Excimer Basics

An overview of excimer laser technology.

BY KATHRYN MASSELAM HATCH, MD; AND JONATHAN H. TALAMO, MD

The field of laser refractive surgery has grown immensely from its inception in the early 1990s. Understanding excimer laser technology, the differences among the available lasers, and how this technology is applied to patient care can be overwhelming for the surgeon, especially given the continual technological advances and updates in the field. Before treating patients, it is important for surgeons to understand not only the advantages of their lasers, but also the limitations and other available options.

FLUENCE

Most excimer lasers are gas lasers that emit pulses of ultraviolet (UV) light with pulse durations of between 4 and 25 nanoseconds. The most common excimer lasers in ophthalmology use a combination of argon and fluorine (ArF) and operate at a wavelength of 193 nm.

Laser energy reshapes the cornea by removing tissue with photoablation. Laser energy is measured in terms of fluence (mJ/cm^2), which ranges from 50 to 500 mJ/cm^2 for standard excimer lasers. The fluence range appropriate for ophthalmic applications is between 120 and 180 mJ/cm^2, and the photoablation threshold for corneal tissue is 50 mJ/cm^2. Below this threshold, only photochemical changes occur. In contrast, high fluence thresholds can cause thermal damage and other undesired results.[1]

BEAM PROFILE

Excimer laser beam profiles may have several patterns: homogeneous (flat), Gaussian, and reverse Gaussian. In a homogeneous beam profile, the fluence is equal at all points. In a Gaussian beam profile, there is greater energy density in the center of the beam than the periphery. In a reverse Gaussian beam profile, the energy is greater in the periphery than the center.

Energy is delivered to the cornea with either a broad-beam or a small flying-spot system. Beam profile is particularly important in broad-beam systems, which were common in the early stages of ophthalmic excimer laser development. These systems allowed fast delivery of laser energy to the cornea, but outcomes were highly dependent upon a homogeneous beam profile.

Smaller flying-spot delivery systems, with spot sizes of 0.5 to 2.0 mm, deliver energy in specific patterns to the cornea to obtain the desired ablation profile. The homogeneity of the beam in this type of delivery system is less important than in a broad-beam delivery system because each spot is overlapped by other spots. The accuracy of ablation patterns theoretically increases, but so do laser treatment times. With increased laser times, saccadic movements and eye rotations may also increase, decreasing the assurance of proper distribution of the laser energy to the cornea.[1] The development of accurate eye tracking has improved the accuracy of excimer laser application.

A hybrid of the two types, the variable-spot scanning laser incorporates a flying spot with adjustable size to create the desired ablation profile.

Most lasers today use either small- or variable-spot scanning. The speed at which laser pulses are applied to the cornea varies from laser to laser. Typical laser pulse speed ranges between 3 and 500 Hz. Lower pulse rates increase laser treatment time and can cause undesired effects with small-spot beams, as it is more difficult to treat adjacent spots consecutively. At extremely high repetition rates, large beam lasers can have increased thermal effects, as there is decreased time for heat dissipation.[2]

ABLATION PATTERN

The ablation pattern is determined by the desired refractive correction. A myopic ablation results in central flattening, whereas hyperopic ablations result in steepening of the central cornea. Broad-beam lasers applied the appropriate prolate shapes through the use of masking devices. Flying-spot lasers obtain the desired ablation by moving the beam's position on the cornea.

TAKE-HOME MESSAGE

- The fluence of standard excimer lasers ranges from 50 to 500 mJ/cm^2.
- Energy is delivered to the cornea with a broad-beam, small flying-spot, or variable-spot system.
- The ablation pattern is determined by the desired refractive correction.
- Custom laser platforms can perform conventional, wavefront-guided, wavefront-optimized, and/or topography-guided treatments.

TABLE 1. EXCIMER LASER PLATFORM CHARACTERISTICS							
Laser (Manufacturer)	**Fluence (mJ/cm²)**	**Speed (Hz); pulse duration (ns)**	**Platform**	**Beam profile; Beam delivery**	**Treatment range**	**Treatment zones**	**Eye tracking**
Visx Star S4 (Abbott Medical Optics Inc.)	160	1.5-20	Wavefront-guided (with WaveScan aberrometer)	Gaussian; variable spot, 0.65-6.5 mm	+5.00 to -14.00 D up to 3.00 D cyl for hyperopia (spherical equivalent [SE] ≤ 6.00 D); up to 5.00 D cyl with myopia; mixed astigmatism up to 6.00 D (myopic sphere less than cyl)	7 mm with blend zone to 9.5 mm	Yes, with IR
Allegretto Eye-Q (WaveLight AG)	130-140	200-500	Wavefront-optimized, wavefront-guided, topography-guided	Gaussian; small fixed-size spot, 0.95 mm	+6.00 to -12.00 D; up to 6.00 D cyl with myopia and up to 5.00 D cyl with hyperopia	8 mm with blend zone up to 10 mm	Yes
MEL-80 (Carl Zeiss Meditec)	150	10-250; 4-6	Wavefront-optimized, wavefront-guided, topography-guided	Gaussian; small fixed-size spot, 0.7 mm	Myopia up to -7.00 D, up to -3.00 D astigmatism, maximum manifest refraction SE -7.00 D	Blend zone up to 9 mm	Yes, with IR
Technolas 217A (Bausch + Lomb)	120	50-120; 18	Wavefront-guided, topography-guided	Gaussian; small spot	+4.00 to -11.00 D, up to 3.00 D cyl with myopia and up to 2.00 D cyl with hyperopia for wavefront-guided, up to -7.00 D with cyl up to -2.00 D	6.0-7.0 mm with blend zone up to 0.875 mm	Yes, with IR
EC500 CX (Nidek)	360	5-50; 10-25	Wavefront-guided, topography-guided	Gaussian; rotating scanning slit	PRK: -0.75 to -13.00 D; LASIK: -1.00 to -14.00 D; myopic astigmatism SE -1.00 to 8.00 D with up to -4.00 D cyl	7-9 mm	Yes
IR = iris registration; ns = nanosecond							

EYE TRACKING AND IRIS REGISTRATION

Active tracking systems and iris registration have enabled surgeons to employ customized treatments based on wavefront technology. Current laser platforms can perform some or all of the following: conventional, wavefront-guided, wavefront-optimized, and topography-guided treatments.

Conventional treatments rely on the patient's refraction to determine a standard ablation profile. The principle of wavefront-guided treatment is based on the reflected light scatter of the eye as determined by aberrometry. This allows personalized treatments adjusted for each eye's aberration profile. Wavefront-optimized platforms, such as that of the Allegretto Eye-Q (WaveLight AG, Erlangen, Germany), use the patient's refraction and attempt to pre-

Before treating patients, it is important for surgeons to understand not only the avantages of their own laser, but also the limitations and other available options.

serve corneal asphericity by compensating for a predicted amount of laser-induced spherical aberration. Topography-guided systems use corneal topography to guide laser treatment.

Tracking and eye alignment are important for wavefront-guided treatments addressing higher-order aberrations. Iris registration (IR), a feature of the Visx WaveScan (Abbott Medical Optics Inc., Santa Ana, California), ensures that the ablation is aligned correctly on the eye. Significant cyclorotation and pupillary shifts can occur from when the patient is upright to when he is lying flat under the laser. Because WaveScan data are obtained while the patient is upright, IR is activated when the patient is lying under the laser. The IR system signals the surgeon if the orientation of the eye is incorrect or the pupil center has shifted.

CONCLUSION

A comparison of currently available laser platforms in the United States is presented in Table 1. A better understanding of excimer laser technology allows the surgeon to optimally utilize the laser to its limits. The next few years should bring further improvements in speed, active cyclorotational eye tracking, and topograpy-guided ablation. ■

Kathryn Masselam Hatch, MD, practices corneal, cataract, and refractive surgery at Talamo Laser Eye Consultants, Waltham, Massachusetts. Dr. Hatch states that she has no financial interest in the products or companies mentioned. Dr. Hatch may be reached at tel: +1 781 890 1023; e-mail: kmasselam@gmail.com.

Jonathan H. Talamo, MD, is the Founder of Talamo Laser Eye Consultants, Waltham, Massachusetts, and is an Associate Clinical Professor of Ophthalmology at Harvard Medical School, Boston. Dr. Talamo states that he is a consultant to Alcon Laboratories, Inc., and Bausch + Lomb. He may be reached at tel: +1 781 890 1023; e-mail: jtalamo@lasikofboston.com.

1. Hardten DR, Haruswirth SG. Comparison of lasers for excimer laser vision correction. In: Brightbill FS, McDonnell PJ, McGhee CNJ, et al, eds. *Cornea Surgery; Theory, Technique, and Tissue.* 4th ed. New York: Elsevier; 2009:789-805.
2. Feder RS, Rapuano CJ. *The LASIK Handbook; A Case-Based Approach.* Philadelphia: Lippincott William & Wilkins; 2007:49-79.