PERSPECTIVE

Refractive surgery

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Refractive surgery, par excellence, is *the* ophthalmic surgery of the end of the millennium. This type of surgery is performed mostly for non-sight threatening conditions; it frequently involves high technology such as lasers and computers; the great majority of this type of surgery is done in the developed world; patients have very high expectations of the surgery and want very detailed explanations about results and complications; and there is a burgeoning medicolegal industry linked to the outcome of refractive surgery.

All these aspects of refractive surgery are starting to be echoed to a greater or lesser extent in many other areas of ophthalmic surgery. To give an example, the concept of detailed informed consent, and linked with it, the use of very lengthy and explicit consent forms, information leaflets, and educational videos are ideas which first appeared extensively in refractive surgery, but are now spreading to other areas of ophthalmology. So if we want to have a feel for the way ophthalmology is going to be going in the next millennium then we need look no further than refractive surgery today.

Definition

Refractive surgery encompasses a range of surgical modalities which have the aim of changing the refractive state of the eye. The techniques effect this change through action on the cornea and/or crystalline lens, as these are the principal refracting components of the eye. The refractive problems that may be addressed by such surgery are myopia, hypermetropia, astigmatism, and presbyopia; sometimes a combination of these may need to be corrected. There is a very wide range of surgical modalities and this range is expanding all the time. The modalities include corneal incisions, corneal sutures, corneal laser ablation, corneal lamellar surgery combined with various ablation techniques, corneal thermal laser, corneal inlays, phakic intraocular implants (IOLs), and lens surgery usually combined with IOLs of various types including multifocal and toric IOLs. The patients who are the potential subjects of this diverse array of surgery vary considerably in the nature and severity of their visual problems. At one extreme there are patients with severe pathology such as post-trauma or post-keratoplasty irregular astigmatism. At the other extreme there are patients with mild refractive errors which are easily corrected with spectacles or contact lenses, but who wish to have surgery to do away with the inconvenience of these devices. This wide spectrum of possible indications for surgery means that the risk/benefit ratio of surgery for an individual patient varies very considerably. For a summary of procedures see Table 1.

Patient assessment

Because of this very wide spectrum of the individual patient's particular clinical situation the preoperative assessment could rightly be regarded as the single most important part of the management of the refractive surgery patient. A thorough history and examination must be performed covering the patient's lifestyle, visual requirements, previous ophthalmic history, and careful examination of both eyes including anterior and posterior segment.

This brief list is not intended to be inclusive but to give an idea of the importance of properly assessing the whole patient and not just the bit of the eye that is to be the subject of the surgical procedure. More detailed technical measurements are also needed to assess the refractive state of both eyes. These include refraction, keratometry, ultrasonic pachymetry, and corneal topography.

A vital part of the preoperative assessment is full counselling of the patient to allow an informed consent to be made. This is probably the most difficult and time consuming part of the consultation, but failure to give information (covering matters such as outcomes and complications) that is adequate to allow the patient to give informed consent for the proposed refractive procedure seems to be one of the commonest causes of subsequent litigation.[1]

Correction of myopia

In general terms refractive surgery reduces myopia by either flattening the central region of the cornea or by reducing or eliminating the refractive power of the crystalline lens.

There is a wide range of surgical techniques to cause flattening of the central cornea, the earliest being incisional surgery in the form of radial keratotomy. The principle of this technique is to incise the peripheral cornea with a series of radial incisions which start near the limbus and end before reaching the central cornea. The procedure works reasonably well for low degrees of myopia. A prospective study of the procedure set up in the 1980s and followed for 10 years showed 60% of patients were within 1 dioptre of the intended result, and that uncorrected visual acuity was 20/20 in 53% of patients, and 85% of patients had 20/40 or better[2]; a more recent study with

Table 1 Summary of procedures

Refractive error	*Principle of treatment*	*Technique*	*Reference*
Myopia	Corneal surgery	Radial keratotomy	2, 3
		Photorefractive keratectomy	4, 5, 6
		Automated lamellar keratectomy	7
		Laser in situ keratomileusis	5, 8, 9, 10
		Corneal rings and inlays	11, 12
	Lens surgery	Clear lens surgery	13, 14
		Phakic intraocular implants	15, 16
Hypermetropia	Corneal surgery	Photorefractive keratectomy	18
		Laser in situ keratomileusis	19
		Laser thermal keratoplasty	20
	Lens surgery	Phakic intraocular implants	15
Astigmatism	Corneal surgery	Arcuate keratotomy	21, 22, 23, 24
		Photorefractive keratectomy	25, 26
		Laser in situ keratomileusis	27
	Lens surgery	Toric intraocular implants	
Presbyopia	Lens surgery	Multifocal intraocular lenses	28, 29

modified techniques showed some improvement in results.[3] One of the longer term problems with this procedure is the incidence of a progressive overcorrection leading to hypermetropia which may worsen over a number of years,[2] and since the advent of excimer laser treatment, radial keratotomy is used less frequently.

Photorefractive keratectomy (PRK) using the excimer laser was developed in the late 1980s and became widely available for the correction of myopia in the early 1990s. The technique involves laser ablation of stromal tissue from the central cornea thereby causing flattening of the central cornea. PRK has the advantage that no incisions are required unlike radial keratotomy; however, the laser equipment is expensive and regression of the corrective effect, sometimes associated with significant corneal opacity, has limited its usefulness in correcting higher levels of myopia (more than −6.00 dioptres). For low to medium levels of myopia, however, PRK is more effective and has a lower incidence of complications. For example Talley *et al* [4] gave the results in a group of patients with attempted correction of −5.00 dioptres or less; 95% of patients were within 1 dioptre of the intended result, 52% had unaided visual acuity of 6/6, and 98% had unaided acuity of 6/12 or better. Treatment of even low myopia has a certain incidence of persisting corneal haze, and this same series had a 3.5% incidence of loss of two lines of best corrected visual acuity. Other complications that may occur are irregular astigmatism, especially so called "central islands", and subjective complaints such as halos. For comprehensive reviews of the literature see the Royal College of Ophthalmologists best clinical practice guidelines[5] and the ophthalmic procedure preliminary assessment of the American Academy of Ophthalmology.[6]

Various types of lamellar corneal surgery have been developed to correct myopia; this type of surgery may use only a microkeratome to achieve the corneal flattening or may be combined with the excimer laser to achieve the desired change in shape.

The lamellar technique using only a microkeratome is known as automated lamellar keratoplasty (ALK). This involves the creation of a corneal flap by the microkeratome. The same instrument is then reset to resect a disc of tissue from the underlying stromal bed of a given diameter and thickness depending on the amount of correction desired. The corneal flap is then repositioned and the surface of the cornea assumes a new flatter shape reflecting the removal of the deeper stromal tissue. The technique is demanding from the surgical point of view, and problems can arise with the cutting of the flap and deeper disc of tissue. Preliminary results suggest the best outcomes are obtained for myopia from the range −5 to −15 dioptres, but there may be problems with undercorrection, loss of best corrected visual acuity, and change at the interface. Manche and Maloney, treating a group of patients with a range of −4.5 to −20.5, found only 18 patients out of 52 at 6 months post-ALK were within 1 dioptre of intended correction, and 44% had 20/40 or better uncorrected visual acuity.[7] To a large extent the development of laser in situ keratomileusis has superseded ALK.

Lamellar surgery combined with the excimer laser is known as laser in situ keratomileusis (LASIK). This technique was developed in the late 1980s and early 1990s and involves the creation of a corneal flap with a microkeratome and then laser to the underlying stromal tissue to produce the desired flattening, followed by repositioning of the flap. So far published studies are relatively short term but results suggest a wide range of myopia can be treated, including high myopia. LASIK seems to give better results with a lower incidence of complications for high myopia (more than −6.00 dioptres) when compared with PRK, although the follow up studies are not as long as for PRK.[5,8–10] An overview of the published results so far suggests for a mean attempted correction of −12.59 dioptres, 49% had uncorrected visual acuity of 20/40 or better, and 67% were within 1 dioptre of the intended correction, with an 8% mean incidence of some loss of best corrected visual acuity.[9] The technique has its own problems and complications, with possible problems related to the creation of the flap, and postoperative problems at the interface.[5,9]

Other methods for changing corneal shape include corneal rings and inlays. These techniques are at a very early stage of development and only small numbers of patients have been treated.[11,12]

The alternative approach to correcting myopia is to alter the refracting effect of the crystalline lens either by removing it (clear lens surgery), or by implanting an additional artificial lens in front of the crystalline lens (either an anterior chamber lens or a so called phakic contact lens). Clear lens surgery gives very good visual results but with an associated, though small, risk of retinal detachment.[13,14] Phakic intraocular implants may be in the anterior chamber or posterior chamber. The most recent developments involve posterior chamber implants. Trials are at a very early stage[15,16] but already associated lens opacity has been reported.[17]

Correction of hypermetropia

In terms of surgical correction this is at a much earlier stage than the correction of myopia. Very similar options apply: the corneal shape can be changed (be made more curved centrally), or lenticular lens power can be changed by clear lens surgery or by the addition of phakic intraocular implants. PRK, ALK, and LASIK are all being tried to correct hypermetropia. PRK uses a large treatment zone and special devices such as an erodible mask or a rotating aperture to produce more ablation in the periphery thereby increasing the central corneal curvature. Early studies had significant regression and problems with irregular astigmatism and corneal scarring but techniques are being modified to try and improve the results.[18] Some preliminary results are also available for LASIK.[19] A novel laser treatment also being trialed in the correction of hypermetropia is laser thermal keratoplasty (LTK). This procedure uses a circumferential arrangement of spot laser burns on the peripheral corneal surface to cause localised corneal tissue shrinkage with a resultant increased curvature of the central cornea.[20] Studies on the lenticular approach to correcting hypermetropia are still at a very early stage.[15]

Correction of astigmatism

Astigmatism may be congenital or acquired: the most severe astigmatism is generally acquired and causes include iatrogenic (such as post-keratoplasty and postcataract), trauma, and keratoconus.

The surgical correction of astigmatism also depends on changing the corneal or lenticular refracting power of the eye although the great majority of techniques involve the cornea.

Arcuate keratotomy is an incisional technique which has evolved from previous incisional methods: it may be combined with compression sutures when treating large degrees of astigmatism—for example, post-keratoplasty. The principle is to make paired arcuate incisions on opposite sides of the central cornea in the axis of the steep meridian. This results in flattening of the steep meridian with a reduction of the astigmatism. The effectiveness of the incisions can be varied by varying their length, depth, and distance from the optical centre of the cornea. Compression sutures can be added in the meridian of the flat axis to increase the curvature of this axis.[21] As most series contain a mixture of causes of astigmatism direct comparison of results is difficult, but the general trend seems to be towards reducing astigmatism by between 50% and 70%. Most surgeons use a nomogram (examples Buzard *et al*[22] and Lindstrom[23]) to determine the variables of surgery, but some (myself included) prefer to use some form of intraoperative keratoscopy or keratometry.[23] Most surgeons use corneal markers with a free hand technique but automated instruments have been developed to make the arcuate incisions.[24]

PRK and LASIK have also been adapted and refined to correct astigmatism. PRK has been used since the early 1990s for treating astigmatism: results are in a similar range to those reported for arcuate keratotomy with one study showing reduction of astigmatism at 6 months post treatment varying from 55% to 70% depending on the degree of associated myopia,[25] although another study gave better results using a multipass/multizone treatment regime (a protocol that involves sequential treatments with different degrees of correction at different zones of the cornea), with a reduction of astigmatism of about 90%.[26] LASIK is now also being used to correct astigmatism and early results are comparable with other techniques.[27]

The lenticular approach to correcting astigmatism involves the use of toric intraocular lens implants when cataract surgery is being performed.

Correction of presbyopia

The surgical correction of presbyopia is still in its infancy although various types of mutifocal intraocular lenses have been around for some years. These lenses work by producing two focal points, one for distance and one for near with the patient learning to concentrate on the appropriate image depending on the circumstances. There are a number of different designs which work reasonably well but accurate biometry and lens centration are crucial, and all types produce some problems with reduced contrast sensitivity and glare.[28] A more recent design has attempted to produce an IOL that mimics accommodation by moving backwards and forwards slightly in the eye, but this design has yet to be perfected.[29]

The future

Refractive surgery is a relatively young subspecialty of ophthalmology but its rate of growth in terms of the number of practitioners and patients, and its rate of development in terms of new technologies and techniques, is very dramatic. It is certain these trends will continue into the next millennium.

On the positive side there are many exciting developments just over the horizon. The wound healing response of the cornea is one of the most important factors affecting the outcome of corneal refractive surgery, both in terms of topography and of complications like corneal haze. It is likely our understanding of this process, will increase dramatically just as it has done with wound healing in trabeculectomy surgery, and this will allow a much better modulation of the healing process both through advances in technique and in the postoperative pharmacological manipulation. Further developments will occur in the way existing laser technology is used with new treatment paradigms involving multizone/multipass methods, and new hardware and delivery systems. Another area that is logically ripe for expansion is the use of corneal topography linked directly to surgical treatment; it will surely be only a matter of time before change in corneal shape during a refractive procedure will be precisely monitored and will directly drive the laser or incisional treatment; indeed pilot systems are starting trials at the moment.

In the medium term the possibilities include new lasers and other new ways of changing corneal shape, and new intraocular lens implants which can in some way provide accommodation.

Another very important aspect of refractive surgery that will continue to develop and improve is the area of informing the patient. One of the current problems is to make patients fully understand what it means, for example, to be undercorrected, overcorrected, have glare, have halos, have corneal haze, or to be anisometropic. It may be possible in the future to have a head set simulator that can reproduce all these possible complications and allow patients to experience them before they make a decision about surgery.

Another less welcome area that awaits us in the future is the problem of long term complications. Many of the procedures described above have a relatively short track record, and thus the long term effects on the health and stability of the ocular tissues are unknown; as an example there has recently been a case reported of late onset corneal thinning following LASIK.[30] There are also other long term consequences for the eye and the eye surgeon following refractive surgery—the implications for transplanting corneas (the author has already experienced a donor cornea with radial keratotomy scars sent from an eye bank), the possibility of underrecording intraocular pressure in an eye that has reduced corneal thickness due to previous refractive surgery, and the effect of previous refractive surgery on IOL power calculations.[31] These problems may be compounded in years to come when a patient forgets to mention, and is not asked, about refractive surgery performed 20 or more years before. These concerns reinforce the importance of randomised controlled trials in refractive surgery with prolonged follow up, and it is disappointing that there have been so few such studies.

Conclusion

It is difficult to envisage the future of refractive surgery at the end of the next millennium when one considers the advances over the past thousand years. Perhaps there will be other ways of changing the focus of light rays using gravitational or electromagnetic forces rather than the principle of refraction which depends on differing refractive indices, or perhaps the blurred images created by refractive errors will be corrected by image enhancement technology implanted into the occipital cortex. On the other hand, maybe the majority of people will still be wearing glasses!

Whatever developments await us in the field of refractive surgery there is one principle of management that will definitely still apply at the end of the next millennium: always consider the whole patient and not just the eyeball.

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