8 Small-Incision Lenticule Extraction

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Cornea refractive surgery began in the late 1970s and early 1980s with radial keratotomy (RK) and moved into the laser arena with the introduction of excimer laser (193 nm) ablation in the 1990s. The Food & Drug Administration (FDA) approval of photorefractive keratectomy (PRK) in 1995 represented the first excimer laser technique for vision correction. The PRK procedure afforded many advantages over the incisional RK procedure: higher predictability, improved safety, and better long-term stability. While the technique is still used today, recovery time is quite long with PRK as the technique requires removal of the corneal epithelium, which must subsequently heal and stabilize. Patients can expect about a month before their vision stabilizes. Laser in situ keratomileusis (LASIK) was developed in the early 1990s with the FDA approval occurring in 1999. The stromal flap created as the first step of this procedure affords overnight recovery with outstanding vision on postoperative day 1. The second step of the procedure is the same as the PRK excimer ablation. The fast recovery, coupled with predictability, safety, and long-term stability equivalent to PRK, led to the ascension of LASIK as the procedure of choice for laser vision correction. To date, more than 40 million LASIK procedures have been performed worldwide. AQ 1

Nevertheless, the penetration of laser vision correction amongst myopic patients throughout the world remains very low. In the United States, for example, in 2012, approximately 700,000 eyes were treated, representing only 1.2% of the population pool.[1] Despite the outstanding safety record of LASIK, fear remains the major barrier to entry for the majority of potential vision correction candidates. These fears revolve around the existence of the flap, concerns over complications, and simply the concept of having laser surgery on one's eyes.

The Small-Incision Lenticule Extraction (SMILE) procedure was developed in the late 2000s and utilizes a single femtosecond laser to create a lenticule-shaped piece of corneal stromal tissue, customized to a patient's refractive correction. The laser also creates a small surface incision through which the lenticule is extracted without the creation of a flap. The SMILE procedure was FDA approved for

spherical myopic treatments in October 2016. In March 2018, the procedure was approved for myopic astigmatic treatments. At the time of publication, SMILE is gaining popularity throughout the world with more than 4 million procedures performed. SMILE may be an attractive alternative to LASIK for those patients fearful of laser surgery: no flap, no sound (excimer laser makes sound), no smell (odor of vaporized corneal tissue from excimer ablation), no pressure (negligible pressure associated with the VisuMax femtosecond laser), and shorter procedure time relative to LASIK. In addition, because there is no flap and the incision is so small, there are virtually no postoperative restrictions on lifestyle. There is also strong evidence that the severity and duration of dry eye symptoms is less with SMILE than LASIK.[2,3]

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Key Indications:

- *Myopia and myopic astigmatism:* −1.00D to −10.00D in spherical power with −0.75D to −3.00D in astigmatic power with manifest spherical equivalent of no more than −10.00D (FDA-approved ranges)

Key Contraindications:

- *Keratoconus or other corneal ectatic disorders:* Normal corneal tomography (and regular epithelial thickness maps if available) is essential for clearing patients for any corneal refractive surgery.

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- *Previous herpes simplex keratitis:* Contraindicated if active disease within 1 year. If more than 1 year, check corneal sensitivity and use oral antiviral medication prophylaxis before and after surgery.
- *Active autoimmune disease:* Lupus, rheumatoid arthritis, Sjogren's syndrome
- *Severe aqueous deficient dry eye*
- *Pregnancy or nursing:* Vision can fluctuate during pregnancy. In addition, antibiotic eye drops are used for several days after surgery while steroid eye drops are used for 7 to 10 days following surgery. There may be some systemic absorption of these medications that could affect the fetus and/or be present in breast milk.
- *Current isotretinoin (Accutane) use*
- *Unrealistic expectations*

Relative Contraindications:

- *Cataract:* Corneal refractive surgery is a good option for patients into their mid-50s with mild, nonprogressive cataract due to risk of retinal complications from refractive lens exchange. Progressive myopia and/or astigmatism changes on manifest that do not match corneal astigmatism usually indicate need for cataract surgery
- *Glaucoma:* If intraocular pressure (IOP) is well controlled with minimal visual field loss, SMILE surgery can be safely performed. It is important to take note of change in corneal thickness as this has an impact on IOP measurements: measured IOP will be lower than actual IOP following myopic corneal refractive surgery.[4] Intraoperative IOP elevation associated with VisuMax laser docking is the lowest of any femtosecond laser and is not a contraindication for patients with mild glaucoma.
- *Optic nerve head drusen or crowded optic nerve:* PRK is not associated with increased IOP as there is no suction ring required and it has been considered a safer option relative to LASIK in this setting. However, the VisuMax affords the lowest increase in IOP of any femtosecond laser or microkeratome at levels that are negligible.[5,6]
- *Epithelial or anterior stromal dystrophies:* PRK may be a more appropriate treatment as it has the therapeutic effect of removing opacities and/or increasing adherence of corneal epithelium in basement membrane disease. LASIK is contraindicated in granular corneal dystrophy type 2 (Avellino corneal dystrophy). There are no reports of SMILE in Avellino corneal dystrophy, but corneal opacities are a relative contraindication (see in the following section).
- *Fuchs' endothelial dystrophy:* Endothelial cell count should be performed before surgery in patients with corneal guttata. Low endothelial cell count places the patient at risk of poor settling of the tissues on either side of the SMILE interface, leading to increased corneal back scatter and poor-quality vision.
- *Corneal opacity:* Any opacity can alter the efficacy of femtosecond laser cutting. Because the laser energies for SMILE are significantly lower than those used for a LASIK flap, care must be taken to identify any significant opacity that will fall within the lenticule zone as treatment can lead to an uncut area, making dissection and lenticule removal challenging.
- *Depression or anxiety conditions if not stabilized:* This is an important relative contraindication for all refractive surgical procedures.
- *Uncontrolled Diabetes:* These patients have a higher risk of infection and slower healing response. Of the corneal refractive procedures, SMILE has the smallest incision and, thus, has the quickest healing time, minimizing the infection risk relative to LASIK or PRK.

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Key Informed Consent Adverse Events:

- Infection
- Glare, halos, starburst from irregular astigmatism (decentered treatment, retained lenticule fragment)
- Suction break requiring conversion to LASIK, PRK, or postponement of surgery
- Residual myopia and/or astigmatism
- Consecutive hyperopia and/or astigmatism
- Corneal ectasia

Informed consent should include a description of the procedure in plain language. For example, "A laser will be used to create a lens-shaped piece of tissue (lenticule) within the cornea (front window of the eye). This lenticule, customized to your prescription, will then be removed by your surgeon through a small surface incision, also created by the laser. By removing this lenticule, your cornea will be flatter and rounder, thus improving your vision without glasses or contact lenses."

Potential alternative treatments, such as LASIK, PRK, phakic intraocular lens implantation, glasses, and contact lenses, should be listed.

A note from the counseling physician should be included and phrased similar to, "I have counseled this patient as to the nature of the proposed procedure, the attendant risks involved, and the expected results." The patient's and doctor's name should be printed and signed with the date as well as with a witness (typically a staff member).

Key Preoperative Considerations:

- Medical history including diagnoses and medications
- Ophthalmic history including diagnoses, drops, and previous surgery
- Contact lens history (e.g., type of lens, wearing and cleaning habits, date of last use)
- Corneal tomography including back surface imaging
- Ocular dominance
- Pupils
- Cover testing at distance and near, with and without glasses, and ocular motility testing
- Confrontational fields testing
- Monocular and binocular uncorrected distance visual acuity (UDVA)

Key Preoperative Considerations:

- Monocular and binocular uncorrected near visual acuity
- Lensometry of current spectacles and corrected distance visual acuity (CDVA)
- Distance-corrected near vision for myopic patients over 40
- Distance manifest refraction
- Slit-lamp examination including fluorescein staining, taking note of location, size, and depth of any corneal opacities
- Tear break-up time
- Goldmann applanation tonometry
- Cycloplegic refraction and CDVA (after dilation with 1.0% tropicamide)
- Dilated fundus examination using slit-lamp and binocular indirect ophthalmoscopy

As with all refractive surgical techniques, the manifest refraction is the cornerstone to a successful SMILE outcome. Consistency in refraction is critical and, therefore, it is desirable to have the same refractionist performing the measurements on all patients. Variations in refraction technique can account for differences in endpoints, which can lead to variability in outcomes. Binocular balance is important to reduce the possibility of postoperative anisometropia. Patients with spectacle- or contact lens–corrected vision rarely need to deal with anisometropia: the power of the spectacle lens or contact lens can be easily adjusted to bring both eyes to a plano endpoint. Since spectacle-/contact lens–corrected patients are not used to it, anisometropia following refractive surgery can be quite noticeable, particularly in the immediate postoperative period. Cycloplegic refraction is particularly important in younger patients who are susceptible to over-minusing. Care should be taken to identify amblyopia in patients with significant anisometropia, asymmetric astigmatism, and a history of strabismus. It is important to counsel amblyopic patients so that they understand the laser procedure cannot fix the "wiring of the eye to the brain", which limits the ultimate visual acuity.

PROCEDURE AND SETTINGS

Video 8.1 shows the key steps of the SMILE procedure. There are two components:

1. Laser treatment
2. Lenticule dissection and removal

The VisuMax laser has two microscopes (laser and operating) one for each of these steps (Figure 8.1).

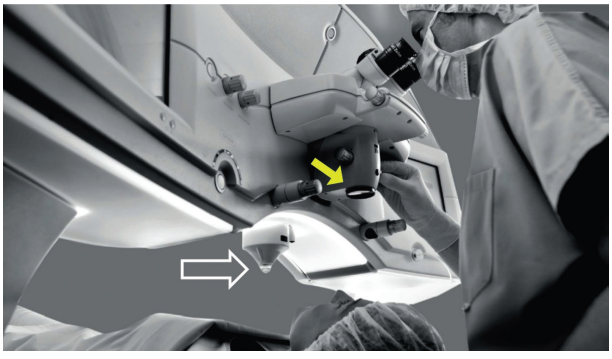

FIGURE 8-1 The VisuMax femtosecond laser (Carl Zeiss Meditec, Dublin, CA) includes two microscopes: A laser microscope (open white arrow) for visualization of the laser creation of the lenticule and an operating microscope (yellow arrow) for visualization of the cornea during lenticule dissection and removal. Photo courtesy of Carl Zeiss Meditec.

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Laser Treatment

Preparation of the Eye

Surgeons may choose to premedicate the patient with an oral anxiolytic agent such as alprazolam 0.5 mg. One drop of proparacaine is placed in each eye of the patient in the preoperative area. Once the patient is positioned on the laser bed, a second drop of proparacaine is placed and the patient is asked if there was any stinging. While it is obviously important to anesthetize the eye, it is also important not to use too much proparacaine as this loosens the corneal epithelium. Because there is some pressure placed on the posterior edge of the surface incision during lenticule dissection, epithelial sloughing can occur. If this occurs, there is some risk of introducing epithelium into the interface, which can lead to epithelial proliferation (much like epithelial ingrowth with LASIK).

The skin surrounding the eye is prepped with betadine swabs. A drop of antibiotic is placed in the eye. The lashes are draped and a lid speculum is placed.

The corneal surface is wiped clean using a Weck-Cel sponge soaked in sterile balanced salt solution (BSS). It is very important to confirm there is no material (e.g., mucous) on the cornea or the patient interface prior to docking. Any material trapped between the interface and the cornea can block the laser shots, resulting in "black spots," which represent tissue that has not been cut by the laser, leading to inability to dissect the lenticule in that area.

Centration

In LASIK flap creation, the femtosecond laser is not performing the refractive correction. Thus, centration of the flap is important but not as critical as with SMILE where the laser

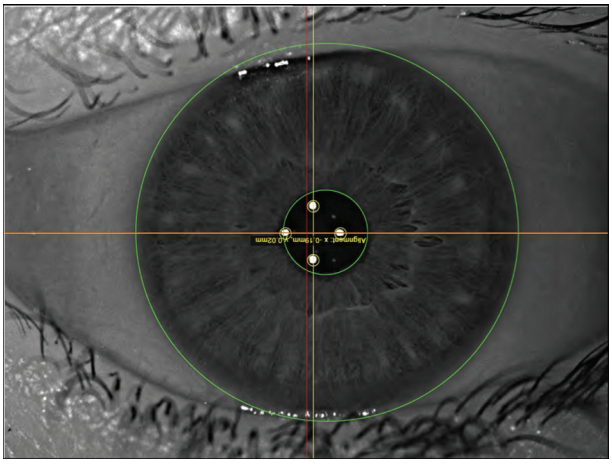

FIGURE 8-2 A verify image, such as this one from the Galilei G4 tomography system (Ziemer Ophthalmic, Port, Switzerland), is useful for the surgeon to confirm centration on the visual axis (cross hairs) when docking the laser to the patient's cornea prior to firing the laser.

is performing the refractive correction. Consequently, care must be taken to properly center the suction ring on the visual axis. Certain diagnostic systems (e.g., Galilei G4 Tomography system, Ziemer USA) take pictures of the iris and pupil with the position of the visual axis within the pupil identified with crosshairs (Figure 8.2). This picture can be printed and taken to the laser suite and used as a reference during docking. By noting the position of the visual axis relative to the pupil through the laser microscope, the surgeon can ensure the eye is appropriately centered during the docking procedure.

Docking

The VisuMax patient interface features a curved applanation glass that only touches the cornea (Figure 8.3). The pressure associated with docking is minimal. It feels like putting a contact lens in the eye of the patient. With no conjunctival touch, there is no subconjunctival hemorrhage with the VisuMax that is commonly seen with other femtosecond lasers that grab onto the conjunctiva.

Laser Treatment

Figure 8.4 shows the tissue planes that define the SMILE lenticule and the opening incision. The posterior aspect of the lenticule is cut first with the laser spiraling in from the periphery. The optical zone is 6.5 mm in the United States. This zone can be decreased to 6.0 mm in sphere-only treatments to remove less tissue. The depth of the posterior aspect of the lenticule is defined by the amount of refractive correction. Next, the lenticule side cut is created, followed by the cap cut (anterior

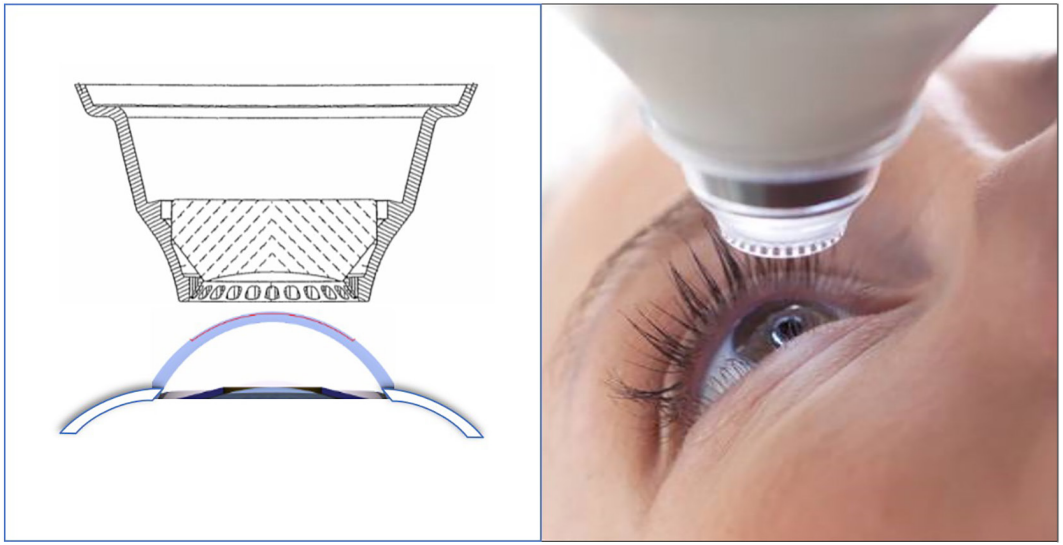

FIGURE 8-3 The disposable VisuMax Femtosecond (FS) laser contact interface only touches the patient's cornea, eliminating the possibility of subconjunctival hemorrhage, which is commonly seen with interface suction rings on other FS laser systems that grab onto the conjunctiva. In addition, the curved applanation window reduces the pressure experienced by the patient. Image courtesy of Carl Zeiss Meditec.
FS.

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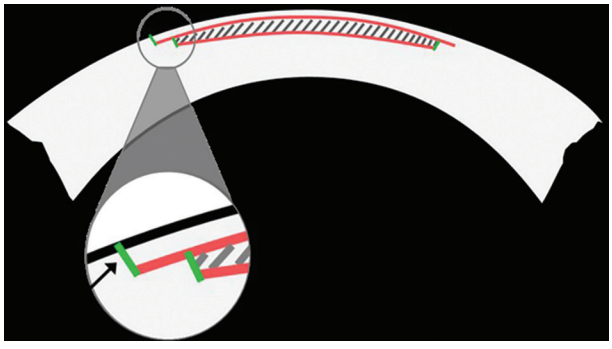

FIGURE 8-4 Schematic showing the posterior and anterior (cap) cuts, the lenticule side cut and the opening incision created by the VisuMax FS laser for SMILE. Image courtesy of Carl Zeiss Meditec.
FS; SMILE, small-incision lenticule extraction.

aspect of lenticule and cap zone). The cap cut proceeds from the center and spirals outward. The diameter of the cap is 7.5 mm in the United States or 7.0 mm if the optical zone is decreased to 6.0 mm in a sphere-only treatment. The depth of the cap is set at 120 microns in the United States. Finally, the opening incision is made superiorly, centered on the 12 o'clock meridian, at the peripheral aspect of the cap cut. This cut up to the corneal surface is typically 60° wide in the United States but can be increased to 90°.

If a suction break occurs during the posterior cut, the procedure should be converted to LASIK or PRK or postponed. If a suction break occurs during the cap cut, the eye can be re-docked using the same patient interface, and the procedure can be completed.

Lenticule Dissection and Removal

Once the patient interface is disengaged following laser treatment, the bed translates the patient under the operating microscope. During transit, the conjunctiva adjacent to the limbus where the surgeon will fixate the eye using forceps can be anesthetized with a cotton swab soaked in 4% lidocaine. A small dissector is used to open the surface incision and define the anterior and posterior planes of the lenticule. A spoon-shaped dissector is then used to separate the anterior plane of the lenticule from the cap. Finally, the dissector is used to separate the posterior plane of the lenticule from the posterior stroma, freeing up the lenticule, which is then removed from the interface. A sponge is used to smooth the anterior corneal surface and make sure there is no missing epithelium from the posterior edge of the surface incision. Antibiotic and anti-inflammatory drops are instilled, and the lid speculum is removed.

Key VisuMax Laser Settings

Choosing the appropriate VisuMax laser settings for SMILE is paramount in achieving an easy dissection and rapid recovery of vision following the procedure. There are two key parameters that can be adjusted: laser spot energy and spot spacing. The VisuMax laser fires 500,000 shots per second to perform the cutting of the lenticule. The higher the spot energy, the more overall energy deposition occurs. The closer the spot spacing, the more overall energy deposition occurs and the longer the procedure takes. If too much energy deposition occurs, opaque bubble layer (OBL) formation can occur. This can distort the tissues, block subsequent laser spots from having their full efficacy, and can lead to more challenging dissection with more tissue manipulation. This, in turn, can delay the visual recovery. Laser spot energy and spacing must be optimized for each individual laser installation. Once these parameters have been determined, the laser will typically perform in a consistent manner assuming temperature and humidity constraints are obeyed.

- *Minimum laser spot energy in the United States:* 125 nJ
- *Maximum laser spot spacing in the United States:* 4.5 microns

It is important to note that, prior to the FDA approval of myopic astigmatism in the United States, surgeons were limited to a 3.0-micron spot spacing. This dramatically increased the energy deposition (high energy), creating more OBL and prolonging the visual recovery (see "SMILE vs. LASIK" section for more details). The goal is to choose the minimum spot energy with the widest spot spacing (low energy) that allows for easy dissection of the lenticule. Care must be taken to avoid choosing too low of an energy, which, if below the plasma threshold of the tissue, will result in no cutting action and a lenticule that cannot be dissected.

POSTOPERATIVE CARE/COMANAGEMENT (FOLLOW-UP SCHEDULE)

Key Postoperative Considerations:

- Immediate postoperative period
- Postoperative drop regimen
- Postoperative limitations
- Treatments for dry eye symptoms
- Transient glare/halos
- Postoperative manifest refraction

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Immediate Postoperative Period

For 3 to 4 hours following surgery, the eyes are light sensitive, scratchy, and tearing due to the reepithelialization that needs to occur at the small surface incision. This is typically a shorter duration than what occurs with LASIK as the incision is only 60° instead of 300° wide. Patients can be given acetominophen/diphenhydrmine (Tylenol PM) following surgery. This, together with the alprazolam administered prior to surgery, assists the patient to sleep through this healing period. When they wake up, the vision will be foggy, like "in a sauna." This will persist for 1 to 3 days typically and is determined primarily by how much OBL occurred during the laser application and how much force was required to dissect the lenticule. The more force is required, the more microtrauma occurs with the interface tissues. This can lead to edema that can take several days to resolve. The edema leads to backscatter of light, causing the foggy vision. In rare cases with significant OBL and difficult dissection, foggy vision can last for several weeks. Post-operative day 1 slit lamp appearance will show ground glass appearance of varying severity, which correlates with level of vision (Figure 8.5). Even best corrected vision can be reduced on postoperative day 1 due to backscatter. AQ 8

Postoperative Drop Regimen

Prophylactic antibiotic drops (e.g., moxifloxacin) three to four times daily should be used for several days following surgery. Anti-inflammatory corticosteroid drops (e.g., prednisolone acetate 1%) should be used three to four times daily for at least 1 week following surgery. If significant OBL and/or challenging lenticule dissection occurs, a stronger steroid (e.g., difluprednate) and/or more frequent dosing should be implemented.

Postoperative Limitations

One of the most attractive aspects of the SMILE procedure for patients is the minimal need for lifestyle restrictions. Because there is no flap, there is no concern of a flap being shifted by rubbing the eye. Consequently, there is no need for the patient to wear goggles while sleeping for a week following surgery. There is also no need to limit the use of eye makeup beyond the first night after surgery. Also, for patients who are active, engaged in sports, which might involve taking a finger to the eye (e.g., basketball), there is no concern over a flap becoming dislodged. The small incision heals quickly, within a matter of hours. Thus, the risk of infection is minimal after the first 24 hours. Consequently, there is no need to limit activities such as swimming beyond a day or two.

Treatments for Dry Eye Symptoms

Dry eye symptoms include any combination of the following: transient blurred vision, particularly toward the end of the day and in patients who spend hours per

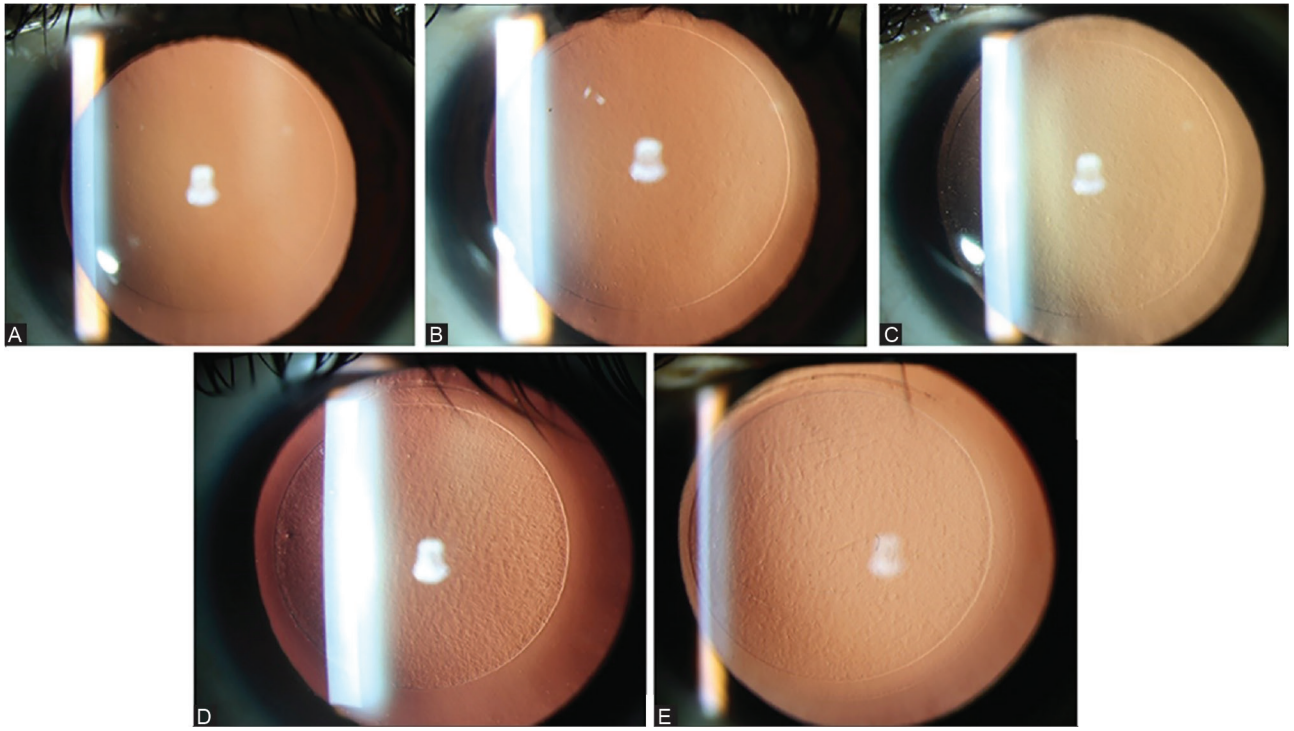

FIGURE 8-5 Retroillumination photographs after dilation showing the five templates of interface roughness grade. **A,** interface roughness grade—0 (clear), **B,** interface roughness grade—1 (mild interface roughness), **C,** interface roughness grade—2 (moderate interface roughness), **D,** interface roughness grade—3 (severe interface roughness), **E,** interface roughness grade—4 (severe interface roughness with Bowman's folds in the visual axis). Reproduced with permission from Sri Ganesh, MD, Department of Phacorefractive, Nethradhama Superspeciality Eye Hospital, Bengaluru, Karnataka, India.

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day looking at monitors or cell phone, intermittent sandy, gritty feeling, mild conjunctival redness, and reflex tearing. Patients undergoing LASIK should expect to experience some or all of these symptoms for 6 to 12 months following surgery, decreasing in severity and frequency as time goes by. This time frame is shortened to 1 to 3 months for patients undergoing SMILE because many fewer subbasal afferent corneal nerves are severed by the 60° small incision compared with the 310° LASIK side cut (Figure 8.6). Consequently, there are fewer nerves that need to regenerate which shortens the period of dry eye symptoms. Treatments include preservative-free artificial tears, punctal occlusion, topical cyclosporine 0.05% or 0.09%, topical lifitegrast 5%, or a short course of low-potency steroid (e.g., loteprednol 0.5%, fluorometholone 0.1%).

Transient Glare and Halos

Patients should understand that, with any refractive surgery, we are instantaneously changing the optics that their brain has become accustomed to. Much like the adaptation that occurs with a new pair of glasses, the patient will experience adaptation to their new optics following SMILE. Nighttime glare and halos may be noticed for several weeks to months following surgery, which will eventually subside as adaptation occurs. These halos are typically less than what is seen following LASIK for the same correction. This is due to slightly less induction of spherical aberration with SMILE compared to LASIK. See the "SMILE vs. LASIK" section for more details.

Postoperative Manifest Refraction

Accurate postoperative manifest refraction in SMILE patients is also very important, not just to confirm accuracy for individual patients, but also to record in a database to generate a surgeon nomogram. Nomograms for sphere and cylinder should be developed based on patient outcomes to improve consistency of refractive results for a given surgeon and laser installation. The accuracy of these nomograms relies on the accuracy of the manifest refraction. Postoperative manifest refraction data should be at least 45 days following surgery to be entered into a nomogram database. Once the surgeon has accumulated 40 to 50 eyes in the database, a nomogram equation can be generated. To use this, a desired sphere and cylinder correction is entered into the system. The nomogram inputs these entries as the "achieved" result and calculates, based on past results, what parameters should be entered into the laser to achieve the desired result. One such example of an outstanding nomogram system is the cloud-based "SurgiVision DataLink Zeiss Edition," which is made available to VisuMax-trained surgeons.[7] Another option that resides on a local computer is "Datagraph-med."[8]

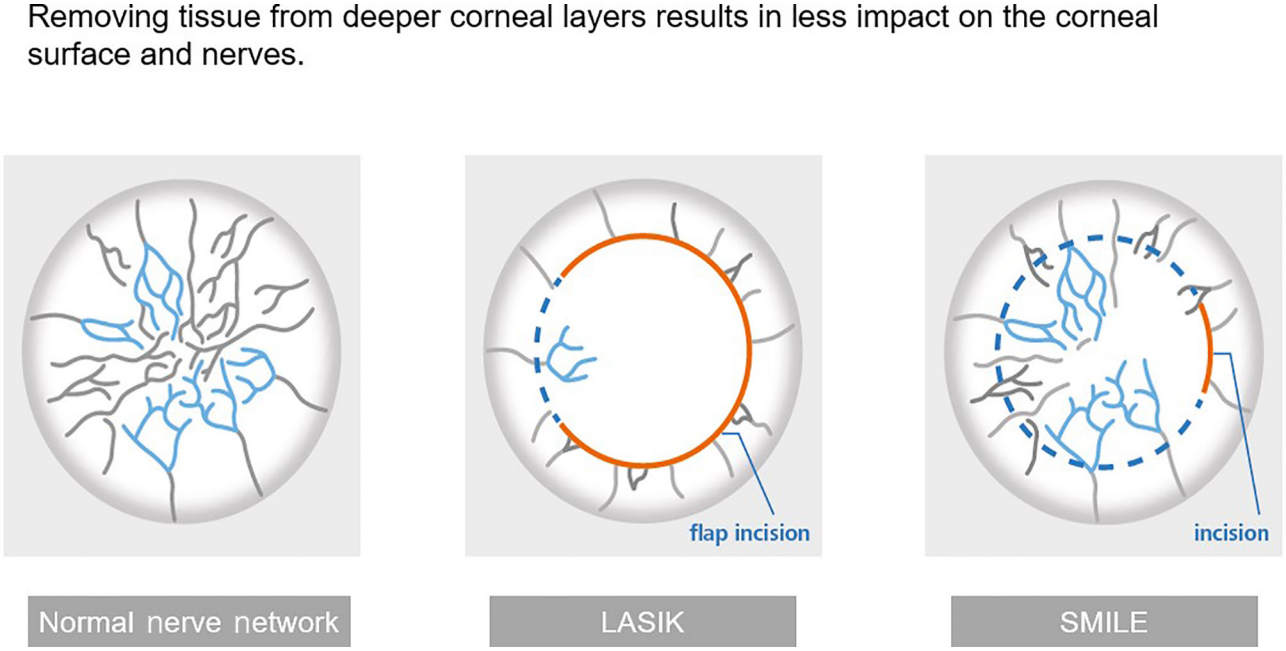

FIGURE 8-6 Schematic demonstrating the reduced severing of subbasal afferent corneal nerves with the small 60° SMILE opening incision compared with the 310° LASIK flap side cut. Image courtesy of Carl Zeiss Meditec.
LASIK, laser in situ Keratomileusis; SMILE, small-incision lenticule extraction.

POTENTIAL COMPLICATIONS AND THEIR TREATMENT

Key Complications to Look For the Following:

- Overcorrection
- Undercorrection
- Epithelial ingrowth/implantation
- Retained lenticule fragment
- Decentration
- Diffuse lamellar keratitis
- Corneal ectasia
- Infectious keratitis

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Overcorrection/Undercorrection

As with any refractive surgery technique, one can expect rare cases where the outcome differs from the intended target. Fortunately, for SMILE, the enhancement rate for patients appears to be roughly one third that of LASIK. In the author's experience, the enhancement rate is less than 1%. The reason for this low enhancement rate has to do with how the SMILE technique is fundamentally different than PRK or LASIK. Once the surgeon has passed the learning curve of the technique, the SMILE procedure is inherently less susceptible to variability in outcomes arising from amount of attempted correction or from differences in surgical technique. For example, the stromal bed is exposed to the air during the excimer ablation with both LASIK and PRK. The time of exposure is related both to the amount of correction and the technique of the surgeon. The differential tissue hydration that results from exposure to air can have an impact on the nomogram and outcomes. A higher correction with PRK/LASIK requires a longer ablation, more tissue drying, and potential overcorrection. In addition, certain excimer lasers correct sphere first followed by astigmatism. In higher myopic corrections, this may lead to variability in the astigmatic correction relative to lower myopic corrections. With SMILE, there is no exposure of the tissue being treated to air. In addition, the laser treatment time is identical regardless of the amount of sphere and cylinder correction is performed. Thus, the variability caused by tissue exposure is eliminated with SMILE. If clinically significant over- or undercorrection does occur, wait for 3 months for refractive stability and then enhancement can be done, either with thin flap (e.g., 90 micron) LASIK or surface ablation.

Epithelial Ingrowth/Implantation

The SMILE procedure requires a surface incision to allow for access and removal of the lenticule. The width of this incision is typically 60° in U.S. and smaller outside U.S. This is significantly smaller than the 310° side-cut incision used with a LASIK flap. While there is a theoretical risk of epithelial ingrowth occurring as a fistula of epithelium extending

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into the SMILE interface, that risk, as it relates to the width of the incision, is less than LASIK. With the advent of femtosecond laser flaps and the ability to create a 90° side-cut angle (vertical angle of perpendicular side-cut and lamellar flap plane), the incidence of epithelial ingrowth decreased dramatically rela-tive to that seen with microkeratome flaps where the side-cut angle was flatter. The SMILE side-cut angle can also be programmed to 90°, thus minimizing the epithelial growth risk. SMILE differs from LASIK in that there is friction placed on the poste-rior edge of the surface incision during lenticular dissection. This friction is not pres-ent during the LASIK flap lift maneuver. Consequently, particularly in older patients with loosened epithelium from topical proparacaine, there is risk of introducing epithelial tags into the SMILE interface. This epithelial implantation can produce an island of epithelial cells that can proliferate, leading to distortion of the corneal surface shape, inducing irregular astigmatism, and decreasing vision (Figure 8.7). The risk of these epithelial islands proliferating is lower than with traditional LASIK epithelial ingrowth where there is a fistula track continuously delivering fresh epithelial cells from the corneal surface. Observation is appropriate in patients who are asymptomatic and show no sign of focal cap thinning, which can occur when the epithelial cells thicken in the interface. Interface irrigation and removal can be easily accomplished if the patient is symptomatic and/or there is evidence of cap thinning.

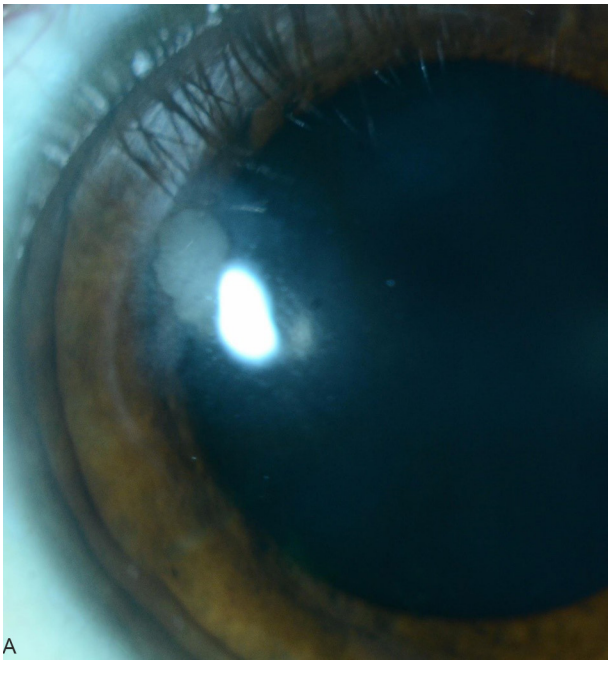
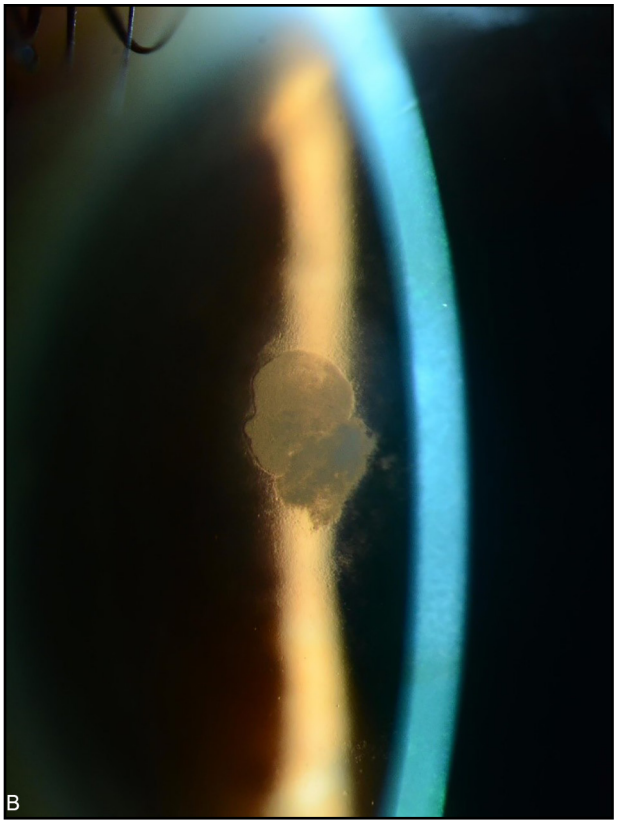


FIGURE 8-7 **A,** Front view of epithelial island resulting from epithelial implantation during SMILE lenticule dissection.



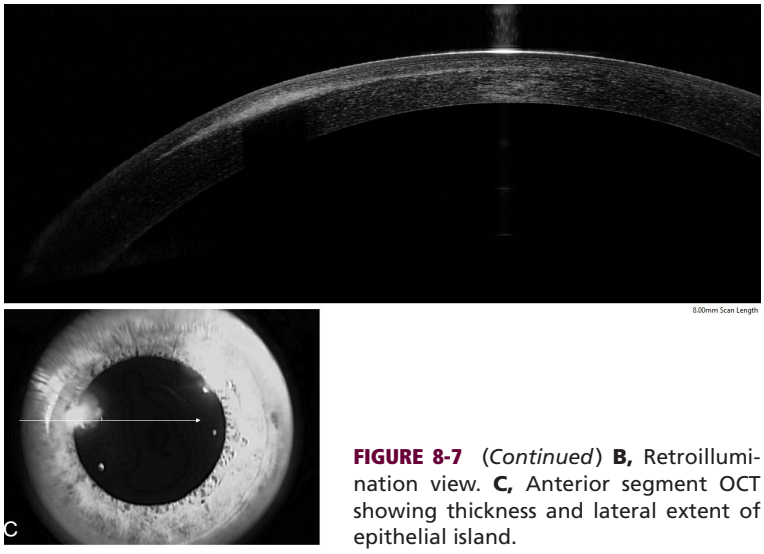


FIGURE 8-7 (*Continued*) **B,** Retroillumination view. **C,** Anterior segment OCT showing thickness and lateral extent of epithelial island.

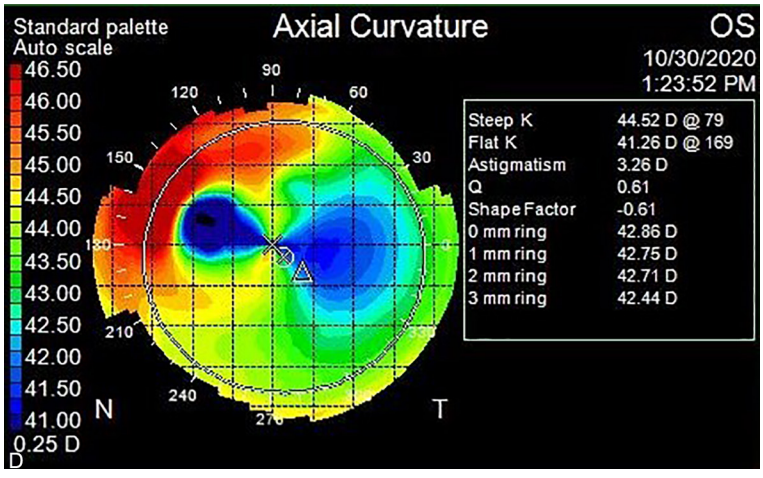


FIGURE 8-7 (*Continued*) **D,** Placido topography demonstrating significant induced with-the-rule irregular astigmatism. Images courtesy of Beeran Meghpara, MD, Co-Director, Refractive Surgery Department, Wills Eye Hospital, Philadelphia, PA.

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AQ 13 OCT, optical coherence tomography; OS, left eye; SMILE, small-incision lenticule extraction.

Retained Lenticule Fragment

Lenticule laceration can occur during dissection, leading to retention of a lenticular fragment. This can be identified at the time of surgery by smoothing out the removed lenticule on the corneal surface to confirm it is 100% intact prior to discarding the tissue. If the lenticule is not inspected upon removal, it is possible that a lenticular fragment remains in the interface. The most likely portion of the lenticule to be retained is a peripheral crescent. In myopic corrections in the United States, the edge thickness of the lenticule is set at 15 microns. Consequently, a retained lenticule crescent is likely to be very thin and will often have no impact on the patient's vision. Conversely, if a patient demonstrates decreased UDVA or CDVA, a tomographic exam showing curvature and pachymetry or an anterior segment optical coherence tomography exam can be helpful in identifying the presence and location of a lenticular fragment. These can then be removed under the operating microscope using dissecting instrumentation and forceps.

Decentration

When creating a flap for LASIK using a femtosecond laser, the flap needs to be reasonably centered to allow the entire excimer ablation, the refractive correction, to fit within the flap. The centration of the treatment, therefore, occurs at the excimer laser, typically using pupil tracking, not at the femtosecond laser. With SMILE, the refractive correction

is performed by the femtosecond laser, thus requiring more accurate centration than is required when creating the LASIK flap. Fortunately, the VisuMax docking design tends to auto-center the treatment on the visual axis. It is possible, however, to get a decentered treatment if the patient is not fixating appropriately on the target light as suction is applied or if the applanation cone is off center when suction is applied. The best way to confirm appropriate centration is to bring a photo into the laser room that shows the position of the visual axis relative to the pupil. This allows the surgeon a reference image to look at during the docking process, confirming that the fixation light (i.e. visual axis) is in the proper location relative to the pupil. Clinically significant decentration can manifest with a mild-to-moderate mixed astigmatic postoperative refraction, poor quality of vision, par-ticularly at night, and a decentered treatment zone appearing on postoperative topogra-phy. If the tomography systems capture corneal wave front information, significant coma will be observed. A topography-guided PRK procedure can be performed (off-label use of excimer laser) to correct some of the aberrations resulting from the decentration.

AQ 14

Diffuse Lamellar Keratitis

Diffuse lamellar keratitis (DLK) is exceedingly rare these days as standardized sterilization techniques have been established to eliminate DLK arising from endotoxin residue on instruments. Epithelial defects or hemorrhage can lead to DLK but these are usually mild and successfully treated with topical corticosteroid drops. If Stage II or III DLK is observed (e.g., wave of white cells in the interface extending into the visual axis or clumping of white cells in the interface), interface washout should be done with BSS as well as injection of corticosteroid into the interface, together with topical steroid drops. Oral steroids can also be added in severe cases of DLK.

Corneal Ectasia

The surface incision with the SMILE procedure, typically 60°, is much smaller than the larger flap incision with LASIK, typically 310°. As a result, the anterior stromal biomechanical strength is relatively preserved, thus reducing the risk of ectasia development in topographically normal eyes. This hypothesis is supported by mathematical modeling.[9] As SMILE matures and long-term follow-up becomes available, studies are looking at the incidence of ectasia at 3 years and beyond.

There are a number of recent papers presenting SMILE treatment for myopia greater than −10.0D. Follow-up ranged from 15 months to 3 years, with no ectasia reported in any of these studies.[10–12] A particularly interesting recent report presents 3-year data for a series of 495 eyes of Egyptian patients with preoperative myopia exceeding −10.0 D in which no eyes developed ectasia over the course of the study, despite the high incidence of keratoconus in the Middle Eastern population.[13]

A review of the literature from 2011 to 2017 found seven cases of ectasia after SMILE in 4 patients after 750,000 cases of SMILE had been performed worldwide. Two of the patients had abnormal topographies in both eyes, whereas only one eye of one patient with normal topography developed ectasia.[14] It is very important to

understand that even though the ectasia risk appears to be lower with SMILE than LASIK for an equivalent amount of correction on the same cornea, the identification of normal preoperative tomographic features is still requisite to avoiding the risk of ectasia with SMILE.

Infectious Keratitis

While exceedingly rare, infectious keratitis can occur, either with introduction of bacteria into the interface from contaminated instrumentation or migration of bacteria into the interface postoperatively prior to reepithelialization of the surface incision. Prophylactic antibiotics should be used just prior to surgery and should be continued for at least several days following surgery. Povidone-iodine prep should also be performed and eyelids should be draped prior to surgery.

VIDEO OF PROCEDURE

Video 8.1—This SMILE procedure uses a single femtosecond laser to create a lenticule in the anterior corneal stroma as well as an incision from the lenticule up to the corneal surface, through which the lenticule is extracted. The procedure begins with docking the laser to the patient's cornea. Care is taken to ensure proper centration over the patient's visual axis. The first cut performed by the laser is the posterior or "power" cut, proceeding from the corneal periphery toward the center. The depth of this cut is determined by the amount of nearsightedness and astigmatism being treated. The next cut, almost imperceptible, is the lenticule side cut. This cut is 15 microns in depth and occurs right at the edge of the power cut. The next cut is the anterior or "cap" cut, proceeding from the corneal center toward the periphery. This cut is currently fixed at 120 microns for lasers in the United States. Notice this cut extends peripheral to the power cut. This larger diameter facilitates the dissection of the lenticule. The final cut is the surface cut, always centered at the 12 o'clock meridian (at bottom of screen) and extends for 60°, allowing access for lenticule dissection. Following laser application, the patient bed translates to the operating microscope so that the surgeon can dissect and remove the lenticule. Lidocaine 4% is used to anesthetize the conjunctiva (swab to the right), allowing the surgeon to grasp the conjunctiva and Tenon's layer to fixate the globe. A dissector is then used to identify the anterior and posterior dissection planes. Following identification, the anterior lenticule plane is dissected first, followed by the posterior lenticule plane. Once the lenticule is freed up, the surgeon reaches in with microforceps and removes the lenticule in one piece. A circular merocel sponge is used to smooth out the cap. Antibiotic and anti-inflammatory drops are applied and the procedure concludes.

EFFICACY

SMILE versus LASIK

Refractive surgeons have become accustomed to rapid, overnight visual recovery, excellent accuracy, and long-term stability with the LASIK procedure. Since SMILE requires the expense of a specific laser (VisuMax) and involves a surgical learning curve to become comfortable performing the procedure, barriers are in place for refractive surgeons to adopt this newer technique. Yet, SMILE has advantages over LASIK regarding postoperative dry eye symptoms, corneal biomechanical properties, and attractiveness of the procedure (single laser, no sound, no smell, no flap). The first question that comes to mind when considering the new procedure is as follows: How do the results from SMILE compare with the stellar results achieved with LASIK? Will my patients still achieve that "WOW" factor I am used to with LASIK?

A study recently published by our group is the first to compare early postoperative SMILE results in eyes treated after the approval of myopic astigmatism correction and expanded energy settings (low energy) with those treated prior to the approval (high energy) and with results from wave front–optimized (WO) LASIK.[15]

The study comprises eyes from a single site in the United States treated by a single surgeon using SMILE and WO LASIK. Our group found that SMILE patients whose surgeries were performed with low energy had significantly better postoperative day 1 (POD1) vision (20/19.86) compared with high-energy patients (20/27.67) ($p < 0.001$). Moreover, the mean UDVA on POD1 for the low-energy SMILE group was equivalent to that of the WO LASIK group (20/19.50) ($p = 0.498$) (see Figure 8.2). Importantly, the percent of patients with UDVA 20/20 or better on POD1 was equivalent when comparing the low-energy SMILE group to the WO LASIK group (Figure 8.8). Furthermore, induced higher-order aberrations were equivalent between low-energy SMILE and WO LASIK at postoperative month 1 (POM1), with the exception of induced SA measured at a 6.0-mm optical zone (OZ), which was lower in the low-energy density SMILE group (0.136 μm) compared to WO LASIK (0.186 μm, $p = 0.034$). AQ 15

These improved outcomes underscore the importance of energy optimization when performing SMILE, a concept that is new to refractive surgeons, who are used to significant flexibility in femtosecond laser energy levels for LASIK flap formation. The bubble pattern appearance resulting from laser application during the SMILE procedure is useful to the surgeon both in anticipating the difficulty of dissection, but also to guide patient expectations for early postoperative visual acuity recovery (see Figure 8.9). By comparison, the bubble pattern appearance following LASIK flap creation using FS laser is much less important with regard to ease of flap dissection and typically has no impact on early postoperative visual acuity recovery.[13] AQ 16 AQ 17

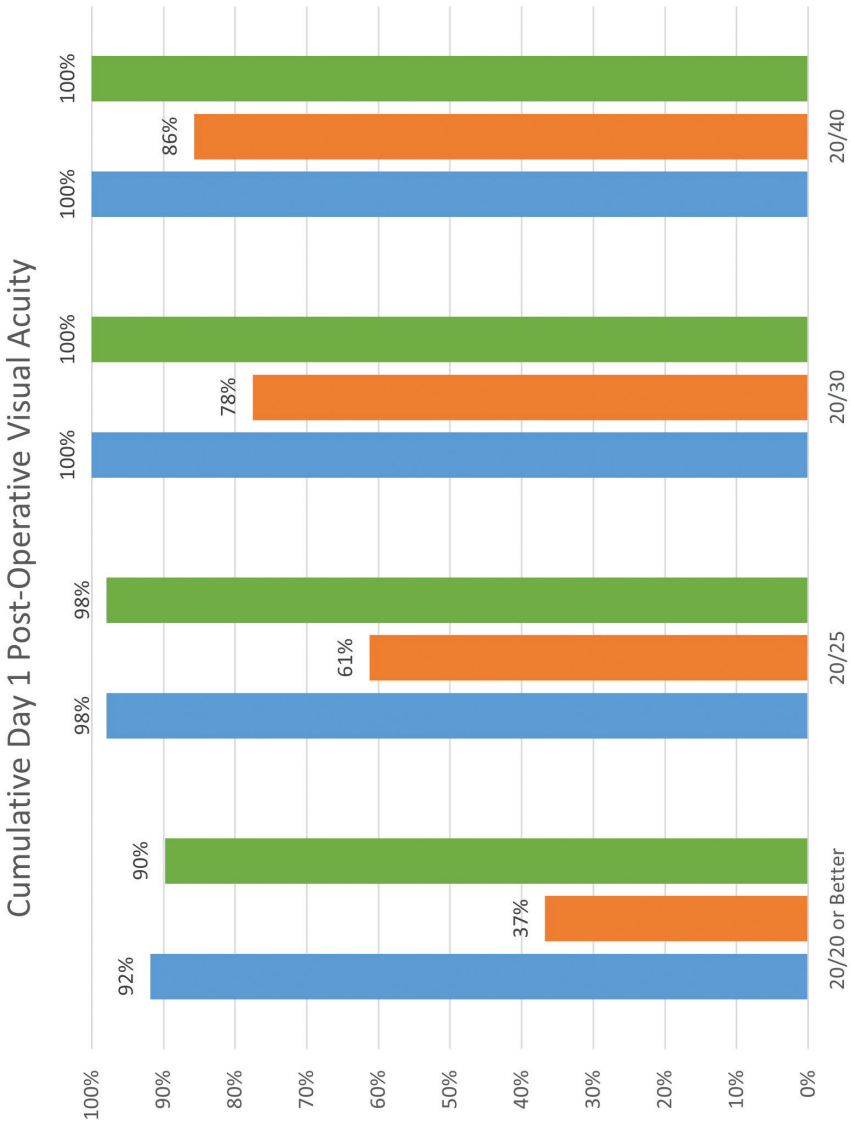

FIGURE 8-8 Cumulative postoperative day 1 uncorrected visual acuities (20/X): Comparison of LE SMILE, HE SMILE, and WO LASIK.
HE SMILE, high-energy small-incision lenticule extraction; LE SMILE, low-energy small-incision lenticule extraction; WO LASIK, wave front–optimized laser in situ keratomileusis.

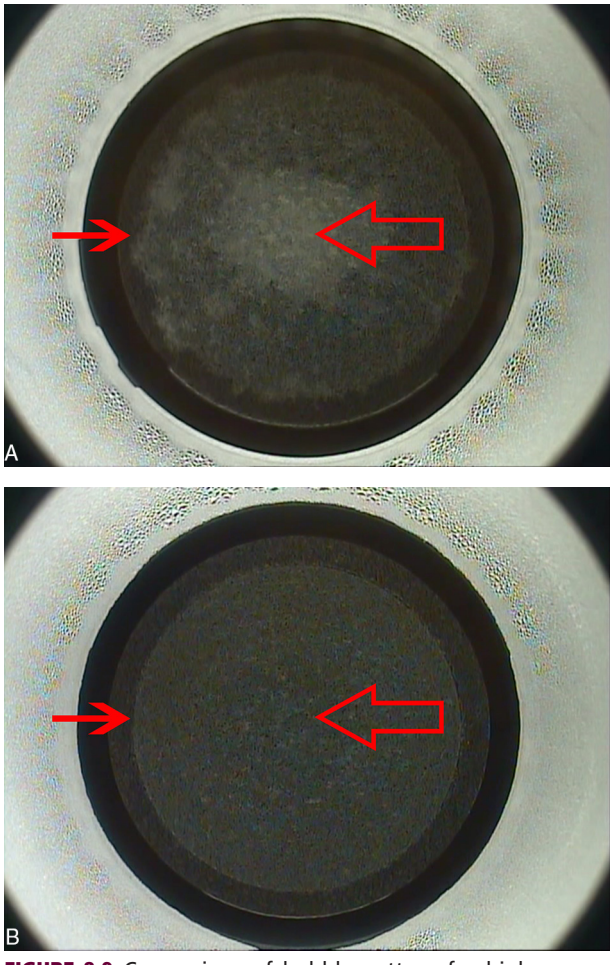

FIGURE 8-9 Comparison of bubble pattern for high-energy optimized treatments: **A,** Bubble pattern with high-energy, manifesting significant OBL in the visual axis and fluffy irregularity at the side cut; **B,** bubble pattern with optimized energy without OBL or black spots and a sharp lenticular border, suggestive of an easier dissection.
OBL, opaque bubble layer.

Long-Term Safety and Efficacy

Ten years after Sekundo et al.'s first published article on SMILE,[1] long-term data demonstrates excellent safety and efficacy of the procedure.

A study by Blum et al. presenting 10-year SMILE data for 56 eyes treated for myopia and myopic astigmatism found 64.3% were within ±0.50D of target, and 82.1% were within ±1.00D at 10 years. UDVA remained stable from 1 month through 10 years with mid regression of 0.30D in manifest refraction spherical equivalent (MRSE).[16] Among the studied AQ 18

eyes, 29% gained at least 1 line of CDVA, 14% lost 1 line, and no eyes lost 2 or more lines, suggesting a favorable safety profile. No ectasia was observed within this cohort, and no patients required management of ocular surface disease after POM3.

The past 2 years have also seen several reports from Turkey and China presenting promising safety and stability data through 5 years.

In two 5-year Turkish studies of 54 and 24 SMILE eyes, respectively, 93% and 91% of patients remained within 0.5D of intended correction, with the majority of refractive error resulting from undercorrection of high myopia. Safety was also evaluated, with Agca et al. reporting 0 of 54 patients and Ayugin et al. reporting 1 eye in 24 (4%) losing a line of CDVA. In neither study, did any patient lose 2 or more lines of CDVA.[17,18]

Chinese studies by Han et al. and Li et al. followed SMILE eyes for 3 and 5 years, respectively. Han et al. found 80% to be within 0.5 D of attempted spherical equivalent at 3 years; whereas Li et al. observed 90% of eyes within 0.50 D of target at 5 years. These studies found 2% and 9% of SMILE eyes losing 1 line of CDVA, with no eyes losing 2 or more lines.[19,20]

CONCLUSION

SMILE represents a promising laser vision correction modality that addresses many of the fear issues that keep refractive surgery candidates on the sidelines: no sound or smell during the procedure, no flap, no pain, and minimal restrictions after surgery. As other ophthalmic surgical device companies develop their version of the technique and bring new equipment to market, further refinement of the technique is inevitable. With visual outcomes, safety, and predictability already comparable to LASIK, and with potential advantages in postoperative dry eye and biomechanical stability, expect SMILE to become a standard technique in the armamentarium of the refractive surgeon for the treatment of myopic astigmatism.

CODING/BILLING MODIFIERS

Myopia H52.1x
Regular Astigmatism H52.22x
Laser surgery is usually not covered by medical insurance. Some insurance companies will offer partial payments.

REFERENCES

AQ 19

1. Kezirian G, Fatnani L, Opoku E et al. Forecast of laser refractive surgery in China 2013–2023. Lecture notes from Physician CEO program, Kellogg Northwestern School of Management, 12/2013.
2. Kobashi H, Kamiya K, Shimizu K. Dry eye after small incision lenticule extraction and femtosecond laser-assisted LASIK: Meta-analysis. *Cornea*. 2017 Jan;36(1):85–91.

3. Zhang Y, Shen Q, Jia Y, Zhou D, Zhou J. Clinical outcomes of SMILE and FS-LASIK used to treat myopia: A meta-analysis. *J Refract Surg*. 2016 Apr;32(4):256–265.
4. Ajazaj V, Kacaniku G, Asani M et al. Intraocular pressure after corneal refractive surgery. *Med Arch*. 2018 Oct;72(5):341–343. AQ 20
5. Vetter JM, Faust M, Gericke A, Pfeiffer N, Weingartner WE, Sekundo W. Intraocular pressure measurements during flap preparation using 2 femtosecond lasers and 1 microkeratome in human donor eyes. *J Cataract Refract Surg*. 2012;38:2011–2018.
6. Vetter JM, Holzer MP, Teping C, et al. Intraocular pressure during corneal flap preparation: Comparison among four femtosecond lasers in porcine eyes. *J Refract Surg*. 2011;27:427–433.
7. SurgiVision Consultants Inc. SurgiVision DataLink Ophthalmic Applications. Available at: http://web.surgivision.net/Home/SVCHome.html AQ 21
8. Datagraph med. Datagraph-med® outcomes analysis software for cataract and refractive surgery. Available at: http://www.datagraph.eu/?menuid=1&getlang=en AQ 22
9. Spiru B, Torres-Netto EA, Kling S, Lazaridis A, Hafezi F, Sekundo W. Biomechanical properties of human cornea tested by two-dimensional extensiometry ex vivo in fellow eyes: PRK versus SMILE. *J Refract Surg*. 2019;35(8):501–505.
10. Yang W, Liu S, Li M, Shen Y, Zhou X. Visual outcomes after small incision lenticule extraction and femtosecond laser-assisted LASIK for high myopia. *Ophthalmic Res*. 2020;63(4):427-433 AQ 23
11. Qian Y, Chen X, Naidu RK, Zhou X. Comparison of efficacy and visual outcomes after SMILE and FS-LASIK for the correction of high myopia with the sum of myopia and astigmatism from −10.00 to −14.00 dioptres. *Acta Ophthalmologica*. 2020 Mar;98(2):e161-e172. AQ 24
12. Zhou X, Shang J, Qin B, Zhao Y, Zhou X. Two-year observation of posterior corneal elevations after small incision lenticule extraction (SMILE) for myopia higher than −10 dioptres. *Br J Ophthalmol*. 2020;104:142–148.
13. Elmassry A, Ibrahim O, Osman I, et al. Long-term refractive outcome of small incision lenticule extraction in very high myopia. *Cornea*. 2020; Jun;39(6):669-673. AQ 25
14. Moshirfar M, Albarracin JC, Desautels JD, Birdsong OC, Linn SH, Hoopes PC Sr. Ectasia following small-incision lenticule extraction (SMILE): A review of the literature. *Clin Ophthalmol*. 2017 Sep 15;11:1683–1688.
15. Hamilton DR, Chen AC, Khorrami R, Nutkiewicz M, Nejad M. Comparison of early visual outcomes following low-energy Small Incision Lenticule Extraction (SMILE), high-energy SMILE and LASIK for myopic astigmatism. *J Cataract Refractive Surg*. 2021 Jan 1;47(1):18-26 AQ 26
16. Blum M, Lauer AS, Kunert KS, Sekundo W. 10-year results of small incision lenticule extraction. *J Refract Surg*. 2019;35(10):618–623.
17. Agca A, Tülü B, Yasa D, Yıldırım Y, Yıldız BK, Demirok A. Long-term (5 years) follow-up of small-incision lenticule extraction in mild-to-moderate myopia. *J Cataract Refract Surg*. 2019;45:421–426.
18. Aygün BT, Çankaya KI, Agca A, et al. Five-year outcomes of small-incision lenticule extraction vs femtosecond laser–assisted laser in situ keratomileusis: A contralateral eye study. *J Cataract Refract Surg*. 2020;46:403–409.
19. Li M, Li M, Chen Y, et al. Five-year results of small incision lenticule extraction (SMILE) and femtosecond laser LASIK (FS-LASIK) for myopia. *Acta Ophthalmol*. 2019;97:e373–e380.
20. Han T, Xu Y, Han X, et al. Three-year outcomes of small incision lenticule extraction (SMILE) and femtosecond laser-assisted laser in situ keratomileusis (FS-LASIK) for myopia and myopic astigmatism. *Br J Ophthalmol*. 2019;103:565–568.

Author Query Sheet

Chapter No.: 8

Query No.	Queries	Response
AQ 1	Please check if FDA has been spelled out correctly.	Yes
AQ 2	"Indications", "Contraindications", "Informed Consent Considerations", etc. have been edited for consistent structure. Please confirm whether it is okay.	OK
AQ 3	Please provide "item head" for each item for the list under "Key Contraindications", if required.	Done
AQ 4	Please check if IOP has been spelled out correctly.	yes
AQ 5	Please check if identified head levels are okay.	yes
AQ 6	Please define FS for figure note in Figures 8.3 and 8.4.	spelled out in 8.3 not necessary after
AQ 7	Please confirm if Key text "Key Post-operative Considerations…" can be moved to the end of its H1 level.	OK
AQ 8	Please define PM.	Tylenol PM is acetominophen/diphenhidramine: helps pt sleep
AQ 9	Please confirm if we can change "Sri Ganesh" to "Dr. Sri Ganesh".	Rec: leave as Sri Ganesh, MD
AQ 10	Key text "Key Complications to Look For…" is placed immediately after H1. Please confirm if this can be moved to end of H1 level.	OK
AQ 11	Please validate sentence beginning "While there is, therefore, a theoretical risk of epithelial ingrowth".	text edited for clarity
AQ 12	Please validate edits to sentence beginning "Placido topography demonstrating".	text edited for clarity
AQ 13	Please define OS in figure note for Figure 8.7d.	done
AQ 14	Please validate edits to sentence beginning "This allows the surgeon".	text edited for clarity
AQ 15	Please define OZ.	done
AQ 16	Please validate edits to sentence beginning "The appearance of the bubble pattern that results from laser".	done
AQ 17	Please define FS.	already defined previously
AQ 18	Please define MRSE.	done
AQ 19	Please expand author group for Ref. [1].	done
AQ 20	Please expand author group for Ref. [4].	done
AQ 21	Please check if author group and title of work for Ref. [7] is okay.	yes

AQ 22	Please check if author group and title of work for Ref. [8] is okay.	yes
AQ 23	Please provide volume for Ref. [10].	updated
AQ 24	Please provide volume and page range for Ref. [11].	updated
AQ 25	Please update volume for Ref. [13].	updated
AQ 26	Please provide volume and page range for Ref. [15].	updated