# Risks and Benefits of LASIK Surgery

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## Abstract

Millions of individuals around the world suffer from refractive error in the eyes and, as a result, poor vision. Laser-assisted in situ keratomileusis (LASIK) is a procedure characterized by the correction of optical dysfunction for those who desire higher visual acuity. There are several pros and cons to undergoing the treatment, and selected candidates should carefully consider how the procedure may affect their quality of life, alternatives to LASIK, and potential risks of receiving the surgery. Studies indicate that this procedure may have positive effects on mental well-being and high overall satisfaction ratings following the surgery due to mostly optimal results. Meanwhile, alternatives to LASIK treatment may offer benefits to certain individuals, including faster healing time, harm reduction, and an option for those who cannot receive LASIK. Following treatment, some patients may experience flap abnormalities, gas bubble formation, rupture of the ocular vessels, disrupted vision, chronic dry eye, and corneal pain. Although rare, these possibilities are important to consider before undergoing LASIK. The purpose of this review is to provide an in-depth summary of each factor to highlight the benefits and risks that certain individuals may experience following surgery. Additionally, we will discuss clinical trials surrounding the healing process and control for postoperative pain following the vision correction procedure.

## Introduction

Laser-assisted in situ keratomileusis (LASIK) is a surgical procedure to correct various visual refractive errors. LASIK is typically an ophthalmic surgical procedure that was patented by Gholam Peyman, MD, in 1989. The surgery quickly became popular on account of its quick recovery time, reduced postsurgical adverse effects, and ideal circumstances or efficacy for surgery (1). LASIK is used to treat myopia, hyperopia, and astigmatisms by changing the physical shape of the cornea and stroma, in turn improving visual acuity (2). The surgery allows the doctor to alter the refractive power in the patient's cornea (1). Nearly 50% of individuals are estimated to suffer from such visual deficits, while close to 16 million LASIK procedures have been performed since the surgery's inception into ophthalmic practice (2).

A refractive error occurs in the patient's eye when the light coming into the eye does not bend light correctly. Clear vision results from the proper flow of light into the retina. The light will first enter the surface of the eye, which then proceeds through the cornea and lens, and lastly, reflects onto the retina (Figure 1). In order to see clearly, when light enters the eye, it proceeds through the cornea through the lens in the before until the reflected light arrives at the retina. Once the light rays reach the retina, the light is transformed into the signals sent to the brain, which become the different shapes, lines, and in turn, objects that we see. Blurry vision is caused by the light rays bouncing into the wrong parts of the eye and not focusing on the retina (3).

Before undergoing LASIK surgery, it is important to have a complete eye examination from the patient's optometrist, who will then refer them to the ophthalmologist for surgery in most states in the United States (4). Only 10 states allow optometrists to perform laser surgery if certified by the Board of Optometry (5). Laser surgeries such as argon laser

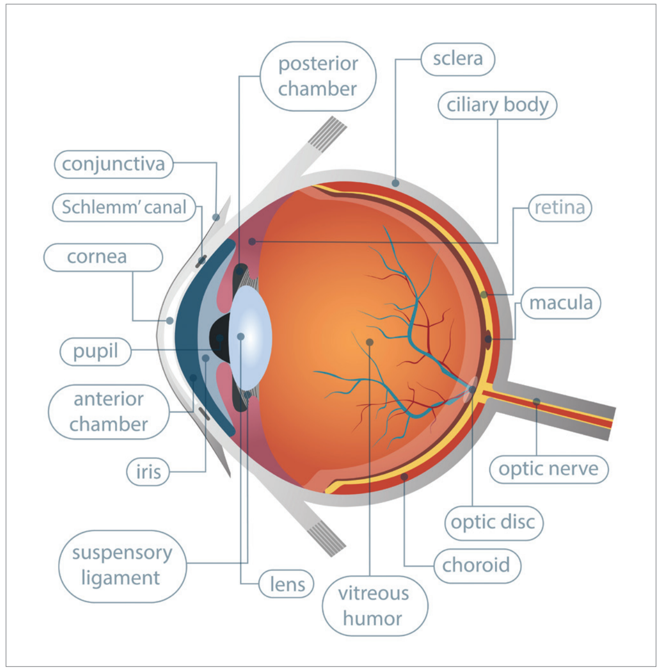


Figure 1. Anatomy of the Human Eye. The human eye is separated into three compartments: the eye's surface, the front of the eye, and the back of the eye. The eye's surface consists of a membrane known as the conjunctiva (64). The tear film coats the outer surface of the eye to maintain lubrication and consists of three layers: mucous (most inner layer), watery (middle layer), and oil (outer layer) (64). The conjunctiva generates the mucous layer, while glands surrounding the eye orbit supply tears to the watery and oil layer (not illustrated) (64). Light passes into the eye through the cornea. Posterior to the cornea is the anterior chamber, which constantly produces aqueous humor, which regulates the eye's pressure. Following the anterior chamber is the pupil, surrounded by the iris, the portion of the eye that contains color. Behind the pupil and iris is the lens, whose primary function is to focus the light that enters the eye (64). The cavity containing the vitreous humor separates the lens and the tissue of the back of the eye, known as the retina. The retina contains photoreceptors that transmit visual signals to the brain in response to light (64). Lastly, the macula of the retina mainly functions in detailed and central vision, and the peripheral retina allows for our peripheral vision. Image from Vecteezy.com (65)

trabeculoplasty (ALT), selective laser trabeculoplasty (SLT), and laser peripheral iridotomy (LPI) treat glaucoma. YAG laser capsulotomy treats complications post-cataract surgery, and photorefractive keratectomy (PRK) treats abnormal vision due to eye refractive errors (5). Alaska and Oklahoma allow optometrists to perform all five types of laser surgery (5). Colorado, Indiana, Kentucky, Louisiana, Wyoming, and Virginia cover four, excluding PRK (5). Arkansas allows optometrists access to YAG, ALT, and SLT surgeries (5). Mississippi only allows for the YAG capsulotomy cataract surgery (5). It is also necessary to have a medical examination by the patient's primary care physician. Typical candidates for LASIK surgery are those with myopia, hyperopia, or astigmatism, but there are other irregularities that doctors may look for before the surgery (Figure 2). They will test for irregular astigmatism, forme fruste keratoconus, and keratoconus to determine whether the surgery will lead to unforeseeable complications. An essential attribute to have before surgery to be a good candidate would be on a stable prescription for at least 1 year staying within 0.5 diopters of the previous refraction (4). Prescriptions are measured in the unit diopters, which is the refractive power equal to the reciprocal, in meters, of the focal length. According to a study conducted in Cleveland, a surgeon had specific criteria for LASIK surgery candidates, which are similar requirements for other practices (6). A patient with myopia should have less than or equal to 10.5 diopters, hyperopia should have less than or equal to 4.50 diopters, and astigmatism should be less than or equal to 6.00 diopters (4). The other measurable requirement of surgery is the corneal thickness consisting of more than 480 µm, measured using ultrasonic pachymetry. It is also important to not have any signs of abnormalities in the cornea that would suggest keratoconus or corneal diseases, or other ocular pathology. Those who are pregnant should not have this surgery (6). If cataracts were detected during the exam using a slit lamp, the patient would not be suitable for LASIK surgery (7).

According to the American Academy of Ophthalmology, keratoconus is the thinning of the cornea and bulging outward, which, as mentioned before, can make the light rays not land correctly on the cornea. The cause of keratoconus is still unknown but is likely genetic and can be connected to excessive eye rubbing, allergies, and connective tissue diseases. Two genetic diseases are known to cause keratoconus: Ehlers-Danlos syndrome and Marfan syndrome (3).

In LASIK treatment, a specialized laser or microkeratome is used to create a corneal flap which is then displaced to change the stromal structure beneath before the flap is repositioned (8) (Figure 3). For individuals with near-sightedness (myopia), the surgery consists of decreasing the overall curvature of the cornea, which would reduce the eye's refractive power (1). High myopia can be a greater risk for post-LASIK ectasia and reduced vision quality (4). In patients who suffer from farsightedness (hyperopia), the corneal surface is flattened, increasing refractive power. This corrective surgery offers promising results to those who have suffered visual complications throughout their lifetime. However, it is important to note several risks (and benefits) associated with the LASIK procedure (1). This review will examine the risks, benefits, alternatives, and studies of LASIK eye surgery.

## Methods

A review of the literature was conducted using selected sources through the PubMed database and Google advanced search and keywords, phrases, and terms such as "LASIK," "Alternatives to LASIK eye surgery," "Benefits of LASIK," and "Risks of LASIK."

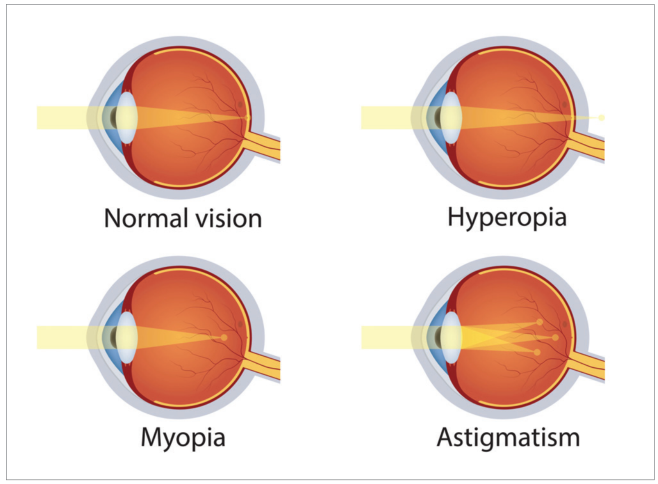


Figure 2. Common Visual Abnormalities Treated with LASIK. Patients with visual abnormalities such as myopia, hyperopia, and astigmatism can undergo LASIK surgery to improve vision by altering the eye's refractive power. Myopia, also known as near-sightedness, occurs when light cannot focus on the retina (1). LASIK would decrease the cornea's curvature for patients with myopia to reduce the eye's refractive power (1). Patients who suffer from farsightedness experience hyperopia due to a flattened cornea surface, thus increasing the eye's refractive power and causing blurry vision of nearby objects (1). Reshaping the cornea during the LASIK procedure can correct the pathway in which light travels through the eye (1). Astigmatism occurs due to an abnormal curvature of the cornea and lens in the eye, light refraction error, and causing blurry vision at varying distances. Image from Vecteezy.com (66).

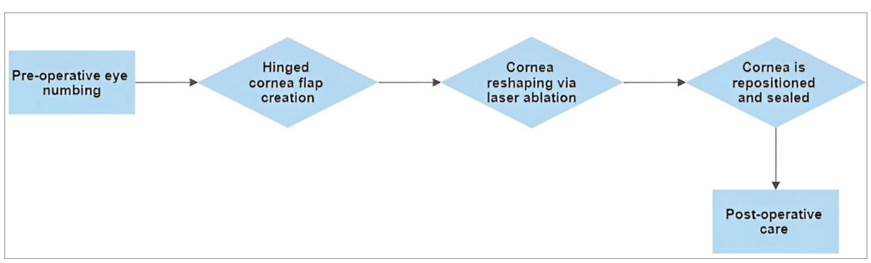


Figure 3. Overview of LASIK Surgery. Before surgery, numbing medication is administered to the eye, and surgical instruments are used to hold the eyelids open. A suction ring is placed on the eye prior to cutting the hinged corneal flap (1). Microkeratome or femtosecond laser pulses reshape the cornea (1). Small amounts of cornea tissue are removed by photoablation based on the patient's indication (1). The corneal flap is then sealed and repositioned to the original position. Postsurgical care can include but is not limited to artificial tear drops, antibiotics, and steroidal eye drops (1).

The articles and journals selected were published during 2023 and the past 30 years. The team evaluated the articles, journals, and authors to ensure appropriate quality and standards. All patients, regardless of age, race, and gender, were included in this paper to expand on the variety and accuracy of LASIK surgery. The team used all the resources to build a list of advantages and disadvantages for any person who has had LASIK or is considering having LASIK completed and the available alternatives to the surgery. The criteria for articles that were selected to be included in this review were those that were peer-reviewed, didn't have any disclosures that are a conflict of interest, and included significant data from the research. Single-patient case studies were excluded from this review. Overall, the literature included needed to be from reputable journals known to have accurate information on this topic.

## Discussion

### Effects of Lasik Procedure on Mental Health and Quality of Life

Individuals who suffer from visual impairment are likely to also suffer from mental disturbances, such as both depression and anxiety, which may lead to significant influences on quality of life and well-being (9). It appears that as visual acuity declines, symptoms of depression worsen, suggesting a clear association (9). Unfortunately, feelings of depression can exacerbate vision loss by affecting personal choices, such as engaging in dangerous behavior (e.g., smoking and drug use) (9). Certain antidepressant medications can promote abnormal neurotransmitter functioning, decreasing visual processing (9). Additionally, it seems that anxiety, including obsessive-compulsive disorder, paranoia, and post-traumatic stress disorder, plays a small role in visual impairment (9). This may be attributed to the feelings of distress surrounding thoughts of living life with a disability (9). Patterns of anxiety are typically seen in adults and children affected by visual disturbances (9). Both depression and anxiety may also lead to diminished social interaction and affect an individual's ability to perform daily tasks (9). These factors are detrimental to the lives of millions worldwide; mental health and quality of life are just a few components that highlight the significance of visual impairment (9).

The LASIK procedure can positively impact the lives and well-being of those with visual impairments that can be corrected by surgical intervention (10). A recent study was conducted to explore the association between LASIK and mental health-related quality of life and the factors that may lead to improved well-being (10). This team of researchers found that refractive surgery had the potential to alleviate psychological disturbances and improve physical ability in the first month following the surgery (10). Factors such as self-esteem, lower stress levels, and confidence were dramatically enhanced (10–25%) (10). Interestingly, the improvements in quality of life may be seen on the first day after the procedure; however, the highest level of quality of life comes later in the recovery period. (10). Unfortunately, these improvements appear to dissipate at the 6-month mark following surgery, suggesting that effects may be temporary, or at least diminish over time (11). Individuals who suffered from complications following surgery, such as double vision or a visual halo, were found to present lower on the quality of health scale, signifying a relationship between quality of life status and mental wellness (11). Researchers also noted that there may be a relationship between the axial length of the eyes prior to surgery and mental health following the procedure (11). This could indicate a connection between the severity of myopia and mental health (11). In another recent study performed in 2020, a team of investigators found that when measured before the LASIK procedure, individuals with longer axial lengths were more likely to experience myopic regression following the surgery (12). This finding further supports the likelihood that those with longer axons in the eye may be subjected to worsening mental health after LASIK (12).

### Satisfaction in LASIK Surgery Patients

Many individuals will choose to receive the LASIK procedure after several years of depending on eyeglasses and contact lenses for visual acuity. These corrective tools can be an annoyance, and contact lenses are known to cause a multitude of infections, such as *Acanthamoeba keratitis*, *Pseudomonas aeruginosa*, and multiple strains of *Staphylococcus* (13,14). Individuals may consider refractive surgery, which is an option for those who suffer from myopia, hyperopia, or astigmatism, as the procedure is typically safe and effective (15). According to a previous study that aimed to define the advantages of LASIK, this procedure is common for a reason (16). The process is predictable, has a short recovery period, involves low discomfort, and enhances visual acuity (16). These are just a few reasons individuals are likely to choose LASIK over other refractive surgery intervention options (16).

An early study sought to define the level of satisfaction in LASIK surgery patients in an attempt to form an association between the procedure and higher visual ability (15). After evaluating a group of 150 patients who had undergone refractive surgery, researchers concluded that 93% of the subjects were satisfied with the overall experience (15). From a more global standpoint, 98.5% of people feel that their initial objectives of better eyesight were achieved following the LASIK procedure, and quality of life was boosted in about 93% of individuals (17). Aside from the abundance of successful surgeries, the most notable complaint among participants appeared to be lower night vision and dry eye (15). The LASIK procedure increases feelings of satisfaction in patients by decreasing refractive error, correcting contrast visual acuity, and enhancing psychological wellness (18).

### Recovery and Healing Period Following LASIK Procedure

LASIK is almost an instantaneous fix to poor eyesight and is a desirable option due to the short recovery period that follows (19). Patients are typically capable of carrying out their day-to-day activities within just one to two days. Within three to six months, they will notice a significant improvement in sight (19). Patients can expect to feel some pain or discomfort following their procedure, as LASIK surgery is still invasive and can be traumatic on the nerves of the cornea (20). It is recommended that patients take certain medications following the procedure to alleviate any secondary injury, such as anti-inflammatory drugs and tear supplements (20). Another factor that must be considered in the healing process is the ability of the eye to regenerate nerves. A prior study measured both the number and density of nerves in the eye following the LASIK procedure (21). When researchers evaluated participants a month following their surgery, more than 90% of subbasal nerves and their density were decreased in the eye (21). Interestingly, two years following the procedure, measurements of nerve density in the cornea presented similarly to pre-surgery (21). However, after three years, nerve density significantly decreased in subjects (21). Stromal nerves appear to recover slowly but not to the same extent as pre-surgery (21). In an early study conducted to evaluate the clinical results following LASIK to treat myopia and myopic astigmatism, researchers found that out of 138 patients, the mean epithelial healing time was estimated to be within three to seven days (22). About 86% of patients presented with clear corneas, and contrast sensitivity was either unchanged or had improved in subjects throughout the healing process (22).

### Children and LASIK Surgery

When typical means of corrective treatment were not helpful in children, LASIK surgery has been used to reduce amblyopia. For this surgery, anesthesia is used for children, and parents must be fully educated on all possible risks. Children are usually still in their developmental stage when they are young, and this surgery will help reduce asymmetry in the eye. Long-term glasses and contact wear can inhibit emmetropization (a process that occurs in childhood, which balances both axial length and focal power of the eye to reduce refractive error during growth) due to the removal of the retinal blur from the lens because the stimulus causes the myopic movement toward emmetropization (23). Emmetropization is having no refractive error and achieving 20/20 vision or the best vision the optometrist can get a patient that is not blurry.

### Risks of LASIK

LASIK risks can be categorized as intraoperative and postoperative complications. Compared to postoperative complications, intraoperative complications are rare, with lower incidence rates (24). Patients are more likely to report post-operative complications at various time points after surgery. Postoperative complications can be described as either early-onset or late-onset (24).

A poor keratectomy can result in an aftereffect of flap abnormalities; the incidence of abnormal flap creations ranges from 0.3% to 5% (25). Abnormal flaps can be defined as those that are irregularly shaped, short, thin, torn, or incomplete (25). A severe flap-shape abnormality is the buttonholed flap. The reported occurrence of this abnormality is between 0.04% and 2.6% (25, 26). The buttonhole-shaped flap can occur when the microkeratome blade exits and enters the epithelium mid-incision (25). A suitable LASIK flap creation grants for a hinge on either side of the cornea (25). Although rare, the entire LASIK flap can become completely displaced from the cornea creating a free cap (25). Various risk factors can contribute to flap abnormalities and are typically screened for preoperatively. Risk factors for flap abnormalities can include corneal scarring, steep corneal curvature, loss of suction during the procedure, power level changes of the microkeratome motor, blade imperfections of the microkeratome, flat corneas, deep orbits, and poorly placed suction rings (25). Intraoperative abnormal flap creation pauses or aborts the LASIK procedure (25).

Flap abnormalities risks such as flap displacements can occur postoperatively. A study of 81,238 eyes calculated flap displacement incidence in individuals who underwent LASIK surgery to correct hyperopia, myopia, or mixed astigmatism (27). Flap displacement is very rare, occurring in 10 of the 81,238 eyes (0.012%), and occurs shortly after surgery, with all displacements occurring within 48 hours of surgery, defined as early flap displacement (ERD) (27). Of the 10 eyes, 7 underwent microkeratome LASIK, concluding that the odds of ERD are 10.53 times higher with this type of surgery (27).

LASIK flaps created by femtosecond lasers are less likely to undergo the aforementioned complications (25). Complications such as rainbow glare and intraoperative gas bubble formation are more common intraoperative risks in femtosecond laser-assisted LASIK (FS-LASIK) compared to mechanical microkeratome LASIK (28, 29).

Rainbow glare is caused by a grating pattern on the back of the LASIK flap resulting in the diffraction of light producing a glare (30). In a consecutive case series study, two groups of 129 patients each underwent FS-LASIK (29). The initial group received FS-LASIK with a femtosecond laser with altered flap cut settings, including a decrease in spot and line separation and pulse energy (29). Compared to the group who received FS-LASIK at the original laser setting, the group with a laser with decreased flap cut settings experienced significantly lower rates of rainbow glare at 1.57% compared to 13.73% (29). Rainbow glare, on average, appeared within the first three months post-LASIK, according to findings of a survey administered to post-operative patients who underwent FS-LASIK with a pulse setting at 60Hz and a spot and line separation of eight micrometers (28). The incidence of rainbow glare using these settings resulted in a 2.32% decrease from a previous study that used an older femtosecond laser model (28).

Gas bubble formation during LASIK is typically not a risk of great concern as bubbles form to create a level of separation in tissue near the lamellar fibers for flap creation (25). These bubbles are known as cavitation bubbles, made up of water and carbon dioxide, which will disappear with the rising of the flap (25). When the cavitation bubbles move into the subepithelium, anterior or posterior stroma and anterior chamber risks such as vertical gas breakthrough and opaque bubble layer formation can arise (31). In a consecutive chart review of 2,886 eyes that had undergone FS-LASIK, four eyes (i.e., four patients) were identified where a gas bubble formation occurred in the anterior chamber, reporting an incidence of 0.14% (31). Since gas bubbles of this nature cannot be resolved by flap lifting, it is of concern that the bubble could affect visual acuity, flap formation, and pupillary tracking (25). The rare incidence of gas bubble formation showed no significant postoperative consequence (31). All four cases of anterior chamber gas bubbles identified had no adverse changes to corrected and uncorrected visual acuity examinations (31).

Intraoperative bleeding of perilimbal vessels of the cornea is a specific LASIK complication (32). This bleeding occurs when a microkeratome blade or a femtosecond laser comes in contact with these vessels (25). At a single ophthalmology practice, 20 cases of intraoperative bleeding were identified in LASIK procedures treating myopia (32). When cases of bleeding were compared to 20 normal LASIK procedures, bleeding caused a higher frequency of interface haze, a higher risk of developing post-LASIK keratitis, and significant visual regression (32). The cause of regression following corneal perilimbal vessel bleeding may be attributed to a wound healing response causing more corneal remodeling in the eye versus a patient that experiences no bleeding (32).

The goal of LASIK is improving vision, but adverse visual changes, retreatment, and visual regression are of concern postoperatively (33). Retreatment rates of LASIK were reported to be 8.2% to 17.5% (33). A prospective study assessed the effectiveness of LASIK retreatment on 157 eyes with primary under-correction and visual regression (33). Almost three-quarters (73%) of the eyes underwent LASIK retreatment for regression, and 27% of the eyes underwent LASIK retreatment for under-correction (33). Before LASIK retreatment, all eyes had a level of residual myopia, and 10.8% of eyes had an irregular flap requiring a recut (33). In most eyes, visual regression was reported within the first six months but can be started up to two years post the initial LASIK procedure (33). Of the 157, 68.8% had a significant improvement in uncorrected vision, noting the success of LASIK retreatment (33). While the efficacy of LASIK retreatment is promising, the cause of visual regressions in patients still needs to be determined (33). Despite retreatment, some patients will have to undergo multiple retreatments in the future (33).

Distorted night vision is reported after LASIK procedures, specifically halo phenomena, which can be described as visual disturbances where someone sees halos or clouded circles around lights at night (34). The halo phenomenon is caused by corneal surface aberrations secondary to the LASIK procedure (34). In addition to halos, visual disturbances such as glare and diplopia are also related to high-order aberration caused by FS-LASIK procedures (35). FS-LASIK causes a change of high-order aberrations on the anterior corneal surface, significantly impacting visual acuity (35). Aberrations are produced due to abnormal corneal flaps and greater ablation depths (35). While vision disturbances after LASIK are common, the occurrence of vision loss from a LASIK procedure is rare at about 0.66% from 2003 through 2019 (36).

Corneal ectasia is a rare risk involving the weakening and thinning of the cornea and the development of astigmatism resulting in visual changes, with an estimated 0.2%–0.9% incidence rate (37, 38). Post-LASIK corneal ectasia is caused by the weakening of the cornea bed during flap creation, excess ablation, or postoperative eye rubbing (37). Risk factors for corneal ectasia include high preoperative myopia, low residual stroma beds, and keratoconus (39). The onset of corneal ectasia varies significantly from one week to many years postoperatively; late-onset cases are caused by a gradual progression of corneal weakness, with symptoms going unnoticed for a while (25, 37).

The epithelium layer of the cornea is subject to damage during flap formation of LASIK procedures, risk of epithelial ingrowth at the flap edge, loosening of the epithelial layer, and thickening of the epithelium layer can occur (40, 41). Epithelial ingrowth is described as a tongue-like or peninsula protrusion from the flap edge (40). Significant cornea epithelial ingrowth occurs more in cases of LASIK retreatment requiring flap re-lifting three or more years after the initial LASIK procedure (42). Higher grades of corneal epithelial ingrowth require immediate treatment and negatively impact visual acuity (40, 42). The incidence of epithelial loosening is rare and can be treated effectively with post-operative eye lubrication and bandage contact lenses (43). When corneal epithelial thickness (CET) is analyzed between post-LASIK eyes compared to healthy eye groups, CET is higher one year later in LASIK-treated groups than in eyes that never underwent LASIK (41).

Over 90% of the time, immediately following the LASIK procedures, a case of dry eye is observed (25). Dry eye symptoms ranged from acute to chronic conditions (25). A retrospective analysis of 88 eyes reported adverse effects of tear film stability, noting a continual decrease in fluorescein breakup time post-LASIK (44). While LASIK did not affect meibomian gland function, it did cause a decrease in tear volume, with a significant reduction reported at two weeks, one month, and three months postoperative (44). Chronic dry eye disease is very treatable, but it poses a risk of negatively affecting the refractive outcomes of LASIK patients and creating corneal surface sensitivities (44). Patients requiring punctual plug treatment were likelier to experience refractive regression (44).

Neuropathic corneal pain (NCP) is frequently accompanied by chronic dry disease; a 26-year retrospective case series concluded the prevalence of NCP was estimated to be 1 in 900 cases (45). Risk factors of NCP included pre-existing neuropsychiatric disorders, pain syndromes, autoimmune disease, and hypothyroidism (45). Treatment of NCP included dry eye treatment, pain, and anti-inflammatory medication, alleviating most NCP symptoms (45). The pathology of NCP is not well understood, but early detection and multifactorial treatments allow for adequate management of NCP (45).

### Alternatives to LASIK Eye Surgery

LASIK is the most common procedure for refractive surgery. The alternatives are photorefractive keratectomy (PRK), Epi-LASIK, laser subepithelial keratomileusis (LASEK), and small incision lenticule extraction (SMILE).

LASEK combines elements from both LASIK and PRK, which loosens the epithelial adhesion of the corneal stroma, where the epithelial is moved away from the treatment area. The ablation of the subepithelial stroma is performed before the loose epithelial is returned to the original position. Compared to LASIK or PRK, some advantages are reducing the flap, haze risk, and reduced visual recovery (46). Bandage lenses are typically used as bandages to keep the epithelial flap mentioned above in the proper position after surgery (47). The bandages can help relieve any irritation or reactions from the surgery (47). These bandages are typically only worn after surgery for a few days, causing no to little damage to the endothelium (47). Hydrogel soft contact lenses have previously been used as bandages due to the handling, comfort, and short adaptations of only three to five days (47). A study compared the types of contact lenses, such as silicon hydrogel and soft contact lenses, used as bandages after surgery (47). The two different types of silicon hydrogel are Galyfilcon A and Balaficon A (47). Results determined that different factors should be considered when choosing the best bandages, such as comfort, deposit resistance, and high oxygen transmission (47). By comparing the ocular response and grading subjective feelings, two different types of silicon hydrogel lenses had an average rating of performance

(47). The silicon hydrogel lenses do not cause hypoxia, which is a complication to any damage to the corneal epithelium (47). Blurry vision and pain can be caused by deposit formation, which can be remedied by eye drops (47).

PRK has a complete removal of the outermost corneal epithelium all the way to the Bowman's layer. It then ablates the stroma, which then redesigns the corneal surface. This is a great option for those patients with myopia of 12 diopters, hyperopia to 5 diopters, or astigmatism of 6 diopters or lower. This is not a treatment for those patients with diseases such as cataracts, glaucoma, dry eye, allergies, or blepharitis. Post-surgery uses topical anesthetics to lower pain with no adverse effects. Steroids are used for the first few months but do have a high risk of ocular hypertension (48).

Small incision lenticule extraction (SMILE) is where a dissector passes through a small 2- to 3-millimeter incision that separates the lenticular surfaces, which allows the lenticule to be extracted. Unlike LASIK, this procedure does not create a flap; instead, the small incision allows the surgery to reduce trauma to the subbasal nerve plexus (49, 50). This treatment was approved by the Food and Drug Administration in 2016. This surgery is typically used for patients with mild dry eyes (50). The benefits to SMILE are the use of only one laser, reducing dry eye symptoms, and better biochemical corneal stability (51).

Epi-LASIK is a surface ablation photorefractive surgery that uses the Centurion EpiEdge epikeratome. This device separates the corneal epithelium from the stroma, which can then be repositioned after the operation of the cornea. Some differences from other surgeries are the cornea is not required to be cleaned with alcohol, and the surgery is mechanical. This surgery is an option for patients with low myopic vision and require protective contact lenses after surgery. LASIK has a shorter recovery time, and patients report less postoperative pain than Epi-LASIK (52).

### Clinical Trials

Many clinical trials have been conducted on the postoperative pain and side effects of LASIK surgery. The use of therapeutic lenses as bandages to aid in the healing process of LASIK has been studied (53). Bandage lenses have been used for a myriad of corneal treatments and are often constructed from the same material as regular corrective contact lenses, known as senofilcon or focofilcon due to their low friction and subsequent decreased mechanical stress on a damaged cornea (54). The trial randomly assigned each patient with two different-sized bandage lenses, an 8.4-mm in one eye and an 8.8-mm base curve in the other (53). This study revealed that tightly fitted lenses allowed for the stability of the epithelial flap created by the LASIK treatment and an increased rate of healing time with a decrease in postoperative pain after the 2-hour mark (53). A separate study from 2019 fitted patients with a similar bandage lens in only one eye, with the opposite eye used as a control, for use only overnight and aimed to determine again the effects of lenses on the epithelial flap healing process (55). Researchers generated self-reported scores for symptoms, including pain and photophobia, as well as physical examination of the flap margins. This investigation also showed statistically significant lower levels of patient discomfort in the treatment group as well as an elevated healing response indicated by observed narrower and smoother margins and lower reflectivity (55).

Other clinical trials looked at the use of topical analgesics for the treatment of postoperative pain. The first trial utilized a 2% lidocaine gel as a topical anesthetic for use during LASIK operations as well as postoperative pain control. In this double-blind, randomized clinical trial, patients underwent bilateral LASIK procedures, with patients receiving lidocaine gel in both eyes or carbomer gel as a placebo and then a verbal scoring of pain throughout the procedure at various steps as well as intervals postoperatively (56). It was determined that the 2% lidocaine addition to the 0.5% proparacaine solution already in use significantly decreased pain both intra- and postoperatively, as well as increased patient compliance throughout the treatment as scored by the physician, which was hypothesized to also increase surgical safety (56). A separate investigation looking at topical treatment for pain focused on the use of diclofenac sodium, which is more commonly known as artificial tears and is a common ophthalmic NSAID (57), and patients were evaluated at five time points over the course of 24 hours following surgery. The maximum benefit was noted at four hours post-procedure, and only a single dose was sufficient to reduce the need for oral pain medication (58).

Dexamethasone inserts were the topic of a separate clinical trial used for the control of pain and postoperative symptoms and were compared to currently used topical prednisolone acetate. Dexamethasone inserts are an extended-release treatment to be placed intracanalicular and can be used for up to 30 days before requiring removal, as opposed to the topical administration of prednisolone administered four times daily at a tapered dosage (59). Results showed an 80% preference toward the dexamethasone insert for control of inflammation, and both received similar levels of dry eye and corneal staining postoperatively. This preference was thought to be due to the decreased need for self-administration of postoperative medications (59). Investigators in a separate trial went so far as to say that this decreased reliance on patient cooperation and adherence to the tapered dosage of prednisolone administration could potentially lead to better surgical outcomes when using the dexamethasone insert (60).

A retrospective investigation which concluded in 2021, found that these methods are often used in combination to treat pain and prevent postoperative complications. Researchers looked at 18 individual cases seen by the same physician over the course of 26 years and noted that there was no single common treatment to reduce symptoms in those who developed dry eye syndrome and corneal pain (52). However, many individuals were able to achieve relief through combinatory therapy, often including topical and oral analgesics and anti-inflammatory medications, bandage lenses, and artificial tears (52). In some instances, multiple publications note the use of gabapentin or tricyclic antidepressants was also used in this multimodal treatment approach to alleviate the negative effects of LASIK treatment, such as corneal nerve pain (52, 61, 62). Additional modalities for the reduction in symptoms post-surgery, including those listed above, as well as the potential for standard cooling therapy for a reduction in inflammation and notes that the inflammatory response control is vital in the reduction of these negative side effects (57).

## Conclusion

Laser vision correction is a growing field and one that has proven to be both an effective and safe method of visual improvement for the past 27 years. Several technological advancements have been made since its emergence, and the process is now quick, involves minimal pain, and entails a quick recovery (63). However, as with all minimally invasive procedures, there are risks associated with the outcome; intraoperative risks include but are not limited to flap abnormalities, flap displacement, vertical gas breakthrough, opaque bubble layer formation, and intraoperative bleeding (25, 49, 32). Common postoperative risks are adverse visual changes, vision acuity regression, and dry eye disease (33, 44). Rare postoperative risks such as high-grade epithelial ingrowth corneal ectasia require immediate medical intervention (37, 40). In many cases, candidates who are not suitable for the LASIK procedure have access to alternative methods of vision correction. Some of these options include (but are not limited to) LASEK, PRK, SMILE, and Epi-LASIK (45).

As for clinical trial research, many current studies aim to compare LASIK to alternative treatments and therapies; however, several still look at postoperative treatment for pain and other negative symptoms, as well as methods to increase healing and recovery. Several topical drugs already exist or are in clinical trials for approval for use during surgery or recovery, including lidocaine and diclofenac sodium (56, 58). Extended-release dexamethasone inserts show promising effects due to their anti-inflammatory components as well as reduced reliance on patients' adherence to self-administered medication schedules (59, 60). Additionally, the use of bandage lenses shows promise as a means of protection and added stability for the epithelial flap during the healing process and has led to an elevated healing response (53, 55). The most current literature supports the recommendation for a combinatorial approach when treating post-LASIK effects and notes that no one-size-fits-all approach has been found to be routinely effective (52).

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## Disclosures

We have no conflicts of interest to disclose.

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