

# Next Generation Refractive Procedures Rely on Excimers

Laser refractive eye surgeries procedures continue to evolve with an emphasis on highly individualized correction and superior depth of field

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Dating back nearly three decades, laser refractive surgery for vision correction represents a suite of well-established and increasingly popular elective medical procedures. For instance, in the US, where elective procedures are more common than in other countries, laser refractive surgery today is the single most popular elective “surgical” procedure. With a range of different procedures and variants now available, the key trends in vision correction surgery involve personalized treatments that provide subtle wavefront corrections for maximum patient benefit, as well as faster lasers to reduce procedure times and minimize patient discomfort.

In this article, we briefly review the status of the main procedure types. We also look at the important excimer laser parameters that impact this application and see how the reality and perception of the excimer have evolved to the benefit of both the ophthalmic surgeon and the patient.

Laser refractive surgeries have long used deep ultraviolet (193 nm) pulses from an argon fluoride excimer laser to perform computer-controlled spatially selective ablation of corneal tissue. The deep UV wavelength is strongly absorbed with a penetration depth of a few microns. And the high photon energy serves to remove material by directly breaking the molecular bonds rather than by intense heating as with an infrared laser. Together with the short (a few nanoseconds) pulse duration, these factors enable precision micro-ablation of tissue with almost no peripheral thermal effects.

Today, there are several different procedures based on this common approach, each with its own advantages and patient suitability profile. In some of these, femtosecond ultrafast lasers have usurped the role of the mechanical cutting tool(s) for ancillary tasks that make up the complete procedure. But their unmatched correction precision means that excimer lasers remain

unmatched as the best tool to do the actual corneal reshaping itself. Laser manufacturers have improved excimer lasers to deliver unprecedented reliability and stability, as well as faster repetition rates to enable shorter procedure times.

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Photorefractive keratectomy (PRK) was the first type of laser refractive procedure. Here, the thin epithelium covering the front of the cornea is mechanically removed to expose the underlying bulk of the cornea called the stroma. The focused spot (193 nm pulsed UV) is then scanned across the exposed stroma in a programmed pattern that permanently reshapes the cornea and thus changes its optical properties. After PRK surgery, the epithelium regrows naturally in just a few days. PRK can be used to correct nearsightedness (myopia), farsightedness (hyperopia), and astigmatism. PRK has been superseded in popularity by LASIK but is still often used where the cornea is considered naturally too thin for LASIK.

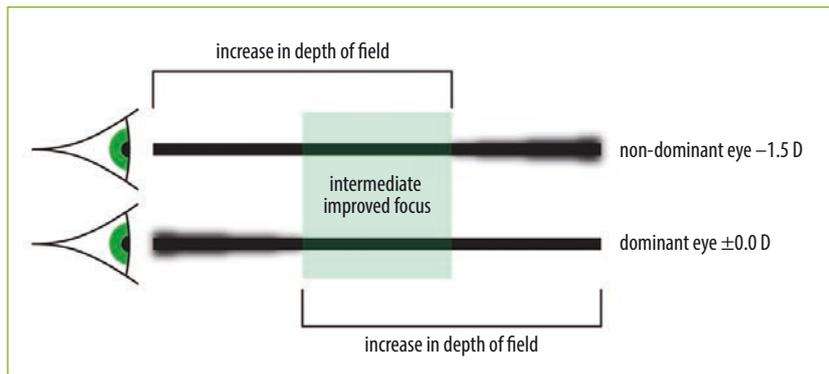


Fig. 1 By using a vertically graded correction, the depth of field for each eye is increased, causing better focal overlap and making it easier for the brain to successfully blend the images from both eyes.

Laser-assisted in-situ keratomileusis (LASIK) is currently the most widely used refractive surgery. Here, a flap is cut in the cornea, but left hinged on one side and then folded back. As with PRK, the laser is scanned across the exposed stroma to cause permanent reshaping. The flap is then replaced over the cornea. One of the main advantages of LASIK is the quick recovery – most patients have clear, corrected vision in just 24 hours. LASIK can be used to treat a range of vision issues, and can be highly personalized according to the measured wavefront properties of the eye that are comprehensively analyzed before surgery.

Femto LASIK is a variation of this. In the conventional procedure, a blade is used to cut the flap, in Femto LASIK, an ultrafast laser is used to cut the flap, arguably offering less discomfort and lower risk of infection. A large proportion of LASIK procedures are currently performed as Femto LASIK.

Laser-assisted sub-epithelial keratectomy (LASEK) is a method that has similarities to both PRK and LASIK. Here, alcohol is used to loosen the epithelium which is then pushed to one side as a flap. After laser ablation, the epithelium is then replaced over the cornea. In yet another variant called epi-LASEK, a plastic blade is used to separate the epithelial sheet from the eye, eliminating the possibility of alcohol killing some of the epithelial cells.

A different procedure, but one that also relies on selective excimer ablation, is called phototherapeutic keratectomy (PTK). Although similar in implementation, the main purpose of PTK is not refractive correction, but rather selective removal of corneal tissue to remove

local irregularities, opaque spots, scars, or other defects that are causing hazy or blurred vision.

### Key trends in refractive surgeries

From the treatment viewpoint, the main trend is the increasing use of personalized treatments that better address more than one vision issue, and deliver a highly corrected outcome. And on the hardware side this is supported by the complete maturation of the excimer laser as a simple tool in these applications.

Early PRK and LASIK were targeted mainly at correcting the spherical power of the eye, i.e., the focal length, sometimes with a small amount of cylindrical power to address astigmatism. But today, many surgeons offer highly personalized treatments such as so-called Wavefront LASIK. Here, the eye's optical properties are fully assessed using interferometry. The surgeon then applies a spatially varying correction across the cornea with the goal of delivering a more optically perfect eye. In addition to improved vision, another advantage of this personalized corrective approach is a reduced incidence of an occasional post-operative problem in early LASIK, namely visual halos due to spherical aberration.

The majority of elective procedures are still performed primarily to correct myopia. However, a significant number of treatments now also address presbyopia, the age-related stiffening of the cornea and lens that leads to reduced ability of the eye to accommodate, i.e., to change focal length from viewing a distant scene to close up reading distance. Without the magical ability to



Fig. 2 ExciStar XS can pulse with a repetition rate at up to 1050 Hz.

fully restore cornea and lens flexibilities, refractive laser procedures cannot yet deliver the complete accommodation of a young eye in a mature patient, but subtle improvements, supported by tool builders and optimized by surgeons, definitely provide superior accommodation than the treatments of even just five years ago. The obvious goal of any refractive surgery is to provide a higher level of independence from needing spectacles. These latest developments are emphasizing including reading as a key part of this spectacle-free outcome. But no-one is claiming these advances are a universal panacea; success in this area is inevitably dependent on a number of patient specific parameters, including the brain's agility to synthesize a single sharp stereo image from two differently corrected eyes.

In LASIK, to treat patients for myopia (or hyperopia) who already have presbyopia, the conventional approach – sometimes called monovision correction – has been to correct each of the

two eyes differently. The dominant eye is corrected for planar wavefront (i.e., distance vision) and the non-dominant eye is corrected for near vision, usually to be myopic up to  $-3.0$  D. In principle, the patient's brain learns to combine the images from the two eyes studies. But in practice, surgeons report that it often takes patients a long time to get used to merging the two images into one picture. Moreover, some studies indicate as few as 59 to 67 percent of patients are ever able to successfully merge the two images to experience sharp binocular vision at near and distance range without the use of eyeglasses. Also, patients that tolerate the method are often left with an uncorrected, compromised gap in the intermediate range, where images are inevitably blurred. In addition to the fuzzy image, this can also cause other side effects such as reduced contrast sensitivity and stereoacuity.

One solution is to correct the dominant eye for infinity whereas the non-dominant eye is corrected to be as much as two times less myopic than

traditional LASIK. More importantly, the curvature of the cornea is shaped so that there is a vertical power gradient (analogous to progressive spectacle lenses) which results in a higher depth of field for each eye (Fig. 1). This results in better overlap between the focal distance for the two eyes and makes it easier for the brain to integrate the images as focused binocular vision – at far distance, reading distance, and at intermediate distances. Advocates of this new approach claim that up to 97 percent of patients treated with this approach gain independence from using eyeglasses.

### Advances in excimer lasers

Coherent is the largest supplier of excimer lasers, supporting critical applications such as display fabrication for smart phones, creating medical (e.g., coronary) stents, and the refractive procedures described here. The demands of these diverse applications have driven the maturation of excimer lasers in two ways. First, new lasers have been developed from the ground up to meet the specific needs of each of these applications. And second, the experience of servicing all these demanding applications has enabled extremely high laser reliability levels, gas lifetimes, and laser tube lifetimes across the entire excimer product line.

The ExciStar family of excimer lasers from Coherent continues to be the dominant choice of refractive surgery builders systems. These lasers made their name with a long-live tube type called Ceratube with extensive use of ceramics that are naturally resistant to corrosion from the (albeit very dilute) fluorine gas. A decade ago, this tube design was displaced by the ALMETA design with even longer tube and gas lifetimes. And now a next-generation tube design is about to push laser longevity reliability even further, with projected gas lifetimes of more than 100 million pulses and expected tube lifetimes of several billion pulses (Fig. 2).

From a patient viewpoint, many potential patients are naturally nervous and mild (oral) sedation is often used for this reason. But a key to minimizing discomfort and overcoming any fear is to minimize the procedure time. The rate limiting factor here is the laser repetition rate. Ten years ago, a 250 Hz rep-

## Company

### Coherent

Santa Clara, USA

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etition rate was the accepted standard, but the Excistar XS can be pulsed already at up to 1050 Hz. System builders exploit this with fast tracking systems, which follow any eye movement during surgery.

What does this mean for the patient? In a typical LASIK system, the excimer laser is focused down to less than 1 mm (FWHM) spot diameter which the twin galvanometers scan across the cornea under surgeon / computer control. For typical myopic patients, this results in ablation times of less than three seconds for each diopter of correction. Total procedure times are around twenty to thirty seconds for each eye.

All these advances are part of the complete maturation of ArF excimer technology. Historically, ArF has always been the most challenging of the commonly used excimer output wavelengths, because of the combination of deep UV photons and fluorine gas – albeit pre-mixed in trace amounts. In the early days of PRK and LASIK, surgeons would have many questions about the laser itself; how many shots will it give for each gas fill, how easy is it to refill the gas inside the laser tube, what is the life expectancy of the tube, how stable is the output power, what are beam hotspots, how much unscheduled downtime might I expect? Today, system builders report that they hardly ever hear this type of question. The ArF excimer's output stability, high reliability, long gas and tube lifetimes, long

optics lifetime and the automated filling with an integrated premix gas bottle have all combined to obsolete these concerns. Today, very few surgeons ask about these sorts of laser details. Simply stated, the ophthalmic surgery community today regards the laser as a highly reliable commodity-type component, based on shared, personal and anecdotal experiences.

## Summary

Laser refractive eye surgeries already have a long history, yet tool builders and surgeons are continually working to develop new techniques and variations designed to deliver better outcomes with less patient discomfort, faster healing and increased independence from eye glasses. At the same time, excimer laser manufacturers have improved these lasers to deliver unprecedented reliability and stability, as well faster repetition rates to enable shorter procedure times. Together, all these advances provide benefits for the surgeon – and more importantly, the patient. The future of laser surgery has never looked more clear.

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