

The Physics and Engineering of Femtosecond Lasers

Surgeons who have already invested in a femtosecond laser system for corneal surgery may ask why they cannot simply upgrade their device to perform cataract surgery.

BY HOLGER LUBATSCHOWSKI, PhD

The market launch of the revolutionary IntraLase femtosecond laser took place more than 10 years ago. Today, in excess of 1,000 systems have been sold, offered by five different manufacturers. In addition to the IntraLase, now owned by Abbott Medical Optics Inc., the other systems include the Femto LDV Crystal Line (Ziemer Group), the Femtec (Technolas Perfect Vision GmbH), the VisuMax (Carl Zeiss Meditec, Inc.), and the WaveLight FS200 (Alcon Laboratories, Inc.). All of these systems are designed only for refractive surgical procedures on the cornea.

Iterations of femtosecond lasers that are designed to perform steps of cataract surgery are newly available, in clinical trials, or under development. They include the LenSx laser (Alcon Laboratories, Inc.), LensAR's Laser System, the Catalys (OptiMedica Corporation), and the Victus (Technolas Perfect Vision GmbH and Bausch + Lomb; not available in the United States). Rowiak GmbH has announced the creation of a prototype.

Surgeons who have already invested in a femtosecond laser system for corneal surgery may well raise the legitimate request to their laser manufacturer to upgrade their system for use in cataract surgery.

Both devices, those used for corneal surgery and those used in cataract surgery, are femtosecond lasers. All of the units use more or less similar laser parameters such as wavelength, pulse duration, and repetition rate as well as, with some restrictions, the same pulse

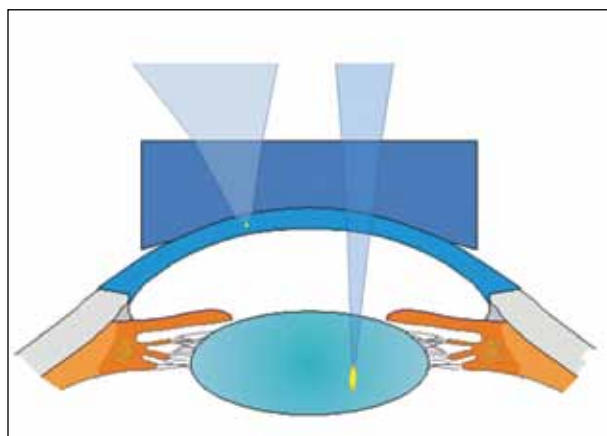


Figure 1. Beam characteristics for corneal and lens application. High-precision corneal surgery requires a small focal volume of the laser focus, which is realized by high numerical aperture optics (left). If a large volume (in lateral and axial dimensions) has to be addressed by the laser's focus, it is much easier to accomplish with optics of a lower numerical aperture (right). The term *numerical aperture* describes the ratio of the focal length to the diameter of the focusing lens.

energy. Moreover, the platforms look the same and use the same workflow: the patient lies on a bed while the eye is mechanically fixed by a suction device.

Diving a little deeper into the physics and engineering requirements for both applications, however, one may consider the upgrade option more critically.

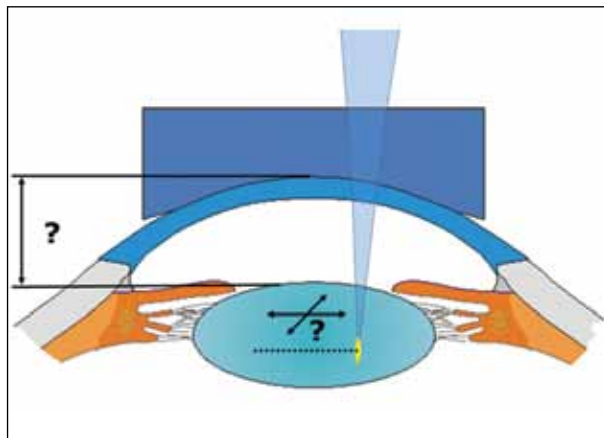


Figure 2. The clinical diversity of eyes in terms of anterior chamber depth and lenticular geometry makes image-guided surgery essential for laser cataract surgery.

PHYSICS AND ENGINEERING

Laser systems for corneal refractive surgery are optimized to precisely cut a smooth area of about 10 mm in width. For lens surgery, the surgeon has to target a volume of 7 mm in diameter and 4 mm in depth. Because the crystalline lens is located significantly deeper inside the eye than the cornea, lens surgery requires laser radiation to pass through a number of refractive surfaces with varying indices of refraction, inducing aberration of the laser beam.

Addressing a large volume with the laser's focus is more easily accomplished by optics of lower numerical aperture (Figure 1). As a consequence, the required pulse energy will be higher, because the focal spot size will increase laterally and axially. Accordingly, the laser's cutting precision will decrease, which is acceptable for nuclear fragmentation, the capsulorhexis, and corneal incisions in cataract surgery. Reduced precision would not be acceptable, however, for corneal refractive surgery.

In addition to a larger focal volume, higher pulse energy is also required in cataract surgery due to the strong scattering losses of laser power inside the sclerotic crystalline lens. As a result, pulse energy must be increased by a factor of 5 to 10 to produce photodisruption of the lenticular tissue compared with current corneal laser surgical procedures. Instead of just "tuning" the laser source, filling this gap may require a stronger machine.

Finally, a navigation system is essential for processing the crystalline lens, because the individual anatomy of the anterior chamber differs among patients. Unlike with corneal procedures where the cutting depth is usually preset, a cataract laser system has to target the various positions of the anterior capsule and must

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maintain an adequate margin of safety relative to the posterior lens capsule (Figure 2).

IMAGING SYSTEM

The three-dimensional imaging system required for cataract procedures can be realized by different optical techniques. Examples include Scheimpflug imaging, confocal imaging, triangulation techniques, and optical coherence tomography (OCT) imaging. Most of the first-generation femtosecond laser cataract surgery systems implement OCT imaging, because it works well with the delivery system of the femtosecond laser beam. Usually, however, the imaging light has a different wavelength on the femtosecond cataract systems compared with the 1,040-nm radiation of the femtosecond laser. On the existing corneal laser systems, the optical elements are coated for this wavelength with regard to optimal reflection or transmission. This 1,040-nm coating substantially interferes with the wavelength of the imaging light—especially in OCT—which may necessitate a complete exchange of the optical elements.

CONCLUSION

All of the considerations discussed herein are technical challenges, not principal barriers. Femtosecond lasers will continue to revolutionize ophthalmic surgery by enabling three-dimensional, highly precise tissue processing. Their effect may be compared with the digitization of office machines. Having one machine that prints, faxes, scans, and copies saves a great deal of space and money, but it will take time to develop laser systems that perform all of the desired functions well. Moreover, for high-throughput applications, a specialized system will remain the preferred choice. ■

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