CME Article

Refractive surgery: the future of perfect vision?

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ABSTRACT

The history of refractive eye surgery is recent, but has seen rapid advancement. Older technologies, such as radial keratectomy, had the problem of overcorrection and epithelial complications. Newer technologies, such as photorefractive keratectomy, laser-assisted in-situ keratomileusis (LASIK) and laser-assisted subepithelial keratomileusis (LASEK), which require the use of laser, has revolutionised eye surgery. However, there are complications, such as corneal hazing, postoperative pain, regression, and poorer correction for high myopes. If not contraindicated, wavefront analysis and femtosecond laser are useful adjuncts to laser photoablation for better visual results. Wavefront analysis improves the precision of laser photoablation by measuring the individual's wavefront aberrations, while femtosecond laser offers an instrument-free means of creating the corneal hinge. Lastly, implantation of intraocular lenses, with or without extraction of the crystalline lens, provides an alternative to laser photoablation for the treatment of high myopia. Clear lens exchange offers refractive correction to presbyopes and people with cataracts. However, complications, such as endothelial cell loss, cataract formation and retinal detachment, exist. In conclusion, refractive eye surgery provides an alternative to wearing spectacles or contact lenses. However, potential patients must be warned of the complications and long-term effects on the eyes.

Keywords: cataract extraction, intraocular lens implantation, LASEK, laser surgery, LASIK, myopia, presbyopia, refractive errors

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INTRODUCTION

Over the last decade, refractive surgery has emerged as an attractive option to people with vision problems. The allure of being less dependent on their spectacles drives some people to seek refractive surgery. Sportspeople and those from certain professions also find it beneficial not to wear glasses. Myopia is a common cause of visual impairment, reaching as high as 70%–90% in some Asian countries.[1] Epidemiological and animal models show that genes, race, ageing and constant near work play a part in the development of myopia.[2]

There is one other factor that has been heavily debated: does wearing spectacles increase the progression of myopia? Animal models suggest that it does via axial elongation of the eye globe. The hypothesis states that wearing glasses stimulates sustained accommodation of the eyes, causing axial lengthening, ocular hypertension and ciliary tonus, which in effect, worsens myopia.[3,4] However, studies on schoolchildren, evaluating the effect of spectacle use on the progression of their myopia, have shown that there is no difference in myopic progression between children who use glasses for distance vision only and children who wear glasses all the time.[5,6] In short, the evidence does not back the hypothesis of myopic progression through spectacle use.

Simply put, myopia can be viewed as a disease of "nature and nurture". This means that it is complex and multifactorial in origin, with both genes and environmental factors influencing its development. The distribution of myopes is skewed towards some parts of the world, and as a corollary, certain races. Myopia occurs in about 70% of the population in Asia, 30% in the Americas and Europe, and 10% in Africa.[7] In addition, there is a higher prevalence of myopia in the developed world compared to the developing world.[8] This "epidemic" of myopia in our society appears to be a recent trend. A recent epidemiological study conducted in the United States shows a higher prevalence of myopia in the younger population, compared to their older counterparts.[9] These observations of societal and age trends give strength to the "nurture" argument of myopia development. So far, glasses and contact lenses have been the mainstay of myopia correction. In the last decade, however, refractive surgery has emerged as an alternative choice of treatment.

Today, laser refractive surgery is quickly gaining popularity among the well-heeled myopic population, with over a million procedures conducted each year in the United States alone.[10] Laser surgery is only the latest in a long line of vision correction aids dating back many centuries. Glasses have a history of about 500 years, rigid contact lenses 60 years, gas-permeable lenses 30 years, and disposable lenses ten years.[11] In concert with contact lens development is the fast-evolving field of refractive surgery. Radial keratotomy has been around for about three decades, photorefractive keratectomy (PRK) for two decades, and laser-assisted in-situ keratomileusis (LASIK), the last decade. Most recently, wavefront technology and phakic intraocular lenses offer more precise and higher myopic correction.

How does refractive surgery compare with glasses and contact lenses? By virtue of their longer existence and greater prevalence, they now serve as benchmarks of efficacy, safety and convenience. This review will explore the evolution of refractive surgery, evaluate its performance to existing benchmarks, and conclude with a recommendation on their use.

RADIAL KERATOTOMY

Corneal surgery for refractive correction has come a long way since it was first attempted. Although reports of corneal surgery date back to the 19th century, it is the pioneering work of a group of international ophthalmologists that ushered in the modern age of refractive surgery. Sato observed that spontaneous breaks in the Descemet membrane resulted in the flattening of the cornea, which led him to make numerous radial incisions on both the anterior and posterior surfaces of the cornea. When the physiological role of the corneal endothelium became clear, Fyodorov and Durnev, as well as other groups of ophthalmologists, introduced anterior cuts to the cornea. Radial keratotomy (RK) is the name given to this incisional procedure. With the release of the Prospective Evaluation of Radial Keratotomy (PERK) results, and the development of nomograms by Assil, Casebeer, Lindstrom and others, the procedure has been greatly modified to a staged approach, with two or more incisions performed, depending on the age of the patient and the degree of myopia to be corrected.[12]

RK, while a relatively effective procedure to correct myopia, has seen its share of adherents decline over the years as newer technologies appeared on the scene. The ten-year PERK study, a randomised controlled trial of 793 eyes operated by RK across nine American centres, showed that 85% of the follow-up patients had uncorrected visual acuity of 20/40 or better, and 60% were within one dioptre of emmetropia.[13] The safety level of RK, where less than 3% of patients experience loss of best-corrected visual acuity, has set the standard for other eye correction techniques.[13] Even though RK has its advantages, there are a number of complications which have contributed to the decline in popularity of this breakthrough procedure.

Many of the specific complications of RK stem from corneal weakness due to incisions to the stromal bed, and poor healing of the avascular cornea. With this in mind, the American-style incision and a raft of nomograms have been designed to improve the predictability and stability of RK. When attention is paid to safety, performance tends to decline, as seen in the greater incidence of undercorrected eyes treated by modern, conservative nomograms.[14] Nevertheless, undercorrection is less of a problem than overcorrection, as it is less disabling and it lends itself to further surgical correction. Overcorrection, especially after the immediate postoperative period, leads to patient frustration and eye stress from the abrupt demand of increased accommodation. Overcorrection is the result of oedema and wound gaping, leading to greater cornea flattening. Overcorrection in the long term, called progressive hyperopic shift, remains a significant problem up to ten years after the operation.[15] Corneal perforation is a more uncommon but sight-threatening complication. There is an incidence of microperforations in 2%–10% of cases while macroperforations occur in 0.45% of cases. Untreated, corneal perforation can lead to infection, retinal detachment,[16] anterior chamber collapse, or even globe rupture, especially in the event of additional trauma.[17] Other side effects, usually transient, include diurnal variation of refraction, and glare and starburst effects. Buzard stated that night-time glare is caused mainly by a combination of night myopia and a smaller optical zone, with the incisions themselves playing a minor part.[18]

The reason for the fallout of interest in RK has to do with both the fast turnover of technology and the inherent limitations of the procedure. Bullous keratopathy, the complication that blinded 75% of Sato's patients,[19] is much less of a problem now. This is a result of the diligent technique revisions by radial keratotomists. Yet, despite the decreasing incidence of complications from RK, through refinements of the technique, the trend to flock to newer, more efficacious technologies continues. Nevertheless, RK remains an important milestone in the history of refractive surgery.

PHOTOREFRACTIVE KERATECTOMY

The excimer ("excited dimer") laser is the invention with the greatest impact on refractive surgery in recent times. Today, it can be seen in two major modalities of corrective operations: PRK and laser keratomileusis. The great attraction of laser is the precision of its cuts and the minimal damage it causes to the surrounding tissue. As early as 1983, Trokel et al performed the first argon fluoride (ArF) excimer laser incision on bovine cornea.[20] At this time, this process of shaping the anterior corneal contour with the ArF laser was called photoablative decomposition.[21] Seiler et al in Germany, and L'Esperance et al in the United States were the first to use the excimer laser for therapeutic purposes.[22,23] Since then, this technique has been used to remove corneal opacities, as well as to create a new curvature for refractive errors, with the latter being termed PRK.

"Excited dimer" is a misnomer for the rare gas-halide mixture that provides the substrate for laser emission. The excimer laser used for corneal surgery is an ultraviolet beam with a wavelength of 193 nm and contains sufficient energy to break intermolecular bonds and eject the remnants at supersonic speed. This laser-tissue interaction is the basis for the smooth cuts evidenced in laser incision. With computer manipulation, the beam can be coaxed and shaped to perform a variety of functions. For myopia, the laser is centred on the optical zone to remove a specific volume of tissue so as to flatten the cornea and normalise the refractive error of the eye. The same goal as RK is reached without incision and its attendant complications. In an analogous fashion, excimer laser aims to correct hyperopia by taking out tissue at the midperiphery, so as to steepen the optical zone of the cornea. Similarly, astigmatism is treated by laser ablation along the affected axis of the cornea.

The results of PRK for myopia appear encouraging. Various reports put its success rate to be equivalent to RK.[24,25] Compared to RK, it has some advantages, being less age-dependent, and although regression may occur, progressive hyperopia does not generally ensue.[26] This last point is borne out by the recently-published 12-year analysis of 120 patients who underwent PRK using a Summit UV 200 excimer laser to correct myopia ranging from -2 to -7 dioptres.[27] It showed that after 12 years, PRK-corrected eyes retained refractive stability after an initial regression. Most of the refractive instability occurred in the first postoperative year.[28,29] This means that to date, there is no evidence of long-term regression or putative stromal remodelling. An indication of the advantages that the excimer laser brings to the field of vision correction, is the improvement in the precision of the task, determined by both computer analysis and the individual surgeon's skill.[30] This bodes well for patient satisfaction in an operation that deals with one of the most important sensory organs of the body.

Like all forms of surgery, PRK has its share of problems. PRK patients often take weeks to gain visual recovery as the healing process occurs. Postoperative pain can be pronounced, reaching a point when narcotic agents are needed. PRK is also associated with stromal haze from collagen and glycosaminoglycan deposition, which may persist up to a year. Perhaps most damaging to patient satisfaction, is the risk of sight-threatening complications such as stromal scarring. Equally important to patients is treatment efficacy, which suffers with progressively higher myopic correction. Regression and clinically significant stromal haze also occur more commonly in high myopes. Because of these shortcomings of PRK, work has continued in finding a better means of delivering laser correction.

LASER-ASSISTED IN-SITU KERATOMILEUSIS

LASIK may be one of the newest incarnations of refractive surgery, but it is based on a principle that was established by Barraquer half a century ago. This principle is that lens refraction can be altered by adding or removing tissue from the corneal stroma. It is no wonder that the word, keratomileusis, stands for the Greek roots *keras* (horn) and *smileusis* (carving).[32] In the 1980s, Ruiz, a student of Barraquer, developed the automated microkeratome, which is used to remove a lenticule of cornea so that work can be done on the stromal bed itself.[33] It soon became clear that automated lamellar keratoplasty (ALK), the technique borne from keratomileusis, and PRK, the surface ablation technique, both had their limitations. The relative shortcomings of these surgical modalities served as the impetus for more innovations in refractive surgery. The next step was the combination of reproducible microkeratome technology and the precision excimer laser. Seiler, Buratto and Pallikaris lay claim to the first tests on human eyes.[34] Pallikaris also coined the term LASIK as an acronym for laser-assisted in-situ keratomileusis.

LASIK involves creating a hinged lenticule of cornea, lifting it to perform laser ablation on the stromal bed, and subsequent replacement of the flap. By applying laser energy directly to the stromal bed, LASIK preserves the integrity of Bowman's membrane and the epithelium. It has a number of advantages over its predecessors. Unlike ALK, it does away with excessive instrumentation and the irregularity of the result. Unlike PRK, LASIK encourages a less vigorous wound healing response due to the sparing of the corneal epithelium and Bowman's membrane.

At the turn of the decade, LASIK was the most popular refractive technique in the USA, when one looked at the surgeons' preferred choice of corrective modality.[35] The majority of them chose LASIK over all other forms of refractive options for mild to high myopia, and mild hyperopia. One of the frequently stated reasons for this is the marked improvement in postoperative side effects, such as pain, visual recovery and stromal haze.[36] As results from clinical trials started to flow in, the reality about the refractive outcomes of both LASIK and PRK become clear: there is little difference between the two in terms of low to moderate myopic correction. This is so because PRK has continued to evolve and improve since its inception. Although a recent retrospective trial of an individual surgeon's work on 619 eyes showed better uncorrected visual acuity in high-myopia LASIK patients compared to PRK controls, the general consensus at the present time is that both modalities give comparable refractive outcomes for low to moderate myopia.[38] LASIK trials showed that 70%–80% of patients with -2 dioptres gained uncorrected visual acuity of 20/20, while more than 98% of them saw 20/40 or better. But when eyes of -9 dioptres were treated, the chances of 20/40 uncorrected visual acuity dropped to 95%, while 20/20 vision was only attained by 50% of the cohort.[37]

Despite the improvement in epithelial complications, other flap-related problems surface with LASIK. The anterior flap makes corneal thickness a limiting factor in laser correction, as there may be a correlation between how much tissue is removed and the risk of keratectasia.[39] 250 μm is the suggested lower limit for residual cornea after photoablation.[40] However, reports of keratectasia in thicker residual beds still persist.[41] The presence of keratectasia in such cases suggests that we do not fully know what causes it. Suffice to say, the laser surgeon must consider corneal thickness in the work-up of any correction procedure. The operated cornea also predisposes to dry eyes, diffuse lamellar keratitis and infection. Additionally, a poorly-formed flap can cause problems with irregular astigmatism. An irregular flap is created in a number of situations, such as when the epithelium is accidentally invaded, when a bi-leveled flap is created, when a buttonhole is made, or when microkeratome malfunction results in an incomplete flap or a free cap.[42] Flap irregularity may even occur postoperatively when poor adhesion and displacement result in vision-distorting striae in the flap. Irregular astigmatism can also be a consequence of the process of laser ablation. Aberrations, such as residual central islands or irregular healing, contribute to visual disturbance at the corneal level. In fact, Oshika et al reported that more coma and spherical aberrations were evidenced with higher order correction.[43] These examples showed that LASIK is not without its problems.

Despite its shortcomings, LASIK represents a quantum leap for refractive surgery. It remains the gold standard against which other procedures are measured.[44] Since 1992, more than 20,000 eyes have undergone PRK or LASIK in Singapore alone.[45] Worldwide, more than a million LASIK procedures are performed each year. These numbers represent the huge demand for LASIK treatment around the world.

LASER-ASSISTED SUBEPITHELIAL KERATOMILEUSIS

There is a dictum, "if at first you don't succeed, try, try again." This is the story of laser correction. When at first you don't succeed, tweak the existing method and incorporate previously unworkable techniques into the latest treatment paradigm. PRK with an epithelial flap was described by Azar and Camellin in 1999.[47] This method has been subsequently named laser-assisted subepithelial keratomileusis (LASEK). While it has been derided as "just another way to spell PRK",[48] it can easily be mistaken for another variant of LASIK. It involves the creation of an epithelial flap using a trephine and some alcohol solution, followed by laser ablation to the underlying stroma. The flap is then repositioned gently over the ablated tissue and allowed to heal. LASEK appears to be a revision of previous techniques, and aims to improve the postoperative time course and healing process, do away with flap trauma, as well as offer an alternative treatment route to patients with thin corneas. Despite the similarities of LASEK with earlier technologies, the debate about its legitimacy may be irrelevant if results show clear superiority over previous techniques.

So far, the results of LASEK are mixed. Despite the impressive early refractive outcomes for mild to high myopes,[49,50] follow-up monitoring of regression or other long-term complications have not been reported yet. Some workers have even gone on to question the viability of the epithelial flap in re-establishing its former role. This speculation is encouraged by cadaver studies showing basement membrane discontinuity in epithelial specimens, and the decreased survivability of epithelial cells with longer exposure to alcohol.[51,52] Additionally, reports are conflicting about the postoperative visual recovery and pain profile of LASEK.[53] Clearly, it is too early to judge the merits of LASEK, and only time will tell if this technique delivers the refractive edge or postoperative advantage to carry it into the new century.

Epi-LASIK (short for the Greek word *epipolis,* which means superficial) is an attempt to correct the deficiencies of LASEK. It uses mechanical technology designed at the University of Crete in response to the concern of epithelial death from alcohol exposure. An epikeratome, a device similar to the microkeratome used in LASIK, creates a corneal flap at the level of the basement membrane, sparing the stromal bed and maintaining the integrity of the basement membrane. This offers the theoretical advantage of faster visual rehabilitation and less haze than LASEK. Results from a series of 234 eyes treated by epi-LASIK showed that 53% had uncorrected visual acuity of 20/40 or better on postoperative day one, which increased to 78% with corneal epithelialisation on days three to seven.[54] Comparative studies between Epi-LASIK and other surface ablation techniques will be of great interest in the future.

WAVEFRONT ANALYSIS

There are two drives pushing the boundaries of refractive surgery, namely: finding the best modality to treat high ametropia, and minimising the side effects and complications of the corrective procedure. In all photoablation therapies, there is an element of patient variability and preventable error that may be too intricate for prevailing computer algorithms to correct. As technology catches up with human ingenuity, new opportunities present themselves to provide finer-detail treatment of refractive error.

The limits of laser technology have been tested ever since photorefractive surgery was introduced. Since the early days of PRK, the broad beam laser has been known to cause corneal irregularity. Coma-like (third-order) and spherical (fourth-order) aberrations and their optical sequelae are seen to increase when the broad beam laser is used to make precise indentations in the cornea without respect to a transition zone.[55] A smaller ablation zone is also a source of induced irregularities.[56] These observations have led to a healthy respect for laser fluence and homogeneity calibration, as well as the development of the scanning spot laser. This new type of excimer laser has the advantage of being mobile and able to shape difficult corneal profiles to the desired contour. Haloes, glare, night myopia and loss of contrast sensitivity are recognised side effects of any correction procedure, whether incisional or laser, causing corneal irregularity. The constancy of these effects under the different techniques raises the question: can anything be done to detect these minute anomalies and warn patients of their predisposition to a less-than-perfect outcome?

The human eye is like a fingerprint. It is individual, and no two persons' are alike. We have the benefit of aberrometers to measure wavefront aberrations in human eyes and assist in custom ablation.[57] The advent of wavefront measurement technology enables the quantification of higher-order aberrations, which are described mathematically using Zernike polynomials.[58] Employing the principles of adaptive optics in astronomy, wavefront analysis objectively measures the ocular distortions created by all the structures of the eye. The aim of this exciting mathematical device is to assist in custom corneal ablation, which should improve the eye's image quality better than just using topography alone. Wavefront assessment can be performed using an outgoing light-sensing device, such as a Shack-Hartmann aberrometer, or using equipment that measures light ray aberrations as they reach the retina, such as the Tscherning and ray tracing aberrometers.[59]

As good as wavefront analysis sounds, there are limitations to how useful it will be in the practical world. For example, it is now clear that the measured aberrations are dependent on pupil size, dynamic state of the eye, and changes that occur in the lens and other structures with age.[60] Larger pupils tend to increase the number of corneal aberrations.[61] Salz reported that pharmacological miosis decreased the symptoms of night vision complaints in symptomatic patients.[62] Using videokeratography, Endl et al found that dilating the pupil from 3–7 mm produced a 14-fold increase in corneal distortions.[63] The great increase in higher-order aberrations found in large pupils, coupled with practical limits to laser size and treatment time, makes neutralising all wavefront distortions virtually impossible. Dynamic aberrations of the eye are difficult to correct as well. Optical distortions are constantly introduced during eye movement or the evaporation of tears. These changes are probably inconsequential due to the constant nature of eye movement. What is consequential are the changes brought on by age, in particular, the increase in spherical aberrations. LASIK increases spherical aberrations, so all patients undergoing such a procedure need to be warned of the process of ageing on the eye. Wavefront sensing should not be used in conditions that limit the efficacy of this technology, such as opacities of the cornea, lens and vitreous. Other factors that may limit the success of customised laser ablation include the variability of eye healing after laser surgery, aberrations introduced by the corneal flap of LASIK, and the consequences of epithelial remodelling.[64]

For a nascent technology, the results of wavefront custom ablation are cautiously encouraging. This guarded assessment is based on studies that show good short-term outcomes of wavefront-guided laser correction despite a postoperative *increase* in optical aberrations.[65] For example, in a trial of wavefront-guided LASIK versus conventional LASIK, Mrochen et al reported a 44% increase in overall optical aberrations at three months in the wavefront-guided group.[66] At the same time, 94% of this group of patients gained uncorrected visual acuity of 20/20 or better at three months. This ambiguous set of results, where excellent visual acuity is achieved at the same time that ocular distortions are increased, serves to highlight our rudimentary understanding of aberrations and their effects. It is known from previous correlation studies that low- and high-order distortions lead to scotopic and mesopic visual symptoms, but the amount of aberration needed to produce symptomatic disturbances is not known. This core knowledge is needed to explain the inexplicable results of the above-mentioned experiment. Some answers are already on the horizon. Wilson alluded to a neural plasticity in all central nervous systems that compensates for the poor visual input from aberrated interfaces.[67] Aberrometers do not provide information about what happens to visual input during central nervous processing from the retina to the visual cortex. Simply put, one cannot simply rely on objective measurement to judge the efficacy of wavefront-guided treatment; subjective responses may be equally important.

Wavefront technology is not the only advance that has contributed to improvements in either the technique or results of laser therapy. Active eye tracking is now considered an essential part of many laser delivery systems. It aims to centre the eye during photoablation to avoid the visual defects of decentration. The older method of centring the pupil using laser crosshairs and manual focusing is thought to be inaccurate because the eye in most cases is not a centred optical system.(68) The precision required of customised laser surgery demands the use of the active eye tracker for predictable results. Wavefront sensing is an exciting new development in the field of refractive surgery. The greater predictability of customised laser ablation, as well as the better refractive outcomes gained from this and other complementary technologies, make refractive surgery more appealing to the ametropic population. A note of caution still remains: these developments are less than a decade old, and more trials are needed to gauge their long-term safety and refractive stability.

FEMTOSECOND LASER

The latest addition to the armamentarium of laser surgery is the femtosecond laser. It is a solid-state laser that is an alternative to the microkeratome. Like the microkeratome, it is used to create a corneal flap in LASIK, but unlike the mechanised instrument, irregular flap thickness and epithelial injury are minimised.(69,70) Two studies have shown improved astigmatic neutrality and less wavefront aberrations with the femtosecond laser.(71,72) However, there has been a reported case of macular haemorrhage after the application of femtosecond laser-aided LASIK.(73) This incident highlights the caution that must accompany the development of exciting new technologies, such as the addition of the femtosecond laser to refractive surgery.

PHAKIC INTRAOCULAR LENSES

Although phakic intraocular lenses (IOLs) have been around for at least half a century, its revival has been heralded by the one clear limitation of laser surgery: its reduced efficacy with high myopia. IOLs are able to correct high myopia because they are not restricted by the limitations of corneal correction. While LASIK is limited to about nine dioptres of myopic correction in an average thickness cornea, IOLs have a higher ceiling of augmentation.(74) They do not alter the thickness or curvature of the cornea, but instead are surgically placed at various junctures at the front of the eye. The different types of IOLs depend on their placement, either in the anterior chamber, using the angle or iris for fixation, or in the posterior chamber, held by the sulcus or capsular bag.

Most of the trials comparing IOLs with laser ablation surgery are for high myopia. This segment of the myopic population may be the most satisfying group to treat for reasons of visual outcome and patient approval. Traditional options for correcting refractive error – glasses and contact lenses – are less stellar as refractive error increases.(75) High myopes using glasses experience distorted peripheral vision due to increased radial astigmatism and curvature of the spectacle field. Contact lenses are no better; there are fewer contact lens options for the extreme myope compared to the mild or moderate ametrope. Successful implantation of IOLs is an outcome that high myopes, dissatisfied with their current visual aid, hope for. On a related note, a complete preoperative assessment of the patient should include his or her expectation of vision correction. A long-term high myope may be satisfied with a postoperative visual acuity of 20/30 as this could be the best-corrected visual acuity preoperatively. Hence, a less-than-perfect refractive outcome may still find a satisfied customer in an extreme myope.

IOL implantation is not problem-free. It is an intraocular procedure that carries the attendant risks of endothelial cell loss, infection, and cataract formation. The complications of IOLs are potentially serious. Endothelial cell loss may be the initial manifestation of bullous keratopathy, a sight-threatening complication that has not yet been seen in IOL-implanted eyes. Half a decade of follow-up series of some of the lenses on the market show 9%–12% endothelial loss, with the bulk of it occurring in the initial phase of the postoperative period.(76,77) The other big risk of IOL implantation is cataract formation, which may arise from surgical trauma. Apart from these surgical complications, other problems surface as a result of the limited space in the anterior and posterior chambers of the eye. Anterior chamber lenses may induce chronic iritis, pupil ovalisation, secondary glaucoma or cystoid macular oedema.(78) Posterior chamber lenses are caught in a double bind. If they are small and low vaulting, they can cause a cataract by contacting the crystalline lens. If, on the other hand, they have high vaults, they may contact the iris, zonules or ciliary processes, causing pigmentary glaucoma, pseudoexfoliation syndrome, uveitis, or even pupillary block, with the latter being seen in blocked peripheral iridectomies.

The United States Food and Drug Administration (FDA) has approved a number of IOLs. Two of the first lenses in the market were the Artisan/Verisyse phakic IOL and the Visian implantable collamer lens (ICL). The Artisan IOL is an iris-supported lens designed to correct moderate to high myopia of -5 to -20 dioptres.(79) In a multicentre clinical trial of 662 patients implanted with Artisan IOLs, the following results emerged: three-year follow-up showed that 92% of patients had at least 20/40 vision, while 44% achieved 20/20 vision.(75) A head-on trial comparing Artisan IOL to LASIK demonstrated the superiority of phakic lens implantation over lamellar photoablation for high myopic correction.(80) The difference in outcome between the two modalities for moderate myopia was less distinct, although one study showed greater patient satisfaction for the Artisan IOL.[81] A similar story can be traced with the Visian ICL. The US FDA multicentre trial of the Visian ICL showed that at three years, 59% had 20/20 visual acuity, and 95% had 20/40 or better vision.[82] Despite the successes, these FDA-approved lenses still suffer from the side effects that are common to IOLs, such as endothelial cell loss and cataract formation. Other serious complications to note, in the case of the Artisan IOL, are retinal detachment (0.6%) and surgical reintervention (4.2%), which had higher rates than historical controls.[75]

From this brief discourse on IOLs, it can be seen that although they hold promise for high myopes, there are still concerns over their long-term safety issues. The evolution of refinement may bring this intraocular procedure to more widespread use.

CLEAR LENS EXCHANGE

Clear lens exchange is similar to IOL implantation in that both these modalities target the lens. So far, the cornea has been the main target of refractive surgery, but this becomes a self-limiting exercise because while the corrected cornea remains relatively stable, the lens changes with age. Presbyopia, or the loss of accommodation with the ageing lens, and cataracts are the bane of corneal correction. Even though the cornea may be surgically fixed, time dictates that the lens will undergo age-related changes and require correction eventually.

Clear lens exchange has come a long way since the days of Fukala and Vacher, who performed the first reported series of lens removal for highly myopic patients in 1890.[83] A ten-year retrospective study of their patients showed a high complication rate. Today, rather than complete lens removal, the procedure involves exchanging the crystalline lens for a stable pseudophakic one. With modern advances heralded by cataract surgery and improved IOLs, clear lens exchange is a viable option for visually-impaired patients who want a more permanent eye correction than what excimer laser can offer. High myopes, hyperopes and astigmatics are poor candidates for excimer laser correction.[84] High corrections result in diminishing predictability, efficacy and safety.[43] Patients with high refractive errors, together with presbyopes and patients with cataracts, are the targets of clear lens exchange.

There are three common types of pseudophakic lenses: monofocal, multifocal and accommodative. The monofocal lens corrects for either near or distance vision depending on the refractive defect of the patient, while the multifocal lens corrects for both distance and near vision with different optical zones of dioptric power. The first US FDA-approved lens of this sort, the Array lens, uses five concentric zones to replicate vision over a range of distances, allowing near vision as well as distance correction. This design comes with a drawback. There are photic phenomena, such as haloes and glare, and loss of contrast sensitivity due to the simultaneous projection of several images on the retina.[85] Studies have shown, however, that uncorrected distance visual acuity, best-corrected visual acuity and patient satisfaction are similar between monofocals and multifocals, although the latter have lower spectacle dependence than their monofocal counterparts.[86]

The aim of the accommodative lens is to mimic the accommodation response of the youthful, phakic eye. Accommodation occurs when the ciliary body contracts, resulting in release of the zonular fibres that suspend the crystalline lens, and increase the curvature of the lens. The Crystalens is the first US FDA-approved lens of the accommodative type. It is a monofocal lens with accommodative ability that allows for binocular vision at all distances. In the FDA clinical trial of 124 subjects implanted with Crystalens and followed-up for a year, 97% possessed 20/20 intermediate vision, 80% had 20/20 distance vision, and 32% managed 20/20 near vision.[87] Compared to multifocal lenses, patients with accommodative lenses experience less photic phenomena because competing retinal images are avoided.[88]

The risk of retinal detachment in patients who undergo clear lens exchange is from zero to 8% percent.[89] High myopia, previous yttrium aluminium garnet (YAG) laser capsulotomy and lattice degeneration are risk factors for this complication.[90] Another common complication, posterior capsular opacification, was reported to be 61% during seven years of follow-up in a clear lens extraction series by Colin et al.[91] Despite the problems of clear lens exchange, this modality offers an answer to the dilemma of the ageing lens. The development of improved biometry, IOL power calculation, lens extraction techniques, and IOL designs, will ensure continued interest in this form of vision correction.

CONCLUSION

This look at the utility of refractive surgery for vision correction has found an industry that is innovative and fast evolving. This flurry of activity over the last 30 years is remarkable, and highlights the determination by various investigators to find the most effective and appropriate refractive surgery for different levels of myopia. This can only bode well for patients. As in all technology, more advances are still to come, but in experienced hands, refractive surgery is a safe, predictable and effective procedure. It has provided lifestyle benefits to the millions of people who have undergone refractive surgery, and enjoyed, for the first time, improved, unrestricted vision. In the hands of an experienced ophthalmologist, refractive procedures can be safe and effective for the well-indicated patient. But like all surgical procedures, refractive surgery has its complications. Some modalities of refractive surgery may not be suitable for everyone. Nevertheless, refractive surgery continues to evolve, fuelled no doubt by the public's insatiable demand for safe, predictable super-vision. As this technology continues to advance, more people will be able to enjoy the benefits of decreased dependence on their spectacles than before.

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Summary Table

Refractive keratotomy	Radial cuts to anterior surface of the cornea
Advantage:	• Accurate and stable correction for low to moderate myopia
Disadvantages:	• Transient night-time glare 30%–50% • Overcorrection leading to progressive hyperopic shift 22% • Corneal perforation 1%–3%

Photorefractive keratectomy (PRK)	Epithelium removed from centre of cornea and excimer laser used to shape cornea
Advantage:	• Accurate and stable correction for low to moderate myopia and low hyperopia
Disadvantages:	• Postoperative pain • Stromal haze 1%–2% • Risk of glaucoma with prolonged use of postoperative topical steroids • Small risk of visual impairment due to stromal scarring

LASIK	Creation of corneal flap and excimer laser re-sculpting of stromal tissue
Advantages:	• Accurate and stable correction for low to moderate myopia and low hyperopia • Good visual recovery and less postoperative pain due to sparing of corneal epithelium
Disadvantages:	• Dry eye syndrome • Risk of flap-related complications • Small risk of sight-threatening keratectasia • More expensive procedure than PRK

LASEK	Creating an epithelial flap, ablating the stroma and repositioning the flap
Advantages:	• Accurate and stable correction for low to moderate myopia • Option for people with thin or flat corneas
Disadvantage:	• Similar to PRK

Epi-LASIK	Creation of corneal flap with an epikeratome and ablating the underlying stroma
Advantage:	• Promising early results for accurate correction of low to moderate myopia

Phakic IOLs	Intraocular lens surgically placed in either the anterior or posterior chambers of the eye
Clear lens exchange	Exchange of crystalline lenses for pseudophakic lenses
Advantages:	• More accurate correction of higher refractive errors than previous techniques • Patients with presbyopia and cataracts are suitable candidates for clear lens exchange
Disadvantages:	• Phakic IOL implantation may be complicated by cataract formation • Endothelial cell loss • Risk of retinal detachment (0%–8%)

SINGAPORE MEDICAL COUNCIL CATEGORY 3B CME PROGRAMME
Multiple Choice Questions (Code SMJ 200708A)

	True	False
Question 1. In general, PRK has a longer postoperative recovery phase than LASIK because:		
(a) PRK causes a large epithelial defect that attracts a stronger leucocyte response.	☐	☐
(b) PRK targets the optical zone which LASIK does not.	☐	☐
(c) LASIK is less dependent on operator-technique than computer-guidance.	☐	☐
(d) LASIK is a safer procedure with a longer history of clinical use.	☐	☐
Question 2. Wavefront technology measures:		
(a) Corneal topography.	☐	☐
(b) Changes that occur in the lens.	☐	☐
(c) Optical aberrations in the eye.	☐	☐
(d) Spherical aberrations.	☐	☐
Question 3. Consideration for clear lens exchange is indicated for the following, except:		
(a) Presbyopia.	☐	☐
(b) Low myopia.	☐	☐
(c) Cataract.	☐	☐
(d) Hyperopia.	☐	☐
Question 4. A difference between LASEK and LASIK is:		
(a) The maintenance of the basement membrane with LASEK.	☐	☐
(b) That LASEK may be an option for thin corneas.	☐	☐
(c) That LASEK involves less pain.	☐	☐
(d) The shorter recovery time with LASEK.	☐	☐
Question 5. Which of the following are possible candidates for LASIK?		
(a) A patient who requests for LASIK because of the nature of his work.	☐	☐
(b) "I hate my glasses and I want to get rid of them!"	☐	☐
(c) A patient who has a history of epithelial basement membrane dystrophy.	☐	☐
(d) A patient who has a high prescription. He understands that he may still require visual enhancement after LASIK.	☐	☐

Doctor's particulars:

Name in full: ______________________________

MCR number: ______________________ Specialty: ______________________

Email address: ______________________________

SUBMISSION INSTRUCTIONS:
(1) Log on at the SMJ website: **www.sma.org.sg/cme/smj** and select the appropriate set of questions. (2) Select your answers and provide your name, email address and MCR number. Click on "Submit answers" to submit.

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(1) Answers will be published in the SMJ October 2007 issue. (2) The MCR numbers of successful candidates will be posted online at **www.sma.org.sg/cme/smj** by 15 October 2007. (3) All online submissions will receive an automatic email acknowledgment. (4) Passing mark is 60%. No mark will be deducted for incorrect answers. (5) The SMJ editorial office will submit the list of successful candidates to the Singapore Medical Council.

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