Reviewing the Current Status of Femtosecond Lasers in Refractive Surgery

Four platforms are currently available, with a new one on the way.

BY GÜNTHER GRABNER, MD

Femtosecond laser technology is all around us now, and many refractive surgeons have chosen to invest in one of the four available technologies. This article will review the current status of those machines designed specifically for refractive surgery, which include the Femto LDV (Ziemer Group, Port, Switzerland), IntraLase (Abbott Medical Optics Inc., Santa Ana, California), Technolas 520F (Technolas Perfect Vision GmbH, Munich, Germany), and the VisuMax (Carl Zeiss Meditec, Jena, Germany). A fifth, designed by WaveLight AG/Alcon Laboratories, Inc. (Erlangen, Germany/Fort Worth, Texas), is rumored to be released this fall. *(Editor's Note: Please see the sidebars throughout this article for specific information on each femtosecond laser platform; all sidebars compiled by Jennifer Kreatsoulas, PhD, Senior Associate Editor.)*

First, before investing in femtosecond laser technology, it is advisable to determine what your specific clinical needs are. Will the laser be stationary in one operating room or will it be transported between locations? Will you use it for flap creation alone or also for therapeutic corneal procedures, such as penetrating keratoplasty (PKP), deep anterior lamellar keratoplasty (DALK), Intacs (Addition Technology, Inc., Des Plaines, Illinois) channel creation for keratoconus, and other indications? Are you interested in new devices, such as intrastromal corneal implants, like the AcuFocus Kamra corneal inlay (AcuFocus Inc., Irvine, California), and new procedures, such as Intracor (Technolas Perfect Vision GmbH) for presbyopia?

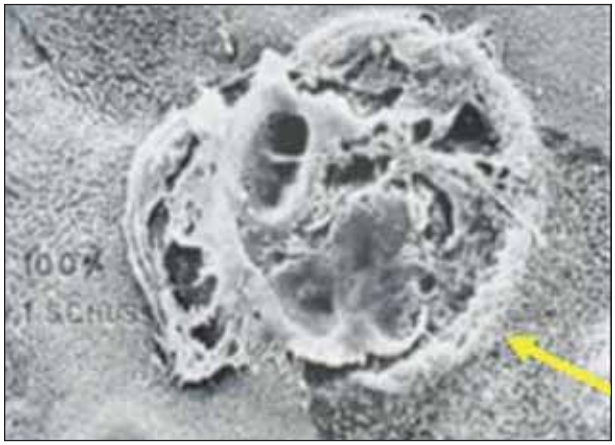

Figure 1. One laser shot on the human corneal epithelium with a femtosecond dye laser.

Most of these questions can be answered by reviewing the technical features, procedures and handling, and clinical benefits and limitations of each system. I highlight these considerations below.

BACKGROUND

Surgeons experimented with femtosecond lasers in refractive surgery as early as the 1990s. I was involved in the early studies with this technology, testing the efficiency of a femtosecond dye laser (less than 10 Hz) to make cuts in the cornea.[1] Although we were able to produce holes in human corneal tissue (Figure 1), the damage zone was

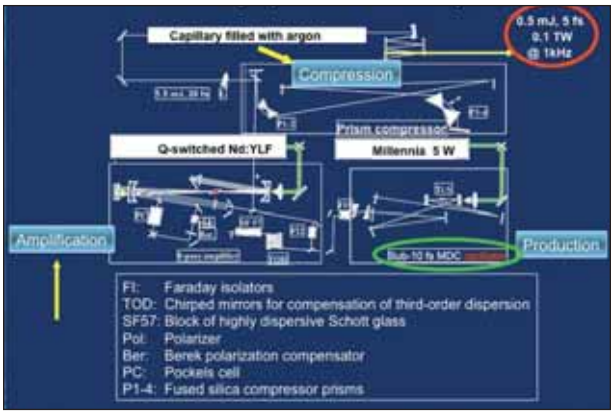

Figure 2. Schematic graph of a femtosecond laser system.

much larger than it was with the excimer laser (range, 6–12 µm vs 0.2 µm). The pulse duration of the laser was 30 femtoseconds. We also could not focus the laser beam at all.

There has been an exceptional amount of development in this arena since our initial studies. The femtosecond laser is a quite complicated machine—a schematic is depicted in Figure 2—and today's platforms have wavelengths in the near infrared range, allowing surgeons to cut the clear cornea with minimal side effects. The ultrashort pulses create a very high energy density, leading to plasma formation and inducing minimal trauma. Now, femtosecond laser technologies focus the laser beam across a small spot size of approximately 1 to 3 µm.

PLATFORMS

Technical features. Comparing the technical specs of each platform (Table 1), the Femto LDV uses an oscillator only, whereas the other three femtosecond lasers all use an amplifier to reach sufficient energy density. This involves several complex optical steps. The central wavelength is similar for all platforms (in the infrared), but the pulse duration ranges from 200 to 800 femtoseconds, and the repetition rate ranges from 40 kHz to more than 20 MHz within the different systems. The Femto LDV has the highest repetition rate (more than 20 MHz), which is why its pulse energy is in the nanojoule range, as compared with the three other lasers, which are in the millijoule range.

TAKE-HOME MESSAGE

- Near-infrared femtosecond lasers create cuts in the clear cornea with minimal side effects.
- Each femtosecond platform uses a slightly different cut pattern.
- Clinical experience with femtosecond lasers continues to grow worldwide.

FEMTO LDV LASER

The Femto LDV (Ziemer Group, Port, Switzerland) is a mobile femtosecond laser system that provides a spectrum of applications in corneal surgery. LASIK flaps with diameters from 8.5 to 10 mm can be created in less than 30 seconds, from suction on to suction off, with a pulse rate in excess of 5,000 kHz. According to company literature, hinge position, hinge angle and width, flap diameter, and flap thickness (90–140 µm) can be selected to create a precisely defined flap. For fixation, the handheld laser delivery system incorporates a suction ring and uses computer-controlled vacuum. The handpiece allows surgeons to control the entire procedure from a single position under the excimer laser's microscope without moving the patient. The optional lamellar corneal surgery module facilitates creation of advanced patterns such as tunnel incisions for intrastromal corneal ring segments, pockets for intrastromal inlays, and deep resections for lamellar keratoplasty. The LDV handpiece incorporates the TopView camera, a video imaging system that delivers a close-up view of the patient's applanated eye. The image-processing software optimizes the image of the eye, allowing the surgeon to center the resection pattern. This capability is available for both LASIK and corneal surgery applications. Detlef Uthoff, MD, of the Bellevue Eye Clinic, Kiel, Germany, told *CRST Europe* that with the Femto LDV there is no fear of LASIK flap complications as there is with mechanical microkeratomes.

"With the Femto LDV, it is our aim to improve safety to the highest level," Professor Uthoff said. "The technology allows more flexibility in the creation of different flaps and of the hinge and hinge localization. Tissue bridges are easy to loosen, and healing is faster and more comfortable for the patient. In the rare case of problems with flap creation, a recut is easy to perform just hours after the initial procedure. Currently, we use the technique only for preparation of the flap, but in the future we will also use the Femto LDV for keratoplasty and tunnel preparation for Intacs (Addition Technology, Inc., Des Plaines, Illinois)."

Ziemer has also unveiled the Femto LDV Crystal Line, an all solid-state laser operating at a pulse rate of greater than 5 MHz. Its crystal-tuned, wavefront-optimized, high numerical aperture optics focuses the laser beam on a tissue volume less than 2 µm across to achieve smooth tissue dissection with minimal thermal effects, trauma, and edema in the corneal tissue. A proprietary smooth in-plane circular rim cut creates a self-sealing flap border that avoids ingrowth and facilitates flap lifting.

TABLE 1. TECHNICAL DETAILS FOR FEMTOSECOND LASER PLATFORMS				
	IntraLase (AMO)	**Femto LDV (Ziemer)**	**Technolas 520F (Technolas Perfect Vision)**	**VisuMax (Carl Zeiss Meditec)**
Laser type	amplifier	diode-pumped Yb oscillator	amplifier	fiber-optic amplifier
Central wavelength	1,053 nm	1,045 ±10 nm	1,053 nm	1,043 nm
Pulse duration	600 to 800 fs	200 to 350 fs	500 to 700 fs	220 to 580 fs
Repetition rate	150 kHz	>20 MHz	40 kHz	200 kHz
Laser pulse energy (max)	5 µJ (±0.5)	10 to 20 nJ	4.6 µJ	50 to 420 nJ

TABLE 2. OPERATING DETAILS FOR THE LASIK FLAP PROCEDURE				
	IntraLase (AMO)	**Femto LDV (Ziemer)**	**Technolas 520F (Technolas Perfect Vision)**	**VisuMax (Carl Zeiss Meditec)**
Cutting pattern	raster	meander, with fast oscillation and slow scan trajectory	spiral out-in	spiral in-out/out-in
Flap diameter	computer controlled	suction ring 8.5, 9.0, 9.5, 10.0 mm	computer controlled	computer controlled
Cutting depth	selectable 90 to 400 µm	distance foil 90, 110, or 135 µm	selectable 100 to 200 µm	selectable 80 to 220 µm
Treatment time (flap)	<20 sec	~15 to 20 sec	25 sec	20 to 40 sec
Spot size	<3 µm	2 µm	1 µm	1 µm
Surface quality	similar to MK	similar to MK	similar to MK	similar to MK
* MK = microkeratome				

Procedures and handling. Refractive surgeons are most interested in the femtosecond laser for its LASIK flap-making capability. Each laser uses a slightly different pattern for cutting. The IntraLase uses a raster cut pattern, the Technolas 520F and the VisuMax use spiral cut patterns, and the Femto LDV uses a meander cut pattern—a fast oscillation with a slow scan trajectory (Table 2).

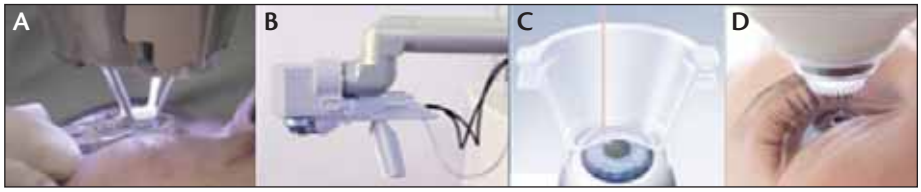

Figure 3. The (A) IntraLase and (B) Femto LDV docking PIs are applanating. The (C) Technolas 520F and (D) VisuMax docking PIs are nonapplanating.

With the LDV, a suction ring, similar to what is built into manual microkeratomes, is used to produce the appropriate flap diameter, and a distance foil is used to select the cutting depth. But the IntraLase, Technolas 520F, and VisuMax use highly flexible computer-controlled diameter and cutting depth selection. The most recent IntraLase model, the iFS, has an added shape (oval) and sidecut angle option. Both strategies aim to achieve a perfectly shaped and planar flap within less than ±10 µm of intended depth. With the computer-controlled systems, the hinge can be positioned at any location and programmed to any desired length.

The procedure time for flap creation is about the same for all four systems, ranging from a little more than 10 seconds to 40 seconds. I say "about the same" because the difference between 10 and 40 seconds is quite irrelevant (within this time frame) to both the surgeon and the patient. Additionally, the spot size and the surface quality are similar across all platforms.

One of the big differences between laser systems is the docking patient interface (PI). The IntraLase and Femto LDV use applanating and the Technolas 520F and the VisuMax use nonapplanating docking PIs (Figure 3). These setups affect intraocular pressure (IOP). We compared IOP during flap creation with the IntraLase, the VisuMax, and the Femto LDV in 40 human donor eyes. Pressures during the cutting period went up to 180.6

INTRALASE iFS LASER

The IntraLase iFS, the fifth-generation femtosecond laser from Abbott Medical Optics Inc. (Santa Ana, California), is designed for LASIK and advanced corneal surgery procedures. Operating at 150 kHz, the device can create LASIK flaps in less than 20 seconds, with cutting depths ranging from 90 to 400 µm. According to company literature, flap dimensions are designed with the IntraLase iFS based on patient factors such as corneal thickness, steepness, diameter, and pupil position. With the IntraLase iFS, surgeons can create uniformly thin, planar flaps that are smooth and evenly hydrated, with reproducible flap thicknesses. Users also have the ability to create straight, angled, or arcuate incisions within the cornea. Multiplanar custom incisions with hermetic sealing properties that require less suture tension can also be created, as well as customized incisions with advanced edge profiles.

The iFS laser, designed to deliver biomechanically engineered and customized flaps, includes comprehensive IntraLase enabled keratoplasty (IEK) and ring-channel formation capabilities.

"The flap-creation time is just about 10 seconds with the iFS," said Michael C. Knorz, MD, of FreeVis LASIK Center, Germany, in an e-mail to *CRST Europe*. "Suction is very reliable, and suction breaks are extremely rare. The centering software allows surgeons to compensate for decentration occurring during placement of the suction ring. Also, a video microscope provides a better view and easier control of the laser flap creation."

According to Dr. Knorz, a member of the *CRST Europe* Editorial Board, a defining feature of the iFS laser is the option to create flap angles up to 150° (reverse sidecuts). "We have shown[1] that flaps with reverse sidecuts have a 1.5-times stronger adhesion than femtosecond laser flaps with 70° sidecuts, and a 3.5-times stronger adhesion than flaps created with mechanical microkeratomes," Dr. Knorz said.

The IntraLase iFS is a full corneal surgical workstation that can be used to perform lamellar or penetrating corneal grafts, carve intrastromal pockets and tunnels, and create relaxing incisions.

1. Knorz MC, Vossmerbaeumer U. Comparison of flap adhesion strength using the Amadeus microkeratome and the IntraLase iFS femtosecond laser in rabbits. *J Refract Surg.* 2008;24(9):875-878.

TECHNOLAS FEMTOSECOND WORKSTATION 520F

The Technolas Workstation 520F (Technolas Perfect Vision GmbH, Munich, Germany) is a versatile system that can be used for flap creation; therapeutic indications; and Intracor, an intrastromal presbyopia treatment in which no flap or lenticule is created. According to the company, surgical procedures with the Technolas 520F are personalized with the easy-to-use CustomFlap and CustomShape software modules. With CustomFlap, surgeons can customize patients' LASIK flap diameter, geometry, thickness, and hinge position.

Recent upgrades to the Technolas 520F include a new laser head to improve accuracy of outcomes and stromal bed quality; faster flap procedures, with flaps produced in 20 seconds at 80 kHz; and new centration software that allows surgeons to recenter the procedure under a curved interface.

Mark Tomalla, MD, a practitioner at the Clinic Niederrhein, Clinic for Refractive and Ophthalmic Surgery, in Duisburg, Germany, has used the Technolas femtosecond laser for 6 years. "The 520F uses a curved patient interface, maintaining the corneal curvature to provide a high level of control and safety, with reduced increase in intraocular pressure," Dr. Tomalla wrote in an e-mail to *CRST Europe*. "The curved patient interface is well suited to intrastromal corneal ring segment procedures and allows complicated therapeutic cases such as penetrating keratoplasties to be performed more safely. When creating flaps with the 520F system, which allows highly individualized treatment approaches, I achieve a high rate of precision.

"The Technolas 520F femtosecond laser performs the minimally invasive, intrastromal presbyopic treatment of Intracor by creating a series of concentric rings within the stroma to bring about a central steepening of the corneal curvature," Dr. Tomalla continued. "Having been involved in the multicenter Conformité Européenne (CE) approval study for Intracor, I now have over 12 months follow-up data, which shows results are stable, with patients gaining an average of 4.8 lines of near UCVA. I consider this procedure to be a highly promising approach for treating presbyopic patients."

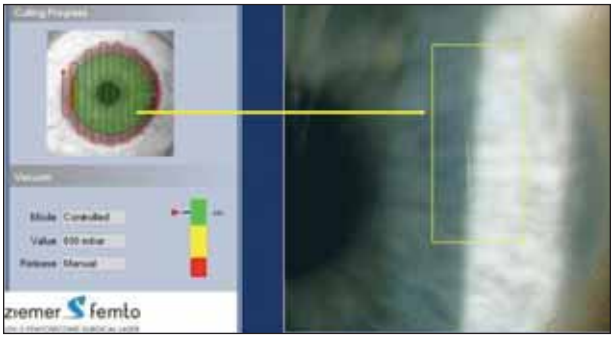

Figure 4. With the Femto LDV, tracks may be visible under the slit lamp.

±21.61 mm Hg with the IntraLase (in the low green zone), approximately 84.9 ±7.3 mm Hg with the VisuMax, and up to 150.9 ±17.2 mm Hg with the Femto LDV, from the time the cut started, after suction and applanation. One trick that we learned is that the headrest of the VisuMax automatically lowers when the pressure on the eye becomes too high.

Applanating systems are technically simpler; however, they may cause tissue deformation and typically higher IOP compared with nonapplanating systems, which cause less tissue stress and obviously have the potential to produce a more natural shape. The drawback with nonapplanating systems is that a 3-D beam control is required to create the curved incision. These differences, in my opinion, do not matter clinically at the present time; however, they may become relevant when companies create the software that allows an incision parallel to Descemet's membrane. Further studies are needed to confirm the clinical benefits of one docking system over another.

Clinical benefits/limitations. Each of the four available femtosecond laser systems for refractive surgery have benefits and limitations. Generally speaking, the main benefits of the IntraLase, Technolas 520F, and VisuMax are the ease of docking and the flexibility with cutting geometry. However, these laser systems are very large and fixed, whereas the Femto LDV is small and mobile, fitting under any operating microscope and excimer laser. Mobility is the largest benefit to the Femto LDV. For surgeons who move machines between operating rooms and mostly aim to perform refractive surgery, this may be the better choice. Sometimes with the Femto LDV, tracks may be visible under the slit lamp (Figure 4); however, these do not cause any clinical effect, and the visual acuity still is quite good.

ADDITIONAL FEATURES

Several femtosecond platforms also have incorporated corneal surgery applications including DALK and PKP. These are available on the IntraLase and Technolas 520F platforms

THE FS-200

The FS-200 femtosecond laser (WaveLight AG, Erlangen, Germany) allows the surgeon to choose the diameter, shape, thickness, depth, angle, and location of corneal flaps and hinges. It is capable of making an array of cuts to treat a variety of corneal shapes and sizes and eliminating the appearance of the opaque bubble layer (OBL). The FS-200 is not yet commercially available.

According to the company, the laser, with a repetition rate of 200 kHz, can make round or elliptical cuts for corneal flaps, as well as sidecuts and reverse cuts for intrastromal corneal ring segments and keratoplasties. The FS-200 laser also has the ability to recenter the flap within a 10-mm diameter area, even after the suction ring has been applied.

A. John Kanellopoulos, MD, Director of Laservision Eye Institute in Athens, Greece, and a Clinical Associate Professor of Ophthalmology at New York University Medical School, described the new FS-200 as a "promising tool in refractive and corneal surgery" in an e-mail to *CRST Europe*. Dr. Kanellopoulos, a member of the *CRST Europe* Editorial Board, and his team in Athens have been using the FS-200 for almost 1 year. Although clinical results with this laser are yet to be studied in large numbers of patients, Dr. Kanellopoulos said there are several promising features of the FS-200.

"With respect to speed, the laser creates myopic LASIK flaps (8-mm diameter, 120-µm depth) in 6 to 7 seconds," Dr. Kanellopoulos said. "Also, the laser uses low energy (8-µm spacing, 0.8 mJ per pulse), produces excellent stromal bed quality, and creates a large applanation area (11-12 mm) on the cornea. The large applanation area allows comfortable margins in hyperopic LASIK (when the desired flap reticule is moved on the planning computer screen, the flap size is not reduced) and an intracorneal pocket is not needed to reduce air pressure during the lamellar cut of the flap. Instead, the WaveLight team has pioneered a vent passage (which our team has dubbed the *chimney*) through the flap hinge and to the corneal surface that allows intracorneal venting during the lamellar part of the flap and [results in] little secondary OBL. Finally, the patient interface cones come precalibrated and are calibrated a second time by the laser itself."

VISUMAX FEMTOSECOND SYSTEM

The VisuMax Femtosecond System (Carl Zeiss Meditec, Jena, Germany) allows surgeons to perform precise, safe, and gentle procedures. With a pulse rate of 500 kHz, the VisuMax performs at exceptional speed. The laser's incision quality and controls enable fast creation of smooth lamellar

and circular cut surfaces, ensuring short treatment times of 20 to 40 seconds for high patient satisfaction. Cutting depths range from 80 to 220 µm. The curved contact interface attaches to the cornea during treatment, flattening it slightly and preventing unnecessarily high intraocular pressure and stress to the eye. Also, minimal laser energy is directed at the eye; as a result, the tissue outside the defined area of the cut remains untouched. Flap cutting, keratoplasty, and refractive lenticule extraction (ReLEx; Carl Zeiss Meditec) are optional treatment applications for the VisuMax.

ReLEx allows surgeons to perform complete laser vision correction with the VisuMax femtosecond laser. Visual acuity correction is undertaken in the intact cornea, helping achieve greater precision and predictability in the planned result. This procedure simplifies corneal refractive laser surgery because the corrective lenticule and overlying corneal flap are created in one step using one laser and avoids movement of the patient between laser systems.

"Having performed more than 1,000 LASIK procedures during the past year and more than 100 ReLEx procedures within the past few months, we are very confident with the VisuMax 500-kHz femtosecond laser," said Jesper Hjortdal, MD, PhD, Director of Corneal and Refractive Surgery, Department of Opthalmology, Aarhus University Hospital, Denmark, in an e-mail to *CRST Europe*. "Treatments are safe with high patient comfort, and our results indicate improved precision and accuracy compared with conventional LASIK."

and in early clinical trials for the VisuMax platform. Intacs channel creation is another feature, which is available on the IntraLase and Technolas 520F platforms and in early clinical trials for the Femto LDV platform. Additionally, the Technolas 520F can be used to perform Intracor, an intrastromal laser vision correction procedure for presbyopia; the VisuMax also has a signature procedure using the femtosecond laser only, which the company has named refractive lenticule extraction (ReLEx), for myopia and astigmatism.

CONCLUSION

Although the total number of procedures performed with the IntraLase (more than 3 million) is significantly higher than with the Femto LDV (approximately 120,000), Technolas 520F (approximately 30,000), or VisuMax (approximately 10,000), the overall clinical experience with femtosecond technology continues to grow. With time, the procedural numbers for each laser system will likely even out.

The current number of procedures performed with each specific laser should not be taken as the sole indicative for the quality of the technology or sway your final decision on which technology to invest in, as each laser was released at a different time. When choosing which femtosecond laser system is right for you, instead consider what your clinical needs are. Assess the technical features, the procedure and handling, and the clinical benefits and limitations of each laser at length before deciding. There is no right or wrong choice; however, investing in one of these technologies is advisable, because it is quite clear that the age of the microkeratome is gone for good. In my clinic, we have not used one for more than 3 years, and we do not want to go back to using one. In the future, we will see even faster lasers—a few femtoseconds only—allowing us to use less energy and enhance special focusing with a higher numerical apperture. Upcoming generations may also switch from the infrared to the ultraviolet wavelength. In closing, I think we should see some very rapid development in the arena of femtosecond lasers for refractive and corneal surgery. This is an interesting time to be a refractive surgeon! ■

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