The argon fluoride (ArF) excimer laser was described in 1976 and was introduced as a surgical tool in ophthalmology in 1983 by Trokel et al. The precision of treatment with the 193-nm ArF excimer laser and, more important, the lack of damage to surrounding tissue, characterized a new mechanism of interaction called ablative photodecomposition, later named photodissociation. This was due to the absorption of ultraviolet (UV) photons by the cornea with sufficient energy to break organic molecular bonds in the tissue.

TECHNICAL PARAMETERS

Early studies of the potential use of excimer lasers focused on determining the best laser parameters (optimal ablation rates, fluence, and wavelength) to deliver smooth surfaces with no thermal damage to surrounding tissue. It was soon discovered that the 193-nm wavelength of the ArF laser produced the best results and predictable ablations, with no variation in threshold energy at different laser pulse rates.

Irradiance is a term that describes amount of energy per unit area. Another term, fluence (energy per unit volume) is more frequently used when describing energy in millijoules (mj) per unit area (cm²). The minimum fluence required to ablate human corneal tissue is 50 mj/cm² with the 193-nm excimer laser, and this does not vary considerably with ablation rates. Additionally, fluence correlates directly with ablation depth per pulse, with a greater efficiency over a range of 150 to 400 mj/cm². Ablation depth varies in different tissues for the same fluence, so scarred tissue can lead to an irregular ablation rate. Fluence must be calibrated daily in most devices to precisely adjust the ablation depth per pulse expected.

The Amaris excimer laser (Schwind eye-tech-solutions, Kleinostheim, Germany) varies the fluence during the treatment; higher energy is applied in the first 80% of the ablation to produce a faster treatment and lower energy in the last 20% to ensure precise treatment with reduced speed.

Excimer lasers can be divided into three categories according to beam profile. The first generation of excimer lasers were broad-beam lasers with high pulse energy and low repetition rates. They required a mechanical iris diaphragm or ablable mask to guide the ablation. The disadvantages of these designs included the presence of hot and cold spots (leading to irregular ablations) and steep central island formation.

Later, scanning slit-beam lasers were developed. In lasers with this design, a long, narrow beam treats along a rotating variable slit-shaped pattern. This technology, still available in some modern excimer lasers, including the EC-5000 and Quest lasers by Nidek, (Gamagori, Japan), provides a smoother treatment versus the broad-beam profile.

Most devices today use flying-spot laser technology, in which smaller-diameter beams (0.5–2.0 mm) are used for better and more accurate results in custom ablations and the correction of irregular astigmatism. Some devices such as the Visx S4, (Abbott Medical Optics Inc., Santa Ana, California), have a variable spot size. Energy is delivered in a Gaussian profile (greater energy density in the center of the beam than the periphery) with the Allegretto Wave Eye-Q (WaveLight AG, Erlangen, Germany) and MEL 80 (Carl Zeiss Meditec, Jena, Germany) lasers. With scanning-slit and flying-spot lasers, there is a high risk of decentration and misplacement of individual pulses, and these devices require accurate eye-tracking systems.

The repetition rate of laser pulses also varies among excimer lasers. Repetition rate correlates directly with treatment time. Longer treatment times allow drying of the corneal stroma and loss of fixation, often leading to irreproducible results.

TAKE-HOME MESSAGE

- The 193-nm wavelength of the ArF laser produces predictable ablations.
- The minimum fluence required to ablate human corneal tissue with this laser is 50 mj/cm².
- The three categories of excimer lasers are broad-beam, slit-beam, and flying-spot.
tion rate was low (6–10 Hz). With scanning-spot technology, the rate had to be increased; otherwise, treatment times would be longer because the small spots require more pulses to achieve the same volume of ablation.

Excessive thermal damage in adjacent tissue can occur with repetition rates higher than 60 Hz. Modern devices use higher rates for faster treatments with scanning spots (up to 500 Hz). In these devices, because the pulses are applied sequentially in different locations of the cornea, the repetition rate in any specified location does not exceed 40 Hz, thereby preventing thermal damage. Table 1 shows the characteristics of commercially available excimer lasers.

### ABLATION PROFILES

Conventional spherocylindrical ablation profiles have been used since the beginning of excimer laser technology. Munnerlyn et al. described the relationship between the ablation depth, amount of diopters of treatment, and optical zone size.

The standard spherocylindrical profile can achieve good visual acuity in most patients; however, it induces higher-order aberrations (HOAs)—mainly spherical aberration—due to induced changes in corneal asphericity. Myopic treatments tend to flatten the center of the cornea, changing the shape of the normally prolate cornea into a more oblate shape, increasing the normally low degree of positive spherical aberration. Hyperopic treatments make the central cornea steeper, leading to a hyperprolate shape and the induction of negative spherical aberration. After treatments, patients can experience reduction in contrast sensitivity, symptoms of halos and glare, and decreased quality of vision. With the standard profile, patients occasionally complain about their vision even with 20/20 high-contrast visual acuity.

Smaller optical zones (less than 5.5 mm) and multizone treatments were originally performed to spare stromal tissue, especially with high degrees of correction. In these conditions, the magnitude of HOAs induced is even greater. Only after the introduction of aberrometry with wavefront technology did our understanding of what was happening in the eye lead to new profiles addressing lower-order aberrations and HOAs.

Treatments based on aberrometry data were soon introduced, and the first customized wavefront profiles were performed by the end of the 1990s, producing better results with respect to contrast sensitivity, halos, and glare. Compared with conventional treatments, reduction in HOAs was observed. However, in most patients, HOAs were increased in comparison with the eye’s preoperative state. To minimize postoperative aberrations, precise centration became an increasingly important requirement. Additionally, more tissue was being ablated with aberrometry-guided treatments compared with conventional treatments. Custom wavefront treatments have improved the results of excimer laser technology in subsequent years; however, the ideal of super-normal vision was never fully achieved, and induction of HOAs still occurs in some patients.

Recently, an optimized profile has been introduced in some modern excimer lasers. The aspheric profile, intended to avoid induced spherical aberration, uses larger optical and blending zones to maintain the cornea’s prolate shape.

### TABLE 1. TECHNICAL SPECIFICATIONS

<table>
<thead>
<tr>
<th>Laser (Manufacturer)</th>
<th>Beam profile</th>
<th>Spot size</th>
<th>Pulse frequency (Hz)</th>
<th>Eye-tracker rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allegretto Wave Eye-Q (WaveLight AG)</td>
<td>Flying spot</td>
<td>0.95 mm Gaussian</td>
<td>Up to 500</td>
<td>400</td>
</tr>
<tr>
<td>Amaris (Schwind eye-tech solutions)</td>
<td>Flying spot</td>
<td>0.54 mm 2 energy levels profile</td>
<td>Up to 500</td>
<td>1,050</td>
</tr>
<tr>
<td>EC-5000 (Nidek)</td>
<td>Slit scanning</td>
<td>1-9 mm Gaussian</td>
<td>Up to 40</td>
<td>200</td>
</tr>
<tr>
<td>MEL 80 (Carl Zeiss Meditec)</td>
<td>Flying spot</td>
<td>0.7 mm Gaussian</td>
<td>Up to 250</td>
<td>250</td>
</tr>
<tr>
<td>Quest (Nidek)</td>
<td>Slit scanning</td>
<td>1X6 mm Slit, can be divided into six 1-mm spots, used individually</td>
<td>Up to 50</td>
<td>1,000</td>
</tr>
<tr>
<td>Technolas 217p (Bausch + Lomb)</td>
<td>Flying spot</td>
<td>2 mm/ 1 mm truncated Gaussian</td>
<td>Up to 100</td>
<td>240</td>
</tr>
<tr>
<td>Visx S4 IR (Abbott Medical Optics)</td>
<td>Variable flying spot</td>
<td>0.65-6.00 mm variable</td>
<td>6-20 (varies during treatment)</td>
<td>Hz not supplied</td>
</tr>
</tbody>
</table>

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The aspheric profile achieves results equivalent to or better than wavefront-customized profiles. Additionally, the optim ized profile does not require wavefront exam input before surgery and is less dependent than wavefront-guided treatments on registration and centration.12 Surgeons with access to both technologies report that they use the optimized profile in 67% to 88% of patients and the custom-guided profile in patients with above-average amounts of HOAs.12

Another treatment option is a topography-guided pro file. The main indications for topography-guided corrections include secondary procedures to correct previously decentred treatments or enlarge small optical zones, primary ablation in irregular astigmatism,13 or conditions that might have poor results with wavefront-guided treatments. Recent studies evaluating the combination of topography-guided ablation and corneal collagen crosslinking in patients with keratoconus or ectasia after LASIK14 have produced promising results.

Recently developed profiles focus on correcting presbyopia by inducing HOAs in a controlled fashion to increase the depth of focus with minimal halos and glare. Negative spherical aberration and coupling of aberrations are promising presbyopia-correcting profiles.15

TRACKING SYSTEMS

The main consequence of a decentred ablation is the induction of coma, which can result in double vision, loss of BCVA, and impaired quality of vision. The new excimer laser devices with smaller scanning spots and topography- or wavefront-guided profiles demand greater precision in treatment centration than older broad-beam excimer lasers did. Since the introduction of tracking systems, better results have been reported.16 Faster (up to 1,050 Hz) and more precise eye-tracking systems have been released with every new generation of lasers,17 but outcomes still depend on good head positioning and proper fixation on the target.16

Approximately 8% of patients undergo more than 10° of cyclotorsion when changing from a seated to a supine position.18,19 More than 10° of displacement in the axis significantly affects results.20 Limbal markings and iris registration are the two most popular methods for ensuring treatment of the correct axis. Limbal markings are the simplest; they allow the alignment of the patient in the laser room according to horizontal marks made on the limbus previously at the slit lamp in the seated position. Iris registration is a feature of some modern excimer lasers (mainly for wavefront-customized treatments), in which the device automatically compensates for cyclotorsion through iris recognition. Although iris registration seems more accurate and reproducible, studies show no statistically significant difference between the techniques; both produce good results.21