WHAT IS THE IDEAL FEMTOSECOND LASER FOR LASIK?

A review of the femtosecond LASIK flaps of yesterday and today.

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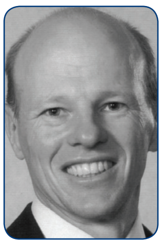

The photodisruptive pulse duration of a femtosecond laser is an incredibly short millionth of a billionth of a second. This is part of the reason why these lasers are so precise and why engineers have been able to greatly improve the safety and efficacy of these devices since their introduction to refractive surgery.

The first widespread application for femtosecond lasers in ophthalmology was the creation of LASIK flaps. A colleague and I compared the safety and efficacy of 20,000 LASIK flaps created with a mechanical microkeratome or the IntraLase FS60 (Abbott Medical Optics) in 2009.[1] Our results confirmed other published reports that femtosecond flaps were superior to microkeratome flaps.[2]

I have not used a microkeratome since that time, but I have used many different femtosecond lasers. Flap creation with early femtosecond lasers produced rough stromal beds and flaps of variable thicknesses, and cutting times of up to 2 minutes were required. In comparison, the newest generation of femtosecond lasers makes flaps in 10 seconds or less, and does so precisely and in a number of shapes.

SIMILARITIES AND DIFFERENCES

Five femtosecond laser platforms are currently commercially available for creating LASIK flaps. Each of these platforms operates on similar principles. The patient lies down, an interface is applied to the cornea, and laser pulses are delivered to the superficial cornea. The laser pulses produce cavitation bubbles—predominantly composed of carbon dioxide, nitrogen, and water—at a predetermined depth. Multiple pulses create multiple bubbles, separated by a few microns, which coalesce to form a cleavage plane of a predetermined shape and thickness.

Despite these similarities, however, there are significant differences among the laser platforms and the flaps they create. In 2008, Lubatschowski classified the systems that were available at that time into two groups.[3] In one group, characterized by high pulse energy and low pulse frequency, he included the IntraLase and Femtec (Technolas Perfect Vision; now Victus by Bausch + Lomb) lasers. The other group, characterized by low pulse energy and high pulse frequency, included the Femto LDV (Ziemer Ophthalmic Systems). Today, however, all manufacturers produce better, higher-frequency, lower-energy lasers, so this distinction is less applicable. This article discusses the similarities and differences in the five current femtosecond platforms and the flaps they create.

IntraLase. The 6-kHz IntraLase femtosecond laser became commercially available in 2000. Evolution of the technology led to higher frequency lasers, and, by 2006, the 60-kHz IntraLase was introduced. Because thin flaps of 100 µm or less could be created precisely, with a standard deviation of 4 µm from intended thickness,[4] the laser procedure was safer than microkeratome flap creation, with lower ectasia risk and no buttonholes. The combination of safety with faster flap cuts (approximately 22 seconds) resulted in the FS60 becoming the most widely used femtosecond laser internationally. Many are still in use today.

Significant advantages of this laser included its ability to program flap thickness and diameter (maximum, 9.3 mm). Additionally, a planar flap of even thickness could be created with 90° sidecuts. The flap produced was less susceptible to shifting, and, if it was lost or removed, the patient's refraction changed only minimally. Furthermore, the hinge could be made nasally or temporally.

However, new side effects also appeared, including the formation of an opaque bubble layer (OBL). The OBL can affect iris recognition and tracking; therefore, a pocket can now be created near the hinge to reduce the OBL. Small corneas are susceptible to CO_2 bubbles tracking into the anterior chamber, which can also affect tracking in some excimer lasers. If this occurs, excimer treatment is delayed. Occasional transient light sensitivity and rainbow glare were other complications of the laser.

In surgery with the FS60, a suction ring is applied to the patient's eye and a patient interface is docked onto the suction ring, which flattens the cornea. In cadaver eye studies, this process raised IOP to about 180 mm Hg.[5] In surgery, the patient transiently loses vision, so he or she cannot fixate dur-

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APPROXIMATE FLAP CUT TIMES OF AVAILABLE LASER PLATFORMS:

WaveLight FS200 = 7 sec
IntraLase FS150 (iFS) = <10 sec
Victus = <10 sec
VisuMax = 10 sec
Femto LDV = 14 sec
IntraLase FS60 = 22 sec

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ing the procedure. However, a significant advantage to the surgeon is the ability to directly observe the creation of the flap during the procedure.

The 150-kHz iFS IntraLase was introduced in 2009. This device creates a flap in less than 10 seconds with lower energy pulses and reduced spot separation compared with previous iterations. Other new features include the ability to program oval flaps and inverted sidecuts that are less susceptible to displacement. The iFS can perform other corneal applications such as axial keratotomy and keratoplasty, but it cannot do femtosecond lens procedures. There are more of these lasers in use than any of the others; more than 5 million IntraLase corneal procedures have been done, and the IntraLase is the subject of the most peer-reviewed literature publications.[6]

Victus. The Femtec laser, launched more than 10 years ago, has been succeeded by the Victus laser. This laser performs corneal applications similar to the IntraLase, but it can also perform lens surgery applications. Like the IntraLase, the cornea module of the Victus allows flap thickness to be selected, and there is a 5-µm standard deviation in planned flap thickness. The laser operates at 160-kHz frequency, and flap creation takes less than 10 seconds. The flap cut can be visualized during treatment. A suction ring is applied to the patient's eye, and the patient interface is docked into it.

Unlike the IntraLase, the Victus patient interface is curved, each laser pulse has lower energy, and the patient's IOP rises only to approximately 50 mm Hg during treatment as measured intraoperatively.[7] Therefore, there is less postoperative subconjunctival hemorrhage and patient discomfort. Pressure sensors in the interface guide the surgeon to align the interface and minimize the IOP rise. If OBL occurs, it is in the region of the sidecut and may have less effect on iris recognition and tracking.

WaveLight FS200 (Alcon). This laser is similar to the IntraLase iFS in many ways. A suction ring is applied to the eye, and the patient interface docks into the ring. The cornea is flattened, so an evacuation canal is created to reduce OBL formation. The flap cut takes about 7 seconds. The cut can be seen by the surgeon during the procedure. The flattening of the cornea raises the IOP to 150 mm Hg,[8] so the patient loses vision.

A ballast control calibration is done on each applanation cone, which accounts for the thickness of the glass and temperature changes in the laser. The flap position can be adjusted after docking of the cone. The laser is suited to a range of corneal applications and offers adjustable hinge positions and sizes; variable sidecut angles; and a range of flap sizes, thicknesses, and shapes.

Sensor-controlled vacuum pumps automatically stop the cutting if vacuum loss occurs. Large flaps (up to 10 mm in diameter) can be made.

VisuMax (Carl Zeiss Meditec). The VisuMax has a low-suction curved interface, and no suction ring is applied to the eye. Small, medium, and large patient interfaces are available, and the surgeon can see the flap being created. The maximum IOP is 100 mm Hg.[5] The patient maintains vision and can fixate on a fixation light, which results in the flap being centered on the visual axis.

The laser has a 500-kHz frequency, so the flap is cut in about 10 seconds with relatively low energy. Flap thickness and diameter can be adjusted, and multiple corneal surgery options are available including femtosecond lenticule extraction and small incision lenticule extraction surgeries. The VisuMax does not perform lens surgery applications.

Patients have reported minimal discomfort with the VisuMax treatment, and subconjunctival hemorrhage is uncommon. OBL does occur.

Femto LDV. This line of lasers has evolved rapidly, from the launch of the first Classic model in 2008, through the CrystalLine, Z2, Z4, and Z6, and, most recently, the Z8. Many of the early generation Classic and CrystalLine lasers are still in use today. All of the lasers share the similar characteristic of being mobile, relatively small lasers. The small 2-µm spots overlap, eliminating tissue bridges, which have to be broken on lifting the flap with some other lasers. The laser pulses are at very high frequency (5 mHz), and therefore very low energy is required. This results in no transient light sensitivity, no anterior chamber bubbles, and rapid recovery of vision. The flap cannot be visualized during the cut. In cadaver and porcine eyes, IOP rose to 200 mm Hg,[9,10] so the patient loses vision.

On early generations of the Femto LDV, the flap thickness was not programmable, and a spacer was applied to the patient interface to produce predetermined flap thicknesses of 90 or 110 µm. The planar flap diameter and flap edge were also not programmable, and an approximately 9-mm flap was produced with an everted (ie, microkeratome-type) profile. In the Z8 laser, the flap depth and diameter are programmable, and an option of a 3-D flap (with 90° sidecut) is available in addition to the everted edge profile. The cut time is about 14 seconds.

The number of corneal and lens applications has increased with newer generations of the laser, and the Z8 has lens surgery capabilities. For corneal applications, no suction ring is applied to the eye; the patient interface is applied directly onto the eye, as with the VisuMax.

CONCLUSION

To answer the question proposed in the headline of this article is daunting, and the list of ideal attributes is long. However, the ideal laser should include the points listed in the chart on this page. Although no single laser meets all the criteria, the currently available femtosecond lasers are all excellent tools. Even the most skilled ophthalmic surgeon's proficiency with blades and mechanical instruments has already been superseded by these lasers, and they will improve further. Femtosecond lasers have ushered in a new age of eye surgery. ■

IDEAL ATTRIBUTES OF A FEMTOSECOND LASER PLATFORM

- ★ The laser should have the ability to consistently create a thin, planar flap of a selected thickness and diameter, with square or inverted edges and with the ability to choose hinge location;
- ★ Centration of the flap should be adjustable after docking;
- ★ Creation of the flap should be as fast as possible, but not so fast that a suction break will cause a transected flap;
- ★ Subconjunctival hemorrhages, increased postoperative dry eye, OBL, rainbow glare, and transient light sensitivity should be eliminated;
- ★ Patients should be comfortable throughout the procedure and be able to maintain vision with a low IOP;
- ★ The surgeon should be able to visualize flap creation at all times, and the user interface and docking should be as simple as possible;
- ★ The patient interfaces should fit into deep-set eyes and narrow palpebral fissures;
- ★ As many additional applications as possible should be available on the same laser; and
- ★ The laser should be reliable—if it fails, however, rapid engineer support is important, as is surgeon clinical support, especially during the early learning phase.

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