Potential Applications for Femtosecond Lasers in Glaucoma

Promising initial results require validation in humans.

By Leonard K. Seibold, MD, and Malik Y. Kahook, MD

The utility of laser therapy in ophthalmology was first discovered in the 1940s with photocoagulation of the retina. Since then, several laser modalities have been adapted for the treatment of glaucoma. In the 1970s, Wise and Witter described the argon laser’s use for the treatment of the trabecular meshwork (TM), and this approach became widespread, with a great deal of evidence-based research supporting its efficacy. In the mid-1990s, Latina invented a new technique for trabeculoplasty that leveraged a Q-switched frequency-doubled Nd:YAG laser with short-pulse applications. Known as selective laser trabeculoplasty, this method is thought to offer advantages over traditional argon laser trabeculoplasty in terms of repeatability due to a better thermal damage profile. Semiconductor diode lasers have also been developed as a means of photocoagulation of the ciliary processes in refractory glaucomas. Now, after years of use in refractive surgery, the femtosecond (FS) laser is the latest laser technology under investigation for applications in glaucoma treatment.

Recent Evolution

Thus far in ophthalmology, the FS laser has predominately been used for experimental ocular imaging, keratorefractive procedures, and more recently, cataract surgery. Jester and colleagues have utilized an FS laser for nonlinear imaging studies of the cornea. The infrared wavelength and FS pulse duration allow for multiple series of high-resolution images of collagen fibers that can be reconstructed into a three-dimensional mosaic. Similarly, Kahook and colleagues have used titanium:sapphire FS laser imaging devices for subcellular resolution of unfixed tissue, including the TM. In 2009, Nagy et al described the use of an intraocular FS laser to precisely perform key steps of cataract surgery. Their initial work led to the first FDA-approved FS laser device for refractive cataract surgery—perhaps the most profound shift in the technology used for the cataract procedure in more than 20 years. The technology has other potential applications, including glaucoma surgery.

Research in Glaucoma

Trabecular Meshwork

In 2005, Toyran et al used an FS laser to perform photodisruption of human TM strips ex vivo. Unlike the minimal disruption of tissue produced by selective laser trabeculoplasty, the authors deliberately made full-thickness ablation channels through the TM. Histologic evaluation of the tissue confirmed the reliable creation of fistulous tracts without collateral damage. Theoretically, these tracts could permit direct access of aqueous humor from the anterior chamber to Schlemm canal. The FS laser is uniquely suited to this application due to its ultrafast pulse durations (shorter than thermal diffusion or shock wave propagation times) and lower fluence threshold, which combine to minimize collateral tissue disruption.

In subsequent work, FS laser photodisruption was performed on the TM of intact, enucleated human and baboon eyes. The FS laser was mounted on a surgical microscope, and the investigators used a goniolens to direct laser energy toward the anterior chamber angle. They used a coaxial helium:neon laser as a guiding beam because of the infrared (not visible) wavelength of the FS laser. High-magnification images confirmed the generation of discrete laser lesions with sharp edges and a lack of damage to adjacent tissue. The juxtacanalicular tissue was not reached in this study, although the researchers thought this goal could easily be achieved through an alteration in laser settings and delivery methods. This approach to addressing the obstruction of aqueous flow at the TM could offer a minimally invasive surgical approach to glaucoma treatment.
performed at the time of laser cataract surgery. Further modification of this technique and planned in vivo studies are underway by multiple groups.

Sclera

Investigators are also evaluating the role of the FS laser in sclera-based glaucoma surgery. The precision of scleral incisions created with the FS laser has great potential to standardize portions of guarded filtration surgery.

Additionally, this technology is being investigated for the creation of intrascleral drainage channels to increase aqueous outflow in a nonperforating method. Initial attempts at deep sclerectomy using the FS laser occurred in 2007. Bahar et al used the IntraLase FS laser (Abbott Medical Optics Inc.) to create both superficial and deep partial-thickness scleral flaps in human cadaveric eyes. After amputating the deep flap, they observed aqueous percolating through the exposed Descemet window. More recently, Chai et al developed a three-dimensional finite element model to predict aqueous humor outflow through partial-thickness drainage channels created in the sclera with an FS laser. After modeling predicted IOP reductions of 67% to 81%, the investigators used perfused rabbit eyes to make the proposed drainage channels and confirmed their creation with spectral domain optical coherence tomography. These subsurface, peri-limbal scleral channels dramatically increased measured outflow facility. In a follow-up study, researchers were able to create similar scleral drainage channels in vivo using the FS laser in rabbits. IOP decreased postoperatively in all treated eyes, with the effect’s becoming greater as the channels’ dimensions increased.

Further testing is required to optimize the laser settings, and no human trials have been published to date.

LIMITATIONS

A few limitations of FS lasers must be addressed to substantiate their role in glaucoma surgery. Most obvious are their high cost and the intensive maintenance current platforms require. One way potentially to decrease the former would be to combine the use of a laser with high-volume procedures like cataract surgery.

Another issue is the inherent light-scattering properties of the sclera, which could lead to imprecise incisions and collateral damage. Although longer laser wavelengths (to 1.7 μm) might overcome this problem, current hardware and software platforms used in cataract surgery are not equipped for higher wavelengths.

Finally, although using an FS laser to create drainage pathways may result in minimal collateral damage, the formation of scar tissue will still be a problem with any stimulation of the wound-healing process.

CONCLUSION

FS lasers have great potential to assist with and improve upon current glaucoma surgical techniques. The initial results of preclinical work are promising but need to be validated in humans. As more FS laser platforms are introduced for cataract surgery, competition will likely drive manufacturers to develop systems that are capable of treating more than one disease. Currently, only a handful of research laboratories are capable of performing advanced research on FS lasers, but greater funding due to increased interest could hasten the speed at which innovations find their way into clinical practice.

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