Management of the Ocular Surface and Tear Film Before, During, and After Laser in situ Keratomileusis

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ABSTRACT
PURPOSE: To identify evidence-based, best practice strategies for managing the ocular surface and tear film before, during, and after laser in situ keratomileusis (LASIK).

METHODS: After a comprehensive review of relevant published literature, evidence-based recommendations for best practice management strategies are presented.

RESULTS: Symptoms of ocular irritation and signs of dysfunction of the integrated lacrimal gland/ocular surface functional gland unit are common before and after LASIK. The status of the ocular surface and tear film before LASIK can impact surgical outcomes in terms of potential complications during and after surgery, refractive outcome, optical quality, patient satisfaction, and the severity and duration of dry eye after LASIK. Before LASIK, the health of the ocular surface should be optimized and patients selected appropriately. Dry eye before surgery and female gender are risk factors for developing chronic dry eye after LASIK. Management of the ocular surface during LASIK can minimize ocular surface damage and the risk of adverse outcomes. Long-term management of the tear film and ocular surface after LASIK can reduce the severity and duration of dry eye symptoms and signs.

CONCLUSIONS: Strategies to manage the integrated ocular surface/lacrimal gland functional unit before, during, and after LASIK can optimize outcomes. As problems with the ocular surface and tear film are relatively common, attention should focus on the use and improvement of evidence-based management strategies. [J Refract Surg 2004;20:62-71]

LASIK in situ keratomileusis (LASIK) is regarded as a safe and effective form of keratorefractive surgery for refractive errors of -12.00 to +3.00 diopters (D). However, as with any relatively new procedure, unforeseen complications can become apparent when significant numbers of surgeries have been performed over a sufficient period of time. The risks associated with LASIK are now widely discussed, including frequent reports of adverse LASIK-induced (or exacerbated) effects on tear secretion and tear quality, corneal epithelial integrity, corneal and conjunctival innervation, conjunctival goblet cell density, and blink function. These adverse outcomes can result in chronic ocular irritation, fluctuations in vision, reduced quality of vision, loss of corneal clarity, poorer refractive outcomes, and an inability to have enhancement surgery. Dry eye is considered the most common complication of LASIK.

Improved management of the ocular surface and tear film before, during, and after LASIK may enhance outcomes after surgery. However, evidence-based guidelines on how to best manage the ocular surface and tear film are currently unavailable. The purpose of this review was to evaluate the current literature in order to propose best practice, evidence-based guidelines for management of the ocular surface and tear film before, during, and after LASIK.

METHODS
This review is based on the methodology for conducting a systematic review of randomized controlled clinical trials. The number of randomized...
controlled clinical trials on management of the tear film and ocular surface with LASIK, however, is limited. Searching Medline for randomized controlled trials (limit term) on the topic yielded four studies. Searching the Cochrane Database of Systematic Reviews for any review on LASIK yielded no reviews. Thus, this review is relatively limited in the strength of the evidence that it can draw upon. Due to the lack of randomized controlled trials, individual studies were not assigned a numerical code for evidence quality and a formal meta-analysis was not conducted. To identify all publications that may be relevant to this review (including those not using a randomized, controlled design), a systematic search strategy was used (Table 1).

**Ocular Surface and Tear Film Before LASIK**

Complications during LASIK and events after LASIK can be influenced by the state of the ocular surface and tear film before surgery. For the purpose of this review, before LASIK refers to the time from the initial consultation with the prospective LASIK candidate up to the day of surgery.

**Implications of Pre-existing Dry Eye Symptoms and Ocular Surface and Tear Film Disorders on LASIK Outcomes**

Dry eye and associated contact lens intolerance motivate individuals to consider refractive surgery.20-23 Dry eye symptoms before surgery were present in 38% of 450 consecutive patients who underwent LASIK for myopia17 and contact lens intolerance, due to dryness and/or soreness, was reported in 48% of 100 myopic patients who underwent photorefractive keratotomy (PRK).20 Tear deficiency before surgery, measured by the Schirmer test, was present in 43% of myopic patients who underwent PRK.27

Pre-existing ocular surface and tear film disorders can have a negative impact on the outcome of keratorefractive surgery in a number of ways. Dry eye symptoms and signs before LASIK are a significant risk factor for experiencing dry eye after LASIK.5,9,28 Poor tear secretion before surgery (Schirmer test value less than 10 mm) was a significant risk factor for experiencing dry eye symptoms after surgery.9 In addition, patients diagnosed with dry eye before surgery have poorer tear secretion, greater ocular surface staining, prolonged recovery of corneal sensation, and more severe and sustained dry eye symptoms after surgery compared to those without dry eye before LASIK.5,28

Ocular surface and tear film disorders before surgery may adversely affect LASIK refractive outcome. In a retrospective study of 88 hyperopic LASIK patients, refractive regression of 1.00 D or more from the refractive target has been significantly associated with dry eye symptoms, greater ocular fluorescein staining scores, and lower tear volumes before LASIK.5 Toda and colleagues, however, in a prospective study involving 543 patients, failed to find significant differences in unaided and spectacle-corrected visual acuity between groups diagnosed with dry eye, marginal dry eye, and no dry eye before LASIK for myopia. Refractive outcome for the group with dry eye before surgery was significantly more myopic at the 5-month but not at the 1, 6, and 12-month time points after surgery.28

Disorders of the ocular surface and tear film before LASIK have been implicated in increasing

### Table 1

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<thead>
<tr>
<th>Literature Search Strategy for Ocular Surface and Tear Film Before, During, and After LASIK</th>
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<td><strong>Medline Search</strong></td>
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the risk of complications during and after LASIK, including epithelial defects and epithelial ingrowth, flap folds, wrinkles and displacement, diffuse lamellar keratitis, and infectious keratitis. However, Toda and colleagues failed to find differences in these complication rates between those with dry eye and those without dry eye before LASIK. Bashour also failed to find an association between Schirmer test readings before surgery and epithelial defects during surgery.

Factors Adversely Affecting the Ocular Surface and Tear Film Before LASIK

Contact Lens Wear—Contact lens wear before LASIK can reduce the predictability of refractive surgical outcome by inducing corneal warpage, and altering tear proteins, ocular surface morphology, corneal physiology, barrier function, pachymetry, and sensation. These factors may increase the potential for complications during and after refractive surgery. No significant differences were found in epithelial healing or regression after PRK between contact lens wearers and non-contact lens wearers.

However, in LASIK studies, tear secretion and corneal sensitivity before and 6 months after LASIK were significantly more depressed in long-term contact lens wearers, compared to non-contact lens wearers. A significant reduction in corneal and conjunctival sensation, both before surgery, compared to normal values, and after LASIK for at least 16 months, was reported in a study involving 48 myopic LASIK patients, 40 of whom were long-term contact lens wearers. This group also had significant reduction in tear clearance and elevated ocular irritation scores for at least 16 months after LASIK, compared to values recorded before surgery. In addition, long-term contact lens wear is often associated with corneal micropannus. Hemorrhaging from peripheral corneal vascularization during the microkeratome pass has been implicated in causing diffuse lamellar keratitis.

The currently available evidence indicates that before LASIK is performed, contact lens wear should be ceased. Patients should not undergo LASIK until corneal topography is stabilized, ocular surface, corneal sensation and tear film are relatively normal, and any micropannus has resolved. A history of contact lens intolerance can serve as a red flag for the potential exacerbation of dry eye problems after LASIK.

Eyelid Disease—Anterior blepharitis and meibomian gland dysfunction must be managed before LASIK to minimize the risk of complications after surgery. Staphylococcus aureus has been isolated in appreciable frequency from patients with anterior blepharitis and was reported to be the most prevalent causative micro-organism for microbial keratitis after LASIK. Management of meibomian gland disease is necessary as meibomian secretions have been implicated in causing interface debris, sterile infiltrates, and diffuse lamellar keratitis.

Ocular Allergy—Ocular allergy has the potential to impact on surgical outcomes due to increased incidence of toxicity reactions to medications and their preservatives. There is increased potential for problems with suction, as the conjunctiva in allergic patients could become more easily irritated in response to mechanical stimuli. Increased mucous in the tear film may lodge in the microkeratome gears and cause incomplete flaps. Also, there is potential for inflammation after surgery due to increased levels of cytokines and chemical mediators released from the inflamed conjunctival and subconjunctival tissues. However, a comparison of LASIK patients with (n = 49) and without (n = 77) a history of allergic conjunctivitis failed to find any significant differences between the groups in terms of uncorrected visual acuity after surgery or risk for complications during LASIK.

Herpetic Keratitis—Patients with a history of actual or suspected herpetic keratitis are best advised not to have elective refractive surgery. In a rabbit latency model, LASIK and surface excimer laser ablation acted as triggers for the reactivation of herpes simplex virus type-1. Other strains of the virus may be reactivated by anti-inflammatory agents used after surgery. The virus can also reactivate after LASIK following penetrating keratoplasty for herpes simplex. In addition, the cornea after herpes may be desensitized and therefore prone to healing anomalies and poor laceration.

Epithelial Basement Membrane Degeneration—Patients with epithelial basement membrane disorders before surgery have an increased risk of incurring epithelial defects during and after LASIK. Dastgheib and colleagues reported epithelial sloughing in 13 of 16 eyes (81%) with epithelial basement membrane degeneration before surgery and sloughing that LASIK should not be performed in eyes with the condition due to the increased risk of epithelial ingrowth and loss of best spectacle-corrected visual acuity. Given that epithelial basement membrane degeneration occurs in 5% of the population, potential LASIK candidates should be questioned before surgery with regard to
symptoms of recurrent erosion and the cornea examined (preferably with fluorescein staining and the dilated pupil as a background) to screen for the condition. Provocative testing of the corneal epithelium with a microspunge applicator has been recommended in patients with suspected loose epithelium. For patients with epithelial basement membrane degeneration, PRK appears to be a more suitable refractive procedure, particularly as PRK combined with phototherapeutic keratectomy (PTK) has been a successful treatment for both myopia and recalcitrant corneal erosions.

**Lid-related Anomalies**—Several disorders of lid aperture, lid/globe congruity, and blinking can pose a problem for the LASIK surgeon and must be recognized and managed before LASIK can be considered. Conjunctivochalasis can interfere with LASIK as the redundant conjunctiva can adversely affect suction and/or jam the microkeratome gears. Large fleshy pterygia also present a challenge as they can induce astigmatism, alter corneal curvature, and may jam the microkeratome gears. Active pterygia can continue to invade the cornea after LASIK. Conditions such as exophthalmos, lagophthalmos, and incomplete blinking have been implicated in causing flap wrinkles, folds, and displacement in the immediate period after surgery. Epiblepharon can be a feature of Asian eyelids and, in severe cases, is associated with trichiasis and corneal punctate epithelial erosions. Contact lens wear will mask the effects of the epiblepharon and these patients may need to consider eyelid surgery to correct the epiblepharon before LASIK, if significant trichiasis and punctate erosions are present.

**Age, Gender, and Medical Conditions**—Older age is one of a number of risk factors for epithelial defects during surgery (odds ratio 2.39/decade or six times greater in those patients over 40 years of age). This has been attributed to both decreased epithelial adhesion and increased friction from drier eyes in the older patients. Epithelial defects have been found to be 10 times more prevalent in patients with fairer skin types.

In terms of gender, there is some evidence to suggest that females may have inferior outcomes after LASIK compared to males. Compared to males, females have shown an increased risk of developing chronic dry eye symptoms and refractive regression after hyperopic LASIK corrections. Similarly, postmenopausal females on hormone replacement therapy have had significantly inferior refractive outcomes after PRK compared to age-matched controls. Although further research is required, clinical experience suggests that the hormonal changes (particularly the reduction in androgen levels) experienced by older females contribute to the dry eye symptoms, abnormal healing, and less than optimal LASIK results observed in this demographic group. Based on the evidence available, older patients, particularly older females, should be advised of the increased probability of experiencing less than optimal outcomes with LASIK. Alternative forms of refractive correction with fewer adverse effects on the ocular surface (e.g., clear lens replacement) should be discussed with the patient.

In terms of medical conditions, patients with diabetes require particular attention. Diabetes has been associated with reductions in tear quality, tear volume, epithelial corneal epithelial health, goblet cell density, and corneal sensation. A recent study indicated that, compared to age and gender-matched controls, patients with diabetes experienced a significantly higher rate of complications after LASIK (47% compared to 7%). This suggests that patients with diabetes should have a comprehensive evaluation of the tear film and ocular surface before surgery and alternative refractive options should be considered.

**Practical Considerations Before LASIK**

Given the aforementioned evidence, routine evaluation of the ocular surface and tear film before LASIK is essential. Anomalies detected during evaluation before surgery should be treated before LASIK is undertaken. LASIK is contraindicated if treatment is unable to control ocular irritation, and restore tear film, corneal surface health, and corneal sensation. Alternate forms of refractive surgery, such as PRK or laser epithelial keratomileusis (LASEK), or an intraocular procedure may be more appropriate for some patients. Compared to LASIK, PRK may cause less severe and fewer sustained adverse effects on dry eye symptoms, tear function, ocular surface health, and corneal sensation for equivalent ablation depths.

If LASIK is deemed to be an appropriate surgical option for the patient, the risks should be clearly explained in the informed consent process. In terms of the ocular surface and tear film, the following risks should be noted: 1) Dry eye symptoms are common in the first few months after LASIK. In most cases, LASIK-induced dry eye is a short-term condition that can usually be managed with artificial tears. 2) LASIK may cause chronic dry eye or exacerbate pre-existing dry eye conditions. Pre-existing dry eye is a risk factor for severe dry eye after
surgery. As noted by the U.S. Food and Drug Administration (www.fda.gov/cdrh/lasik/risks.htm), candidates for LASIK should be aware that there is a risk of developing severe dry eye syndrome. 3) If severe and/or chronic ocular surface and tear film disorders occur after LASIK, enhancement surgery may not be possible. If enhancement surgery cannot be performed, contact lenses may not be able to be worn comfortably and/or safely after LASIK. 4) To optimize LASIK outcomes and accelerate recovery of the ocular surface and tear film after surgery, long-term management of the ocular surface and tear film may be required.

**ocular surface and tear film during lasik**

For the purpose of this review, during surgery encompasses both the preparation before surgery on the day of surgery and the surgical period itself. Management of the ocular surface and tear film during the immediate period after surgery is discussed as part of the next section of this review (see After LASIK section).

**Use of Topical Anesthetics**

Excessive and/or repeated dosing of anesthetic can be toxic to the corneal epithelium and stromal keratocytes. Overuse of topical anesthetic can result in epithelial toxicity, epithelial defects, diffuse lamellar keratitis, and epithelial ingrowth. Topical anesthetic should be used just before surgery to minimize epithelial damage during surgery.

**Flap Reference Marking**

Gentian violet dye used for flap reference marking is toxic to the corneal epithelium and stroma and has been implicated in causing diffuse lamellar keratitis. However, there is no direct evidence to support this. An alternative approach is to imprint the axis marker on the ocular surface without dye. This method leaves an indentation mark for at least 30 minutes, which can adequately facilitate correct flap alignment.

**Management of Ocular Surface Epithelia During the Flap Cut, Stromal Ablation, and Flap Reposition**

Corneal epithelial defects during LASIK affect up to 5% to 10% of patients. Damage to the corneal epithelium must be minimized as trauma can result in stromal swelling and failure of flap adhesion, epithelial ingrowth, recurrent corneal erosions, diffuse lamellar keratitis, infection, flap distortion, flap keratolysis, corneal scarring, epithelial hyperplasia, and loss of spectacle-corrected visual acuity. Johnson and colleagues reported that the risk of developing diffuse lamellar keratitis increased 13-fold if epithelial defects occurred.

The amount of ocular surface trauma encountered during the LASIK procedure can be reduced through the use of appropriate lubricants and by minimizing physical interference with the ocular surface. A combination of balanced salt solution and carboxymethyl cellulose (Celluvise, Allergan, Irvine, CA) has a lower coefficient of friction compared to the dry plate or balanced salt solution alone and, when used during surgery, reduces trauma. Recently, in a retrospective, non-randomized comparative study, 116 eyes received non-preserved carboxymethyl cellulose 0.5% prior to the LASIK flap cut and a combination of carboxymethyl cellulose and balanced salt solution during the flap cut; 72 eyes received no lubrication during surgery. The group that received lubrication during surgery had a significantly lower incidence of epithelial defects (3% vs. 13%).

In terms of microkeratome technique, releasing suction after the forward pass and sliding the microkeratome off the eye without activating the back pass reduces the risk of epithelial defects. Finally, although it may seem self-evident, trauma to the ocular surface during LASIK can be reduced by simply minimizing physical interference with the ocular surface. Excessive manipulation, wiping, scraping, and dehydration of the flap and ocular surface epithelia during surgery can increase trauma and epithelial sloughing during surgery.

When epithelial defects occur, bandage contact lenses have been recommended to improve patient comfort, prevent further flap damage, and facilitate flap adhesion.

Epithelialization of large defects may be retarded by the sensory denervation of the flap cut. Although still at the investigative stage, 20% solcoseryl eye gel and topical antioxidants appear to promote corneal epithelial healing and improve flap anomalies after LASIK.

**Ocular Surface and Tear Film After LASIK**

In this section, changes that occur to the ocular surface and tear film after LASIK are described. Mechanisms underlying these changes are then examined. Together, this information provides a rational basis for presenting recommendations on how to best manage the ocular surface and tear film after LASIK. For the purposes of this review, after LASIK includes the immediate period after surgery and the ongoing management of the LASIK patient.
# Table 2
### Reports (Reference Numbers) of Changes in Tear Film and Ocular Surface Parameters Before and After LASIK for Myopia

<table>
<thead>
<tr>
<th>Time After LASIK</th>
<th>1 to 2 wks</th>
<th>1 mo</th>
<th>3 mo</th>
<th>6 mo</th>
<th>12 mo</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tear secretion</td>
<td>= 6</td>
<td>▼ 9</td>
<td>▼ 6, 7, 9, 38</td>
<td>▼ 10, 38</td>
<td>▼ 10, 38</td>
<td>▼ 7</td>
</tr>
<tr>
<td>Tear volume</td>
<td>▼ 17</td>
<td>▼ 17</td>
<td>▼ 8, 17</td>
<td>= 17</td>
<td>= 17</td>
<td>8: Comparison was to control group (rather than values before surgery)</td>
</tr>
<tr>
<td>Tear osmolarity</td>
<td></td>
<td></td>
<td>▲ 10</td>
<td>▲ 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tear clearance</td>
<td>▼ 6</td>
<td>▼ 6, 7</td>
<td>= 7</td>
<td>▼ 6</td>
<td>▼ 7</td>
<td>▼ 7</td>
</tr>
<tr>
<td>Tear stability</td>
<td>▼ 9, 17</td>
<td>▲ 17</td>
<td>▼ 7, 10, 17</td>
<td>= 7, 17</td>
<td>= 17</td>
<td>▼ 10</td>
</tr>
<tr>
<td>Ocular surface staining</td>
<td>▲ 6, 17</td>
<td>= 6</td>
<td>▼ 17</td>
<td>= 17</td>
<td>= 17</td>
<td>= 6, 17</td>
</tr>
<tr>
<td>Blink rate</td>
<td>= 7</td>
<td>▼ 7</td>
<td>▼ 7</td>
<td>▼ 7</td>
<td></td>
<td></td>
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<td>Meibomian gland/ lipid layer anomalies</td>
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<td>= 17</td>
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<tr>
<td>Goblet cell density</td>
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<td>▼ 17</td>
<td>▼ 17</td>
<td>= 17</td>
<td>= 17</td>
<td></td>
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<tr>
<td>Corneal epithelial permeability</td>
<td>▲ 64</td>
<td>▲ 64</td>
<td>▼ 64</td>
<td>▼ 64</td>
<td>▼ 64</td>
<td>▼ 64</td>
</tr>
<tr>
<td>Corneal sensation</td>
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<td>▼ 6, 38, 52, 63</td>
<td>▼ 38, 52, 53, 63</td>
<td>▼ 6, 63</td>
<td>▼ 6</td>
<td>▼ 6, ▼ 6, ▼ 6</td>
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<tr>
<td>Conjunctival sensation</td>
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<td>▼ 6</td>
<td>▼ 6</td>
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<td>▼ 6</td>
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<tr>
<td>Topographic corneal surface irregularity</td>
<td>▲ 6</td>
<td>▲ 6</td>
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*Note: As discussed in the text, the characteristics of the patient population can impact on signs of tear film and ocular surface dysfunction after surgery. Differences between studies may be due to differences in study methodology or to differences in the characteristics of the patient population studied.*
Symptoms of LASIK-induced Dry Eye

Symptoms of ocular surface irritation are prevalent in patients after LASIK. In a study of 450 patients undergoing LASIK, reporting of dry eye symptoms increased from 38% before LASIK to 69% at 2 weeks after LASIK. In a smaller study (58 patients, 96 consecutive eyes), dry eye symptoms increased from 15% before LASIK to 85% at 1 week after LASIK and 59% at 1 month after LASIK. Battat and colleagues reported that ocular irritation symptom severity scores were significantly elevated in 40 patients at 1 week, 1 month, and 12 and 16 months after LASIK compared to scores before LASIK. Similarly, Toda and colleagues reported that subjective scores for dryness were significantly increased at 1 and 3 months and 1 year after LASIK.

Signs of LASIK-induced Dry Eye

Numerous studies have identified changes in the ocular surface and tear film after LASIK for myopia (Table 2). Although these studies have differed in study design, sample size, and methods of measurement for particular signs of dysfunction, there does appear to be some consensus about changes that occur after LASIK. There is strong and relatively consistent evidence showing that myopic LASIK causes punctate epitheliopathy, elevated tear osmolality, and decreases in tear secretion, tear volume, tear clearance, tear film stability, goblet cell density, and blink rate. The evidence is less consistent, however, in terms of when these clinical signs dissipate.

Mechanisms of LASIK-induced Dry Eye

Surgical Trauma to the Ocular Surface—All ocular surgical procedures disrupt the ocular surface and tear film. Trauma to the ocular surface that occurs during LASIK has been proposed as a cause of tear film instability, punctate epitheliopathy, and recurrent corneal erosions after LASIK. Trauma from the suction ring could be a contributing factor to the loss of perilimbal conjunctival goblet cells after LASIK. The shearing forces of the traversing microkeratome and excessive drying and wiping of the ocular surface during surgery could damage the microvilli of the superficial epithelium.

Ocular Surface Sensory Denervation—LASIK disrupts the normal organization of corneal innervation and induces a corneal anesthesia or hyposthesia, lasting up to 6 months. However, in patients with dry eye before LASIK, patients who have worn contact lenses long-term before surgery, or patients who have superior hinged flaps or deeper ablations, the return of corneal sensation to levels observed before surgery appears to take longer than 6 months and is associated with more persistent dry eye signs and symptoms. Another study reports that corneal sensation after LASIK recovers within 6 months and that nasally hinged flaps were associated with a significantly greater decrease in corneal sensation than superior hinged flaps. Measurement of corneal sensation in clinical studies following LASIK generally involves use of the Cochet-Bonnet esthesiometer, which can be open to subjective bias; more work is required in this area to standardize the methodology, including masking techniques and use of non-contact methods of esthesiometry.

Investigative studies have suggested this loss of sensory denervation is one of the leading causes of tear film anomalies and punctate epitheliopathy after LASIK. In non-LASIK studies, reduced corneal and conjunctival sensitivity results in reduced tear secretion, tear clearance, goblet cell density, and blink frequency, as well as increased tear osmolarity and ocular surface staining. All of these anomalies are features of the eye after LASIK and support neurotrophic mechanisms as a main cause of dry eye after LASIK.

As sensory denervation can mask symptoms of ocular surface irritation, patients who have LASIK-induced tear film and ocular surface problems may only become aware of symptoms as the damaged nerves regenerate. This temporal feature of sensory denervation makes it difficult to correlate symptoms and signs after LASIK.

Inflammation—The inflammatory changes observed after LASIK may contribute to chronic dry eye symptoms and signs after LASIK. Reduction in tear secretion and tear clearance in eyes after LASIK have been proposed to cause an increase in the concentration of pro-inflammatory cytokines and matrix degrading enzymes in the tear film. This could stimulate upregulation of other inflammatory mediators, leading to further inflammation and damage to the ocular surface. Increased cytokine levels in the tear film may exacerbate the LASIK-induced corneal nerve damage, thus further decreasing corneal sensation and further impairing lacrimal gland function. These theories are yet to be verified in experimental studies.

Alterations to Surface Topography and Corneal Curvature—A number of studies have linked changes in corneal profile after LASIK to symptoms and signs of dry eye. Irregularities within the interface, together with the gutter of the flap and the
irregular shape of the cornea after LASIK, have the potential to alter the normal relationship between the lids and the corneal surface and, hence, change the spreading of the tear film across the ocular surface. A reduction in the spread of tears during blinking could create areas of non-wetting or stagnation of tears. This could result in increased tear evaporation and areas of ocular surface desiccation.\textsuperscript{9,10,14,75}

Type of Correction, Characteristics of the Flap, and Ablation Profile—Evidence suggests that tear film and ocular surface problems and dry eye symptoms after LASIK may be affected by the type of correction performed, the characteristics of the flap, and the ablation profile. LASIK for hyperopia appears to induce more severe and more sustained dry eye symptoms and greater adverse effects on the ocular surface and tear film, compared to LASIK for myopia.\textsuperscript{3,14,17} This may reflect greater corneal sensory denervation effects with hyperopic LASIK due to the larger flap and mid-peripheral ablation. Also, an increased number of older patients, who are more likely to experience dry eye, have hyperopic LASIK.

**MANAGEMENT OF THE OCULAR SURFACE AND TEAR FILM AFTER LASIK**

Artificial tears are a critical component of the ocular surface and tear film management strategy after LASIK. Carboxymethyl cellulose-based, hydroxypropyl methylcellulose-based, and sodium hyaluronate-based artificial tears have been recommended to protect and regenerate the ocular surface and tear film.\textsuperscript{3,17,20,21,75,76} Some researchers recommend that artificial tears be used beyond the immediate period after surgery, for at least 1 month after LASIK, if not longer.\textsuperscript{7,17,22,28,75} Evidence shows that the signs of ocular surface and lacrimal gland dysfunction can last for up to 12 months after LASIK, and hence provide a rational basis for using artificial tears as a long-term management strategy.

Use of punctal plugs, both before and after LASIK, is a suitable technique for managing dry eye after LASIK when tear supplements alone are insufficient.\textsuperscript{2,3,17} Punctal occlusion can significantly improve ocular surface staining and tear secretion and reduce dependence on artificial lubricants.\textsuperscript{77} Punctal plugging will only be effective if tear deficiency is present, the punctal opening opposes the globe, and any inflammatory lid disease has been treated. Punctal occlusion in non-tear deficient eyes is contraindicated as it can decrease tear production, tear clearance, and ocular surface sensation.\textsuperscript{78}

Management of the ocular surface and tear film can be optimized by enhancing the immediate environment after surgery. To minimize drying of the ocular surface and reduce the risk of flap folds, wrinkles, and dislodgment, patients should not be situated in a low humidity environment. If this cannot be avoided in the immediate period after surgery, use of a moisture chamber, as well as lid taping or bandage contact lenses, have been proposed.\textsuperscript{20,21}

**DIRECTIONS FOR FUTURE RESEARCH**

The following areas deserve further research attention with regard to the management of the tear film and ocular surface in LASIK.

1) Prevalence Studies—Controlled prospective prevalence studies are needed to define the magnitude, severity, and duration of the postoperative LASIK dry eye phenomenon.

2) Screening Methods and Patient Profiling—Research is needed to identify which patients are at greatest risk of developing severe and/or chronic forms of dry eye following LASIK. Further evaluation is required of the effect of contact lens wear and pre-existing ocular surface and tear film disorders on the development of chronic dry eye after LASIK and the effectiveness of various pre-treatment strategies in minimizing the incidence and duration of chronic ocular surface and tear film dysfunction after LASIK.

3) Mechanistic Studies—Research is required to determine the relative contribution of the mechanisms proposed for chronic LASIK-induced dry eye.

4) Surgical and Management Strategies—Studies are required to investigate which surgical techniques (e.g., flap size, hinge size and orientation, lubricants during and after surgery) minimize damage to the ocular surface and tear film. Agents/strategies to promote rapid epithelialization of intraoperative epithelial defects require further investigation.

5) Comparison of LASEK vs. PRK vs. LASIK—Comparative studies are required to examine the impact of each type of surgery on the integrated ocular surface/lacrimal gland functional unit and to identify which patients would be best suited to each technique.

6) Wavefront-guided LASIK—The effects of tear film and ocular surface disorders on wavefront aberrations warrant further investigation.\textsuperscript{79}

7) Novel Treatment Agents—The role of topical cyclosporine A\textsuperscript{80} and topical nerve growth factor\textsuperscript{81} warrant further attention given their potential role.
in the prevention and/or management of chronic and/or severe dry eye after LASIK.

SUMMARY

This review has identified evidence-based management strategies that should improve current management of the ocular surface and tear film before, during, and after LASIK. Additional research is required to identify areas where management can and should be improved. Evidence-based management strategies are the key to ensuring that patients who elect to have LASIK are managed in the best possible way.

REFERENCES

Ocular Surface and Tear Film Before, During, and After LASIK/Albietz and Lenton


74. Mathers WD. Why the eye becomes dry: a cornea and lacrimal gland feedback model. CLAO J 2000;26:159-165.
