An overview of contemporary refractive surgery

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Learning Objectives

1. Understand the indications for refractive surgery
2. Appreciate the various options available for correction of refractive errors
3. Understand the advantages and disadvantages of various forms of refractive surgery
4. Recognise common complications of refractive surgery

An overview of contemporary refractive surgery

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Introduction

NB: This reading material should be studied in conjunction with refractive surgery lectures 1&2 for most contemporary clinical trial details and explanation of all terms

In the new millennium, refractive surgery has become increasingly accepted and popular with both clinicians and the public. Indeed, it is estimated that in the next twelve months more than one million individuals will undergo some form of **photorefractive surgery** in the USA. However, whilst some surgical procedures have fallen by the wayside, it has become increasingly difficult for the potential candidate for refractive surgery to separate the facts from the hype. Certainly, laser refractive surgery in particular has been subject to intense marketing campaigns in the USA, UK and Australasia. Current controversies and topics of interest in refractive surgery will be covered briefly in this review and related lectures.

Why has refractive surgery become such an important topic? Perhaps it is because in refractive surgery, unlike other ophthalmic surgery, one is dealing with essentially healthy eyes with normal visual acuity prior to surgery. Perhaps it is also because, not only the ophthalmic media, but also the popular media has become increasingly interested in ocular surgical techniques *per se*, and in particular, refractive surgery. Indeed, LASIK, made it to the **cover of Time magazine** as early as 1999. However, in the midst of hyperbole and claim and counter claim we must remember that up to five percent of eyes undergoing refractive surgery will have minor, but quite tolerable side-effects, whereas, perhaps 1% of eyes will develop significant, visually compromising complications. Since the techniques are increasingly complex and evolving, but often are based upon pre-existing techniques, this presentation will briefly cover the evolution of current techniques and place the benefits and risks in context.

Development of refractive surgical techniques

Of course for a surgical technique, or techniques, to be popular, there has to be appropriate demand. The normal distribution of refractive errors is generally around emmetropia, typically with more individuals in the hyperopic group than in the myopic group. Nonetheless, many of the refractive surgical procedures have been aimed at myopia, and although myopes represent a minority of the population, uptake of refractive surgery has been particularly high in this group. Perhaps, unsurprisingly, those with highest myopia are more likely to seek treatment.

Of course, although refractive surgery is now closely associated with laser developments, aspects of refractive surgery have been performed for centuries, and some techniques which have become increasingly popular, such as **clear lens extraction** for high myopia, were first postulated 250 years ago! Indeed, a number of contemporary incisional, thermal, and lamellar techniques have their basis in surgical developments that occurred around 100 years ago.

Radial Keratotomy

This is mainly of historical interest although a large number of myopic individuals have previously undergone **Radial Keratotomy or RK** as it is widely known. RK became popular in the USA in the 1970s, and until relatively recently retained elements of popularity in North America. In developing countries, where access to laser technology is more limited, RK still appears to have a limited (reduced cost) alternative role to laser-refractive surgery, although it has **largely disappeared** in Westernised countries.

Generally, results for a low myopia, in the range to perhaps –1.00 to –3.00D, are not dissimilar for RK and PRK. However, although radial keratotomy has now been reduced to a **four incision technique (mini-RK)**, some of the original problems still persist, such as the predisposition to bursting injuries, progressive hypermetropia (approx +0.1D per annum), loss of best spectacle corrected visual acuity, fluctuating vision throughout the day, and night-time symptoms such as starburst.

A concern that is often expressed in regard to any refractive surgery, is that in may weaken the globe to **potential trauma**. A study by Peacock et al clearly highlighted that radial keratotomy eyes are weakened and will rupture with less trauma, however, there is no statistical difference between the force required to rupture a normal eye and those treated by PRK or LASIK.

EXCIMER LASER TECHNOLOGY

Excimer laser technology is now familiar to most in the eye Healthcare arena. These lasers use ultraviolet light at a wavelength of 193 nanometres. However, although, excimer laser technology is often thought to be relatively new, and therefore not fully tested, 2003 marked the 20th anniversary of Professor Stephen Trokel's initial experiments with the excimer laser on bovine corneas. The initial food and drug administration (FDA) safety studies are now almost 20 years old, and the larger FDA clinical studies closed with the acknowledgement that excimer laser PRK could be safely used up –7.00D of myopia in 1995!

What are the intrinsic properties of excimer lasers? As previously stated this is an ultraviolet laser that works at 193nm. The ultraviolet photons in the beam are absorbed by the first tissue, or fluid, that the laser interacts with, causing fragmentation of tissue into small molecules which are ejected from the surface of the tissue at supersonic speeds, giving rise to the characteristic clapping sound of laser treatment. Being a non-thermal laser, there is minimal collateral damage to surrounding tissue and each pulse tends to remove one quarter, or less, of a micron of tissue.

CURRENT TREATMENT OPTIONS WITH EXCIMER LASER ABLATIONS

1. **PRK / PARK –** epithelium removed entirely
2. **LASEK -** epithelial flap created with alcohol then elevated and repositioned
3. **Epi-LASIK -** epithelial flap created by epi-microkeratome and repositioned
4. **LASIK -** Epithelial/Bowman's/Stromal flap created by microkeratome or laser

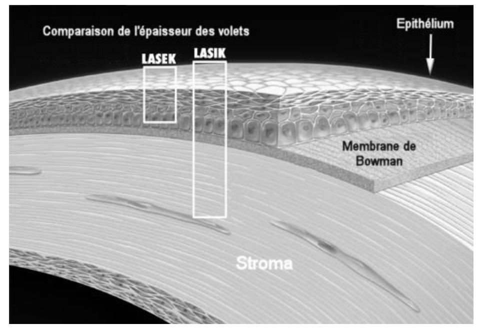
Early developments in PRK correction of myopia

The author has been involved in corneal refractive surgery techniques since 1991. In particular this included prospective studies of PRK in the early nineties, and prospective studies of LASIK the mid Nineties. All of these studies involved standardized techniques of assessment including a full ophthalmic workup, very extensive preoperative counseling, an extensive fully informed consent process, and a one to two week "cooling off" period for potential subjects. Some of these aspects and their evolution will be discussed in the lecture.

There are a number of relative contraindications to laser refractive surgery and these include local ocular conditions such as: extreme myopia, extreme astigmatism, relatively thin corneas, contact lens related corneal warpage, keratoconus, dry eye disease, herpes simplex keratitis, and

disorders of eyelid position. Any pre-operative assessment must include computerized corneal topography, either Placido-based, or preferably, Orbscan/Pentacam slit scanning topography
In general, treatment of myopia involves a circular or "round" symmetric ablation pattern with greater ablation centrally than peripherally, whereas, treatment of myopic astigmatism usually involves creation of an "oval" asymmetric ablation pattern. In contrast, the objective of hypermetropic corrections is to steepen the central cornea, rather than flatten the central cornea as in myopic ablations. Therefore, hyperopic ablations are rather ring-shaped, removing more tissue in the mid-periphery of the cornea, to cause central steepening of the cornea.

Surface based photorefractive surgery involves the mechanical removal of the corneal epithelium, followed by the chosen excimer laser ablation parameters. One of the disadvantages of surface based PRK is that it produces mild to moderate pain for 24 to 48 hours. Despite newer analgesic techniques, approximately one in ten patients still find PRK painful in the postoperative 24 hours. The epithelium heals in 48 to 72 hours, but continued stromal healing can be associated with haze and regression of refractive effect.



In one of the prospective studies carried out by the author (1993-1995), when attempted versus achieved refractive correction was assessed six months after PRK treatment using a VISX 2020B laser, it was readily noted that the scatter of outcome results increased significantly above eight dioptres of attempted myopic correction. Similar patterns were noted by a number of other investigators, and for this reason, by the mid-1990s, most refractive surgeons in the UK began **to limit magnitude of surface based treatments** up to –7.00 or perhaps –9.00D of myopia.

Although the VISX 2020 studies utilised a 6.00mm ablation zone, earlier studies had used ablation zones of around 4.0mm diameter. The attraction of smaller diameter zones is that the smaller the diameter the less deep the ablation needs to be, conversely, larger diameter ablations require a greater central depth of ablation. Unsurprisingly, these smaller diameter zones were associated with **night-time visual symptoms**, which affected almost half of the patients in early studies, although this had reduced to one in ten when David Gantry et al reported on the St Thomas' studies and 1-5% with larger blended ablation zones. As previously mentioned, one of the disadvantages of PRK is the development of **corneal haze**. This haze is more common in higher attempted corrections, i.e. deeper ablations, but fortunately, in the majority of eyes haze tends to diminish with time although it may persist in a very small minority of eyes.

Although surface based excimer laser treatments have improved with increasing improvements in laser technology in the last five years, it is interesting to note **significant PRK success as early as 1995** - Schallhorn et al had performed a study of 30 navy personnel with myopic PRK treatments up to –5.50D, in which **all eyes obtained 6/6 unaided** vision at one year, and equally importantly, no eye lost best spectacle corrected visual acuity!

In the late Nineties the introduction of scanning spot lasers provided the potential for wider smoother ablations and heralded better outcomes with fewer side-effects for both surface based and LASIK surgery for myopia and myopic astigmatism. In another prospective study by the author, utilizing scanning spot technology for excimer laser PRK and PARK (including subjects with up to 2.5 dioptres of astigmatism), it was noted that for eyes with a maximum of –5.00D spherical equivalent, 97% achieved 6/9 or better vision unaided, and three-quarters obtained 6/6 or better unaided vision.

From the preceding data it can be seen that for more than ten years surface-based PRK and PARK has been able to provide a safe and accurate correction of myopia up to –5.00D although others have shown exceptionally good results with good safety up to around -7.00D.

LASEK and Epi-LASIK

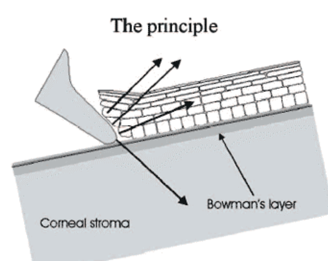
In the last ten years there has been a dramatic **shift from surface based PRK** to LASIK, with PRK probably representing no more than 10-20% of photorefractive cases currently being performed in many countries. Although LASIK is technically more demanding than PRK, the perceived advantages of minimal discomfort, more rapid visual recovery and less refractive regression have resulted in its current popularity. However, fears of LASIK flap complications and the possibility of keratectasia in deep ablations, or thin corneas, has maintained a small market niche for PRK.

Surprisingly, recent developments in wavefront (aberration) driven excimer laser ablations have aroused renewed interest in surface based ablations – since the creation of a LASIK flap creates new higher order aberrations that can confound the planned wavefront corrections. Interestingly, in the United Kingdom, surface based excimer laser procedures have become increasingly popular with an approximate spilt of: LASIK 50%, LASEK 40% and PRK 10% (personal communication Mr Sunil Shah FRCOphth – President of British Society of Refractive Surgeons).

LASEK is seen by some surgeons as no more than a slower PRK procedure, whereas, others see it as a procedure half-way between PRK and LASIK that combines the advantages of both. LASEK is performed like LASIK and PRK under topical anaesthesia, however, rather than simply removing the epithelium or utilising a microkeratome to cut a 160 micron flap, a trephine / marker is used to cut 55 microns through epithelium to anterior Bowmans. The epithelium is then treated by the application of 2-3 drops of 18% ethanol for 20-60 seconds. This enables the central epithelium to be detached and rolled back on an eighty-degree wide, uncut hinge. The ablation is then performed in exactly the same fashion as occurs in a standard PRK. Immediately after the ablation the flap is irrigated and rolled back into the original position.

Interestingly, laboratory studies have shown that higher concentrations of ethanol and durations longer than 20-30 seconds result in progressive loss of epithelial cell viability and careful attention to procedural timings is vital to good LASEK results.

The somewhat confusingly named **Epi-LASIK** is not a LASIK procedure but rather a micro-keratome variation of LASEK. Instead of alcohol and manual elevation of the epithelial flap, an epi-microkeratome i.e. a keratome designed to only cut to the junction of epithelium and Bowman's, is used to elevate an epithelial flap (but unlike LASIK does not cut Bowman's or Stroma). Since no alcohol is utilised the epithelium should theoretically be healthier when repositioned following the excimer laser ablation, which is performed in exactly the same manner as a PRK.



In comparison to PRK, both LASEK and Epi-LASIK are frequently **claimed to be less painful and result in less haze** and reduced refractive regression. In comparison to LASIK, both LASEK and Epi-LASIK eliminate the microkeratome stromal cut, enable treatment of thin corneas and eyes with narrow inter-palpebral fissures, and can be used to treat eyes in subjects with professions or lifestyles unsuitable for LASIK treatment.

Epithelial Flap Viability

There has been significant debate as to whether the epithelial cell layers produced by **LASEK and Epi-LASIK** are truly viable. In an important recent study, Tanioka H et al (2007) performed a series of experiments to assess epithelial integrity and cell viability in epithelial flaps prepared with the epi-LASIK procedure. Epithelial flaps were prepared by epi-LASIK surgery. After immediate fixation, they were examined by light and electron microscopy. To assess cell viability in fresh epithelial flaps, bio-staining experiments were performed. Light and electron microscopy showed that most of the inspected areas showed epithelial nuclei and cytoplasm at significantly reduced density and associated discontinuity of the basement membrane. Biostaining experiments revealed that **approximately 90% of the basal cells in epithelial flaps were dead** cells. The authors concluded that most basal cells in epithelial flaps prepared with different epikeratome devices were actually dead.

Comparing Efficacy, Safety and Patient Satisfaction – PRK vs LASEK

Hashemi et al (2004) in a prospective, randomized, paired comparison of laser epithelial keratomileusis **(LASEK)** and photorefractive keratectomy **(PRK)** for myopia less than -6.50D compared predictability, efficacy, safety, and patient satisfaction. Patients with spherical equivalent refraction in the range -1.00 to -6.50 D were enrolled in this prospective study, each randomized for choice and sequence of LASEK and PRK on each of their eyes. Mean baseline refraction was approximately -3.50D. At 3 months, 100% of LASEK eyes and 97% of PRK eyes had uncorrected visual acuity ≥20/40, and 79% of LASEK eyes and 82% of PRK eyes had uncorrected visual acuity ≥20/20, the mean final refraction was 0.08D in LASEK eyes vs 0.12D in PRK eyes. Epithelial healing time and pain in LASEK and PRK eyes were not statistically different, and patients were equally satisfied. The authors concluded that **LASEK had similar predictability, efficacy, safety, and patient satisfaction to PRK in the treatment of low to moderate myopia**.

Comparing Pain after PRK, LASEK, Epi-LASIK

Postoperative discomfort and prolonged visual recovery until the epithelium closes remain the biggest disadvantages of LASEK compared to LASIK, however, early claims of advantage in terms of reduced pain following LASEK/epi-LASIK compared to PRK have been increasingly challenged. Chayet's group (2007) reported on a prospective observer-masked randomized study of subjects who received Epi-LASIK (Moria Epi-K) in one eye and PRK in the contralateral eye. Interestingly, **Epi-LASIK and PRK were noted to result in similar pain on postoperative day one, but Epi-LASIK actually demonstrated statistically more pain than PRK on days 3 and 6!**

O'Doherty et al (2007) reported on a study to compare mechanical epithelial separation using the epi-LASIK technique with alcohol assisted separation (LASEK). Patients deemed suitable for surface ablation were randomized to receive **epi-LASIK** in one eye and **LASEK** in the other eye. If epi-LASIK failed, the procedure was converted to photorefractive keratectomy **(PRK),** forming the third comparison group. The outcome measures were postoperative pain, vision, refraction, and haze and patients were followed for 3 months There was a 33% rate of conversion from intended epi-LASIK to PRK. Epi-LASIK patients were found to have significantly less pain only in the first 2 hours after surgery but **at 4 hours all patients had the same levels of pain,**

which improved to minimal or no pain at 24 hours. Absolutely no significant difference was noted among groups for vision, refractive error, and haze. They concluded that Epi-LASIK offers comparable visual and refractive results to other surface ablation, however, there was a **high rate of flap failure and conversion to PRK.**

Surface-based wavefront treatments – a return to PRK?

Perhaps most importantly, if wavefront ablations become increasingly popular, as seems predicted by recent trends, it is likely that the surface based treatment, minimum epithelial healing, minimal haze, and lack of a potentially aberration-inducing LASIK flap, may make PRK or its varants – LASEK or Epi-LASIK - the preferred procedure to maximise the potential benefits of wavefront-driven excimer laser procedures.

Other techniques for low to moderate myopia

Nonetheless, despite the success of PRK and LASEK, other techniques have been investigated, most notably the **intra-corneal ring** was promoted heavily in the late nineties as a reversible technique for the correction of myopia up to –3.00 D to –4.00 D. Essentially this is a PMMA ring, or laterally two segments, that are inserted into the mid-peripheral corneal stroma, at approximately two-thirds depth, this has the effect of flattening the central corneal curvature and the degree of flattening is proportional to the thickness of the ring. Although the ICR does have the advantage of being an extra-ocular procedure, which does not involve the visual axis and is reversible, it only corrects myopia up to around -4.00 D. This level of correction is already covered by procedures such as PRK and LASIK. This technique has evolved into the **Intacs technique for keratoconus.**

<u>LAMELLAR REFRACTIVE CORNEAL SURGERY: LASIK</u>

The preceding techniques have all dealt with low to moderate myopia (up to –7.00D), whereas, since the late nineties, the refractive frontiers have remained extreme myopia, moderate hypermetropia, and presbyopia. The development of excimer laser lamellar refractive surgery was seen as a new dawn in tackling these frontiers, and a rapid expansion of lamellar techniques occurred from 1995 onwards.

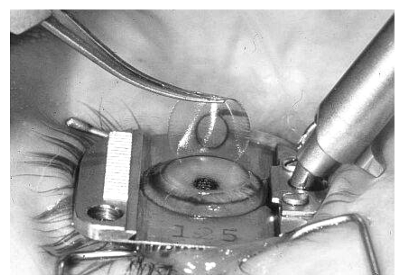
Of course, there is little new under the sun in refractive surgery, and whilst the elements of incisional and refractive lens surgery preceded the expansion of incisional refractive surgery by more than 100 years, the lamellar surgery techniques have clear origin in the seminal works of Jose Barraquer in the 1960s. The initial techniques of Barraquer were further developed by Ruiz, to become **Automated lamellar keratoplasty** (ALK), when he introduced the concept of a microkeratome planar cut to the stromal bed. In ALK, a free cap is created and a second pass of the keratome to achieve the refractive correction treats the stroma. Two workers, Pallikaris and Buratto, independently applied excimer laser techniques to the initial surgical techniques of Barraquer and Ruiz to create the concept of **Laser in situ keratomileusis (LASIK).**

In LASIK a flap is created with a superior or nasal hinge, and the surgical correction is obtained by an excimer laser ablation on the exposed stroma, much in the same fashion as PRK. However, following completion of the ablation, the superficial flap is replaced into its original position, completely covering the ablation zone and leaving only a fine peripheral incision rather than a large epithelial defect as occurs in PRK. In the last three years the microkeratome has been increasingly superceded by the **Intralase femtosecond laser** to create the corneal flap.

The advantages of LASIK are largely related to the creation and repositioning of the flap, these include: the fact that it is essentially painless, there is minimal corneal healing, visual recovery is usually rapid within hours to days, interface haze is a very rare, it can be used to treat a greater range of refractive myopic and hyperopic errors than surface based PRK and it is relatively easier to perform retreatments (typically 3-10% of eyes may undergo an enhancement or retreatment).

Of course a number of disadvantages occur in any highly technical procedures such as LASIK, these include the expense of the equipment, the complexity of microkeratomes, the possibility of corneal flap complications and postoperative flap displacement, and rare complications such as sterile interface keratitis (DLK) and late ectasia of the cornea.

When one considers all of the **benefits of LASIK compared to PRK**, how do they stack up to in direct comparison. The best early paper on the subject probably comes from Peter Hersh et al (1998), who performed a randomised, prospective study of 220 eyes with a mean, high, pre-operative myopia of approximately -9.25D. It must be remembered that this study was performed around 1997 and published in 1998 and there have been significant advances in both software and hardware since that time. None-the-less, six months post-treatment in this study of high myopia, there was little difference in unaided vision between the two groups, with the PRK group demonstrating two-thirds of eyes with 6/12 or better vision, compared to 56% in the LASIK group, whereas, 26% of the LASIK group obtained 6/6 unaided vision compared to 19.1% of the PRK group.



Interestingly, regression of myopic correction was less than 10% in each group, with marginally more regression in the PRK group (at 0.89D compared to 0.55D in the LASIK group), six months after treatment. However, the most significant difference in this randomised, prospective study of PRK versus LASIK in high myopia, was that **only 3.2% of eyes in the LASIK group lost two lines of BSCVA, compared to almost 12% in the PRK group at the six month review**. Therefore, whilst unaided visual acuity and predictability of outcome was not significantly different for many aspects of this study, LASIK was significantly safer in terms of avoiding loss of BSCVA – although a number of individuals in both PRK and LASIK groups would regain lost lines of BSCVA by 12 months post treatment.

An early study carried out by the author, the University of Dundee prospective LASIK study, was a single surgeon, single centre prospective study carried out between 1996 and 1999 using a Technolas 117 and 217 laser. It treated a wide range of myopia from –1.00 D. to –15.00 D. The first 108 eyes were divided into three groups on the basis of spherical equivalent: low to moderate myopia -1.75 to –8.00D, high myopia -8.10 to –12.00D, and a final group of 32 eyes with extreme myopia greater than –12.10D with a mean of –14.76D. Follow up over 12 months demonstrated relative stability of refraction, with **regression essentially limited to the first three months**, followed by stability and a tendency to myopic under correction with increasing attempted correction. Even in these early studies, 60% of eyes with less than –8.00D of pre-operative myopia achieved 6/6 or better and 79% reached 6/12 or better vision. Eyes that only achieved 6/12 or poorer vision, were retreated such that all eyes achieved 6/12 unaided, or better, at latest follow-up.

Interestingly, Bruce Allan's group in Moorfields, London (2007) recently reported a **meta-analysis/systematic** review to examine possible differences in efficacy and safety between LASIK and PRK for correction of myopia. Only seven prospective random controlled trials (PRCTs) were identified comparing PRK (683 eyes) and LASIK (403 eyes) for correction of myopia. More LASIK patients achieved UCVA > or = 20/20 at 6 months (odds ratio, 1.72; P = 0.009) and 12 months (1.78, P = 0.01). Loss of > or =2 lines of BSCVA at 6 months was less frequent with LASIK. Data from 14 LASIK (7810 eyes) and 10 PRK (4414 eyes) FDA laser approval case series showed that more LASIK patients achieved UCVA of 20/20 or better at 12 months (1.15, P = 0.01), significantly more LASIK patients were within +/-0.50 D of target refraction at 6 months (1.38, P<0.00001) and 12 months (1.21, P = 0.0009). Thus they concluded that **LASIK appears to have efficacy and safety** superior to those of PRK. However, they noted that the data examined are from studies conducted 5 or more years ago. It is therefore unclear how these findings relate to the significantly refined present-day methods and outcomes.

Trends in refractive surgery

It is interesting to note the changes in refractive surgical trends at the turn of the millenium, in a survey of the members of the American Society of Cataract and Refractive Surgeons (2000), it was noted that whilst in 1997 40 percent of surgeons performed PRK, and only 18% performed LASIK, by 1999 this trend had reversed such that 58% performed LASIK and 25% performed PRK. Interestingly, in 1999, the majority of cataract and refractive surgeons would perform PRK up to –3.00 D., whereas, 92% would perform LASIK to correct –7.00 D and 58% up to –12.00 D. Only 4% of surgeons implanted phakic intraocular lenses in this 2000 study. Although, media and industry reports have predicted the disappearance of PRK and its complete replacement by LASIK, worrying complications such as interface keratitis and keratectasia, have led to the resurgence of interest in modified PRK in the form of LASEK/epiflap techniques. The area of intra-ocular phakic and accommodating IOLs has grown exponentially in the last 5 years.

Small spot scanning lasers

Earlier lasers, such as the VISX and Summit models, available in the early to mid-nineties, used a **wide-beam laser** approach to produce 5.00 to 7.00mm diameter ablations. Alternative technologies such as slit scanning lasers (Nidek) and spot scanning lasers (Technolas) became more popular as the decade progressed.

The advantages of a **small spot laser** (diameter 0.5-2.0mm) include the facility to have near infinite ablation profile flexibility without masks, diaphragms or slits. This technique has eliminated central islands, with minimal acoustic shock and a lesser propensity to haze formation following surface-based treatments. The sophisticated algorithms, with multiple overlapping spots, enable the production of very smooth ablations and large blend zones. Some older lasers provide a compromise by using a broad beam laser to produce the majority of the refractive correction and a small spot-scanning beam to correct astigmatism and produce blend zones.

However, the cost of such complex ablations is the requirement for a longer ablation time and improved centration of the ablation zone on the eye. Interestingly, microsaccades of the eye have a frequency of 100hz or greater and can reach speeds of 150 millimetres per second, which makes earlier laser trackers, with a sampling rate of 20-60Hz, redundant. Indeed, for a laser ablation spot to be within less than 30 microns of where it is intended, an active tracker needs to "lock-on", realign mirrors and enable firing of the laser spot within approximately 10 milliseconds.

Active laser tracking

Unlike wide beam excimer lasers, which are relatively less sensitive to decentration, and using which the surgeon can actually see the effect of the ablation and the relative centration, there are no real indicators as to continued proper centration once a small spot laser commences. In this regard, the majority of contemporary lasers are now small spot scanning lasers. None-the-less, proper centration of the pupil, relative to the aiming beam, either by head holding or use of an ocular suction device can provide surprisingly good results. Indeed, mean decentration from pupil centre has generally been reported to be <0.5mm using non-tracker techniques – however, it is the range of decentration relative to pupil size, rather than the mean, which is important.

Importantly, proper centration and tracking becomes increasingly vital with the use of wavefront or aberration driven ablations and small spot lasers *per se* benefit from trackers. Notably, not all so called "eye trackers" perform the same function. Indeed, "passive" tracking merely limits the latitude of ablation decentration by switching off the laser when eye movement reaches a certain pre-set maximum latitude, whereas, "active" tracking follows the ocular movements and places the laser spots appropriately. In a practical sense, an active tracker must work all the time or it doesn't work at all.

The precise details of the tracking systems are proprietary, however, although the stated acquisition sampling-rate varies from 50Hz to 4000Hz with associated laser frequencies from 50-200Hz, it is generally acknowledged that for a tracker to be useful an "overall response time" of around 10 milliseconds or less is vital. This response time is constituted by three main components a) the time taken to acquire an image of the eye and its location b) the time to realign the mechanical mirrors to aim the laser shot (the longest period) and c) time to fire the laser. Currently there are at least three types of laser system in that meet this response time criterion (maximum response time in brackets) – the Bausch and Lomb Technolas 217z (Zyoptix) laser (<10.7 msec), the Allegretto spot scanning laser (<10 msec) and the Summit Autonomous Ladar system (<10msec). All three systems utilise tracking for conventional ablations and wavefront driven ablations.

Early results of studies using tracking systems have currently shown minimal advantages in terms of better, unaided vision but have shown some benefit in terms of reduced, induced higher order aberration. Trackers are coming to the market that can actively address torsional eye movements during the laser procedure.

Wavefront Technology

Traditionally refractive surgery has only addressed lower order aberrations in the form of spherical and cylindrical correction. However, the wavefront produced by an eye is a complex three-dimensional "surface" which can be broken down into an infinite number of mathematical expressions called Zernike polynomials.

Spherical and cylindrical refractive errors are quantified by the first two "orders" of Zernike polynomials, and are of a parabolic and saddle-shape respectively. Although this analytical technology has been available for some years, the most recent and exciting clinical application of measuring wavefront aberration is in regard to photo-refractive surgery. Until recently, refractive surgical techniques could only correct the lower order aberrations of the eye, and with many techniques higher order aberrations are actually increased. Under-corrected or induced higher order aberrations may result in symptoms of glare, halos and difficulties in mesopic and scotopic conditions.

In an attempt order to correct both lower and higher order aberrations of the eye, a new technique of laser refractive surgery has been developed. This requires extensive pre-operative assessment, including corneal topography and quantification of ocular aberrations using an objective aberrometer, eg Zywave. The data from these two analyses are mathematically linked into a combined format that creates an individualised excimer laser ablation.

Although initial clinical results are very encouraging, "Wavefront-guided LASIK/PRK" is a relatively new technique of the last 4-5 years and the results of larger, longer-term clinical studies are awaited with interest. Indeed, initial industry hyperbole raised the concept of "eagle" or "supervision", with the prospect of complete correction of higher and lower order aberrations to produce a flat wavefront for the custom-treated eye. However, it is now generally acknowledged that whilst wavefront or custom cornea can reduce higher order aberrations, one of the significant benefits is actually the reduction of the induced higher-order aberration that is normally associated with photorefractive surgery. This may result in higher quality unaided vision and a significant drop in night vision symptoms.

In an early collaborative project between the University of Auckland Department of Ophthalmology and Eye Institute (2003), a large prospective study of eyes undergoing either 217z LASIK Planoscan (conventional) or 217z LASIK Zyoptix (wavefront) was established. Data on approximately 500 subjects with a minimum of three months follow-up are shown below. Although myopic treatments up to –10.00D, or very occasionally –12.00D, were included, the majority of eyes (87.3%) underwent treatment for a spherical equivalent of –7.00D or less.

LASIK Procedure	Eyes	Pre-op Sph Equiv +/- Std Dev	Pre-op Range of Myopia	3 month Sph Equiv +/- Std Dev	**Unaided Vision**				
					6/5	6/6	6/9	6/12	<6/12
Planoscan	296	-3.81D +/- 2.32D	-0.75 to –12.5D	-0.17D +/- 0.30D	20%	60%	15%	1%	4%
Zyoptix (wavefront)	170	-4.87D +/- 2.16D	-1.00 to –12.4D	-0.08D +/- 0.39D	41%	41%	14%	1%	4%

Netto et al (2006) produced an **evidence-based overview** of wavefront-guided ablation: evidence for efficacy compared to traditional ablation. They noted that more than 400 reports investigating wavefront applications in refractive surgery exist, but studies comparing the outcomes of wavefront-guided treatment with conventional treatment are few in number and available studies do not overwhelmingly demonstrate superior visual results attributable to a wavefront-guided approach. They concluded, "that while wavefront-guided refractive surgery provides excellent results, evidence is limited that it outperforms conventional laser in situ keratomileusis that incorporates broad ablation zones, smoothing to the periphery, eye-trackers, and other technological refinements. However, it is evident that wavefront-customized ablation holds a promising future and merits ongoing investigation."

Surgical correction of hyperopia

Whilst the correction of moderate to high myopia and astigmatism by a variety of surgical techniques has become both predictable and safe, the surgical correction of extreme myopia, **moderate hyperopia and presbyopia remain significant challenges**. A major, international review (2002), by a panel of corneal and refractive surgeons, carefully considered decision-making, potential difficulties and controversies encountered when approaching the surgical correction of hyperopic eyes. In regard to surgical options for moderate hypermetropia (>+3.00D), only three procedures were generally considered suitable – LASIK, phakic intraocular lens and phaco-refractive clear lens extraction - as highlighted in discussion of hypothetical case studies. These options have not changed significantly in the last five years.

Whilst the authors considered the use of all three techniques, LASIK was stated as a definite option for a hypothetical eye with high hyperopia of +5.00/+1.00D x 90 by only one panellist, although all panellists thought it should be considered for a less hypermetropic eye (+3.00/+1.25D x 85). Interestingly, very limited enthusiasm was expressed for phakic intraocular lens surgery in a 25 year-old patient, though all panel members would consider this procedure for an identical refractive error in a 45 year old with presbyopia. **Phacorefractive clear lens exchange** was also reserved, by all authors, for the older, presbyopic, hypermetrope.

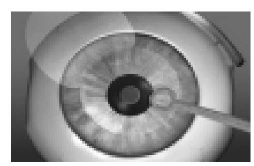
It would appear that the best surgical solution for moderate hypermetropia of +3.00D to +4.00D or greater is still an evolving situation despite increasing and more refined choices. Indeed, it is salutary to note that in a younger subject, with a hypothetical error of +5.00/+1.00 x 90, all six panellists in the 2002 study were in agreement that one key option was not to recommend surgery at all, and to await further surgical developments in this dynamically changing field!

<u>Intra-ocular and other options: extreme myopia, hypermetropia and presbyopia</u>

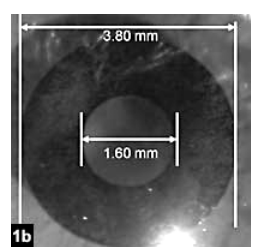
A. Corneal

Conductive keratoplasty (CK) is a relatively non-invasive, in-office procedure for the correction of low hyperopia, hyperopic astigmatism, and management of presbyopia. It serves as an alternative to laser-based refractive surgery with essentially no intraoperative or postoperative complications. It is a nonlaser, no cutting procedure that delivers focal radio-frequency energy to corneal stroma in a circular fashion to steepen the cornea. Conductive keratoplasty has been shown to be successful for the management of presbyopia although the refractive effect appears to wane with time.

Pallikaris' group (2006) reported two year follow up of a study. Preoperatively, the mean manifest refraction spherical equivalent was +2.11D (range -0.50 to + 4.13 D); at 12 months, it was -0.52D and at 24 months, -0.50 +/- 0.77 D. At 24 months, the mean MRSE was within +/- 0.50 D in 61% of eyes, within +/-1.00 D in 83%, and within +/-2.00 D in all eyes. At 24 months, the uncorrected visual acuity was 20/20 or better in 37% of eyes and 20/40 or better in 97%.



The AcuFocus ACI 7000™ is designed to treat presbyopia, which affects more than 50 million people in the United States. The ACI 7000 corneal inlay uses a "pinhole" effect and is implanted in the cornea under a LASIK flap in a simple outpatient procedure.



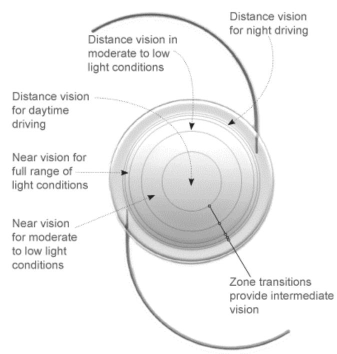
The device incorporates technology that increases the patient's depth of field, thereby improving near vision. The ACI 7000 has been designed to maintain normal corneal physiology and corneal health through multiple pores in the device. The procedure does not involve tissue removal nor does it permanently alter the cornea, so **pre-implant vision can generally be restored** if the inlay is removed. Studies involving several hundred subjects are currently under way and two of five Australasian sites are based in NZ in Auckland and Christchurch.

B. Intraocular

Phakic Intraocular lenses. Lovisolo and Reinstein DZ (2005) have recently performed an analytical review of the data available in the field of phakic intraocular lens implantation Clinical

studies of phakic intraocular lenses demonstrate increasing promise for the correction of refractive errors not amenable to mainstream excimer laser refractive surgery. The main issues currently revolve around adequate lens design (VHF ultrasound study suggests that custom-design and sizing may be the most effective and safest approach for every phakic IOL model), because these devices will be required to remain physiologically inert and anatomically compatible with internal ocular structures and relations for several decades. The possibility of safe removing or exchanging the IOL should remain a feasible option over time. They concluded that it is of utmost importance that we continue to critically evaluate current encouraging short-term outcomes, which are being extrapolated to the longer term by ongoing high resolution imaging and monitoring of the anatomical and functional relations of implanted phakic IOLs.

Clear lens extraction and multifocal vs monofocal lenses. In a systematic review for the Cochrane Database, Leyland and Pringle (2006) note: "good unaided distance visual acuity is now a realistic expectation following cataract surgery and intraocular lens (IOL) implantation. Near vision however still requires additional refractive power usually in the form of reading glasses. **Multiple optic (multifocal) IOLs** are available which claim to allow good vision at a range of distances. It is unclear whether this benefit outweighs the optical compromises inherent in multifocal IOLs."



Ten trials were identified, and a further three are pending review. There was significant variability between the trials in which outcomes were reported. Unaided distance acuity was similar in multifocal and monofocal IOLs. There was no statistical difference between multifocal IOLs and monofocals with respect to the proportion of participants achieving 6/6 best corrected visual acuity. Unaided near vision was improved with the multifocal IOLs. Total freedom from use of glasses was achieved more frequently with multifocal than monofocal IOLs. Adverse effects included reduced contrast sensitivity and the subjective experience of haloes around lights. The authors concluded that multifocal IOLs are effective at improving near vision relative to monofocal IOLs. Whether that improvement outweighs the adverse effects of multifocal IOLs will vary between patients.

Motivation to achieve spectacle independence is likely to be the deciding factor.

Conclusions

Refractive surgical procedures have been available for more than a century although they only became increasingly popular and well known with the spread of radial keratotomy in the 1970's. Excimer laser photo-ablative surgery has been refined for almost 20 years and this continues to evolve with the advent of active-trackers, wavefront driven ablations and technique modifications such as LASEK. However, whilst techniques continue to develop at startling speed, as evidenced by the limitations of LASIK in moderate hyperopia and extreme myopia, no single technique currently provides a panacea for those seeking surgical correction of refractive errors. Intra-ocular options are being increasingly employed for high myopia and presbyopia. Combining corneal and intra-ocular **(Bioptics)** techniques to maximise outcomes in individual eyes may be required.

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