopia, irregular astigmatism and infective corneal ulcer. Patients with corneal dystrophy should understand that these conditions can recur after treatment, just as they do after corneal transplantation.



VISX Inc., Sunnyvale, Calif.

Fig. 9: As in PRK for myopia, hyperopic photorefractive keratectomy (H-PRK) uses the excimer laser to remove small amounts of corneal stroma. Instead of flattening the centre of the cornea, the laser ablates the tissue in the periphery of the cornea, thereby steepening the cornea.

Summary

Refractive surgery has undergone tremendous advances over the past 20 years. The use of the excimer laser has revolutionized the surgical treatment of refractive errors. We can now achieve a level of accuracy in modifying the cornea that was unattainable before the laser era. The results of refractive surgery are gratifying, with over 90% of patients achieving uncorrected visual acuity of 20/40 (6/12) or better. Although refractive surgery techniques involving the excimer laser are generally safe and effective, there are some risks. These can be minimized through careful patient selection with detailed history taking and physical examination to detect possible contraindications. A careful and meticulous surgical technique coupled with frequent

Table 5: Common indications for phototherapeutic keratectomy

Corneal dystrophy
Anterior basement membrane dystrophy with recurrent erosions
Reis–Buckler's dystrophy
Granular dystrophy
Lattice corneal dystrophy
Keratoconus*
Salzmann's nodular corneal degeneration
Anterior corneal scarring
Posttraumatic
Postinfectious
Herpetic
Trachomatous
Pterygium
Related to wearing contact lens
Apical scars in keratoconus
Irregular astigmatism
Posttraumatic
Postsurgical

*The cornea is flattened for better fitting of contact lens.

postoperative follow-up help to reduce the incidence and severity of complications. The experience of the surgical team also affects the outcome and the rate of complications, especially with the use of LASIK. In the next millennium, we can expect the laser technology to continue to improve, with more compact machines, homogeneous beam profile, lower maintenance costs, accurate eye tracking and customized ablation, allowing the correction of irregular astigmatism. A better understanding of the biological response of the cornea to laser treatment may allow modulation of the wound healing response for more precise correction. The future of laser surgery for refractive errors is to continue to improve the outcomes, minimize complications and explore new techniques.

Competing interests: The University of Ottawa Eye Institute is a beta test site for new hardware and software for excimer laser surgery related to PRK for VISX Inc., Sunnyvale, Calif. Dr. Jackson has received honoraria as a certified trainer for VISX and travel assistance and speaker fees for presenting data at international meetings.

References

1. Curtin BJ. *The myopias: basic science and clinical management*. Philadelphia: Harper & Row; 1985. p. 30-59.
2. Wang Q, Klein BE, Klein R, Moss SE. Refractive status in the Beaver Dam Eye Study. *Invest Ophthalmol Vis Sci* 1994;35:4344-7.
3. Katz J, Tielsch JM, Sommer A. Prevalence and risk factors for refractive errors in an adult inner city population. *Invest Ophthalmol Vis Sci* 1997;38:334-40.
4. Chew SJ, Tseng P. Refractive errors: etiology, incidence, prevention, and non surgical management. In: Serdarevic ON, editor. *Refractive surgery: current techniques and management*. New York: Igaku-Shoin; 1997. p. 1-18.
5. Jain S, Arora I, Azar DT. Success of monovision in presbyopes: review of the literature and potential applications to refractive surgery. *Surv Ophthalmol* 1996;40:491-9.
6. Seiler T, McDonnell PJ. Excimer laser photorefractive keratectomy. *Surv Ophthalmol* 1995;40:89-119.
7. Steinert RF, Bafna S. Surgical correction of moderate myopia: Which method should you choose? II. PRK and LASIK are the treatments of choice. *Surv Ophthalmol* 1998;43:157-79.
8. Corbett MC, Prydal JI, Verma S, Oliver KM, Pande M, Marshall J. An in vivo investigation of the structures responsible for corneal haze after photorefractive keratectomy and their effect on visual function. *Ophthalmology* 1996;103:1366-80.
9. L'Esperance FA Jr. Choosing the appropriate PRK patient. *Focal Points* [American Academy of Ophthalmology] 1998;16(9):1-14.
10. Koch DD, Kohnen T, McDonnell PJ, Menefee RF, Berry MJ. Hyperopia correction by noncontact holmium:YAG laser thermal keratoplasty: US Phase IIA clinical study with 2-year follow-up. *Ophthalmology* 1997;104:1938-47.
11. Trindade F, Pereira, F. Cataract formation after posterior chamber phakic intraocular lens implantation. *J Cataract Refract Surg* 1998;24:1661-3.
12. Jackson WB, Agapitos P, Mintsioulis G, Casson E, Hodge WG. VISX STAR PRK for the treatment of myopia and myopic astigmatism. Paper presented at the annual meeting of the International Society of Cataract and Refractive Surgery; 1998 Nov 6-7; New Orleans.
13. Jans RG. Staged high myopia excimer laser surgery. Paper presented at the annual meeting of the American Society of Cataract and Refractive Surgery; 1998 Apr 18-22; San Diego.
14. Gartry DS, Larkin DFP, Hill AR, Ficker LA, Steele AD. Retreatment for significant regression after excimer laser photorefractive keratectomy. A prospective, randomized, masked trial. *Ophthalmology* 1998;105:131-41.
15. Pop M. Prompt re-treatment after photorefractive keratectomy. *J Cataract Refract Surg* 1998;24:320-6.
16. Corbett MC, O'Brart DPS, Warburton FG, Marshall J. Biologic and environmental risk factors for regression after photorefractive keratectomy. *Ophthalmology* 1996;103:1381-91.
17. Corbett MC, O'Brart DP, Marshall J. Do topical corticosteroids have a role following excimer laser photorefractive keratectomy for myopia? *J Refract Surg* 1995;11:341-7.
18. Marques EF, Leite EB, Cunha-Vaz JG. Corticosteroids for reversal of myopic regression after photorefractive keratectomy. *J Refract Surg* 1995;11(3 Suppl):S302-8.
19. Higa H, Couper T, Robinson DIM, Taylor HR. Multiple photorefractive keratectomy retreatments for myopia. *J Refract Surg* 1998;14:123-8.
20. Lin DTC. Corneal topographic analysis after excimer photorefractive keratectomy. *Ophthalmology* 1994;101:1432-9.
21. Talamo JH, Lee S, Wagoner MD. Management of ablation decentration following excimer photorefractive keratectomy. *Arch Ophthalmol* 1995;113:706-7.
22. Taylor HR, McCarty CA, Aldred GF. Predictability of excimer laser treatment of myopia. *Arch Ophthalmol* 1996;114:248-51.
23. Pallikaris IG, Siganos DS. Excimer laser in situ keratomileusis and photorefractive keratectomy for correction of high myopia. *J Refract Corneal Surg* 1994;10:498-510.
24. Hersh PS, Brint SF, Maloney RK, Durrie DS, Gordon M, Michelson MA, et al. Photorefractive keratectomy versus laser in situ keratomileusis for moderate to high myopia. *Ophthalmology* 1998;105:1512-23.
25. Gimbel HV, Anderson Penno EE, Van Westernbrugge JA, Ferensowicz M, Furlong MT. Incidence and management of intraoperative and early postoperative complications in 1000 consecutive laser in situ keratomileusis cases. *Ophthalmology* 1998;105:1839-48.
26. Wilson SE. LASIK: management of common complications. *Cornea* 1998; 17:459-67.
27. Smith RJ, Maloney RK. Diffuse lamellar keratitis. A new syndrome in lamellar refractive surgery. *Ophthalmology* 1998;105:1721-6.
28. Dausch D, Smecka Z, Klein R, Schröder E, Kirchner S. Excimer laser photorefractive keratectomy for hyperopia. *J Cataract Refract Surg* 1997;23:169-76.
29. Jackson WB, Casson E, Hodge WG, Mintsioulis G, Agapitos PJ. Laser vision correction for low hyperopia: an 18-month assessment of safety and efficacy. *Ophthalmology* 1998;105:1727-38.
30. Vinciguerra P, Epstein D, Radice P, Azzolini M. Long-term results of photorefractive keratectomy for hyperopia and hyperopic astigmatism. *J Refract Surg* 1998;14(2 Suppl):S183-5.
31. Zuckerman SJ, Aquavella JV, Park SB. Analysis of the efficacy and safety of excimer laser PTK in the treatment of corneal disease. *Cornea* 1996;15:9-14.
32. Migden M, Elkins BS, Clinch TE. Phototherapeutic keratectomy for corneal scars. *Ophthalmic Surg Lasers* 1996;27(5 Suppl):S503-7.
33. O'Brart DP, Muir MG, Marshall J. Phototherapeutic keratectomy for recurrent erosions. *Eye* 1994;8:378-83.
34. Ohman L, Fagerholm P, Tengroth B. Treatment of recurrent corneal erosions with the excimer laser. *Acta Ophthalmol (Copenh)* 1994;72:461-3.
35. Orndahl M, Fagerholm P, Fitzsimmons T, Tengroth B. Treatment of corneal dystrophies with excimer laser. *Acta Ophthalmol (Copenh)* 1994;72:235-40.
36. Fagerholm P, Ohman L, Omdahl M. Phototherapeutic keratectomy in herpes simplex keratitis. Clinical results in 20 patients. *Acta Ophthalmol (Copenh)* 1994;72:457-60.
37. Thomann U, Meier-Gibbons F, Schipper I. Phototherapeutic keratectomy for bullous keratopathy. *Br J Ophthalmol* 1995;79:335-8.
38. Stark WJ, Chamon W, Kamp MT, Enger CL, Rences EV, Gottsch JD. Clinical follow-up of 193-nm excimer laser photokeratectomy. *Ophthalmology* 1992;99:805-12.

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Appendix 1: Terminology

Visual acuity

Visual acuity is a measure of the sharpness of vision. The Snellen chart is the most common method of measuring it. A visual acuity of 20/20 (metric 6/6) means the ability to see the 20/20 line at 20 feet away. A visual acuity of 20/40 (6/12) means the ability to see only the 20/40 line clearly from 20 feet away, whereas a person with 20/20 vision should be able to see the same line from 40 feet away.

Uncorrected visual acuity

The visual acuity measured when a person is not wearing any spectacles or contact lens

Best spectacle-corrected visual acuity (BSCVA)

The visual acuity measured when a person is wearing the most suitable spectacles to correct the refractive error

Loss of lines of BSCVA

When a person is no longer able to see the line of the Snellen chart that he or she saw before refractive surgery, some loss of vision has occurred. The amount of loss can be quantified by describing the number of lines lost on the Snellen chart. For example, a change from 20/20 (6/6) to 20/30 (6/9) is a loss of 2 lines of BSCVA