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Clinical implications for the optometrist when assessing post LASIK patients

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Abstract

Laser assisted in situ keratomileusis (LASIK) has dominated the field of refractive surgery in the new millennium with many patients opting for it as an alternative to spectacles or contact lenses. LASIK appears to have been largely successful from a patient's perspective. Research in the area of refractive surgery has also been extensive with many studies highlighting the successes while others cautioning against its widespread use. Due to its popularity optometrists are bound to encounter patients that have had LASIK. Most often optometrists are not directly involved in the surgical process although some are involved in co-management. Irrespective of their involvement the optometrist should be knowledgeable in this field. This review highlights some aspects that all optometric clinicians should be aware of when managing post LASIK patients. (*S Afr Optom* 2013 **72**(4) 173-184)

Key words: Refractive surgery, LASIK, complications of LASIK, dry eye, LASIK induced ischemia.

Introduction

The concept of refractive correction other than with spectacles or contact lenses has spanned centuries from the time of ancient Chinese sleeping with sandbags on their eyes to do a form of corneal flattening to reduce myopia, to techniques involving the excimer laser. Many patients are now considering refractive surgery as the first option for the correction of refractive error, particularly LASIK[1, 2] and optometrists are often approached for advice on this option. Furthermore patients are likely to consult optometrists post refractive surgery regarding their visual requirements. It is imperative therefore that optometrists familiarize themselves with the current techniques, indications, contraindications and clinical implications of LASIK.

LASIK induces changes that impact on the visual examination of a patient which include the reduction in best corrected visual acuity, poor night vision especially when driving, the need for dry eye management, an alteration in corneal sensitivity and integrity, monitoring for iatrogenic keractasia, possible inaccuracies of clinical measurements, the relevance of dilated fundus examinations post-operatively and a decrease in contrast sensitivity function. This paper will present an outline of what the optometrist should be aware of when consulting patients post LASIK.

Blurred vision

The goal of LASIK, like for any other form of refractive surgery, is to reduce the refractive error and hence improve unaided visual acuity (VA) ideally to 6/6. Therein lies the "perceived" success of refractive surgery. The optometrist examining a post LASIK patient, however, may expect to find VA poorer than

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6/6, herein also referred to as blurred vision, which may either be transient or permanent. Transient blurred vision, often in the form of haze, may occur in the first 12 to 24 hours due to small epithelial defects or stromal oedema, but should rarely last longer than about 48 hours[3]. Corneal haze has been attributed to increased reflectivity of the anterior stromal keratocytes that are involved in the healing process[4].

Persistent blurred vision, without spectacles or contact lenses, following LASIK can be related to variations in the healing response of each patient, an incorrect evaluation of pre-operative refractive error, incorrect computer software and spontaneous regression that limits the accuracy of the surgical outcome relative to the attempted correction[5-7]. These factors can result in the patient being overcorrected that is, a myope becoming hyperopic or a hyperope becoming more hyperopic. Early presbyopes and presbyopic patients will experience poor vision at near if they become even mildly hyperopic from an originally myopic state which may necessitate a hyperopic LASIK procedure, or the use of some other refractive surgery such as laser thermokeratoplasty[5]. On the other hand, undercorrections occur frequently in patients with high refractive errors[8, 9]. Patients with residual refractive errors will complain of poor distance vision especially at night. Enhancements, which involves a retreatment, will thus be required and in some cases other forms of refractive surgery, other than LASIK, may need to be considered[3, 7]. Alternatively, if further refractive surgery is not indicated, then the optometrist may provide spectacles or contact lenses in an attempt to correct the residual error.

Visual acuity may also be reduced by astigmatism induced post-operatively which tends to be 'with-the-rule' but more often irregular, and may be linked to a host of factors including thin corneal flaps, poor microkeratome function, incorrect markings, incorrect ablation profile, central island formations, decentration of the ablation zone, folds in Bowman's layer and variations during healing of the flap including flap wrinkling and torsion[3, 5, 10-12]. Residual astigmatism can be reduced by removing any interface material or debris from the flap[10], however, if the cause is otherwise the optometrist may use rigid gas permeable lenses as a possible option for correction.

Patients may experience blurred vision after a period of time due to regression which refers to the post-operative refractive error slowly going back to the original refractive error. This can happen in the early post-operative period of between one and three months and generally stabilises between three and six months after the surgery[13, 14]. Regression has, however, also been reported in the long term, minimum of 10 years post operatively, by Oruçoğlu *et al*[15] who concluded that although a significant reduction in the myopic refractive error was achieved with LASIK, there was significant regression in the long term. Shojaei *et al*[16] also reported that despite improvements in various nomograms, ablation profiles and technology, regression is still found in about a fifth of patients that undergo refractive surgery. Regression is said to occur more often in the high myopes and has been attributed to irregular re-epithelialization and hyperepithelialization, particularly at the edge of the ablated area[17]. A 10 μm epithelial thickness increase will result in 1 D of regression[18]. Steroids are of little benefit in reversing regression therefore an enhancement may be necessary but can only be performed if there is sufficient residual corneal thickness[10].

Optometrists can also expect to find a reduction in the best corrected VA (BCVA) obtainable following LASIK with refractive correction[13, 19-25]. Optometrists therefore may find that it is not possible for the patient to achieve 6/6 visual acuity with any residual prescription including the use of rigid contact lenses, or even through a pinhole. Several explanations have been put forward for the reduction of BCVA following refractive surgery including the induction of irregular astigmatism, poor post-operative healing, mechanical damage, inflammation, poor surgical technique, interface abnormalities and central islands[26-28]. Another explanation involves resultant corneal irregularity. Corneal shape may deviate from the simple sphero-cylinder of a fairly regular cornea to one of a more irregular cornea, as well as from a prolate (flatter in the periphery) shape to an oblate (steeper in the periphery) shape, resulting in a consequent increase in positive spherical aberrations hence limiting the spectacle corrected vision[28, 30]. Furthermore, it has been postulated that the transparency of the cornea could be compromised following surgical intervention due to an alteration in the arrangement of the collagen fibrils, which could impact on transparency[31, 32]. The optical aberrations may be perceived as haloes, ghost images, and slight distortions and the optometrist may find patients complaining of shadows around objects. These optical aberrations may or may not interfere with normal VA but will affect the optical quality of the post-operative image hence any refractive error measured objectively may not be accepted subjectively[4, 33- 35]. All of these factors are expected to affect the refractive capability of the cornea and thus would impact on threshold VA following LASIK.

Difficulties with night driving

Optometrists are bound to encounter complaints from post LASIK patients about night vision especially when driving[36]. Fan-Paul *et al*[37] predicted an increase in the number of patients complaining of scotopic and mesopic vision disturbances following refractive surgery and as more people undergo refractive surgery this issue could become a major public health problem. More recently, Zheng and Song[38] have reported the decline in night vision and experience of glare following LASIK as a major concern. These symptoms have been related to the induction of higher order aberrations such as spherical aberration after refractive surgery[36]. Furthermore, the debilitating effects of any small residual prescription will be experienced more under dim illumination. Night vision and glare vision thresholds of myopes appear to be reduced following LASIK with high myopes appearing to be affected more than low and moderate myopes[39].

Night glare is often experienced as a result of the pupil diameter exceeding the optical zone created by LASIK hence more light enters through the peripheral cornea, which has not been reshaped resulting in myopic blur circles which degrades the retinal image[40- 42]. Glare may also result from scattering through an oedematous cornea[42]. Patients complain of haloes, ghosting and decreased vision at night[3, 41] which is not easily solved because increasing the optical zone diameter will necessitate a greater ablation depth, which in turn could result in the formation of central islands leading to astigmatism.

Difficulties with driving at night following LASIK have often been found due to glare[43]. El Danasoury[44] reported that many patients experienced night glare, although many of them did not report it. In some patients night vision becomes so debilitating that they just stop driving[39]. In Germany, a study reported that seven out of ten patients were found unfit to drive at night according to German law, due to glare following LASIK[43]. Hence LASIK with certain occupations requiring good night vision must be considered with caution (pilots and truck drivers).

Alió, Piñero and Muftuoglu[36] reported an improvement in night vision symptoms and spherical aberration induction with corneal wavefront guided ablations but in the retreatment procedure. The expected reduction of higher order aberrations with wavefront guided ablation has, thus far, not been achieved[45]. For now, it is thus up to the optometrist assessing the post LASIK patient to determine the remediation before any retreatment is considered. Spectacles should be prescribed for any residual refractive error which can help optimize vision at night. Certain tints and coating on these spectacles can also be considered and tried in an attempt to minimize the glare effects. Rigid contact lenses may also be tried.

Dry eyes

Patients who undergo LASIK experience dry eye symptoms which are said to last for about one month after the surgery[7, 46-49]. Tuisku *et al*[50] however, reported that some patients are still symptomatic even five years later complaining of pain, burning, foreign body sensation and stickiness of eyelids. The dry eye condition is linked to many factors including damage to the conjunctival goblet cells, loss of corneal sensitivity, decrease in the blink rate and changes in corneal curvature[7, 48, 51-53]. However, Tuisku *et al*[50] reported, from a study on 20 subjects, that there were no clinical signs of a tear deficiency and that the symptoms may be more related to corneal neuropathy rather than a dry eye condition. Earlier, Toda *et al*[49] had hypothesized that tear secretion from the lacrimal gland and mucin expression on the corneal epithelium may be suppressed by the damage to the corneal sensory innervation during flap formation in LASIK. This theory was supported by the finding that basic tear secretion is derived from the reflex mediated corneal sensitivity and therefore decreased sensitivity may result in hyposecretion[54]. The quality of vision can be affected by the induction of dry eye[55]. The dry eye condition may be treated with artificial tears, which may be required for long-term use but as the exact course is unknown this form of treatment may or may not be effective. Punctal plugs have also been found to be effective in managing dry eyes in post LASIK patients[53].

Photophobia

Optometrists may find many post LASIK patients being more sensitive to light for variable periods following surgery. This finding has been related to scattering of light by the oedematous or irregular cornea[3]. The use of tinted spectacles or sunglasses may provide some relief to the patient.

Loss of corneal sensitivity

Loss of corneal sensitivity has been associated with various refractive surgical procedures including LASIK. A confocal microscopic investigation of the normal cornea revealed that the nerves are located directly below Bowman's membrane and in the anterior stroma[56]. During LASIK the sub-basal nerve fibre bundles and the superficial stromal nerves are cut, with only those in the hinge being spared[57, 58]. Hannush[59] reported that the sub-basal corneal nerves return after about two years, while stromal nerves return by three years. A much shorter period of recovery of corneal sensation was reported by Kumano *et al*[60] who found that by one year after LASIK the corneal sensitivity is not significantly different from the pre-operative values. Bragheeth and Dua[52] found that corneal sensitivity can be reduced for six months or more and that even though the corneal sensitivity may return it is uncertain whether corneal innervation ever fully returns to normal. Stapleton *et al*[61] reported that there was only partial recovery of corneal sensitivity three months after surgery. Patel *et al*[62] however, reported that the regrowth of sub-basal nerves is not complete until years after surgery.

The ablation depth and the ablation diameter were found to also impact on the decrease of corneal sensitivity and its recovery[52, 63]. The deeper the ablation depth, the greater the decrease in corneal sensitivity and the longer the time taken for corneal sensitivity to recover.

Thus, the cornea is compromised when this sensory capability is drastically reduced. This is particularly important since good corneal sensitivity is essential for normal corneal structure and function as well as for the early detection and diagnosis of corneal disorders[52, 57]. Furthermore, corneal hypothesia may compromise the protective blink reflex, reduce the rate of mitosis of the corneal epithelium, delay wound healing and can be associated with decreased tear flow, all of which could have clinical implications[64-66]. A comprehensive and careful slit lamp examination should thus be conducted on all post LASIK patients.

Weakening of corneal tissue

During the ablation process a lot of debris is produced by the excimer laser[58]. Presently, it is not known where these by-products go to. Concern thus arises about the carcinogenic effects of these monatomic and diatomic particles, as well as, the effect of rapidly expanding gases on corneal tissue integrity[58].

Furthermore, refractive surgery leads to a change in the biochemical composition, curvature and thickness of the cornea and it also alters natural tissue relationships[1, 8, 59, 67, 68]. There is a reduction in keratocyte density[69] for at least five years after LASIK which is significant as keratocytes play a protective role against infection in the cornea as well as in wound healing. The cornea can also be mechanically weakened following LASIK due a poor wound healing response[70, 71]. Cronemberger *et al*[72] found a significant reduction in ocular rigidity and corneal resistance after LASIK. Not surprisingly therefore an outbreak of *Mycobacterium chelonae* keratitis related to reduced corneal resistance was documented in a post LASIK patient, for which the cause was relatively unknown[73, 74].

Diffuse lamellar keratitis (DLK) is usually referred to as "Sands of Sahara" [8]. Causes seem to include contaminants on the microkeratome blade including residue of cleaning solutions, interface debris or bacterial toxins triggering off an inflammatory reaction, and thus anterior chamber activity[7, 68, 75]. These multi-focal infiltrates are culture-negative and noninfectious[76] and tend to occur within a week of surgery, however, sometimes may even occur several months after surgery[77]. Symptoms include pain and photophobia with signs of ciliary hyperaemia and lacrimation. Although visual acuity is not affected, visual quality is affected because of the scattering of light and may have a similar effect on vision as stromal haze has following PRK[7]. Treatment of

DLK involves topical steroids or oral corticosteroids, together with the lifting and irrigation of the flap[30, 76, 78]. Again, optometrists should therefore be conducting a thorough slit lamp examination when examining post LASIK patients to be able to screen for such conditions.

The structural integrity of the cornea is compromised following LASIK[79]. The corneal flap is expected to be particularly weakened and thus must be monitored carefully especially in patients that are involved in contact sports[80]. Patients who are involved in such sport either professionally or for recreation should be advised accordingly. Possible complications of LASIK resulting from altitude and pressure changes on a weakened cornea remain unknown. A study by Dimmig and Tabin[81] found a fluctuation of vision in three out of six LASIK patients who climbed up Mount Everest to 17600 ft. Clare *et al*[82], however, indicated stable refraction in post LASIK eyes with prolonged exposure to altitude and hypoxia.

Corneal ectasia

Corneal ectasia, regarded as one of the more serious side effects of refractive surgery, refers to progressive thinning and weakening of the central cornea, and has been reported when the residual corneal thickness is less than 300 μm [7, 43, 70, 84]. Other risk factors associated with keractasia have since been identified and include a reduction in the biomedical strength of the cornea, *forme fruste* keratoconus, high myopia, a pre-operatively thin cornea, an unexpectedly thick flap and pregnancy[84-87]. It can occur a month or years after the surgery[9, 88-90]. Wirbelauer and Pham[91], following a pilot study, suggest the use of intra-operative optical coherence pachymetry as a safety feature to monitor flap and residual stromal thickness in an effort to avoid iatrogenic corneal ectasia.

It is important therefore that the optometrist assesses corneal topography on post LASIK patients with particular attention to the corneal apex so that any changes can be identified early on and treatment instituted. Penetrating keratoplasty or hard contact lenses may be required following the development of keractasia[92] but more recently corneal cross linking, which appears to stabilize the cornea biomechanically, has been found to be effective in halting the progression of keractasia even though the sustainability of this effect is still questionable[84, 93].

Fitting contact lenses after LASIK

Contact lens fitting has been reported as being more challenging and less successful following LASIK[23]. Contact lenses post LASIK can be required for many reasons including keractasia, irregular astigmatism, epithelial flap defect *et cetera*, and can be fitted successfully following LASIK[94]. More often it is rigid contact lenses that will be required as hydrogel lenses do not provide optimal vision performance due to the resultant irregular corneas[23]. Patients with significant corneal irregularity will require trial fitting using a wide spectrum of rigid contact lenses but often with one that extends over the sclera as well and has a reverse geometry profile[23, 94].

Determining the power of the Intraocular Lens (IOL)

Caution must be applied when determining the power of an IOL following cataract extraction in the post LASIK patient, as the keratometry readings as well as axial length measurements taken postoperatively are not always accurate[1, 95, 96]. Keratometry readings on a post LASIK cornea are not accurate as the refractive index of the cornea is altered following ablation[96, 97]. The axial length appears to change due to a reported shift of the posterior cornea forward following LASIK[96]. It is therefore important that these readings are taken pre-operatively and that the patient and future clinicians are able to access them.

There are numerous formulae that may be used when determining the IOL power[95-97] but it is best that keratometry and axial length measurements are taken pre-operatively to allow for an accurate determination of IOL power. Furthermore, post LASIK patients requiring IOLs should be informed that the calculation of power for the IOL may not be accurate hence affecting their vision post cataract surgery.

Retinal Integrity

There have been cases of posterior segment complications following LASIK particularly in moderate to high myopes[22, 98, 99]. It has been suggested that any retinal haemorrhage may be due to some pre-existing pathology[100]. Hence, Arevalo *et al*[101] suggested that all patients considering LASIK should have an OCT performed to identify at risk patients.

Excimer laser photoablation has, however, been found to generate an acoustic shock wave, which travels at the speed of sound through the cornea[3, 102, 103].

It has been postulated that this acoustic shock-wave may be damaging to the retina and that exposure of the retina to the laser may result in macular damage, posterior vitreous detachment, fibrosis, traction, cystoid macular edema and hole formation possibly due to vitreomacular interface and vitreoretinal changes[99, 102, 104, 105]. Ruiz-Moreno and Alió[106] reported a low incidence of retinal disease including choroidal neovascularization, macular hole and macular haemorrhage following LASIK in myopic patients.

The application of the suction ring has also been linked to vitreoretinal changes even though the incidence of retinal detachment following LASIK has been found to be low[98, 101, 107]. Daftarian *et al*[99] reported the suction ring to have caused an increase in the axial length of the eye and that 95.6% of their subjects who required treatment for retinal detachment had suffered a posterior vitreous detachment. The risk of retinal detachment in myopic eyes is definitely increased during the LASIK procedure[3, 108] and a dilated fundus examination and assessment of macula integrity should be performed routinely by the optometrist examining post LASIK patients.

Effects of an acute increase in Intraocular Pressure (IOP)

Ocular health assessment of the post LASIK patient should also involve an assessment of the retinal nerve fibre layer which has recently become easier and more efficient with the use of optical coherence tomography. The IOP may reach up to 65 mmHg during the lamellar cut with the microkeratome during LASIK and such high in-vitro IOP values can be dangerous for eyes at risk[107, 109-110]. A study by Piette and colleagues[111] found that a temporary elevation of IOP does result in measurable changes to the optic nerve head topography, and in particular the retinal nerve fibre layer thickness. The effect of this sudden increase and then release of IOP on the posterior segment of the eye during LASIK has not been fully investigated[107, 112]. McCarty *et al*[112] have reported a reduction in nerve fibre layer thickness following LASIK. Retinal nerve fibre damage, especially in high myopes who have thinner retinas, has also been reported by Shah and Ilango[100]. Furthermore, a study by Ozdamar and Ocakoglu[113] found a compensatory temporary increase in blood flow to the lamina cribrosa region of the optic nerve head post-operatively suggesting LASIK-induced ischemia. It is also postulated that the sudden increase in IOP exerts a mechanical stretch on the vitreous base along with the mechanical stress induced by the shock waves of the laser[99, 106] which could subsequently result in retinal haemorrhages and detachment. An assessment of the nerve fibre layer thickness, retinal integrity and central visual fields during an optometric examination of a post LASIK patient is thus warranted.

Effect on contact tonometry readings

Corneal changes during refractive surgery result in Goldmann tonometry underestimating IOPs in both myopes and hyperopes[67, 114-118]. This underestimation was initially thought of as being due to the thinning of the stroma and flattening of the central cornea[119]. However, it is now believed to be multifactorial being influenced also by preoperative IOP, ocular rigidity, age, corneal epithelial thickness and tear film thickness[72, 120]. These changes can result in the intraocular pressure being underestimated by between 3 to 10 mmHg [7, 100, 115]. This underestimation is of particular concern since it could delay the diagnosis of elevated IOP in post LASIK patients[116, 121]. Suggested alternatives for IOP assessment in post LASIK patients are the use of dynamic applanation tonometers such as the Pascal dynamic contour tonometer which is not influenced by corneal thickness or rigidity[67]and more recently the Schiotz tonometer[72] and the Tono-pen at the corneal limbus[117]. Furthermore, Fan *et al*[118] found that the IOP measurement was more accurate when measured on the peripheral cornea rather than the central cornea in post LASIK patients. Optometrists should therefore interpret IOP readings taken with Goldman Applanation tonometry with caution and should also bear in mind that the greater the preoperative IOP the greater the expected underestimation of the IOP post-operatively[120].

Reduced contrast sensitivity

Contrast sensitivity is important when considering visual quality. Any alteration or reduction in transparency of the optical components and in their modulation transfer function (MTF) will impact on contrast sensitivity. The optical quality of the cornea, hence its MTF, will determine the quality of the image produced and is dependent on two major parameters, namely the surface regularity and its shape[122]. Following LASIK, there is a change in the shape of the cornea from prolate to oblate, which has been identified as the main reason for the reduction in optical quality and thus functional vision as it induces Seidel aberrations, which include spherical aberration, primary coma, astigmatism, trefoil, Petzval curvature and distortion[4, 122-127]. Furthermore, Ondategui *et al*[128] reported a decrease in the cornea's MTF following LASIK. This results in patients experiencing blurry vision especially under mesopic and scotopic conditions[123, 124, 129].

Wavefront-guided custom treatments are said to reduce the incidence of higher order aberrations following LASIK and hence improve optical quality[130]. Shah[100] had argued that wavefront corrections may not be able to eliminate the induction of higher order aberrations following LASIK completely due to the flap inducing its own series of aberrations. Furthermore, corneal surface irregularities such as flap striae, which induce significant optical aberrations and distortions but cannot be detected by commercial wavefront devices, will cause a degradation of optical performance[35]. Phusitphoykai *et al*[131] and Keir *et al*[132] found no statistically significant difference in the post-operative higher order aberrations following wavefront-guided LASIK compared to conventional LASIK.

Intraocular scatter has also been identified as a cause of a decrease in low contrast vision and contrast sensitivity following LASIK[7, 42]. Intraocular scatter has been linked to micro-surface irregularities which often occur during LASIK due to the lamellar cut, leading to scattering of light across the retina[33, 128, 133]. Additionally, Perez-Gomez and Efron[134] reported observing fine metallic debris at the corneal flap interface even six months after LASIK which can cause a certain amount of scattering of light and therefore impact on contrast sensitivity.

An initial decrease in contrast sensitivity particularly in the low and intermediate spatial frequencies may be expected[135]. This has been attributed to corneal haze. Arbelaez and Knorz[136] and Holladay, Dudeja and Chang[122] however, still noted this reduction in the longer term in post LASIK patients. Montes-Mico, Espana and Menezo[137] found that contrast sensitivity was reduced even further under mesopic conditions particularly at high spatial frequencies as these frequencies are primarily affected by defocus and optical aberrations. This reduction in contrast sensitivity may be linked to the reduction in vision at night.

Availability of donor corneas

Corneas that have undergone LASIK cannot be used in full thickness penetrating keratoplasty due to their abnormal shape and altered biomechanical properties following surgery[138]. It is vital therefore that patients opting to be cornea donors must indicate if they have had previous corneal refractive surgery[1]. Considering the number of individuals that are opting for refractive surgery there is also considerable concern regarding the future availability of donor corneas.

Conclusion

Refractive errors change during a person's lifetime and the goal of optometric care is clear, comfortable and single vision for the patient throughout their life. Eye care in many countries has been compartmentalized into those services delivered by ophthalmologists and those by optometrists. As primary eye care practitioners, however, it becomes the responsibility of optometrists to be well versed and educated in all aspects of eye care even though they may not be directly involved in certain areas, such as refractive surgery. Optometrists will encounter post LASIK patients in their practice and they must be able to manage these patients effectively.

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