Chapter

When LASIK Goes Wrong or LASIK Complications Dilemmas

Fanka Gilevska, Maja Bohač, Smiljka Popović Suić
and Mateja Jagić

Abstract

Laser in situ keratomileusis (LASIK) is one of the most commonly performed refractive surgical procedures. During the last two decades, surgical procedure has evolved, but still, there are several intraoperative and postoperative complications possible. Every young LASIK surgeon spends most of the reading time on LASIK complications. They are not frequent, but you have to know precisely what to do when they happen. This chapter should be a guide, based on literature and experience, on how to deal with intraoperative, early postoperative, and late postoperative complications. This chapter will include managing irregular flaps, buttonholes, and free flaps. The treatment scheme for DLK, epithelial ingrowth, and PISK, and when is the time for flap re-lifting. How frequent should be patients' visits not to miss the complication on time? When is the right time for LASIK reoperation? Post LASIK corneal ectasia and how to perform cross-linking over LASIK. Young surgeons need precise guidelines, not just theoretical treatment options to achieve optimal visual outcomes after LASIK procedure.

Keywords: LASIK, complication, DLK, PISK, epithelial ingrowth, ectasia

1. Introduction

Refractive surgery has made great strides over the last two decades. Technological advances have not only been made at the level of keratorefractive surgery, but also in cataract surgery-the introduction of femtosecond lasers, small incision surgery, and presbyopia-correcting IOLs. LASIK is currently the most commonly performed surgical procedure in refractive surgery. Nowadays, postoperative visual acuity less than 20/20 after refractive surgery has become unacceptable given the growing patients' demands for perfect vision and the fact that the vast majority of patients have 20/20 vision achieved with spectacle or contact lens correction preoperatively. Complications in keratorefractive surgery are extremely rare, and serious side effects occur in less than 0.4% of cases. This chapter will present an overview of all known complications of the LASIK keratorefractive procedure with a recommendation for their management.

2. LASIK complications

2.1 Preoperative complications

2.1.1 Anesthesia

Corneal refractive procedures are performed with topical anesthetic drops (0.5% propacaine, 0.5% tetracaine, and 0.4% oxybuprocaine). Preoperative cleaning of the operative region consists of application of Iodine 5% in the conjunctival fornices for 15 seconds. Both the anesthetic and the iodine may cause epithelial weakening, punctate erosions, or irregular corneal surface. (238) Care about the amount of anesthetic and Iodine used prior to the procedure is essential for the protection of the epithelium. Use of viscous artificial tears during the procedure may interfere with the work of microkeratome and should be avoided [1].

2.1.2 Eyelashes, foil, speculum

Securing the operative surface with transparent adhesive foil over the eyelashes, selection of the appropriate speculum providing enough space for the microkeratome, and choice of the proper microkeratome for the given eye anatomy is very important in creating regular flaps [1].

2.1.3 Conjunctiva

Adequate examination of the whole anterior segment, conjunctiva, limbal region, and fornices is very important precondition for successful surgery. Irregularities in the limbal region, scleral elevations, nevus, and tumor prominence in the region of conjunctiva, limbus, or fornices may cause irregular vacuum suction, pseudosuction, and potential vacuum loss which may result in irregular flap due to improper lamellar incision [1].

2.2 Intraoperative complications

2.2.1 Microkeratome-related complications

Automated microkeratome creates a precise cut on the cornea which represents the flap. It consists of an oscillation blade attached to a head and both work with independent motors (one for the oscillation of the blade, other for the movement forward and backward). The surgeon chooses adequate rings for the different diameters and steepness of the cornea, the thickness of the flap (from 90 to 120 microns), hinge position, and its diameter [2].

2.2.1.1 Incomplete or irregular corneal flap

The incidence of incomplete flap is 0.3–1.2% [3]. Incomplete flap occurs when the microkeratome is stopped before the planned hinge position. Stopping of microkeratome most often occurs due to collisions with eyelids and eyelashes, speculum and/or foil, and due to suction (vacuum) loss during passage. The cause can also be of a mechanical nature-a defect in the dissection head (knife) or in the motor unit of the microkeratome [1, 4, 5]. Irregular flaps often result in lack of enough space for laser

ablation, also they carry the risk of profound epithelial ingrowth which can result in corneal scarring in the visual axis or even flap melting.

What shall we do?

Every irregular flap has its own irregular bed underneath. If we leave the flap untouched, smooth healing will result and best corrected visual acuity achieved. If we ablate the bed under the irregular flap, then we create an inadequate match for the flap, and it can result in higher order aberrations and loss of best corrected visual acuity. Flap which has only peripheral irregularities, with a diameter larger than intended ablation area (OZ), procedure can be continued with careful flap reposition, and BSCL is case with epithelial defects.

In a highly irregular and thin flap (usually created by a lamellar cut at or above the Bowman's layer) with an inadequate stromal bed, Bowman membrane remains in the central zone or larger in diameter, the procedure is aborted, and re-treatment is postponed for 3–6 months with setting larger and deeper flap cut then initial [1, 4]. When Bowman membrane remains out of the central zone and is small in diameter, treatment can be continued with additional antimetabolite application (Mytomycine C) for 15 s to prevent the epithelial ingrowth. Surface procedures (PRK) after LASIK can increase the risk for corneal haze formation, but in cases where irregular flap is small, and hinge is positioned in ablation area (OZ), LASIK procedure needs to be aborted and surface ablation is preferred retreatment procedure within 3 months [3].

2.2.1.2 Perforated (buttonhole) flap

The incidence of perforated flap (buttonhole) is 0.1−0.6%, and for too thin flap 0.1−0.4% [6]. Flap perforation occurs when the blade of the microkeratome enters the corneal surface-Bowman membrane and epithelium during the passage, usually in the central part of the flap (**Figure 1**). Too thin flaps occur when the blade of the dissection head does not penetrate deep enough into the cornea but stays close to the surface. Perforated flaps are more common in steep corneas (>46.0 D), and inadequately
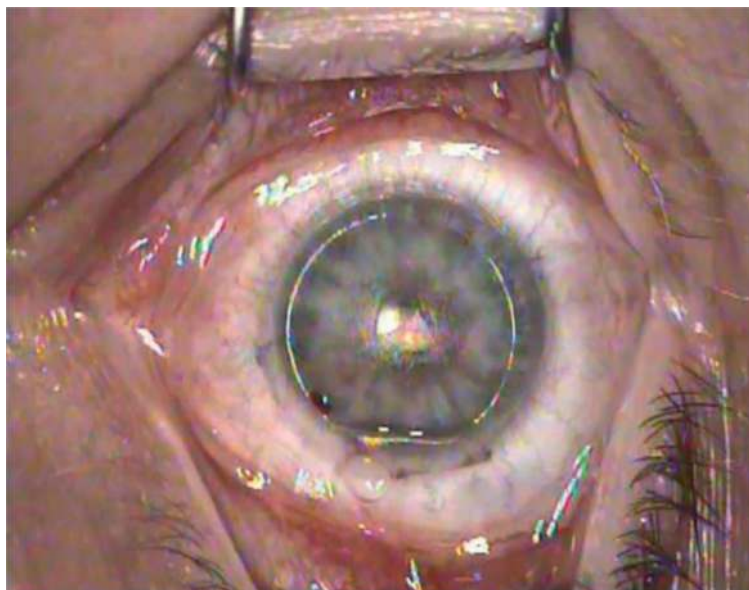
Figure 1.
Intraoperative finding in case of buttonhole flap. Visible central area of Bowmann membrane remains after the flap lift.
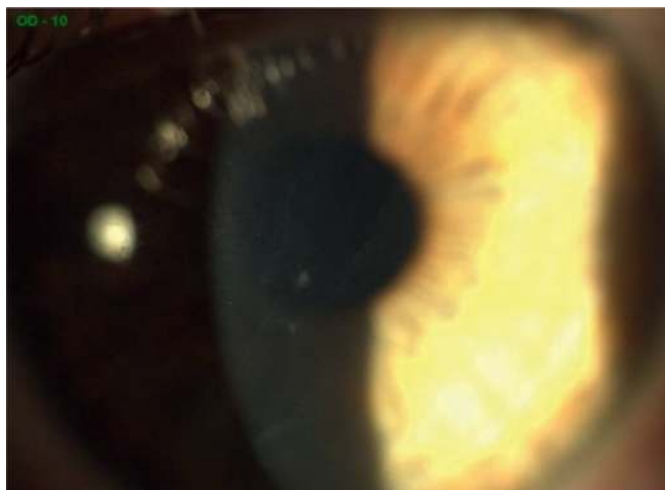
Figure 2.
Post operative finding after reponed flap. In this case procedure was aborted - flap was reposition.

achieved vacuum that causes poor adhesion of the cornea and microkeratome blade, also in flat and small corneas where corneal suction puts cutting plane below the blade [7, 8]. It can also be mechanical in nature due to uneven cutting speed in manual microkeratome, blunt blades, weak blade oscillations, and due to mechanical damage to the blade of the microkeratome dissection head. Perforated flaps are one with the worst visual outcome compared to other intraoperative complications, usually resulting in irregular astigmatism and epithelial ingrowth [1, 7, 8].

What shall we do?

When procedure results in a perforated flap, procedure is aborted, and retreatment is planned after minimum of 3 months, preferably surface ablation (**Figure 2**). In case of LASIK retreatment, a flap with larger diameter and greater thickness should be set [3, 6, 9].

2.2.1.3 Free flap (free cap)

The incidence of free flaps is 0.1–1.0%. The size of the flap depends on the volume of the cornea protruding above the vacuum ring. In the case of protrusion of a small amount of tissue, a free flap is formed. Free flaps are more common in flat corneas with keratometric values <41.0 D, in an insufficient vacuum, when selecting a too small vacuum ring, or in inadequately adjusted microkeratome stoppers [1].

What shall we do?

Adequate cap repositioning on the stromal bed, air dried for at least 3–4 minutes and bandage contact lens placed over for the next few days is crucial for the best visual outcomes. The patient should stay in hospital and be rechecked within 1–2 hours for flap position and its adherence to stromal bed. Dislodging or flap folds that may result from strong eyelid pressure should be treated immediately [1]. In case of excessively edematous flap that tends to dislocate, 10-0 nylon sutures should be used [4]. In case of intraoperative flap loss, procedure is aborted, and after epithelization, refractive error (usually hyperopic shift) can be managed with contact lens or flap reconstruction [10].

2.2.1.4 Corneal perforation

Penetration into the anterior chamber, that is, entry into the anterior chamber with full corneal thickness, may occur during lamellar dissection or even excimer laser photoablation. Perforations can range from simple corneal perforations to perforations with iris and lens damage with or without loss of vitreous. Perforation can occur on extremely thin corneas, in old corneal scars, ulcers, or after previous refractive surgery [1, 11]. Cases with corneal perforation usually have poor visual outcomes due to scar formation and recurrent epithelial ingrowth in perforated plane [12].

What shall we do?

If corneal perforation occurs during flap creation, suction should be immediately stopped. Larger perforation requires surgical repair with suturing under sterile conditions, while small perforations can be managed by flap repositioning and BSCL.

2.2.1.5 Decentered flap

Thin and irregularly decentered flaps can occur during flap formation with both microkeratome or femtosecond laser. The causes are multifactorial and include poor positioning (centering) of the vacuum ring, too low achieved vacuum on the cornea, poor corneal lubrication, poor quality of the blade, pre-existing corneal pathology or microkeratome malfunction [13].

What shall we do?

Since there is likely an unexpected visual outcome after performing centered ablation in a case of decentered flap, it is advised to abort the procedure.

2.2.2 Femtosecond-related complications

The femtosecond laser is a solid-state Nd: Glass laser that works near the infrared spectrum at a wavelength of 1053 nm and produces ultrashort pulses lasting 10−15 s. The laser is based on the principle of nonlinear absorption (corneal tissue is transparent to infrared laser radiation of moderate intensity and without absorption) and the principle of photoionization (laser-induced optical break), which leads to photodisruption. Small tissue volumes are vaporized with the formation of cavitation gas bubbles that gradually disperse into the surrounding tissue and consist of carbon dioxide and water [14–16]. Flap formation is today the most common application of femtosecond lasers, where during clinical practice the superiority of femtosecond lasers over mechanical microkeratomes is slowly indicated in terms of reducing the incidence of intraoperative complications and the ability to personalize switch parameters (diameter, thickness, lateral incision, and hinge) [15, 16].

2.2.2.1 Opaque bubble layer (OBL)

The formation of cavitation bubbles in the lamella between the flap and the stroma, which are directed to the peripheral specially designed pockets, is a standard process of flap formation. In the case of their passage into the deeper stromal layers, or even into the anterior chamber, their confluence occurs, and an opaque layer is formed which interferes with the excimer laser eye tracking system and takes up to several hours to resorb. The penetration of the bubbles into the anterior chamber

occurs due to the migration of cavitation bubbles through the 14 piscleral, schlemm canal, and trabecular meshwork into the anterior chamber [17]. Risk factors are thick cornea, small flap diameter, hard docking technique, and low laser frequency or energy [18, 19]. This complication has become very rare since the reduced vacuum pressure on the eye, reduced energy, and increased speed of femtosecond lasers [17, 20–22]. Higher order aberration (HOA) induction, especially trefoil, was reported in cases with OBL [23, 24].

What shall we do?

The presence of OBL suggests flap adhesion so it is advised to perform flap dissection carefully. In case of OBL persistence after flap lift, it will temporarily preclude pupillary tracking for excimer laser ablation. Therefore, waiting for a few minutes and allowing it to disappear is advised. When smaller cavitation bubbles appear in AC, excimer laser treatment can be performed by disabling automatic pupil tracking and proceeding the treatment with manual tracking. Prophylaxis: Setting a larger flap diameter flap and preferring the soft docking technique can reduce the risk of OBL occurrence [18, 19].

2.2.2.2 Vertical gas breakthrough (VBG)

Vertical gas breakthrough (VGB) occurs in the presence of corneal scar or abnormality in the Bowman's layer when the gas dissects vertically towards the stroma or epithelium [25]. When cavitation bubbles penetrate the corneal subepithelial space incomplete flaps or even buttonhole flaps may form while breaching the epithelial layer results in epithelial defect. Bubbles can also penetrate the space between the cornea and the *applanation* lens, preventing laser-treating the cornea. This leads to the formation of tissue bridges and makes it difficult or sometimes impossible to separate the flap from the adjacent stroma. Incidence of VGB is 0.03−0.13% according to the literature [25, 26].

What shall we do?

When the VGB appears, the femtosecond laser treatment should be continued to avoid a partial flap. After assessing the position of the VGB within the flap, further actions are considered: *when* VGB is affecting the visual axis or ahead of the advancing edge of the flap, the flap should not be lifted, and surgery should be aborted [26].

2.2.3 Photoablation-related (excimer laser ablation related) complications

2.2.3.1 Decentered ablation

Centered (over the pupil zone) ablation is crucial for optimal visual outcome, so every deviation in ablation position compromises the visual outcome [4]. Decentration of the ablation zone can occur due to the movement of the laser beam before the excimer laser ablation itself and due to the eye movement during the excimer laser ablation [27].

Decentration is more common in the correction of larger refractive errors (longer excimer laser ablation allows more eye movements), and in patients with poor uncorrected visual acuity who fix the target point even worse due to additional image blur due to corneal dehydration.

During surgery, the decentralized ablation zone may go unnoticed and result in irregular astigmatism and consequent poor visual acuity, dysphotopsia (glare, halo),
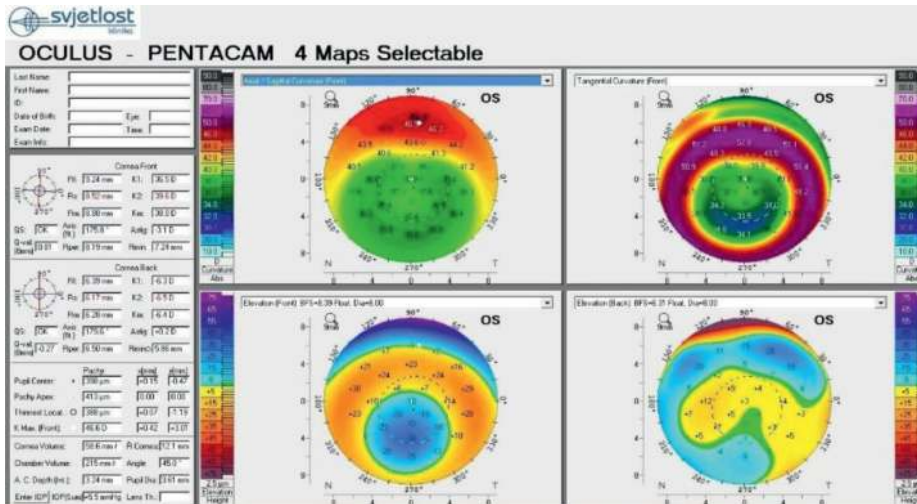
Figure 3.
Decentered ablation after myopic excimer profile.

and monocular diplopia. Usually, it can be presented as asymmetric corneal contour in topography (one side steepening, other side flattening) (**Figure 3**). Decentration can be graded as mild (0−0.5 mm), moderate (0.5−1.0 mm) and severe (>1.0 mm). The magnitude of symptomatic decentration and consequent vision problems varies from patient to patient [1, 27, 28].

What shall we do?

When highly decentered ablation is noticed, with large amount of HOA induction, temporarily miotics can reduce dysphotopsia. After 3 months, customized ablation profiles should be used for retreatment: wavefront- or topo-guided PRK or LASIK procedure [29].

2.2.3.2 Central island

Central islands are diagnosed by corneal topography and are defined as central steep areas of unablated cornea within the treatment zone, defined by their size and keratometric power (>2 mm and > 3D) (**Figure 4**). According to the literature, central island can be considered in every steep corneal zone that affects visual acuity and induces visual disturbances [4, 30]. Central islands are extremely rare in flying spot lasers and can be caused by excimer laser factors (gas dynamics, acoustic corneal shock waves made by laser beams, temporal degradation of laser optics), factors affecting uniform excimer laser delivery like fluid accumulation in the central corneal zone (uneven corneal hydration), and by corneal healing [31]. Central islands cause irregular astigmatism, dysphotopsia (halo, glare, ghost images), loss of best corrected visual acuity, decrease in contrast sensitivity, and monocular diplopia [1, 32].

What shall we do?

It is advised to wait for at least 6 months for stabilization of corneal topography and refractive status since vast majority of central island cases regress spontaneously (up to 80%). If there is a retreatment procedure required, wavefront- or topo-guided ablation profile needs to be planned, since irregular and complex corneal topography [33]. In cases of extremely irregular topography and risk of ending with questionable results of retreatment, rigid-gas permeable lenses can be used for correction.
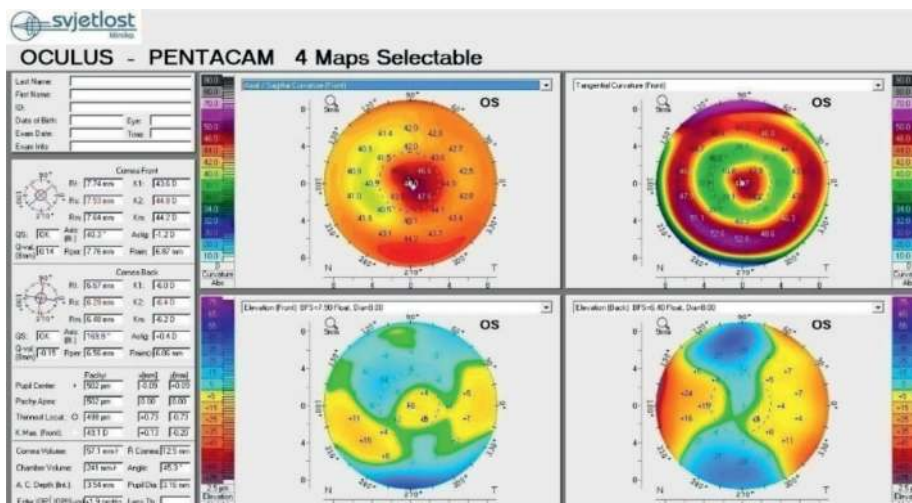
Figure 4.
Central island in patient with buttonhole flap.

2.2.4 General introperative complications

2.2.4.1 Epithelial defect

Epithelial defects are usually caused by the passage of microkeratome over the dry corneal surface or over the epithelium loosened by excessive use of anesthetic drops prior to surgery. Also, a higher risk occurs in patients with history of recurrent erosions, epithelial basement membrane dystrophy (EBDM), drying of the flap, and iatrogenic trauma with surgical instruments [34, 35]. Epithelial defect can be accompanied by stromal oedema and inadequate flap adherence, which increases the risk of inflammatory response as DLK, even epithelial ingrowth [36].

What shall we do?

In case of smaller epithelial defects, frequent use of artificial tears, preferably conservative-free postoperatively is recommended with higher dose of topical corticosteroids in the next few postoperative days, primarily to prevent development of DLK. For larger defects (3 or more mm) bandage soft contact lens needs to be applied to ensure smooth epithelial healing.

2.2.4.2 Interface debris

Interlamellar contamination (debris) may consist of connective and skin epithelial cells, Meibomian gland secretions, talc from the gloves, sponge fibers, metallic particles from microkeratome, and eyelash [4] (**Figure 5**). Interface debris should be carefully differentiated from an infectious or inflammatory reaction. However, impurities can support infectious or sterile inflammation of the cornea and cause mechanical disturbances in vision when placed on the visual axis [1, 37].

What should we do?

In most cases, debris does not induce inflammation since it is biodegradable, but it should be observed. However, if there is any suspicion of an inflammatory reaction or large amount of debris covering the visual axis, causing significant visual disturbances, it should be managed with flap lift and thorough irrigation [38].

Figure 5.
Interface debris visible at 1ˢᵗ postoperative day.

2.3 Postoperative complications

2.3.1 Early postoperative complications

2.3.1.1 Flap striae

Flap striae occur in 0.03–3.5%, according to the literature [39] and are usually observed the next day after the surgery at the slit-lamp examination, best in retroillumination or with fluorescein staining at cobalt-blue light (**Figure 6**). In cases where flap is edematous, epithelial microstriae can present within 7 days postoperatively. Striae can be classified as micro- and macrostriae. Microstriae are irregularities in epithelial layer, where macrostriae result as full-thickness flap-folds. AT higher risk are cases with high refractive error ("tenting" effect due to the flap and stromal bed

Figure 6.
Vertical flap striae at 1st postoperative day without flap dislocation.

contour mismatch), misalignment during repositioning, excessive manipulation of the flap during surgery, and flap contracture [3, 4, 40].

What shall we do?

Flap striae involving visual axis (inducing irregular astigmatism and optical aberrations) should be treated. When microstriae are presented early after the surgery, gentle stroking in a perpendicular way (flap sliding technique) with wet surgical sponge is sufficient [41]. Macrostriae must be managed with flap re-lift, stroking with surgical sponge on both stromal and epithelial side of the flap, and then careful flap repositioning. Fixed striae and flap-folds often present with epithelial hyperplasia, therefore epithelium and stromal bed debridement are necessary along with flap lift, repositioning, and stroking.
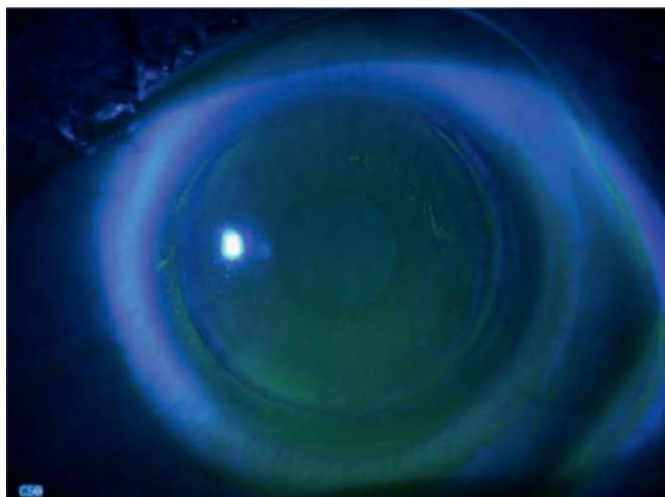
2.3.1.2 Flap dislocation

Dislocation of the flap most commonly occurs in the first 24 hours after surgery before epithelial healing of the lamellar incision occurs (**Figure 7**). However, dislocations are possible several months after the procedure, usually after ocular trauma (**Figure 8**). Flap dislocation is considered an emergency and should be treated immediately to prevent folds and epithelial ingrowth. Patients present with sudden onset blurred vision, often associated with pain in the early postoperative period, the most common cause is mechanical due to lid squeezing, forceful blinking, and rubbing of eyes. Larger diameter flaps, thinner, and those with a small hinge are more susceptible to movement. In some cases, after repositioning the flap, DLK, interface haze, or epithelial ingrowth can occur [1, 42, 43].

What shall we do?

Dislodged flap needs to be managed with flap lift, debridement of stromal bed and stromal side of the flap for possible epithelium (preventing ingrowth), interface irrigation, and flap repositioning. Careful flap handling, soft stroking, and meticulous edge drying are of great importance. BSCL is often applied, and patient is rechecked after half an hour to confirm the flap position and edge adherence [35, 44].

Figure 7.
Dislodged flap due with associated vertical striae due to eye rubbing at 1st postoperative day.

Figure 8.
Late flap dislocation 3 months after LASIK procedure due to blunt eye trauma. Patient presented 2 hours after the trauma occurred.

2.3.1.3 Residual refractive error (under- or overcorrection)

Residual refractive error has been reported in up to 50% of LASIK cases [45]. Hypocorrection is the most common complication after primary LASIK and is usually diagnosed within the first few weeks after surgery. Hypercorrections are more common after repeated procedures and in elderly patients due to slightly dehydrated cornea (>50 years). Hypo- and hypercorrections are associated with excimer laser ablation algorithm, inaccurate nomograms, age, height of refractive error [45–48], and even environmental factors can affect the amount of tissue ablation depth (temperature, humidity, and atmospheric pressure) [49]. Additionally, cyclotorsion from erect to supine position and poor centration of eye during laser ablation can cause postoperative astigmatism [50].

What shall we do?

After confirmed refractive and topography stabilization, re-lift with LASIK or PRK enhancement can be done. There is a slight risk of epithelial defects postoperatively and epithelial ingrowth in case of flap re-lift [45, 51].

2.3.1.4 Diffuse lamellar keratitis (DLK)

Diffuse lamellar keratitis (DLK) is a diffuse sterile inflammation of the lamella between the flap and the stroma (interface). It has been reported in 0.13% to 18.9% of cases [52, 53]. Inflammation may occur within 24 hours or be delayed for several days after the procedure. The course of inflammation is variable, it is possible to gradually reduce, increase or persist the inflammation. Etiological DLK is an allergic or toxic reaction caused by debris left in the lamellae—tears, mucus, corneal epithelial cells, connective tissue or skin, Meibomian gland secretion, glove powder, metal particles or wax from knives, leukocytes or blood from the pannus. An immune response to a temperature-resistant toxin from a sterilizer is also possible [36, 54–59].

Another etiology of DLK is related to the use of femtosecond lasers and photo-disruption caused by microscopic tissue injury enhanced by inflammatory mediators from the surface of the eye. DLK was much more common in older models of

femtosecond high-energy lasers. Today, only mild transient lamellar keratitis is seen on the periphery of the flap associated with slightly higher energies required for the formation of lateral incisions [36, 58, 59].

Symptoms include discomfort, mild to moderate pain, foreign body sensation, tearing, and light-scattering, A typical lamellar infiltrate is composed of white granular opacities limited to the lamella, without epithelial defects and reactions in the anterior chamber, while conjunctival injection can be present. DLK is divided into four stages or degrees by Linebarger et al. (I degree mild, IV degree melting of the flap) for the purpose of appropriate treatment in a timely manner and prognosis (**Figures 9** and **10**) [1, 60].

What shall we do?

When presented at grade 1 or 2, an intensive topical steroid is necessary and recheck within next 24−48 hours is crucial for early identification of cases progressing to grade 3. Early flap lift and irrigation of interface with intensive topical steroids in grade 3 should reduce the risk of progression to stage 4. There are some recommendations for introducing peroral Doxycycline in addition to standard treatment regime for advanced grades. Even though, usually there is no major benefit of any intervention after progression to grade 4 [60].
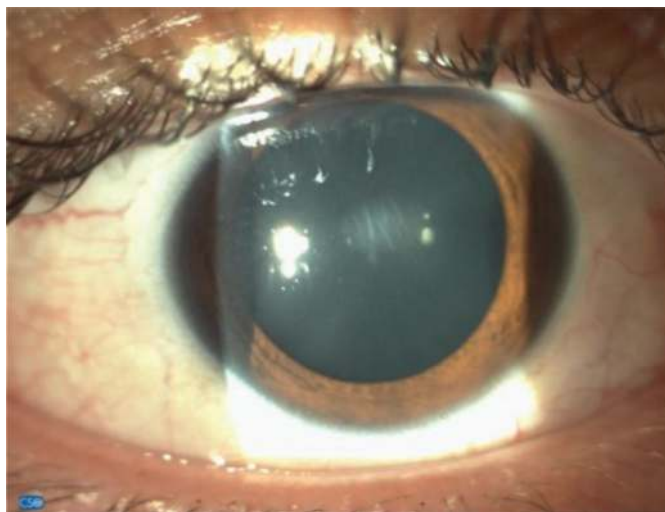
2.3.1.5 Central toxic keratopathy (CTK)

CTK is a rare acute, non-inflammatory central corneal opacification that occurs within days of uncomplicated LASIK or PRK. Incidence is reported in 0.02%−0.016% of cases [61, 62], and the etiology is unknown, but enzymatic degradation of keratocytes is suspected. Activated keratocytes without inflammatory cells with initial loss of stromal keratocytes and subsequent gradual repopulation were found by confocal microscopy. CTK causes central corneal haze, (**Figure 11**), thinning of corneal stroma, and flattening of the anterior corneal surface, mostly without affecting the posterior surface. It is important to differentiate it diagnostically from stage IV DLK. Unlike DLK, CTK develops acute within 3−9 days postoperatively as central opacification, rarely associated with conjunctival hyperemia, or ciliary flush.
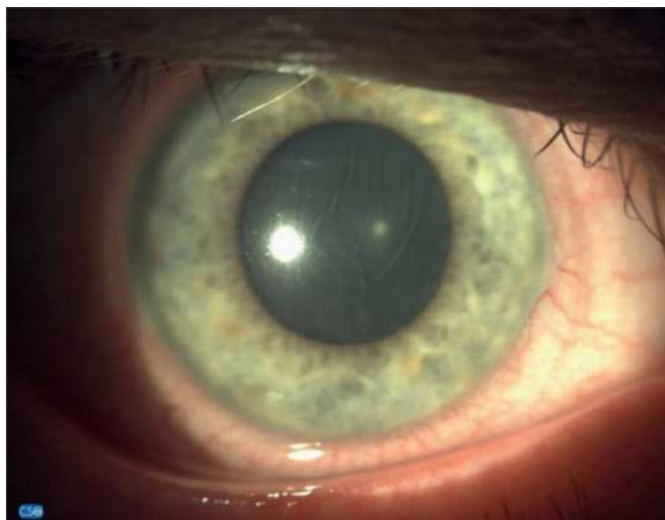
Figure 9.
DLK at grade II, inflammatory reaction visible throughout complete interface, without signs of melting.
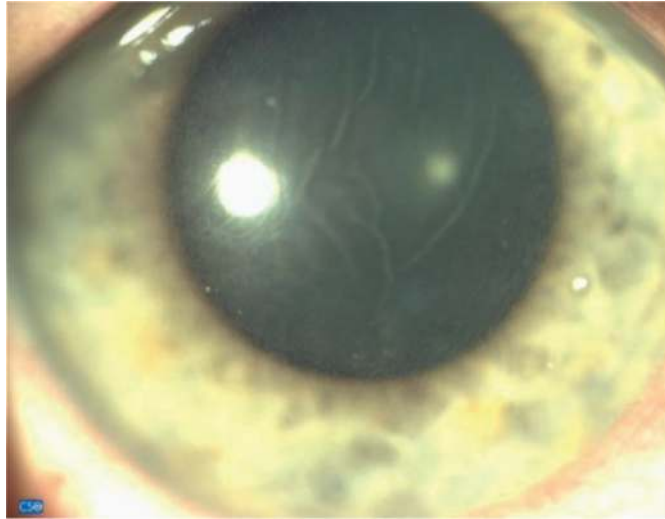
Figure 10.
DLK in advanced grade, visible inflammatory reaction forming characteristic shifting sands phenomenon "sands of Sahara".

Figure 11.
Central toxic keratopathy in patient presented 5 days after LASIK procedure. Visible centralized opacification that extends anteriorly or posteriorly from the interface.

What shall we do?

Since CTK is a non-inflammatory condition, steroids are not indicated, thus they may hamper the healing process. Usually, there is spontaneous recovery without specific therapy needed. Recovery phase takes up to 18 months, where slight central opacification can remain, but corneal thickness increases and hyperopic shift decreases [61, 63–66].

2.3.1.6 Pressure-induced stromal keratitis

PISK, also known as interface fluid syndrome [67] is a relatively rapid response to corticosteroids that presents with elevated intraocular pressure and fluid accumulation in the lamella between the flap and the adjacent corneal stroma. The amount of

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fluid varies and can be very small and clinically present as diffuse stroma opacity or large, clinically clearly separating the flap from the adjacent stroma. PISK is often misdiagnosed with DLK, bud the main difference is occurrence at least 5–7 days postoperatively, with high IOP and poor response to corticosteroids, au contraire. Hence, it is extremely important to differentiate it diagnostically from DLK in order to discontinue corticosteroid therapy. The values of intraocular pressure due to fluid are centrally falsely low, while peripheral measurements show somewhat more accurate results [63, 68].

What shall we do?

Management includes cessation of corticosteroid therapy and introduction of anti-glaucoma therapy for avoiding glaucomatous optic nerve damage [69, 70].

2.3.1.7 Infectious keratitis

Infectious keratitis is a rare but potentially devastating and sight-threatening complication after LASIK. It is rare, with 0.034–0.2% cases with decreased incidence over the years [71, 72]. It can be caused by viruses (Adenoviruses, Herpes simplex virus), bacteria (Staphylococcus, Pseudomonas), atypical mycobacteria, fungi, and parasites (Acanthamoeba). Infectious keratitis is divided into early (within the first two postoperative weeks) and late (occurs 2–3 months after surgery). Early infectious keratitis is caused by staphylococci and streptococci (most often methicillin-resistant staphylococci), and late atypical mycobacteria and fungi. The risk of infection is blepharitis, dry eye, intraoperative epithelial defects, intraoperative contamination, prolonged epithelialization after surgery, and certain professions (medical professionals). Symptoms may include pain, lightheadedness, tearing, decreased visual acuity, image duplication, shadows, and haloes. Examination on a biomicroscope may show ciliary injection, epithelial defects, anterior chamber reaction, and hypopion. Fungal keratitis, although significantly rarer than bacterial, should be considered in the differential diagnosis [1, 73–76].

What shall we do?

When it comes to infectious keratitis, prophylaxis is preferred over treatment. Proper use of sterile gloves, caps, instruments, and betadine wash of eyelids prior to the surgery will reduce the risk of infection. In observed infectious keratitis, management includes flap lift, scraping of bed, and irrigation of bed with antibiotics. In early onset, the best choice is vancomycin and amikacin in late-onset. Cessation of corticosteroids is obligatory, and topical fourth-generation fluoroquinolone and vancomycin (early onset) or amikacin with vancomycin 5% or topical clarithromycin and 4th generation fluoroquinolone for late-onset [72]. After culture isolation and the accompanying sensitivity antibiogram, local antibiotic therapy is revised. Sometimes, in case of severe infection, flap amputation is needed, both for therapeutic and diagnostic reasons [73].

2.3.1.8 Stromal melting or flap melting

Stromal melting is mostly unilateral and occurs 2–5 weeks after LASIK. It most commonly occurs after epithelial defects, thin and/or irregular flaps, perforated flaps, epithelial ingrowth, and deep lamellar keratitis. It may also be associated with systemic immune diseases such as thyroiditis, systemic lupus, Sjögren's disease, rheumatoid arthritis, eczema, and erythema. The disease is usually self-limiting for 21–45 days and results in variable intensity of opacification (leukemia) and regular or

incorrect astigmatism. Melting of the flap is very likely caused by apoptosis induced by an implanted layer of epithelial cells caused by epithelial ingrowth. Epithelial ingrowth, as well as possible melting of the flap edge, is more common in reoperations, especially in hyperopic eyes, than in primary operations [77–79].

2.3.1.9 Transient photosensitivity

It is characterized by light-headedness and mild pain with normal visual acuity but without inflammation. It occurs a few days after the procedure and can last for several weeks. The complication is related to the high energy and low frequency of mostly older generations of femtosecond lasers, and the hypothetical cause is the stimulation of keratocytes and corneal nerves by the shock waves of the femtosecond laser [80].

2.3.2 Late postoperative complications

2.3.2.1 Refractive regression

Regression is the return of diopters in the direction of primary refractive error documented in several arrivals 3–6 months after LASIK. Regression is more common after hyperopic LASIK, observed in nearly 30% of hyperopes and 5.5–27.7% of myopes [81]. Regression after LASIK is associated with an increase in corneal thickness and curvature. Potential mechanisms involved in regression include nucleus sclerosis, stromal synthesis and remodeling (wound healing), compensatory epithelial hyperplasia, decreased flap thickness, an anterior shift of cornea, and iatrogenic keratectasia [82].

What shall we do?

After confirmed refractive stability, within 3–4 months, enhancement with LASIK re-lift, PRK, or even LASEK can be advised.
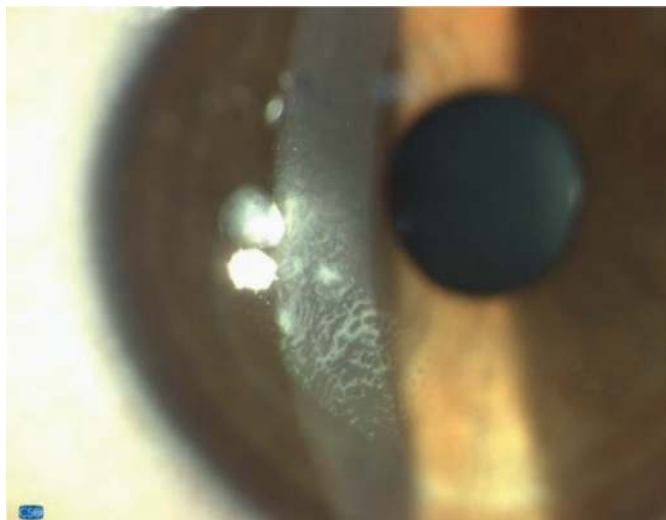
2.3.2.2 Epithelial ingrowth

Epithelial ingrowth at the terminal periphery of the flap is normal flap healing. Clinically significant epithelial ingrowth occurs when a fistula develops under the flap, which allows epithelial cells to migrate in the lamella between the flap and the stroma and causes opacification. It occurs in 0−3.9% of cases undergoing primary treatment and 10−20% in re-treatment cases [83]. In primary uncomplicated LASIK, a higher incidence of epithelial ingrowth was observed in the treatment of hyperopia, in microkeratome compared to femtosecond lasers, LASIK after radial keratotomy, intraoperative epithelial defects, and in the elderly. After repeated procedures and application of therapeutic soft contact lenses, an increased incidence of epithelial ingrowth was observed, as well as in operations performed three or more years after primary LASIK. Isolated epithelial islets rarely cause problems (**Figure 12**). However, if the ingrowth is connected to the superficial epithelium and continues to grow and reach the visual axis, it can cause distortion of the flap surface and the development of irregular astigmatism (**Figure 13**). Symptoms of epithelial ingrowth include light-headedness, glare, decreased visual acuity, and foreign body sensation. Theoretically, there are several ways in which epithelial cells can get into the lamella: by mechanical indentation on the microkeratome blade or with water during irrigation after photoablation, and by ingrowth of cells derived from peripheral epithelium.

Biomicroscopically, epithelial ingrowth is shown with epithelial beads in the lamella formed by dividing epithelial cells, fluorescein accumulation at the edges of

Figure 12.
Epithelial cell collection under the flap.

Figure 13.
Epithelial ingrowth from flap margin advancing to the central part of the interface.

the flap or even below the flap, fibrotic demarcation line at the leading edge of epithelial ingrowth, keratolysis, or melting of the flap edge [63, 84–87]. Patients usually present with foreign body sensation and dysphotopsia (glare) in the early stages and decreased visual acuity in later stages.

What shall we do?

In the initial stages (grade 1) observation is recommended, but for advanced stages, flap lift, thorough mechanical debridement of epithelial cells with profound wash of stromal bed, and Mitomycine C 0.02% application for preventing ingrowth recurrence (observed in one-third of cases) [83]. Some literature advise low energy (0.6 mJ) Nd-YAG laser for treating ingrowth [83, 88].

2.3.2.3 Induced and iatrogenic keratectasia

Iatrogenic keratectasia is a serious complication seen in 0.033−0.6% cases [4, 89] associated with a weakening of the mechanical strength of the cornea. It is clinically presented by progressive weakening of uncorrected visual acuity and increase in myopia, and by progressive increase in corneal curvature visible on corneal topography (**Figure 14**). Iatrogenic keratectasia occurs several weeks to several years after the procedure. The flap does not contribute to the biomechanical strength of the cornea, and all biomechanical stress is tolerated by untreated deeper parts of the cornea. Risk factors include irregular corneal topography, thin central corneal thickness (<450 μm), low residual corneal thickness (<250 μm), young age, and high spherical refractive error equivalent [90–92].

What shall we do?

In the case of keratectasia, prophylaxis as careful and detailed screening of corneal topography is of most importance. When progressive ectasia is observed, collagen Cross-linking is performed. Additionally, rigid gas-permeable CL or intracorneal ring segments can restore vision. For advanced cases, anterior lamellar keratoplasty or event perforative keratoplasty is required [89, 93].

2.3.2.4 Dry eye

Corneal refractive surgery can induce or even worsen dry eye symptoms (**Figure 15**). Dry eye syndrome causes discomfort, fluctuations in vision quality, delayed healing and epithelial damage, and can lead to regression of refractive error and reduced vision quality. In most patients, the symptoms are mild and do not cause interference, and pass within 6 months when the healing period ends. According to the literature and clinical practice, dry eye is observed in more than 90% of cases [94]. The main risk factors for chronic dry eye after surgery are preoperative dry eye and female sex [95–98]. Symptoms of dry eye are thought to be caused by denervation and cutting of nerve fibers during flap formation,
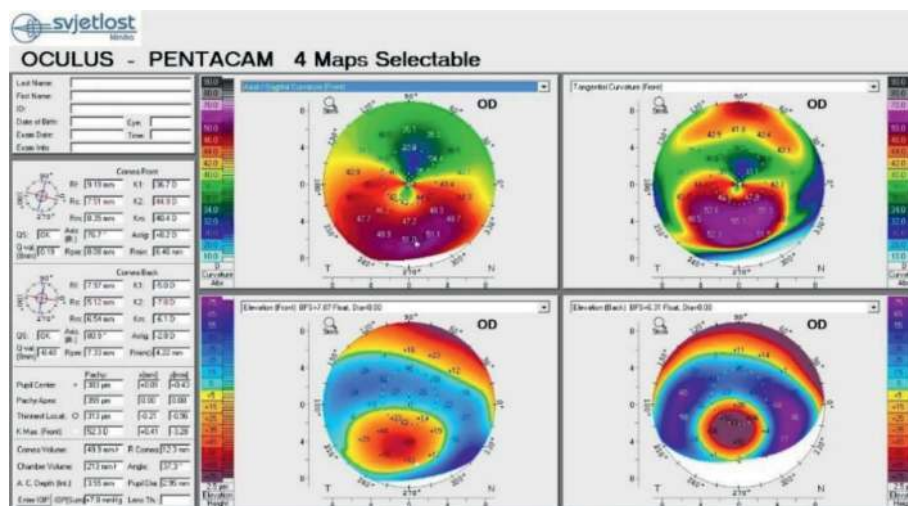
Figure 14.
Iatrogenic corneal ectasia 1 year after LASIK procedure.

Figure 15.
Severe dry eye 1 month after LASIK procedure.

excimer laser removal of corneal tissue, and corneal reshaping. Denervation causes a decrease in corneal sensitivity and interrupts the flow of information from the cornea to the lacrimal system. Lack of corneal sensitivity can lead to a decrease in the number of blinks, and to a lack of information about the need to produce a larger amount and/or a specific tear component. Improvement in corneal sensation and DED by 3–6 months occur in most cases, but corneal innervation can be delayed by 2–3 years [99].

What shall we do?

The choice of patients and the treatment of dry eye symptoms before the procedure are extremely important. Standard therapy includes artificial tears for prolonged period of 6 months or longer, and topical corticosteroids (currently most commonly used is low dose hydrocortisone) [100]. In severe cases of DED, topical cyclosporine drops and Punctal Plug instillation for occluding tear punctum.

2.3.2.5 Night vision disturbances

The main cause of decreased vision quality and glare symptoms is an increase in spherical aberration in the centrally flattened cornea. Symptoms worsen at night due to the physiological dilation of the pupil and the entry of light rays through the untreated periphery. Glare can also cause decentralized ablations, too small optical zones, newly formed lens blurring, and induced astigmatism. Patients with scotopic pupils larger than 7.5 mm and high myopic corrections are most often affected. Fortunately, most symptoms resolve over time without treatment due to cortical adaptation [101–104].

3. Conclusions

It is of the greatest interest for every refractive surgeon to perform safe surgery and successfully treat possible complications. Therefore, meticulous knowledge of intraoperative and postoperative complications will ensure timely and appropriate preventive measures to reduce the occurrence of complications, their early detection, and appropriate management in order to achieve optimal results.

Conflict of interest

The authors declare no conflict of interest.

Author details

Fanka Gilevska[1], Maja Bohač[2], Smiljka Popović Suić[2] and Mateja Jagić[2]*

1 Eye Clinic Sistina Oftalmologija, North Macedonia

2 University Eye Clinic Svjetlost, Croatia

*Address all correspondence to: mateja.jagic@svjetlost.hr

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