Principles and Applications of the Femtosecond Laser

A recently published book reviews considerations for this relatively new technology.

BY MARK TOMALLA, MD

Just a little more than 10 years have passed since the femtosecond laser was first used to create a LASIK flap. Now, the laser can be applied across the entire spectrum of corneal surgery, including therapeutic corneal treatments, intrastromal femtosecond laser incisions, and intrastromal refractive correction. This device has also found application in cataract surgery. In collaboration with Gerd U. Auffarth, MD; Josef F. Bille, PhD; G.I.W. Duncker, MD; Kristian Hohla, PhD; Mike P. Holzer, MD; Laszlo Kiraly, MD; Michael C. Knorz, MD; Georg Korn, PhD; Frieder H. Loesel, PhD; Udo Ludwig, Dipl Ing; Tobias H. Neuhann, MD; and Anna Sasse, MD, I recently wrote a book reviewing femtosecond laser technology and its applications.[1]

This compilation provides an introduction and historical overview; lays out the physical principles of the generation and amplification of ultrashort laser pulses; explains laser-tissue interaction, multiphoton imaging, and biomechanical modeling of the femtosecond laser; describes the clinical applications; discusses refractive surgery techniques with the femtosecond laser; and explores prospects for future use.

USE IN OPHTHALMOLOGY

Laser is an acronym for *light amplification of stimulated emission of radiation*. As such, it is a novel source of radiation that has been used for a wide range of purposes, from scanning barcodes and entertainment technology (eg, CD players) to medical applications. Its use in ophthalmology is straightforward, mainly because the human eye is one of the most accessible organs. Furthermore, the transparency of the eye allows easy diagnostics and treatment throughout the entire globe.

> Femtosecond lasers provide ultra-precise intrastromal tissue manipulation and ablation.

Following on the use of excimer lasers to ablate corneal tissue, femtosecond lasers were introduced to provide ultra-precise intrastromal tissue manipulation and ablation. LASIK flap cuts and intrastromal refractive procedures with this technology utilize the properties of laser-tissue interaction to achieve optimal results and increase procedural safety. Today, the breadth of intrastromal treatments possible with the femtosecond laser include mechanical tunnel incisions for implantation of intrastromal corneal ring segments (ICRS), penetrating keratoplasty (PKP), anterior lamellar keratoplasty (ALK), posterior lamellar keratoplasty, and astigmatic keratotomy.

CORNEAL TREATMENT BENEFITS

Depending on the corneal treatment, the femtosecond laser has many clinical advantages. In patients with keratoconus, the femtosecond laser is beneficial because it is not always possible to employ mechanical cutting techniques. The laser allows personalization of the tunnel depth, width, and total diameter for ICRS placement and has led to the development of new geometric graft shapes for use in PKPs. It also permits a variety of incision angles and diameters for treatment.

Another advantage of the femtosecond laser is that it creates a precisely defined graft thickness (up to 400 µm) for ALK treatments, meaning the surgeon can apply an individualized approach to each treatment. During endothelial transplantation with the femtosecond laser, no suture is needed, which decreases the amount of induced astigmatism. (The drawbacks are that the maximum permissible depth value is 400 µm, and that for this treatment to be beneficial with the femtosecond laser, preoperative diagnostics must be more precise.) Femtosecond ALK is a possible treatment for high degrees of astigmatism when LASIK, LASEK, or phakic IOLs are contraindicated.

REFRACTIVE TREATMENT BENEFITS

Refractive treatments performed in part with the femtosecond laser have come a long way since the initial 10-kHz models. When used for creating the LASIK flap, these early lasers would leave tissue bridges, which required significant time and manipulation to separate, often caused clinically significant corneal edema, and in some cases resulted in poor visual results. Later and current generations of the femtosecond laser achieve smoother flap beds, induce faster healing, and generate better postoperative vision.

The benefits of using the femtosecond laser for the creation of LASIK flaps are numerous. First, the hinge position, length, diameter, and thickness of the flap are precise and can be individualized depending on the treatment. Second, the geometry of the sidecut can be created at different angles, corresponding to the patient interface. Third, there is full visual control during the entire procedure. Fourth, intraoperative complications are rare.

OUTLOOK

The femtosecond laser has already given rise to

TAKE-HOME MESSAGE

- Flap cuts and intrastromal refractive procedures with the femtosecond laser utilize the properties of laser-tissue interaction to achieve precision and safety.
- Early femtosecond laser models left tissue bridges behind after flap creation; however, newer models generate smoother flap beds.
- Further developments may facilitate customized incision placement and geometry as well as direct monitoring of the ablation response.

> The surgeon can apply an individualized approach to each treatment.

high-performance techniques in ophthalmology; however, we are optimistically awaiting the development of future applications. For starters, femtosecond-assisted cataract surgery is on the brink of acceptance, with several surgeons now testing its safety and effectiveness. (See *New Generation of Femtosecond Lasers Emerges*, page 55.) Furthermore, another potential application for the femtosecond laser is creating thin canals to prevent extensive intraocular pressure in glaucoma patients. (However, this would require alteration of the direction of the laser beam using mirrors.)

Femtosecond platforms are also beginning to integrate diagnostic technologies into their systems to measure the patient's eye directly under the device. This software records essential corneal parameters, including corneal thickness, while the eye is docked so that treatment occurs only in the intended area. Further development in this area may facilitate customized incision placement and geometry as well as direct monitoring of the ablation response.

CONCLUSION

The maturation of ultra-fast laser technology—the femtosecond laser—has increased the capacity at which ophthalmologists can treat patients. With today's wavefront-based customized procedures, this combination should yield results closer to the supernormal vision patients so desperately want. As surgeons, our main task will be to adapt surgical procedures to femtosecond technology so that we can achieve its maximum benefit in as many treatments as possible. ■

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1. Tomalla M. Femtosecond Laser—Principles and Application in Ophthalmology. Bremen, Germany: UNI-MED Verlag AG/International Medical Publishers; 2010.