



THE EVOLUTION OF THE FEMTOSECOND LASER AND ITS ROLE IN GLAUCOMA



Each technological iteration can expand the potential uses.

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The history of femtosecond lasers in ophthalmology dates back 30 years to when a graduate student at the University of Michigan accidentally injured his eye while adjusting the mirrors of an experimental laser. The research on this laser was being conducted in the laboratory of Gérard Mourou, PhD, who went on to win the 2018 Nobel Prize for his work on a high-intensity laser pulse technique called *chirped pulse amplification*. At the time of the accident, no one was thinking about medical applications for the laser, but the perfectly circular damage to the student's eye impressed the ophthalmologists who saw it, including Ronald Kurtz, MD. Dr. Kurtz and Tibor Juhasz, PhD, who were separately investigating

femtosecond laser applications, ultimately founded Intralase (later acquired by Johnson & Johnson Vision) and, in 2001, launched the first commercial femtosecond laser for creating flaps in corneal refractive surgery.

Femtosecond laser flaps quickly became standard practice for corneal refractive surgery in the United States owing to their association with reduced complications and increased precision. Laser flaps are highly reproducible, which enabled the introduction of tissue-preserving, thin-flap LASIK techniques. Surgeons found flap size and architecture as well as the flap-bed interface to be more customizable with a laser than a mechanical microkeratome. Patients like the concept of bladeless surgery, which facilitated

the adoption of the procedure.

Approximately 24 million people have undergone LASIK with a femtosecond laser flap to date.

Both excimer and Nd:YAG lasers had been evaluated as possible replacements for bladed incisions and cuts, but the femtosecond laser proved to be better suited to such ocular applications. Its intense, ultrashort, ultrafast pulses can be focused tightly on a small space and volume to make precise incisions in ocular tissue. Cuts are created by making multiple adjacent or overlapping laser spots, and the laser can be focused on layers inside the eye to create nonpenetrating incisions.¹ Because the laser pulses are short, they do not heat the tissue or send cavitation shock waves through adjacent tissue, thereby protecting the

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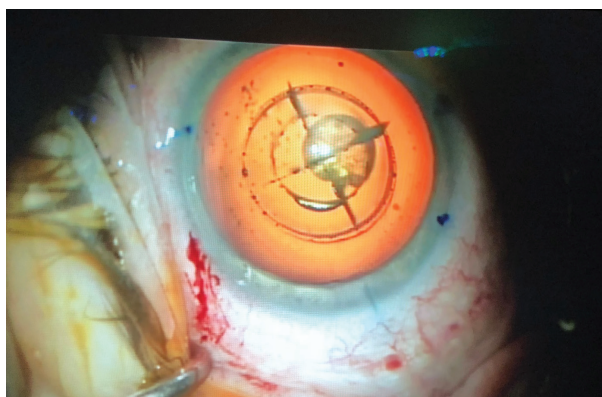


Figure 1. Fragmentation with a femtosecond laser can soften the crystalline lens and reduce the amount of manual manipulation and energy required to remove a cataract.



Figure 2. The FLIGHT procedure combines the precision of a femtosecond laser with the accuracy of micron-level image guidance.

eye from undesirable effects. The near-infrared wavelength (1,030–1,064 nm) of femtosecond lasers is not absorbed by transparent media such as the cornea and lens.¹

EXPANSION OF FEMTOSECOND LASER TECHNOLOGY

In refractive surgery, the use of femtosecond lasers has progressed from flap creation to all-laser lenticule procedures such as small-incision lenticule extraction and small-incision lenticule keratomileusis. The femtosecond laser has also revolutionized corneal transplant surgery. In 2009, Marjan Farid, MD, and Roger Steinert, MD, showed that cutting zigzag incisions in donor and recipient corneas with a femtosecond laser could improve penetrating keratoplasty outcomes.² Creating such highly precise, advanced corneal shapes was not possible with manual trephination of corneal grafts. Femtosecond laser-cut tissue has permitted the development of a range of complex transplant procedures, including deep anterior lamellar keratoplasty, Descemet stripping endothelial keratoplasty, and Descemet membrane endothelial keratoplasty.

In 2010, femtosecond laser platforms were introduced that could perform some steps of cataract surgery (eg, surgical incisions, astigmatic keratotomy, capsulotomy creation, and lens fragmentation; Figure 1). Although the superiority of laser cataract surgery over manual cataract surgery has not been established, many surgeons find the enhanced precision of femtosecond lasers invaluable. A well-formed capsulotomy facilitates proper IOL centration, and highly predictable arcuate incisions help to achieve the excellent refractive outcomes expected by patients who choose premium IOLs. Additionally, the ability to presoften the cataractous lens and reduce manual manipulation is valuable in complex cases, such as eyes with narrow angles, weak zonules, or dense nuclei.

FEMTOSECOND LASERS IN GLAUCOMA

Preclinical and clinical studies have evaluated several applications for the

femtosecond laser in glaucoma. The furthest along the regulatory pathway is a noninvasive, femtosecond laser image-guided high-precision trabeculotomy (FLIGHT) treatment that is performed with the ViaLuxe Laser System from ViaLase, a company led by Dr. Juhasz.

A custom-engineered optical scanning system enables the delivery of tightly focused femtosecond laser pulses into the iridocorneal angle, thus permitting precise photodisruption of the trabecular meshwork (Figure 2). The ability to noninvasively create a direct conduit between the anterior chamber and Schlemm canal is unique to the FLIGHT procedure.

The safety profile of the nonthermal photodisruptive mechanism of femtosecond lasers is well documented and has been shown to minimize potential scarring of adjacent tissues. Preclinical work showed that the FLIGHT treatment did not damage adjacent tissues.³ Two-year results from the first-in-human clinical trial of FLIGHT were recently published.⁴ In this pilot study of 18 eyes, mean IOP decreased by 34.6% from baseline to 24 months after treatment, and 82.3% of eyes achieved at least a 20% reduction in IOP on the same number of medications or fewer. The laser was used to treat only 5° of the angle, but it is technically capable of creating multiple channels in one session and re-treating any quadrant (including the temporal quadrant) multiple times if necessary. Two years after treatment, well-defined channels remained patent, with no visible evidence of closure or scarring and no device-related serious adverse events.

In preclinical studies, femtosecond lasers have also been used to create subsurface photodisruption in the sclera for nonpenetrating deep sclerectomy⁵ and transscleral channels and grooves for scleral implants.⁶ It has been hypothesized that a femtosecond laser sclerectomy could minimize wound inflammation and fibrosis and improve the results of filtration surgery.⁷

Initial clinical trials in humans have indicated safety, but additional clinical data and real-world experience are needed to show how the trabecular meshwork and sclera respond to laser treatment and where FLIGHT and other femtosecond laser procedures might fit into the glaucoma treatment paradigm. Patients' positive perception of lasers is another factor. Minimally invasive or noninvasive interventions that do not rely on patient compliance are valuable for clinicians and appealing to patients.

CONCLUSION

Each iteration of femtosecond laser technology can expand its potential uses in glaucoma care. During this evolution, it is important that glaucoma specialists keep an open mind about the potential for modernizing techniques with the femtosecond laser. They may discover that there are unique advantages in terms of adoption, access, precision, safety, and/or consistency of outcomes, as seen in other areas of ophthalmology. ■

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