

Refractive surgery and the ADF

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ONCE CONSIDERED ONLY by the courageous, refractive surgery has become an everyday alternative form of visual correction. Our ability to permanently correct refractive errors safely and reliably has improved over the last decade. This has been made possible by improvements in our understanding of corneal anatomy and physiology and the development of remarkable new tools.

ADF policy¹⁻⁴ has kept pace with these changes, moving from prohibition to provision of refractive surgery. Arguably, many service personnel have a greater need for refractive surgery than civilians. Their work is often physically challenging and is often in hostile environments where other forms of vision correction can have serious drawbacks.

How do shortsighted Army commanders ensure maximum safety of those in their charge in action or exercise when spectacles are fogged, wet, damaged, lost or removed to wear headgear? A myopic infantryman is probably as dependent upon his glasses as he is on his rifle.

Reports are heard of infantry in Operation Desert Storm who removed their glasses in windy dusty conditions because they saw better that way. Chemical protection masks can be designed to correct myopia, but if the soldier dons the wrong mask under threat of gas attack, two soldiers are disabled.

Contact lenses are not a solution to these problems for several reasons. One is the considerable risk of suppurative keratitis, a potentially blinding condition that requires urgent ophthalmological attention to maximise the chance of maintaining vision.

This condition has been estimated to affect one in 2500 daily-wear contact lens wearers per year, and one in 500 extended-wear contact lens users per year.⁵ The figures are no better for disposable contact lens wearers.⁶ This surprising statistic validates the ADF ban on contact lens wear on deployment. In the last 20 years contact lenses have made few improvements to increase their safety.

Added safety for service personnel is not the only issue. Good uncorrected vision can actually enhance performance. The US Navy (USN) found that uncorrected visual acuity was the only statistically significant predictor of performance at Top Gun training (Captain SC Schallhorn, personal communication). The

Abstract

- ◆ Refractive surgery has a great deal to offer the ADF in terms of improved operational readiness, efficiency and safety of personnel in dangerous environments.
- ◆ Refractive surgery is efficacious, but serious and bilateral complications can arise.
- ◆ Appropriate services will not be provided by simple outsourcing. The ADF would benefit from actively managing refractive surgery for selected personnel.
- ◆ Adequate expert manpower within the permanent forces and reserve forces is available for a refractive surgery program.

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distorted spatial orientation caused by glasses possibly explains the observation. Interestingly, US naval aviation pilots quickly relearn spatial judgements after undergoing photorefractive keratectomy (PRK).⁷

US forces experience

The USN has been performing laser refractive surgery at Naval Medical Center San Diego since 1993 under the supervision of Captain Steve Schallhorn, Director of Cornea and Refractive Surgery (and also a former F-14 pilot and Top Gun instructor).

To date the US Navy has performed over 10000 PRK procedures, including surgery on 1400 aviator eyes. More recently, about 3000 laser in-situ keratomileusis (LASIK) procedures have been performed.

The initial impetus for large scale refractive surgery came, not from the medical fraternity, but from Unit Commanders. They were quick to see the potential operational benefits. The Commander of USN Special Forces, the SEALs (Sea/Air/Land Commandos), was among the first to seek help for shortsighted personnel in his command. Others since have enthusiastically embraced and financed the surgery, leading, sometimes unwillingly, their medical colleagues.

The US Army, under the supervision of Colonel William Madigan, has eight laser centres and will soon be performing surgery at a rate of 30000 eyes per year. Priority goes to front line soldiers, as the demand outstrips the supply of surgeons.⁸

The US Air Force (USAF) has five "Warfighter Refractive Surgery Centers" and predicts that more than 7000 procedures will be performed each year. At the Wilford Hall Refractive Surgery Center, a USAF establishment, the focus is on active-duty pilots and in-flight refuelers. Here the USAF has performed more than 3500 procedures since opening 18 months ago.⁸

The ADF has recently identified a group of Service personnel who are offered funded surgery. They are: rotary wing aircrew,



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ejection seat aircrew, Special Forces personnel, Clearance Divers, Army work divers, Explosive Ordnance Disposal personnel and Surface Finishers.¹

Conditions treated by refractive surgery

Myopia (shortsightedness) and myopic astigmatism (shortsightedness with blurred focus) are the main refractive errors in the age group we are considering. Hyperopia (or hypermetropia; longsightedness), hyperopic astigmatism and mixed astigmatism are also treatable but are less common.

About 15%–20% of Caucasians are myopic.⁹ In Asian races the incidence is higher by a factor of as much as four.^{10,11} This incidence of myopia appears to be increasing in communities where there has been a shift to an urban lifestyle and is said to support a contribution of environment to the pathogenesis of myopia.¹²⁻²⁰

Myopic progression appears in the teen years, stabilising in most at about age 18,²¹ and ceasing at completion of body growth.²² In a meta-analysis of some 500 articles,²³ it was estimated that 20% of students with no myopia had developed myopia by their fourth year after entry to an academic environment.

Before World War Two, the USN would not accept any degree of myopia in officers. Were myopia to develop in a midshipman at United States Naval Academy (USNA), Annapolis MD, training was discontinued. Despite requiring a Snellen fraction of 6/6 (ie, normal visual acuity) as an entry qualification before 1937 there were losses of up to 31% per year to developing low myopia.²⁴

The entry restrictions to USNA were strengthened to allow only those with a hypermetropic “reserve” on cycloplegic refraction. It was found that if this “reserve” was less than +1.00 dioptres (D), then there was only a 50% chance of staying in and receiving a commission. Even the elite class of 1941 who could leap this monumental refractive hurdle still lost 8% to myopia as the shift to myopia progressed with physical maturation.

A later study of naval officers²⁵ and a study of airline pilots^{26,27} showed nearly a quarter became myopic by the end of their training.

These data remind us that the restriction on myopic individuals entering pilot training



1. Protective clothing prevents the wearing of glasses. Above: Open circuit compressed air breathing apparatus (OCCABA) is used in firefighting or in situations of toxic hazard. Spectacles are not worn and vision correction cannot be fitted. Below: Mark V chemical-biological-radiological or nuclear defence (CBRND) rig precludes the use of glasses. Hearing seems not to be a problem.

Pictures: www.defence.gov.au



2: Flying high performance aircraft is an intensely visual task. Detection and discrimination of small targets, depth perception and near vision are all important. Picture: www.defense.gov

in the ADF⁴ can only reduce, not eliminate, myopia among trained pilots. Indeed, Mork²⁷ found myopic pilots in the RAAF, but fewer than were flying in the less refractively restrictive USAF.

There will always be a number of shortsighted personnel in uniform no matter what the restriction on entry. Recently, recruitment has become more relaxed regarding low levels of myopia. Safe refractive surgery might significantly affect recruiting and retention.

The optical state in myopia

In myopia, the overall optical power of the eye must be reduced in one way or another if the subject is to see clearly beyond their far point. The far point is located at the distance, in metres, of the reciprocal of their refraction. For a person of normal vision (known as an emmetrope in optical parlance) with a refraction of 0.00 D the far point is at 1/0.00 metres, ie, infinity. For a myope of -5.00 D the far point is, therefore, at 20cm and all objects beyond this point become more blurred with increasing distance.

Concave lenses held before the eye will reduce the optical power, as will contact lenses with a flatter surface than the cornea. It is optically better to correct refractive error at the corneal plane, as with contact lenses or refractive surgery, rather than at the spectacle plane. With spectacles, significant spatial distortions occur, even in correcting low refractive errors.

All that is required to correct say, a -5.00 D refraction in an eye with a cornea of radius 7.5 mm, is to flatten it to a radius of 8.45 mm (Figure 3). Correction of hyperopia requires increasing the curvature of the cornea by a similar amount. Correction of astigmatism requires a differential flattening or increasing, or both, of the radii of the corneal meridians of maximum and minimum curvature. Making these small changes is conceptually simple, but is a very complex problem in practice.

Origins of refractive surgery

Refractive surgery dates to the 19th century, when Lans demonstrated the effect of applying heat to the cornea to treat astigmatism.²⁸ Attempts at directly resculpting the cornea to the appropriate curvature were of

limited success because physical means were too inaccurate.²⁹ The shape could be altered by making incisions to weaken the cornea, with consequent flattening, for example radial and astigmatic keratotomy (RK and AK).

While it was probably not suspected at the time, an observation made in 1981 at the laser effects laboratory of the USAF School of Aerospace Medicine was to herald a new era in surgery. It was found that a 193 nm ArF excimer laser could cleanly cut rabbit corneal epithelium,³⁰ without the heat damage associated with other wavelengths. The corneas subsequently recovered completely.

Srinivarsan, working at IBM in 1983, defined the effects of 193 nm lasers on organic materials.³¹ To demonstrate the extreme accuracy of the laser he cut grooves in a human hair. (Figure 4). The process was shown to be quite distinct from the photovaporisation of the CO₂ laser, in which heat damage to adjacent tissue occurs. The tissue effect was termed *ablative decomposition* or more commonly, *photoablation*. These observations indicated that optical control of the corneal surface might be possible due to the submicron accuracy of corneal sculpting allowed by this wavelength.

Five years later, McDonald used an excimer laser to perform the first surface ablation on a sighted eye.³² The procedure was called photorefractive keratectomy (PRK). Rapid progress since then has resulted in the current spot-scanning excimer lasers with complex eye trackers (Figure 5), and the newer surgical techniques; Laser in-situ keratomileusis (LASIK) and laser subepithelial keratomileusis (LASEK).

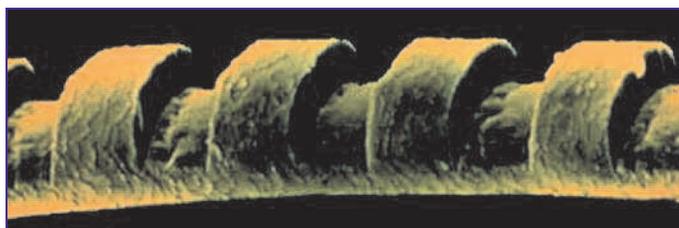
Growth in refractive surgery

Alcon Australia, manufacturers of excimer lasers, estimate that 30 000 laser refractive procedures, mostly LASIK, were performed in Australia last year, and the number is growing.

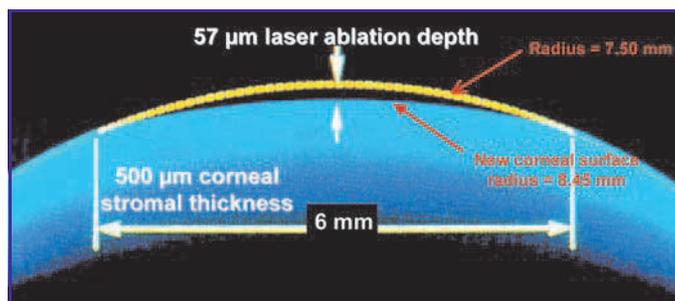
In the USA, industry sources report huge growth in refractive surgery, with nearly two million procedures performed in 2002, making it possibly the most common surgical procedure in the USA.^{33,34}

Refractive surgery today

LASIK, LASEK and PRK all use excimer laser for photoablation of corneal stroma to reshape the refractive surface of the eye. In the case of myopia, maximal tissue removal occurs in the centre of the optical zone at the rate of about 10 μm per dioptre of desired correction within an optical zone that is usually 6 mm in diameter.



4: A human hair cut by Srinivarsan with a 193 nm excimer laser to demonstrate the accuracy of photoablation of organic material (IBM).



3: Tissue ablation in LASEK. The diagram is of a corneal cross-section and explains the concept of corneal sculpting. In this case of a -5.00 D myopic correction, 57 μm of stromal tissue is ablated from the centre and less from the periphery. Such a procedure is conceptually simple, but reality is more complex.

The key features of LASIK, LASEK and PRK are to be found in the Table. A full description of the surgery and postoperative care are beyond the scope of this article.

Understanding the outcomes of refractive surgery can be difficult and a universal approach has been developed.³⁵ Some understanding of uncorrected visual acuity (UCVA; vision without glasses), best-corrected visual acuity (BCVA; vision with the best possible lens in front of the eye) and other refractive terms is required.

If, after surgery, the UCVA is less than the BCVA, then there must be residual refractive error, either an under or over correction. This is an index of efficacy.

The closer the mean refraction of a group of surgical subjects is to 0.00 D (emmetropia) and the smaller the standard deviation, the better the surgery. These are indices of precision and accuracy.

If there is a change in BCVA after surgery compared with BCVA before surgery, then there has been a surgically induced degradation or enhancement in visual quality. This change is measured by the number of lines of BCVA gained or lost on the Snellen test. This number is independent of the residual refractive error. This is an index of safety.

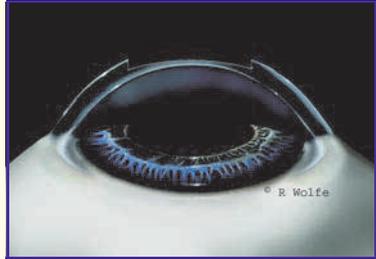
Of the many papers describing refractive surgery outcomes, some lack sufficient numbers or sufficient scientific rigor to be really useful in a military context. Others describe outcomes using older broad beam excimer laser systems, which were clearly inferior to today's spot-scanning lasers. Nearly all studies are on civilian populations that differ significantly to service populations, not only in health, age and sex distribution, but, more importantly, in visual requirements.

Of more relevance are studies like the USN Aviator Retention Study.³⁶ This is a four year, prospective non-randomised investigation of PRK in naval aviators who have over 1000 total flight hours. It plans to recruit 500 subjects who meet the US Food and Drug Administration (FDA) eligibility criteria.

As well as evaluating PRK, the study will aid in retention of aviators who no longer meet visual standards. Postoperative tests include contrast sensitivity and night carrier landing simulation, as well as objective indices of flight performance and an aviation psychometric questionnaire.

Outcomes for the first 254 eyes are available in the preliminary report of the study. The mean preoperative

Key features of current laser refractive surgery procedures

Type of surgery	Lamellar procedure	Surface ablation procedures	
	LASIK	LASEK	PRK
			
Technique	Epithelial and stromal flap 130–200 μm. Laser ablation under flap. Flap replaced. Stays in place because of tissue adhesion, epithelial and stromal healing.	Epithelial flap created and replaced after laser ablation to stromal surface. Flap held in place by contact lens for four days. Epithelium reattaches.	Epithelium removed and discarded. Laser ablation to corneal surface. Contact lens inserted and removed at 4+ days. Epithelium regenerates.
Postoperative recovery (military personnel)	No pain. Near final result on day 1. Need to protect eye from trauma for one week. Antibiotic and corticosteroid drops for one week. Most are deployable after one week. Most return to normal duties day 1 or 2. Seen for medical follow-up one day, one week, one month, six months and one year after surgery. Repeated surgery to enhance result possible at three months, if required.	Frequently, but not always, much less pain than PRK. Topical corticosteroid, tapering over one month or titrated as needed. No good data on speed of recovery but appears to be high. Seen for medical follow-up one day, four days, one week, one month, six months and one year after surgery. Repeated surgery to enhance result possible at three to six months, if required.	Mild discomfort to severe pain for four or more days. Return to work often at a week. Vision may take one to three months to recover before flying or deployment is possible. Seen for medical follow-up one day, four days, one week, one month, six months and one year after surgery. Might require more checks to titrate topical corticosteroid up to three months. Repeated surgery to enhance result possible at three to six months, if required.
Advantages	Reliable rapid visual rehabilitation over very wide refractive range. High patient acceptance. Ten years experience of the technique.	Outcomes similar to or better than PRK, avoids pain usually and no flap complications. Inadequate data to suggest wider safe refractive range than PRK.	Large experience – 15 years. Technically simple. Low procedural cost. No risk of flap complications.
Disadvantages	Higher procedural cost. Significant surgical skill needed. Possibility of flap complication and iatrogenic keratectasia. Can worsen pre-existing dry eye for six months.	Possibility of corneal haze, scarring and regression, possibly less so than with PRK (yet to be formally confirmed). More discomfort and slower visual return than LASIK.	Possibility of corneal haze, scarring and regression, particularly with greater myopia. Postoperative care more complex. Slower visual rehabilitation than LASIK.

refraction was $-2.87 \pm 1.68D$ (range, +1.75 to $-8.00D$). Three months postoperatively the mean refractive error had reduced to $-0.06 \pm 0.44D$ (range, +2.38 to $-1.25D$). Ninety-seven per cent were within $\pm 1.00D$ of emmetropia.

The postoperative UCVA is an important index of efficacy. Ninety-three per cent achieved a Snellen fraction of 6/6 or better, 85% achieved 6/4.8 (ie, higher than normal visual acuity) or better and 59% were 6/3.8 or better at three months postoperatively. PRK and LASIK have similar visual outcomes in the low myopic group.³⁷⁻⁴⁰ There are more LASIK outcomes than PRK outcomes in the recent literature, so they are reviewed below.

LASIK for low myopia resulted in visual acuity of 6/6 or better in between 37% and 83% of subjects.⁴¹⁻⁴⁸ A recent meta-analysis of outcomes⁴⁸ took a weighted mean of outcomes and found 55.1% achieved 6/6 or better. The figure is nowhere near the 93%

found so far in the USN Aviator Retention Study of PRK. The meta-analysis included data from up to a decade ago, when technique and equipment were less developed, and from a wider range of subjects, presumably with a lower level of fitness to the naval group. The USN results are similar to those gained by experienced surgeons using the most modern lasers.^{49,50}

Refractive surgery may result in under or over correction, and the effect of surgery may regress towards the original refraction. Regression is stable by three months.^{51,52} Regression is directly related to the attempted correction.^{53,54} An enhancement procedure is performed at three months if necessary. Most studies report a rate of enhancement surgery of 0.7% to 36%.⁵⁵⁻⁶¹

Factors favouring a low enhancement rate are more accurate primary correction and high threshold to offer enhancement. The latter factor is important in ADF outsourcing of refractive surgery,

as an outcome considered satisfactory by the surgeon in civilian practice might not satisfy the high requirements of an ADF member's occupation. Surgeons need to have a clear understanding of Service requirements. A higher enhancement rate is expected in Service personnel.

No significant complications have been reported in the USN Aviator Retention Study. A loss of more than two lines of BCVA on the Snellen test is considered a significant complication of refractive surgery. None of the eyes in the study suffered such a loss. Forty-five per cent of aviators gained one or two lines of BCVA.

This level of safety is repeated in most other recent studies of LASIK and PRK on civilian populations.^{37,40,41,45,49,50} In my own experience, I have noted no cases of loss of more than two lines of BCVA in the last 873 consecutive eyes treated with LASIK and LASEK (refractive range: -13.00D to +6.00D and up to 6.00D of astigmatism) on the LADARVision 4000 excimer laser (Alcon Inc., Fort Worth, TX, USA).

Return to flying in the Aviator Retention Study required the pilot to report no subjective problems with vision, have 6/6 vision and stable refraction (less than 0.5D change in two weeks). At four weeks, 79% were judged fit to return to flying, at eight weeks the figure was 93% and all had returned to flying by 12 weeks (mean time to return, 5.125 weeks).

On 1 April 2000, Lieutenant Commander Kevin Mannix underwent PRK. On 17 May 2000 he made aviation history as the first post PRK aviator to perform a carrier landing. On his carrier qualification (CQ) evolution he scored an "OK-3 wire", or the best score possible. His surgeon, Lieutenant Commander David Tanzer demonstrated his confidence in his own work by travelling in the back seat of the F/A-18D on the night CQ evolution.

At the direction of the Chief of Staff, the USAF developed an operational study of PRK. Lorusso has presented results of the USAF PRK Study (158 eyes of 79 patients).⁶² All were within $\pm 1.00D$ of emmetropia. Johnson reports an unusually large number of complications of PRK in this study,⁶³ of which the significance is not clear.

It is one thing to improve vision, but it is important to investigate whether tangible benefits flow from mass refractive surgery programs. Tanzer looked at subjective and objective indices of flight performance.⁶⁴ He used self assessment and objective measures such as landing grades of day, night and carrier arrested landings, comparing performance preoperatively and postoperatively. He concluded "Improvement in subjective and objective performance may be attributed to the aviator's reduced reliance on spectacles and/or contact lenses."

Recruiting is always a significant issue. In the "Accessions into naval aviation following PRK" study,⁶⁵ the USN plans to study 500 student naval aviators and student naval flight officers who have had laser refractive surgery.

Refractive surgery and defence environments

Refractive surgery has been evaluated in a number of environments in which Service people might find themselves more frequently than the civilian community.

The USAF looked at high altitude exposure,⁶⁶ exposure to increased and reduced G forces (Gz),⁶⁷ and the use of night vision goggles.⁶⁸

Subjects one year after PRK were subjected to chamber-simulated 12 hour 10000 ft flight with "in-flight" data collection.⁶⁶ They were also subjected to a 20-minute simulated 35000 ft unpressurised flight. No statistically significant change in keratometry or refraction was found.

The USN performed a similar study.³⁶ They took 32 post-PRK subjects including Naval Flight Officers and Flight Surgeons and subjected them to prolonged altitude in the hypobaric chamber at Marine Corps Air Station Miramar. No change in their vision was recorded.

Hyperbaric refractive stability after LASIK has been demonstrated in acute exposure.⁶⁹

One USAF study of 19 subjects who had PRK of both eyes 6 and 12 months previously looked at refractive and keratometric data before and after +Gz and -Gz exposure. No significant change in refraction occurred.⁶⁷

The USAF took post PRK subjects and measured their visual acuity in night vision goggles.⁶⁸ Mean visual acuity was unchanged in the first year, with a small drop at two years.

The USN conducted a similar study at Naval Strike and Air Warfare Center, Naval Air Station Fallon, where they evaluated 30 subjects' performance in night vision goggles after PRK.³⁶ They found no negative effects.

To truly validate refractive surgery in any Service-based program, not only visual results need analysis but also the impact the visual improvement actually has on performance. Marksmanship and flight testing are examples in which performance is easily measurable. These sorts of assessments should be the focus of further work.

Quality of vision issues

Visual acuity measurements clearly do not tell all about vision. It is possible, but unusual, to have significant visual problems despite 6/6 vision, such as problems with glare, haloes, or diminished night vision. Another measure of visual function is contrast sensitivity. High contrast optotypes (ie, visual targets, such as Snellen charts) are used to measure visual acuity. Measuring the threshold of resolution of lower contrast optotypes or sinusoidal gratings gives the contrast sensitivity (which can be measured under bright, dim or dark conditions).

The relationship between different levels of contrast sensitivity and the efficiency of performing a task such as flying is not established, although significantly reduced contrast sensitivity is known to be a risk factor for motor accidents.⁷⁰⁻⁷² A lack of normative data makes testing of contrast sensitivity not very useful clinically. Grimson at Naval Medical Center San Diego has begun to define normative contrast sensitivity data for naval aviators and the non-aviator population.⁷³ He has concluded that (a particular test of) contrast sensitivity shows promise for future screening of pilot applicants.

Schallhorn found an initial dip in contrast sensitivity but no long-term loss or loss of subjective quality of vision following PRK.⁷⁴ Other authors have found the same pattern in LASIK with no net contrast sensitivity change.^{75,76} Holladay noted a lowering of

“functional vision” for low contrast targets in low light.⁷⁶ This is attributed to a rise in spherical aberration of the eye associated with excimer laser ablation profiles. Perez-Santonja, however, reported an increase in contrast sensitivity at six months in moderate to high myopia.⁷⁷ Mutyala et al had similar findings but found a permanent contrast sensitivity reduction in myopia when LASIK is performed above -13.75 D and astigmatism above 5.25 D.⁷⁸

Yates⁷⁹ and Baldwin,⁸⁰ working in the USAF, demonstrated a drop in low contrast acuity six months after PRK when their patients’ pupils were pharmacologically dilated. One per cent of their subjects were two lines of BCVA worse off than normal control subjects with pharmacologically dilated pupil sizes of 8.5 mm average diameter. The difference had disappeared by 12 months. This drop was not seen under normal viewing conditions without dilated pupils. The relevance of these findings is doubtful as the test situation mimics no normal viewing conditions, occurs in only 1% of subjects, and goes away by 12 months.

Reduced night vision after PRK and LASIK has been reported, particularly in association with small zone ablations done by older lasers.⁸¹⁻⁸³ If the optic zone of treatment is small, the treatment large and the patient’s dark pupil is large, serious night vision problems might arise. There are also reports of night vision problems occurring with larger optic zones of treatment using more modern lasers.^{84,85} However, Frieta et al identified a net gain in night vision following PRK.⁸⁶

Spherical aberration is an optical entity in normal eyes. It is often made worse by refractive surgery. Minimisation of surgically-induced aberrations and treatment of naturally occurring aberrations is the focus of ongoing work, discussed below.

Complications of refractive surgery

In a defence force context, complications of refractive surgery threaten to disqualify personnel from service or service in a particular role.

A complication that causes an important defect in subjective quality of vision might not be admitted to by the patient and might not show up on routine vision testing.

A complication might occur during deployment.

The Aviator Retention Study³⁶ reported no serious complications. There was one data entry error, which was quickly corrected, and one recurrent corneal epithelial erosion, which resolved.

Johnston⁶³ has reported a significant number of complications in the USAF PRK study.

Complications of LASIK have recently been reviewed.⁸⁷⁻⁸⁹ They include corneal infection (suppurative keratitis), diffuse lamellar keratitis, flap creation complications, flap slippage and iatrogenic keratectasia (a condition with similar features to keratoconus).



5: This is an example of a modern excimer laser system. An important feature of the author’s Alcon LADARVision 4000™ laser is the small (0.8 mm) beam diameter. A unique feature is a 4000 Hz very fast eyetracker which follows random saccadic eye movements during the treatment. This technology is a product of NASA’s Strategic Defense Initiative. The tracker component uses reflected “laser radar” and was originally designed to track incoming missiles. (Photo courtesy Alcon Laboratories Inc.)

Flap slippage can result from minor trauma in the first few days after surgery, the greatest risk occurring in the first 24 hours^{90,91} A Medline search found 17 cases of late dislocation up to 38 months after surgery. In most, trauma was severe.⁹¹⁻⁹⁶ Most patients suffered no long-term problem and vision was restored after repositioning the flap.

It has been of concern that LASIK might be unsuitable for defence because of the possibility of late dislodgement of the flap. It should be kept in mind these are very rare occurrences. In a presentation to the Military Ophthalmology Symposium of the Australasian Society of Cataract and Refractive Surgeons, Schallhorn described tests with an animal model which showed that it takes severe trauma, associated with other ocular damage, to dislocate a LASIK flap.

While very rare, suppurative keratitis is a complication worth considering because it can be bilateral and severe. It is the only complication that could reasonably cause blindness.

It can occur as a result of corneal trauma or as a result of contact lens wear.

Corneal infection has been described after LASIK and PRK. A Medline search (to April 2003) reveals reports of 61 cases of post-LASIK infections.⁹⁷⁻¹¹¹ There is no way to determine the exact incidence as the level of reporting is uncertain. Most practitioners consider an approximation of the incidence of suppurative keratitis following LASIK at about 1:10 000 cases. Outcomes after treatment of the 61 cases were fair, with a range of final vision from 6/6 to light perception only, with a mean of 6/12. Such a complication, even if unilateral, however, might not allow Visual Standard 6 (minimal visual requirement 3), the lowest visual standard consistent with ADF service.

What is more disturbing is that 18 of the 61 reported cases were bilateral. In many of the cases the same, unsterilised microkeratome and single-use blade were used for the second eye. In another, bilateral infections followed the use of a new, sterile blade for the second eye, but an unsterilised microkeratome.

The safety of bilateral, simultaneous LASIK surgery has been established,¹¹² but the practice of re-use of the single-use blade is known to be associated with a thinner and potentially unsafe flap in the second eye.^{113,114} Using a single-use blade for both eyes is a common cost-saving practice in refractive surgery, but the risk of cross-contamination is too great for this practice to be recommended to the ADF.

Other serious complications can be avoided if adequate screening tests are used and appropriate contraindications are observed. Induced dry eye and iatrogenic keratectasia are important examples.

Future ADF policy needs to specify the standards it requires of refractive surgeons if surgery is to be outsourced. It is likely that what is considered by some to be a satisfactory community standard might not be an appropriate standard for the ADF.

Wavefront sensing and adaptive optics

An optical prescription for glasses makes use of the simple optics of the prism, sphere and cylinder. These optical principles only hold for paraxial rays, those close to the central axis of an optical system, or in the case of the eye, the centre of the pupil.

The behaviour of light rays in an optical system with a large aperture, for example a human eye with a large pupil under low light conditions, is quite different. The departure of the reality from the rules of simple optics is manifest in phenomena known as aberrations. The most important one, spherical aberration, was first investigated and measured by Young in 1801¹¹⁵ and Tscherning in 1898.¹¹⁶

Adaptive optics can be defined as the intentional design of optics to compensate for measured aberrations.¹¹⁷ Babcock developed the concept of adaptive optics in 1953.¹¹⁸ The principles were applied to military purposes, and in the 1970s were directed towards antimissile defence systems. In 1991 the US Defense Department declassified the work. It was taken up by astronomy to improve optical images of celestial bodies.¹¹⁹

In 1997 Liang and Williams optically corrected a human eye and were not only able to improve contrast sensitivity and visual acuity with their optical device, but were able to make use of the reduction in aberrations to image retinal photoreceptors.^{120,121}

This work leads to the exciting idea that adaptive optics might be sculpted directly on a cornea with an excimer laser, after measuring aberrations with an aberrometer or wavefront measuring device. The aim is to correct the refraction over all points in an enlarged pupil, rather than just the central point as we do with conventional surgery, glasses and contact lenses.

Laser sculpting of the cornea guided by wavefront measurements are now commonly referred to as “wavefront treatments”. Most excimer laser manufacturers are designing or have released working models, which require ongoing refinement. One system, the Alcon LADARVision 4000 “LADARWave” already has US FDA premarket approval.¹²²

The original market hype suggesting “super vision” using wavefront treatments has been toned down, but early results in some studies are encouraging. Kraff reports Snellen test results of 6/6 in all of group of patients with low myopia, with 58% having better postoperative UCVA than preoperative BCVA.¹²³ A recent study of LADARWave technology shows a statistically significant increase in contrast sensitivity after wavefront treatment.¹²⁴ I use these treatments routinely now when appropriate.

The USN is generating normative wavefront data. Wavefront measuring of the vision of USN jet pilots shows low levels of aberrations, as expected, but a slightly increased incidence of a 3rd order aberration, called coma, in which light entering the lens at an angle is distorted (Schallhorn, presentation to the Military Ophthalmology Symposium of the Australasian Society of Cataract and Refractive Surgeons). It might be that some aberrations are, in fact, helpful.

Wavefront measuring devices are going to teach us much about visual quality. They are becoming important tools in other ophthalmic research as well as forming the basis for better refractive surgery. Dr Dan Durrie, in presenting the prestigious Barraquer Lecture to the American Academy of Ophthalmology, said recently that wavefront sensing was one of the top five advances in ophthalmology in the last 25 years.¹²⁵

Provision of services

Most commercial providers in this country provide good surgery, but cannot be expected to understand special service needs and military refractive surgery.

Elsewhere I have presented business plans that would see appropriate surgery provided at a lower cost. The plans range from establishment of an ADF laser centre, to simply taking over the postoperative care and some preoperative assessment.

Even adopting this minimalist option would:

- Ensure recommended postoperative checks actually occur. Personnel at distant ADF bases must currently travel to a laser centre in a state capital for follow-up four or five times over the first year.
- Ensure that independent assessment of the quality of outsourced surgery could be made.
- Facilitate service assessment for suitability to return to work or deployment.
- Ensure reliable reporting of outcome data and adverse incidents.
- Reduce costs.

The ADF could then be prescriptive about the technology to be used, the type of surgery to be performed, the indications, the contraindications, the screening tests to be used as well as aspects of surgical technique. It is for similar reasons that the US Forces have now abandoned outsourcing of refractive surgery.

Conclusions

Properly applied, refractive surgery offers the ADF:

- Increased operational efficiency for up to 20% of its personnel.
- Increased personal safety on active duty.
- Probable, but unquantified, enhancement of performance of those with a need for a high level of vision.

The issue is an operational one and not measurable by simple health economics. That is not to say that quality of life, personal wellbeing and elimination of optical prescription costs are not important as well.

Modern warfare requires more of vision and comes with more optical and protective devices that make spectacle wearing difficult. Trends in recruiting have resulted in liberalisation of vision standards, so we have more spectacle wearers in uniform.

Fortunately these trends are coincident with the appearance of vastly improved refractive surgery.

It is appropriate to recognise the need and the understandable desire of Service men and women for refractive surgery, and plan a large scale program, learning from the US experience. Military refractive surgery is an idea whose time has arrived.

Over the years refractive surgery has borrowed heavily from military scientific work. The use of excimer lasers on tissues, the laser radar technology of very fast eye trackers and the principles of adaptive optics are excellent examples. It is fitting then, that this pioneering work comes back to the aid of its original sponsors in a way the scientists of the time would not have imagined.

Competing interests

I declare no financial interest in any of the products mentioned in this article.

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