THE BENEFITS OF A LOW ENERGY FEMTOSECOND LASER

The FEMTO LDV: One to start, others to follow.

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FOREWORD | The use of femtosecond laser systems in ophthalmology has led to the development of myriad novel procedures and to the increased precision and safety of surgery over the past 2 decades. Femtosecond lasers apply ultrashort infrared laser pulses to the ocular tissue precisely and predictably; their main advantage is minimizing damage to surrounding tissues. In anterior segment surgery, femtosecond lasers can now be used for LASIK flap creation, intrastromal corneal ring segment tunnel creation, lenticule extraction, cataract surgery, ocular surface procedures, pterygium surgery, and various lamellar and penetrating corneal therapeutic procedures. Several platforms are available, but the FEMTO LDV (Ziemer) is the only one that can be used for all of these applications and uses the lowest pulse energy of any available femtosecond laser system.

The goals of this article are threefold: to discuss the main advantages of low energy, to provide a historical perspective on its use, and to review clinical data.

A Physical and a Historical Perspective

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Femtosecond lasers with a low pulse energy, like the FEMTO LDV (Ziemer), produce higher precision. Designing a low pulse energy laser, however, presents challenges. It's easy to say, "Let's use low pulse energy," but there is a lot of know-how and high technology behind it. For example, the optic system in a low energy laser needs to be placed close (less than 1 cm) to the eye. A long focal length like is used in other systems fires the laser beam from approximately 15 cm above the eye (Figure 1).

A high frequency is necessary to cut the same amount of tissue in a faster way. The lower the pulse energy and smaller the focus size, the higher the repetition rate needs to be. Usually, microjoule lasers function with repetition rates in the kilohertz (kHz) range. Nanojoule lasers, like the FEMTO LDV, which have a higher numerical aperture (NA) and smaller spot size, function with repetition rates in the megahertz (MHz) range. And again, this is not easy to achieve.

The earliest femtosecond lasers had a small NA, so they were forced to use high pulse energies. They also operated with a low repetition rate of approximately 15 kHz. Technical improvements helped to reduce the pulse energy step by step and increase the repetition rate in the range of several 100 kHz. The FEMTO LDV, however, sparked a quantum leap in innovation. When it came on the market, it had a repetition rate in the megahertz range and only a few nanojoules of pulse energy were needed. This has not changed today. Other femtosecond laser systems now try to slowly decrease their pulse energy and increase their repetition rate.

Ziemer's laser concept is unique, and therefore conventional systems can only adapt in small steps and cannot operate in the full low energy range. Ziemer continues to have the lowest pulse energy laser.

With these parameters, the FEMTO LDV reduces the potential for undesirable side effects such as tissue rupture and gas bubbles leading to opaque bubble layers in the stromal tissue. Further, the small spot size and overlapping spots delivered with Ziemer's lasers produce complete tissue dissection and eliminate tissue bridges.

CONCLUSION

The FEMTO LDV was introduced to the market in 2005. At that time, it was hard to convince surgeons that this small laser system, with its lower pulse energy and higher repetition rate, had advantages over higher pulse energy femtosecond lasers. Over the years and as more surgeons gained experience with this platform, others have come to appreciate the difference between the laser systems and have shared their clinical results (see below). More light has been shed on the advantages of low pulse energy laser systems for anterior segment surgery. Ziemer is the pioneer and trendsetter in this field.

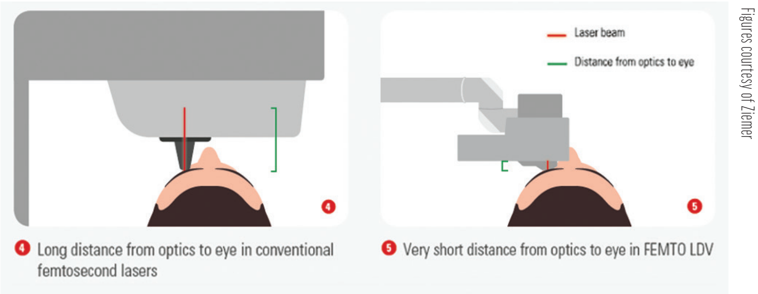

Figure 1. To achieve a small focal volume, the femtosecond laser beam has to be focused with a large angle. Theoretically, a larger focusing angle can be achieved through the use of a very large lens diameter (2), which would lead to much bulkier and much more expensive laser systems, or it can be achieved with a very short focal distance (3). The FEMTO LDV uses a lens with a very short focal distance comparable to those commonly used in confocal microscopy, which provides large focusing angles for strong focusing.

An Exploration of the Clinical Data

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Several femtosecond laser platforms and one nanosecond laser platform for corneal and cataract surgery are available today. Selecting the right platform for one's practice requires an exercise in deciding how the laser system would be used and, once incorporated, how it could help to enhance the patient experience and produce optimal surgical outcomes.

I have used a variety of femtosecond laser platforms, and I have participated in many studies that have looked at the safety and efficacy of these devices, including the FEMTO LDV. This laser applies the lowest amount of energy of any femtosecond laser system to the eye, which results in increased precision. My contribution to this article outlines a few studies that demonstrated several advantages of a low energy laser in the settings of keratorefractive, corneal, and cataract surgery.

STUDY RESULTS

LASIK. Early studies with low energy femtosecond lasers were performed on a theoretical model and suggested that they may be better than high energy lasers. In these nonbiological studies, lasers were fired into water to determine the effect of cavitation bubbles. Thereafter, studies conducted in rabbit models showed that the amount of keratocyte cell death and inflammatory reaction after flap cuts with a femtosecond laser were lower with a low energy laser versus higher energy systems.[1] In these studies, we were able to confirm that the low energy laser did not damage the keratocytes.

The implication of these results is that a low energy laser system provides better control, produces less collateral damage when the laser is cutting the cornea, and induces less wound-healing response following the laser cut. Further, it may promote faster visual recovery for patients.

Pterygium surgery. We have also shown that a low energy laser has benefits for pterygium surgery.[2-6] Because of the larger NA, a low energy laser like the FEMTO LDV can cut through opaque tissue such as the conjunctiva. The patient interface of the Ziemer lasers applanates perfectly parallel to the surface plane, which helps to produce accurate cuts. Further, the laser pulses are guided through an articulated moveable arm to a handpiece, allowing adjustments to be made to the angulation of this surgery tool in six dimensions and a much better applanation on the surface. My colleagues and I showed that the FEMTO LDV can cut a 60-µm thin graft of the conjunctiva very accurately and reproducibly irrespective of the surgeons' experience.

Lenticule extraction. My colleagues and I have also shown the advantages of a femtosecond laser system for lenticule extraction. Corneal Lenticule Extraction for Advanced Refractive Correction (CLEAR) is the latest lenticule extraction procedure, and it is intended for the correction of -0.50 to -10.00 D sphere and up to -5.00 D cylinder.

We have shown that the level of energy applied to the eye for a low refractive correction (eg, -3.00 D) and for a higher refractive correction (eg, -6.00 or -9.00 D) was similar.[7] With an excimer laser ablation, however, the amount of energy applied to the eye increases as the level of refractive error being treated increases to remove the tissue in the stroma.[7] With a lenticule extraction procedure like CLEAR, for correction of high myopia, the lenticule is getting thicker, but it does not require an increasing amount of energy being put into the cornea to achieve the refractive correction.

Laser cataract surgery. New clinical data is also emerging that further shows the advantages of a low energy laser system in cataract surgery.[8-13] One recent case-controlled study showed that, on day 1 postoperative, corrected distance visual acuity was significantly better after laser cataract surgery with a low energy laser (FEMTO LDV Z8) compared to conventional phacoemulsification.[9] A low energy laser platform therefore might provide distinct visual rehabilitation advantages in the early postoperative period.

Another potential advantage of low energy lasers compared to high energy lasers is that they decrease the extent of prostaglandin E2 (PGE2) surge and therefore oxidative stress. In one study in which I participated, the FEMTO LDV Z8 induced significantly more PGE2 compared to conventional phacoemulsification (175.6 ±125.3 pg/mL vs 68.8 ±47.6 pg/mL, respectively) but resulted in no significant difference in malondialdehyde and aqueous flare levels compared to routine cataract surgery with phacoemulsification. It also caused the lowest PGE2 release (without NSAIDs) during the capsulotomy compared to high energy systems—only twofold compared to conventional surgery versus 4- to 12-fold with other high energy laser systems.[8-13]

In that study, we also determined that induction of oxidative stress strongly correlated to the effective phaco time (EPT). Because EPT was significantly shorter for laser cataract surgery versus routine cataract surgery,[14] this could further reduce oxidative stress.

CONCLUSION

Due to myriad benefits shown in the literature, I believe the future of femtosecond laser technology is low energy. The lower the energy applied to the eye, the more protection for the surrounding ocular tissues and the better the opportunity to avoid side effects and poor postoperative outcomes. Further, it opens the possibility for new areas of application, such as pterygium surgery. ■

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