Surface Ablation – A Review

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Abstract: Excimer surface ablation techniques for refractive error correction have become popular, mainly in patients with a possible risk of complications after lamellar surgery. Improvements in the understanding of corneal biomechanics, wound healing modulation, laser technologyincluding ablation profiles and various methods of epithelial removal have expanded the scope for surface ablation. In this review, we describe the preoperative assessment, techniques (photorefractive keratectomy, laser assisted sub-epithelial keratectomy, epithelial laser-assisted in situ keratomileusis), outcomes, andcomplications of surface ablation techniques. Surface ablation techniques will continue to evolve, with potential improvements in results accompanying future sophisticated ablation profiles and advanced laser technology.

Keywords: excimer laser, PRK, epi-LASIK, LASEK, photo refractive keratectomy, surface ablation.

Introduction

Correction of refractive error using excimer laser energy was initially introduced in the form of photo refractive keratectomy (PRK).[1] Surface ablation is a term referring to the application of excimer laser directly on to the anterior stromal surface. The excimer laser is applied to the stroma after the epithelium is removed. There are various ways in which the epithelium can be separated from Bowmans layer and then the epithelium is either discarded or fashioned as a flap and replaced. Surface ablation does not require intra-stromalflap formation and therefore has no risk offlap - related complications, flap-induced higher order aberrations, diffuse lamellar keratitis and epithelialin growth. Also, there is minimal risk ofect asia than with other modes of refractive surgery. However, surface ablation is associated with haze formation, especially in corrections of higher refractive errors, and may need modulation of the wound healing. The main excimer surface ablation techniques include PRK, trans-epithelialPRK (t-PRK), laser-assisted sub-epithelial keratomileusis (LASEK) and epithelial laser-assisted in situ keratomileusis (epi-LASIK).[2]

Preoperative assessment, indications and contraindications

The preoperative assessment of a potential candidate for refractive surgery comprises a complete ophthalmic, medical and occupational history as well as a comprehensive ophthalmological examination including refraction, tonometry, slit-lamp examination, fundus examination, corneal topography, pachymetry, pupillometry and aberrometry.

Indications

(1) Correction of myopia (up to -10 dioptres [D]), hypermetropia (up to +6 D), and/orastigmatism (up to 4 D)[3] (although this differs between surgeon and laser)

(2) A better option in situations like treatment of patients (eg. army personnel, contact sport athletes, those involved in martial arts/boxing) with risk of LASIK-flap complications[4,5]

(3) Patients with relatively large pupils (who may suffer from glare and halos in the event of flap decentration and an abrupt border of their wider-than-the-flap-diameter ablation)[6,7]

(4) Patients with recurrent corneal erosions, anterior basement membrane dystrophy and corneal surface irregularities[5,8]

(5) Patients with laser-assisted in situ keratomileusis (LASIK) complications in fellow eye[5,8]

(6) Patients with very deep-set eyes, small palpebral fissures, or very prominent orbital roofs[8]

(7) Chronic blepharitis patients, mainly if lid massages are required[9]

(8) Patients with veryhigh or low keratometry readings, low pachymetry,and situations that may predispose to irregular, thin,or buttonholed flaps[10-12]

(9) Patients with previous surgery involving the conjunctiva (e.g. trabeculectomy bleb, scleral buckle)[5,8]

Contraindications

Absolute contraindications include keratoconus, active infection of cornea and conjunctiva, previous herpes zoster ophthalmicus infection and severe dry eye.[3] Relative contraindications include unstable progressive myopia, irregular astigmatism, herpes simplex keratitis, previous corneal surgery, active, recurrent or residual ocular disease, corneal scar, uveitis, retinopathies and significant lagophthalmos. Also, a risk of developing glaucoma later shouldbe taken into consideration because of potential difficultieswith intraocular pressure measurements aftercorneal refractive surgery.[13]

Systemic diseases such as diabetes mellitus, atopy, pregnancy or lactation(hormonal effects could alter refractive errors), connective tissue diseases (systemic lupus erythematosus, rheumatoid arthritis) may be consider edrelative contraindications, if uncontrolled. Patients with uncontrolled diabetes may suffer from poor epithelialhealing and may have an unstable refractive error. Patients with autoimmune disease may also suffer poor or inadequate healing, activation of associated ocular disease and severe dry eye.[2,14]

SURFACE ABLATION TECHNIQUES

PRK

PRK is performed by complete removal of the corneal epithelium and basement membrane using mechanical debridement, alcohol-assistedremoval, laser-assisted removal (t-PRK) or a combination of these methods.

Mechanical epithelial debridement

The epithelium is removed either with a blade or with a brush such as an Amoil's rotary brush and then moistened by a damp polyvinyl acetate (PVA) sponge immediately before excimer laser treatment to equalize the distribution of fluid on the cornea .[15,16] The anterior cornea lstroma is then reshaped by photo ablation using a 193 nm or 213 nm argon-fluoride excimer laser.[17] A bandage contact lens (BCL)is applied until the epithelium is healed(typically after 3 to 5 days).[18] The outcome of this technique is influenced by the wound healing response as the central Bowman layer is ablated.[19] Sometimes, the wound-healing response leads to a regression of the desired effect over time and also the formation of subepithelialhaze.[20,21] Higher intended corrections may lead to less predictable outcomes, accompanied by an increased formation of subepithelial haze.[22]

Alcohol-assisted epithelial removal

18–20%ethanol is placed inside a 7–9.5 mm central corneal well (to avoid spillage on the untreated areas)for 20–40 seconds.[23] The alcohol is then absorbed with a dry PVA sponge and residual alcohol is washed away. After drying the surface, the loosened epithelium is then peeled off the surface (epitheliorhexis) using a dry sponge, blade or a specially designed epithelial scrape and discarded. Some refer to this technique as epithelium-off LASEK. Reports reveal that epithelial removal using alcohol is safe, fast, and easy to perform compared with mechanical debridement. Also, this technique can produce sharp wound edges with a clean, smooth Bowman layer and that the central epithelium can be translocated in part or en toto.[24,25]

Trans-epithelial PRK

The epithelium is removed using excimer laser. The cornea undergoes an epithelialablation within a fixed diameter. The lights of the operating room are turned off as blue fluorescent light is emitted to ablate the epithelium. Disappearance of the blue fluorescence indicates that the epithelium has been removed.[26]Accuracy of this technique depends upon regular epithelial thickness across the treatment zone and similar epithelial thicknesses between two eyes. This technique can provide variable outcomes when laser surface enhancement is proposed after previous refractive surgery due to areas of epithelial hyperplasia causing variable epithelial thickness.[2,26]

LASEK

This technique was described independently by Shah (who named this Epiflap), Azar and Camellin, who all performed this initially in 1996 .[27-29] The aim of LASEK is to preserve the epithelium so that visual rehabilitation can be accelerated and corneal haze can be reduced. Four primary techniques have been described. In the Azar flap technique, multiple marks are made around the corneal periphery.[30] Alcohol is applied to the corneal surface using a corne almarker and is absorb edusing a dry cellulose sponge after 30 seconds. One arm of a modified Vannas scissors is then insert edunder the epithelium and traced around the delineated margin of the epithelium, leaving a hinge of 2-3 clock hours of intact margin, preferably at the 12 o'clock position. The loosened epithelium is peeled as a single sheet using a PVA sponge, leaving it attached at its hinge. After performing stromal laser ablation, an anterior chamber cannula with balanced salt solution (BSS) is used to hydrate the stroma and epithelial flap. The epithelial flap is replaced on the stroma using the cannula under intermittent irrigation and care is taken to realign the flap using the previous marks without causing epithelial defects. The flap is then allowed todry for 2 to 3 minutes and a BCL is placed.

The Camellin technique uses a sharp, partial thickness trephination of the epithelium prior to the application of alcohol to allow better diffusion into the epithelium.[29] The Vinciguerra butterfly technique creates a thin para central epithelial line from 8-11 o'clock, whereby a spatula is used before application of alcohol.[31,32] The epithelium is separated from Bowman layer, proceeding from the center to the periphery on both sides. After drying the surface, excimer laser ablation is performed.

The McDonald technique is alcohol free: A round cataract blade is used to make a small linear abrasion through which a LASEK spatula is slipped. Using that hole as a fulcrum, a spatulating motion is made and the epithelium peeled off. A dedicated curved cannula is slipped under the epithelium and a tear substitute is injected to create a dome in the epithelium. The raised epithelium is bisected with a Vannasscissors and parted sideways before stromal ablation.[33]

Epi-LASIK

A mechanical deviceor epikeratome with a blunt blade is used to separate the epithelium.[34] However, it needs a vacuum suction ring. After irrigating with BSS, the corneal epithelium is dried using a sponge and the cornea is marked peripherally with a standard LASIK marker. The sub epithelial separator is applied to the eye and suction is activated by a foot pedal. The oscillatingblade separates the epithelium producing approximately a flap of 9 mm, leaving a 2–3 mm nasal hinge.[35] After removing the suction ring, the epithelial sheet is reflected nasally using a moistened sponge to expose the corneal stroma for ablation. After stromal ablation, the cornea is irrigated with BSS and the epithelial sheet is repositioned with the help ofthe markings and adhered for 2–3 min. ABCL is then placed. Many surgeons use epi-LASIK for definitive epithelial removal and the epithelial flap is not repositioned following excimer laser ablation .[36-38] This approachis a variant of PRK.

Epi-Bowman Keratectomy

Epi-Bowman keratectomy is a novel variant of PRK. Instead of a metallic blade, an instrument with a copolymer tip is used to remove the epithelium layer by layer. [39]

WOUND HEALING EFFECTS

Visual rehabilitation after surface ablation and subsequent haze formation depend upon re-epithelialization.Healing of the cornea is initiated by the release of inflammatory cytokines such as interleukin-1, tumour necrosis factor alpha and Fas ligand by the damaged corneal epithelium.[40] This in turn, leads to apoptosis of the underlyingstromal keratocytes at the damaged epithelium and also some distance into the stroma.[41] Reflex lacrimal gland secretionincreases both tear production and the concentration of various growth factors, which initiate and assist both epithelial and stromal healing responses.

After 12-24 hours of the initial injury, adjacent keratocytes start to migrate and proliferate within the anterior stroma, while inflammatory cells start to migrate into the region viatears and directly from limbal blood vessels.[42,43] Keratocytes, which migrate and proliferate within the anterior stroma, are prompted to transform into a myofibro blastic form through cytokines, such as hepatocyte growth factor released from the lacrimalgl and and transforming growth factor (TGF-b) from overlying epithelial cells. Migrating bonemarrow-derived monocytes may also transform into fibroblastic cells within the anterior stroma providing another potential source of cells to repopulate the anterior stroma.[44] Histologically, haze appears to be associated with highly reflective myofibroblastic cells and disorganized collagen deposition, which may be more responsive to treatment with anti-inflammatory agents.

The wound healing response is complex and subject to inter-individual variation, which can result in both delayed and excessive epithelial and/or stromal healing processes. The objective of refractive surgery is to produce a regular dependable healing process, which does not interfere with either the shape or clarity of the treated corneal surface.

Surface ablation techniques, which retain at least a partially intact epithelial basement membrane, might improve or regularize healing. Studies have shown efficacy in reducing the levels of TGF-b through the use of epithelial flap techniques when compared with PRK.[45] However, factors such as the retention of dead epithelial cells within the epithelial sheet, raise the potential to paradoxically prolong the immediate healing response, whereas transection and removal of the epithelial flap might allow relatively quick reconstitution of an epithelial surface with the regeneration of a new basement membrane; hence the use of epi-LASIK, which is aimed at the preservation of a healthy epithelial flap. The epithelial flap cleavage plane lies within the basement membrane between the lamina lucida and the lamina densa in LASEK, whereas the cleavage plane may lie under the basement membrane in epi-LASIK, depending on the device used .[38,46,47]

Adjunctive use of Mitomycin-C

Mitomycin-C (MMC) is a DNA alkylating agent, derived from Streptomyces caespitosus. It in hibits DNA/RNA replication, especially in rapidly dividing cells such as fibroblasts and can suppress wound healing. Its use as an adjunctive medication applied intraoperatively immediately after stromal laser ablation in PRK to suppress wound healing and there by reduce haze and regression of correction was first suggested by Talamo and colleagues over two decades ago.[48] Its efficacy has been proven both in experimental work and now through large-scale clinical usage. The advantages of low concentration, short duration of MMC (0.02%for 15–60 seconds) are evident, producing clear corneal stroma after the procedure whether used in conjunction with PRK, LASEK or Epi-LASIK. The resulting anterior corneal stroma, however, is significantly devoid of cellular repopulation even at 6 months after surgery.[49]

There is uncertainty regarding optimum concentrations and peri-operative application times. In a retrospective study, Thornton, Xu and Krueger reported less haze in eyes undergoing high myopic corrections, greater than -6.00 D and with an ablation depth deeper than 75 mm, treated with0.02% MMC compared to0.002%.[50] Concerning application times, Virasch and colleagues in a retrospective, comparative case series observed no significant difference in final visual acuity or haze with the application of MMC 0.02% for 12 seconds compared with 1 and 2 minutes.[51] In contrast, in a study of human eye bank eyes, Rajan and colleagues reported that the administration of MMC 0.02% for 60 seconds resulted in optimum modulation of corneal wound healing characterized by decrease dactivation of keratocytes and normal epithelial differentiation.[52]

Obviously, there are concerns regarding itsun known long-term complications. A better understanding of both the corneal wound healing and its response to the various surgical and therapeutic interventions are required to enable development in this field both to improve visual outcomes and to reduce complications.

POSTOPERATIVE MANAGEMENT

The objective of immediate postoperative manage mentis to promote epithelial healing, preserve the epithelial flap following LASEK or Epi-LASIK, reduce postoperative pain and minimize the risk of complications such as inflammation and haze.

Contact lens

A BCL protects the de-epithelialized cornea, decreases pain and may result in faster re-epithelialization. It is placed over the cornea until epithelialization is complete, which is usually by postoperative day.[4] Patients with a BCL soaked in ketorolac0.45% solution had less pain immediately after the surgery than patients with a regular BCL.[53] The use of a BCL can cause corneal hypoxia, especially with low-oxygen trans missibility BCLs (low Dk). Also, extended wear non-silicone hydrogel lenses and lowDk lenses may be associated with higher ratesof infection.[54]

Topical corticosteroids

Topical corticosteroids, ranging from fluorometholone 0.1% to prednisolone acetate 1%, may be used for some weeks following surgery to modify the inflammatory response. The healing epithelial defect and the BCL may both lead to sterile infiltrates, which can also be treated by topical corticosteroids. There is a thought that topical corticosteroids delay the normal healing response and visual recovery and hence are not used in all treatment regimes.[55]

Topical non-steroidalanti-inflammatory agents (NSAIDs)

Topical NSAIDs inhibit cyclo-oxygenase activity in the arachidonic acid cascade and thus reduce inflammation without the side-effects of steroids. Alcohol application for epithelial removal for PRK and epithelial flap construction for LASEK may cause up regulation of COX-2, expression of vascular endothelial factor and other pro-inflammatory cytokines.[56] Topical corticosteroids and NSAIDs are useful in these situations. However, NSAIDs also decrease prostaglandinsynthes is, which is essential for protein and DNA synthesis in epidermal cells and hence could have adverse effects on the corneal epithelium on long term application.[2] NSAIDs are therefore, commonly used in the initial 3-5 days postoperatively until epithelialization is complete. Also, they are highly effective in relieving pain following surface ablation.

Topical antibiotics

Topical antibiotics, such as fourth generation quinolones, provides broad spectrum activity against both Gram-negative and Gram-positiveorganisms. There is an increased risk of infection with the use of a BCL over a healing epithelial defect, so antibiotic cover is mandatory with BCL use.[2]

Tear substitutes

Surface ablation damages fewer corneal nerves than LASIK and hence induces fewer dry-eyesymptoms.[57] However, there is a vast variation in dry-eye symptoms mainly due to decreased corneal sensitivity and blinking rate, which can also occur after surface ablation.[58] Additional mechanisms that can worsen dry eye include toxic conjunctivitis medicamentosa from postoperative drops and a flatten edcorneal surface with altered tear flow dynamics.[59] It is advisable to use preservative free tear substitutes for an extended period.

OUTCOMES

The primaryoutcome measures of any refractive surgery are predictability, uncorrected distance visual acuity (UDVA), the stability of visual outcomes, loss of corrected distance visual acuity (CDVA), retreatment, and safety. There has been much debate in the literature as to which surface ablation technique issuperior. Clinical studies comparing the different surface ablation techniques are summarized in Table 1 .[60-70]

PRK has the most long-termresults, as it is the oldest surface ablation procedure. Hyperopic PRK results are often less reported than myopic PRK results.[71-75] An initial myopic over-correction is described, after hyperopic PRK which occurs within the first month and resolves between 3 and 6 months postoperatively.[72-75] The results of hyperopic surface ablation correction remain less accurate than those of myopic correction but continue to evolve. Clinical studies comparing surface ablation to LASIK are summarized in Table 2. [76,11]

COMPLICATIONS

Corneal haze

Haze is a typical association with corneal wound healing, starting at 4–6 weeks and then resolving by 6-12 months. [77] The altered keratocytes are transformed into myofibroblasts that deposit collagen and cause the type of dense haze that is persistent and defined asscar tissue. Sub-epithelial haze after PRK is believed to result from light scattered by scar tissue and is more severe with increased ablation depth.[78] Haze is measured subjectively by forward light scattering and has been graded by Hanna on afive-point scale 0–4+, with grade 2+ or more being classed as clinically significant enough to distort vision.3 It is hypothesized that there is reduced corneal haze with the LASEK and epi-LASIK techniques because the surface stroma gets protected from exposure to inflammatory cells in the tear film by the epithelial flap. Less inflammatory cell invasion causes less inflammatory damage and less corneal haze. Intraoperative use of MMC 0.02 % for 15 to 60 seconds is found to be usefulto reduce haze formation.[79,80] Some surgeons adviseoral vitamin C, 500 mg daily, in the postoperative period and others reserve MMC for the treatment of dense haze that is recalcitrant to topical corticosteroids. They first remove the epithelium, then scrape the underlying haze carefully before applying MMC with a sponge and finally, wash the eye thoroughly to avoid contact of other ocular structures with MMC. Another approach is cooling the ocular surface with an ice-chilled irrigation solution before and/orafter surface ablation to lessen the wound-healingresponse and thus haze formation and pain perception, though solid proof is unavailable.[59]

Pain

Early postoperative pain is the major limitation of PRK technique. The de-epithelialized cornea following PRK results in direct exposure of the nerve endings leading to pain.[81] It usually takes 3 to 5 days for the complete epithelialization of cornea. Various approaches to relieve early postoperative pain include the application of a BCL, use of a cold BCC, topical NSAIDs, topical cycloplegics, topical anaesthetics and oralanalgesics.[78,82] Topical NSAIDs have been associated with complications such as superficial punctate erosions, subepithelial infiltrates, epithelial defects and delayed corneal epithelial healing.[53] These complications are more often with diclofenac, which is no longer commonly used.[83,84] However, the safety of ketorolac ophthalmic solution has been well established by multiple studies.[85,86] Topical cycloplegics may reduce the pain over the first 2-3 days, although this has an effect on visual acuity monitoring.[2] Topical anaesthetics such as Tetracaine 1% used conservatively not more than 6 times for the first 24 hours postoperatively, can also help in relieving the pain.[78] Use ofa BCL soaked in Acuvail (a preservative-free solution containing carboxymethylcellulose and ketorolac tromethamine0.45%) has been shown to provide better analgesia for a longer time than conventional methods ofpain relief after trans epithelial PRK.[53] The adsorbed ketorolac on the BCL is released within the first hour after the concentration of drug is stable, thereby reducing the pain immediately after surgery.[53]

Infection

Infection after surface ablation is rare but potentially vision threatening. The risk for bacterial keratit is following surface ablation ranges from 0.01% to 1.0% and is likely significantly higher than after LASIK secondary to the creation of a large epithelial defect and the use of a BCL. Common organisms seen with keratit is include Staphylococcus aureus, coagulase negative Staphylococcus, and Streptococcus[11,87,88]. Antibiotic prophylaxis should exert adequate cover against these organisms. There have also been a few reports of fungal and my cobacterial keratitis after PRK and LASEK, implying that the size of epithelial defect is not the only factor[89,90].Viral keratitis has also been reported after PRK, though whether it is directly related is unknown.91,92Valacyclovir has been suggest edprophylaxis if there is a prior history of herpes simplex keratitis[93].

Ectasia

Ectasia is a rare condition in which the eye become sprogressively more myopic with irregular astigmatism, topographic steepening, corneal thinning and results in a loss of uncorrected and corrected distance visual acuity.[94] Iatrogenic ectasia occurring after refractive surgery has beendescribed as the most severe complication.3The risk for ectasia appears to be lower after surface ablation than after LASIK.[95] This complication is best avoided by careful patient selection.

Dry eye

The occurrence of dry eye following surface ablation is less compared to LASIK because surface ablation damages fewer corneal nerves than LASIK.[57] Reports show that there is faster rehabilitation of corneal sensitivity and tear function after surface ablation.[96,97] It is advisable to avoid topical medications with preservatives in the postoperative period. Permanent or temporary punctal occlusion may reduce severe dry-eye symptoms.[59]

Stromal incursion of the dull epitome blade

This complication is unique to epi-LASIK and may lead to a stromal defect resulting in irregular astigmatism with decreased visual acuity.[98] A flawless blade before epithelial flap preparation must be ensured to avoid this potentially severe complication. If the stroma is dissected as in LASIK, it is best repositioned and allowed to heal.

Incomplete epithelial removal

Incomplete removal of epithelium in PRK could be a cause for an irregular refractive result. Residual epithelium can be identified immediately as the epithelium fluoresces upon exposure to UV radiation. Delayed removal of the epithelium can lead to stromal hydration changes and unpredictive refractive results.[99]

Glare and haloes

Glare and haloes may be caused by the formation of corneal haze or may occur when the pupil diameter extends beyond the optical zone of excimer treatment. This usually occurs in low-light environments but may also occur in patients with large photopic pupils. Decentered ablation profiles may also lead to increased symptoms of glare and haloes. Decentrations less than1.0mm are likely to be visually insignificant, but tho semore than 1.0 mm can cause glare, halos, mono culardiplopia, and decreased vision.[100]

CONCLUSION

Surface ablation techniques appear to be useful for patients in need of refractive surgery, especially when the aim is to preserve 50-100 mm of corneal stroma. They may be indeed useful in selected eyes where LASIK is contraindicated. Refractive and visual outcomes are excellent and comparable to those after LASIK. Also, there is evidence to suggest that there may be less induction of higher-order aberrations with surface techniques. Long-term stability and safety are found to be satisfactory. However, surface ablation techniques are associated with more inconvenience, discomfort, and slower recovery than LASIK.

Disclosures: None of the authors has a financial or proprietary interest in any material or method mentioned.

Table 1. Clinical studies comparing the different surface ablation techniques

Study	Number of eyes	Surface ablation technique	Follow-up period	UDVA	Dioptres with attempted correction	Remarks
Lee et al.[60]	27	PRK	1 week 3 months	37% with ⩾20/25 56% with ⩾ 20/25		UDVA higher with LASEK; no significant differences in spherical equivalent; more haze and pain with PRK
	27	LASEK	1 week 3 months	57% with ⩾ 20/25 63% with ⩾ 20/25		
Pirouzian et al.[61]	32	PRK	1 week 1 month	Mean, 20/27 Mean 20/21		No significant differences in UDVA
	32	LASEK	1 week 1 month	Mean 20/28 Mean, 20/20		
Cui et al.[62]	140	PRK	1 month 12 months	44-96% with ⩾ 20/20 (Mean, 73%) 67-79% with ⩾ 20/20 (Mean, 70%)	24-79% within ± 0.5 (Mean, 43%) 57-92% within ± 0.5 (Mean, 64%)	No significant differences
	140	LASEK	1 months 12 months	52-82% with ⩾ 20/20 (Mean, 71%) 73-82% with ⩾ 20/20 (Mean, 75%)	29-71% within ± 0.5 (Mean, 47%) 70-88% within ± 0.5 (Mean, 74%)	
Teus et al.[63]	47	LASEK	1 day 1 week 1 month 3 months	87% with ⩾ 20/40 89% with ⩾ 20/40 100% with ⩾ 20/40 79% with ⩾ 20/20	89% within ± 0.5 95% within ± 1.0	UDVA better on 1st day and 1st month in LASEK; larger proportion of eyes within ± 0.5 of attempted

		Epi-LASIK	1 day 1 week 1 month 3 months	64% with ⩾ 20/40 87% with ⩾ 20/40 96% with ⩾ 20/40 66% with ⩾ 20/20	77% within ± 0.5 93% within ± 1.0	correction in LASEK; safety index better in LASEK; 9% LASEK lost >1 line CDVA; 15% epi-LASIK lost > 1 line CDVA
Hondur et al.[64]	25	LASEK	1 month 3 months 6 months 12 months	72% with ⩾ 20/20 80% with ⩾ 20/20 92% with ⩾ 20/20 92% with ⩾ 20/20	84% within ± 0.5 92% within ± 1.0 92% within ± 0.5 96% within ± 1.0 92% within ± 0.5 96% within ± 1.0	No significant differences
	25	Epi-LASIK	1 month 3 months 6 months 12 months	60% with ⩾ 20/20 80% with ⩾ 20/20 92% with ⩾ 20/20 92% with ⩾ 20/20	88% within ± 0.5 92% within ± 1.0 92% within ± 0.5 96% within ± 1.0 92% within ± 0.5 96% within ± 1.0	
Ghanem et al.[65]	51	PRK	2 days 2 weeks 1 month 3 months 6 months 12 months	Mean UDVA 20/59 96% with ⩾ 20/40 Mean UDVA 20/33 43% with ⩾ 20/20 100% with ⩾ 20/40 89% with ⩾ 20/20 96% with ⩾ 20/20 94% with ⩾ 20/20	8% haze 14% haze 16% haze 94% within ± 0.5 100% within ± 1 .0 8% haze	No significant differences; 2% LASEK lost >1 line CDVA; 0% PRK lost >1 line CDVA

	51	LASEK	2 days 2 weeks 1 month 3 months 6 months 12 months	Mean UDVA 20/72 92% with ≥ 20/40 Mean UDVA 20/33 43% with ≥ 20/20 100% with ≥ 20/40 89% with ≥ 20/20 96% with ≥ 20/20 94% with ≥ 20/20	14% haze 24% haze 26% haze 86% within ± 0.5 98% within ± 1.0 8% haze	
Kulkarni et al.[66]	163 361	Epi-LASIK (retained flap) LASEK (retained flap) Epi-LASIK	3 months 6 months 12 months 3 months 6 months 12 months	79% with ≥ 20/20 86% with ≥ 20/20 89% with ≥ 20/20 88% with ≥ 20/20 94% with ≥ 20/20 93% with ≥ 20/20		No significant differences; 8% Epi-LASIK lost > 1 line CDVA; 3% Epi-LASIK (flap off) lost >1 line CDVA;
	277 199	(discarded flap) LASEK (discarded flap)	3 months 6 months 12 months 3 months 6 months 12 months	89% with ≥ 20/20 92% with ≥ 20/20 94% with ≥ 20/20 76% with ≥ 20/20 86% with ≥ 20/20 86% with ≥ 20/20		4% LASEK lost >1 line CDVA; 7% LASEK (flap off) lost >1 line >1 line CDVA
Sia et al.[67] (contralateral eye study in moderate-high myopia)	84	PRK with MMC	1 month 3 months 6 months 1 year	44% with ≥ 20/20 76.2% with ≥ 20/20 93.5 % with ≥ 20/20 97% with ≥ 20/20	58.3% within ± 0.5 63.4 % within ± 0.5 81.8 % within ± 0.5 83.3 % within ± 0.5	1.3% PRK-MMC lost >1 line CDVA at 3 months 3.7 % PRK lost >1 line CDVA at 1

	84	PRK without MMC (fellow eye)	1 month 3 months 6 months 1 year	59.5 % with ⩾20/20 86.6 % with ⩾20/20 89.6 % with ⩾20/20 96.9 % with ⩾20/20	40.5 % within ± 0.5 63.4% within ± 0.5 72.7 % within ± 0.5 84.6 % within ± 0.5	month
	83	LASEK	1 month	63 % with ⩾20/20	48.8% within ± 0.5	1.4% LASEK lost >1 line CDVA at 3 months
Yuksel et al.[68]	22	LASEK	1 year	95 % with ⩾20/25		No significant differences
	20	Epi -LASIK	1 year	95 % with ⩾20/25		
Reily et al.[69]	100	PRK	6 months 1 year			Epi -LASIK has a slight advantage over LASEK and PRK in the early postoperative period considering
	100	LASEK	6 months 1 year			
	97	Epi -LASIK	6 months 1 year			pain; Epi - LASIK has less significant haze
Hansen et al.[70]	46	PRK with cooling	4.6 years (average)		63% within ± 1.0	PRK with cooling was more effective than LASEK in decreasing initial significant haze
	35	LASEK	6 years (average)		35% within ± 1.0	

UDVA = uncorrected distance visual acuity, PRK = photorefractive keratectomy,
LASEK = laser-assisted subepithelial keratectomy, Epi-LASIK = epithelial laser in situ keratomileusis,
CDVA = corrected distance visual acuity, MMC = mitomycin-C
(Adapted from Azar DT, Gatinel D, Ghanem RC, Taneri S. Refractive Surgery3rd ed. Elseiver Inc.; 2019.)

Table 2. Clinical studies comparing surface ablation with LASIK

Study	Number of eyes	Technique	Follow -up period	UDVA	Dioptres with attempted correction	Remarks
Randleman et al.[76]	136	ASA	1 day	54% with ⩾ 20/10		LASIK had statistically better UDVA until 3 months, when a larger proportion of ASA eyes had ⩾ 20/20
			2 weeks	29% with ⩾ 20/20		
				88% with ⩾ 20/40		
			3 months	82% with ⩾20/20	86% within ± 0.5	
				99% with ⩾ 20/20		
	136	LASIK	1 day	90% with ⩾ 20/40		
			2 weeks	58% with ⩾ 20/20		
				96% with ⩾ 20/40		
			3 months	71% with ⩾20/20	82% within ± 0.5	
				97% with ⩾ 20/40		
Ghadhfan et al.[11] (low -moderate myopia with SE < -6.00 D)	323	LASIK	< 1 year	55% with ⩾ 20/20 98% with ⩾ 20/40	91% within ± 0.5	No significant differences
	67	LASEK	< 1 year	48% with ⩾ 20/20 94% with ⩾ 20/40	84% within ± 0.5	
	49	m-PRK	< 1 year	74% with ⩾ 20/20 92% with ⩾ 20/40	92% within ± 0.5	
	37	t-PRK	< 1 year	65% with ⩾ 20/20 100% with ⩾ 20/40	95% within ± 0.5	
Ghadhfan et al.[11] (high myopia with SE -6.00 to -11.25 D)	141	LASIK	< 1 year	28% with ⩾ 20/20 85% with ⩾ 20/40	72% within ± 0.5	t-PRK more likely to achieve > 20/30 CDVA;
	37	LASEK	< 1 year	30% with ⩾ 20/20 84% with ⩾ 20/40	76% within ± 0.5	t-PRK more likely to achieve within ± 0.5

	20	m-PRK	< 1 year	25 % with ⩾ 20/20 80% with ⩾ 20/40	70 % within ± 0.5	D of attempted correction; 2.7% LASEK lost >1 line CDVA; 0.7% LASIK lost >1 line CDVA; 0% m -PRK, t-PRK lost >1 line CDVA
	22	t-PRK	< 1 year	36 % with ⩾ 20/20 95 % with ⩾ 20/40	95% within ± 0.5	

UDVA = uncorrected distance visual acuity, ASA = advanced surface ablation,
LASIK = laser in situ keratomileusis, SE = spherical equivalent, D = dioptres,
LASEK = laser-assisted subepithelial keratectomy, m-PRK = mechanical debridement photorefractive keratectomy,
t-PRK = transepithelial photorefractive keratectomy, CDVA = corrected distance visual acuity
(Adapted from Azar DT, Gatinel D, Ghanem RC, Taneri S. Refractive Surgery3rd ed. Elseiver Inc.; 2019.)

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Amazing Eye Facts

1. The eye is the fastest muscle in your body – hence why when something happens quickly, we say 'in the blink of an eye!'
2. While a fingerprint has 40 unique characteristics, an iris has 256. This is why retina scans are increasingly being used for security purposes.
3. Geckos can see colours around 350 times better than a human, even in dim lighting.
4. Dolphins sleep with one eye open.
5. The largest eye on the planet belongs to the Colossal Squid, and measures around 27cm across.
6. Most hamsters only blink one eye at a time.
7. Guinea pigs are born with their eyes open!
8. A worm has no eyes at all.
9. Some people have a fear of eyes; it's called ommatophobia