

Lasers in Ophthalmology

BY STEPHEN L. TROKEL

Any projection into the future of ophthalmic laser surgery must recognize the long history underlying the ophthalmic experience with lasers. By comparison, other medical applications are "Johnny-come-latelies" to laser use. For many years, retinal photocoagulation was the only widespread laser application in surgery and medicine. This early application was based on clinical experience starting in 1954 with non-laser (*i.e.*, xenon arc) retinal photocoagulators. In spite of their bulk and clumsy application interface, they provided a body of clinical experience that prepared the eye surgeon for the advent of laser technology.

PHOTOCOAGULATION AND ABLATION

The pioneering use of the ruby laser was quickly supplanted by the argon laser, now the clinical standard for ophthalmic photocoagulation against which all new laser coagulators are measured. The first clinical indication for laser photocoagulation was treatment of retinal holes, but its use has expanded many fold as new therapeutic applications developed. The effectiveness of pan-retinal photocoagulation (PRP) to stabilize diabetic retinopathy, and trabecular meshwork photocoagulation (ALT) to lower intraocular pressure increased the use of lasers by ophthalmologists because diabetes and glaucoma are common diseases. Argon laser use increased further when photocoagulation was shown to be effective in creating holes in the iris (iridotomy) to treat narrow angle glaucoma. Other less common, but important uses of the argon laser photocoagulator are treatment of macular degenerations, adjunctive use in vitreo-retinal surgery using an endolaser probe, and treatment of neoplasms and vascular malformations involving the eye and adnexa.

Many other photocoagulators have been used in an attempt to develop a superior clinical result, broaden the applications, or reduce costs. These include devices studied primarily because they produced other wavelengths, and those that use different technologies to produce the laser light. Among the former are the krypton and dye lasers; among the latter are the frequency doubled Nd:YAG and, recently, the diode laser. The slit lamp biomicroscope has displaced the hand-held direct ophthalmoscope for most

ophthalmic applications. Alternative delivery systems used by eye surgeons include the indirect ophthalmoscope, which allows treatment of the peripheral retina, fiber delivery used for the endoscopic probe (argon) in vitreo-retinal surgery, the fiber delivery used for transscleral ciliary body coagulation (Nd:YAG), and filtering sclerostomy (holmium).

EXPLORING DIFFERENT WAVELENGTHS

Different wavelengths have been explored to find clinical advantages that exploit or compensate for the many pigments distributed within the human eye. Among these pigments are xanthophyll, a yellow pigment in the macula; melanin, in the retinal pigment epithelium, which has the greatest absorption of any site; red blood cells that are distributed evenly throughout the choroid, unevenly throughout the retina and may, in pathological states, be scattered throughout the vitreous body and other preretinal media; and yellow brown pigment in the crystalline lens that absorbs and scatters light.

The lasers most widely used to explore the clinical possibilities of different wavelengths have been the krypton, dye, and recently the diode lasers, although Nd:YAG lasers have been explored in their flash lamp pulsed configurations. One successful new configuration has been the frequency doubled Nd:YAG which, when run at cw and quasi-cw modes, is a reliable alternative to the argon laser, simultaneously supplying an infrared wavelength for ciliary body coagulation. More recently, the diode laser—with its attractive low-cost, small size, and extreme reliability—has been introduced into clinical practice.

There has been considerable confusion and some controversy as to the therapeutic equivalence of these different wavelengths when compared to the clinical standard of the argon laser. While much was said of the advantages of the dye and krypton lasers in selective photocoagulation, it has become apparent that retinal coagulation results principally from absorption of laser light by melanin. Coagulation of the neuroretina appears to be largely secondary to thermal energy arising from light absorbed in the retinal pigment epithelium. This suggests, and clinical experience confirms, that the coagulation process itself is relatively independent of wavelength. However, ancillary clinical effects make selection of the optimal laser wavelength less certain. Longer wavelengths as from the krypton laser (yellow 531 nm, red 647 nm), or the dye lasers at similar wavelengths will penetrate retinal tissues more deeply without being absorbed or scattered by pigments in the inner neural layers, red blood cells in the preretinal media, or early cataracts.

Because these longer wavelengths are scattered less than at the blue end of the spectrum, they penetrate through turbid media with less loss of energy in the beam and allow treatment through hazy preretinal media. This is the most distinct advantage of longer wavelengths. But there are two



disadvantages of the greater penetration: First, these lasers cause greater discomfort because the laser coagulation penetrates deeply, producing painful deep choroidal temperature elevation. Second, the deeper penetration makes it difficult for the surgeon to evaluate the amount of coagulation required, because little change is visible at the retinal surface when a larger fraction of the energy is absorbed at deeper layers. While the cw Nd:YAG laser has not found favor as a slit lamp delivered coagulator, its greater penetration is being exploited for transscleral applications to coagulate the ciliary body. This laser treatment is viewed as an alternative treatment to painful cryotherapy for patients with end stage glaucoma.

Diode laser photocoagulators offer simplicity and compact design. The development of high-power semiconductor diode lasers and diode laser arrays (840-910 nm) have made compact near-IR laser photocoagulators possible. The laser is portable and may be attached directly to an existing slit-lamp biomicroscope. Diode lasers pose the same problem as the krypton or Nd:YAG in that their retinal use is accompanied by more pain and a deeper treatment endpoint that is more difficult to assess. There are diode lasers operating at shorter wavelengths and outputs that will make them suitable for clinical use.

In spite of extensive clinical investigations into different laser wavelengths to enhance the distribution of absorbed thermal energy, substantial clinical differences have not been demonstrated. Dye lasers, because of their high maintenance costs, have only a limited advantage over other photocoagulators.

PHOTODISRUPTORS AND OPTICAL BREAKDOWN

The most widely used laser system in ophthalmology is the Nd:YAG pulsed laser photodisruptor due to its ability to interact with non-pigmented tissues within the eye—the most important of these being the opacified posterior capsule. Neodymium:YAG photodisruptors have found a valuable clinical role in producing controlled incisions in any strand, membrane, or adhesion inside the eye without regard to pigmentation. In addition to incising posterior capsules that opacify after cataract extraction, synechiae and vitreous strands can be severed, and the iris punctured. The electric field strengths produced by the focused beam are so intense that they strip electrons off atoms and create a plasma, which makes the laser action independent of the absorbing properties of the tissue to be sectioned. This small plasma is hot and makes a hole in the tissue through the shock wave associated with tissue vaporization. Today, most photodisruptors are Q-switched with a pulse duration of about 10 nanoseconds.

Considerable effort has been expended to create a sustained electron stripping or "optical breakdown" of tissue while minimizing the shock wave. This has been done by

using extremely short laser pulses in the picosecond and even the femtosecond range. These lasers, typically operating at about 1 kilocycle, have low energy in each pulse. However, the pulses are so short that they achieve high powers and will cause optical breakdown at their focal spot. The associated shock wave of the individual pulses are reduced with the shorter pulsewidth.

These lasers are being explored as an alternative to simple photodisruption of membranes and capsules. Their role in iridotomy is also being investigated. Two interesting new applications are based on their ability to soften a cataract prior to its extraction and to section vitreous membranes. They are also being used to investigate potential corneal applications, including intrastromal photodisruption to alter the corneal curve and thus the refraction of the eye. The breakdown is dependent upon the distribution of energy within the focal volume, which is dependent upon accurate focusing and a uniform optical matrix.

Diagnostic uses of lasers in ophthalmology include low power HeNe lasers used in scanning laser ophthalmoscopes and corneal surface analysis. The scanning laser ophthalmoscope produces retinal images by scanning the retinal area tracked by a detector and produces a video image. Substantial image processing can be done. The small concentrated light that scans the retina can be controlled so that light can be placed on the retina to test function of selected areas.

PHOTOCHEMICAL ABLATION

Excimer lasers are being widely investigated for their safety and efficacy in keratorefractive and therapeutic surgery. The effectiveness of the excimer laser is based upon its ability to ablate surface areas of the cornea to fractional micron precision. The excimer laser for corneal surgery ablates a predetermined curve onto the surface of the cornea. This effectively alters the corneal curvature and the refraction of the human eye. Despite encouraging early results with this laser, the substantial questions of long-term safety and efficacy must be answered before it is accepted into widespread clinical use.

LOOKING AHEAD

The extraordinary range of clinical applications developed over the past 30 years makes it difficult to anticipate the future. We have had our false starts and blind alleys, but laser applications have moved forward and will continue to do so. Clearly, research into basic laser tissue interactions is the underpinning of any potential clinical applications. We feel the need for more compact, less expensive, more reliable laser sources. The best example of this is the cumbersome excimer laser for corneal surgery. Ablation occurs at 193 nm, but this wavelength has not been optimized, nor is there any information about optimum pulsewidths and power peaks necessary to create the effect. Obviously, issues of size and cost are real when considering the far UV. The fourth and



fifth harmonics of Nd:YAG and alexandrite lasers can emit at 205 and 213 nm in a variety of pulse configurations and are being evaluated for this application.

The newly available diode lasers are of great interest. They are being widely studied in association with exogenous chromophores, such as indocyanine green, for novel applications. Techniques are being developed to seal incisions and to control tissue temperature in a defined volume. New shorter wavelength diode lasers will certainly be of interest and will no doubt have an impact upon existing photocoagulator systems.

Two things seem certain. First is the improvement of current devices. Toward this end, we want coagulators that are reliable, independent of external cooling, and requiring only house current. Tunability would be desirable to aid in clinical investigations and continue the effort to find optimal wavelengths. A research laser with the ability to vary pulsewidth and frequency in the range from 1.7-1.9 μm would be the mainstay of development of future products. Clearly, a Q-switched fiber transmissible laser in this region would have substantial surgical impact. The success of the holmium laser for creating sclerostomies suggests that fiber-

delivered high power pulses may well have a role in the treatment of glaucoma or the fractionation of cataracts. In spite of the success of tissue ablation with the holmium laser, the ideal filtering procedure would not require incision into the eye and should be done by using a laser surgical technique that aims laser light into the trabecular meshwork to improve fluid drainage from the eye. Perhaps the continuous high powered photodisruptors will prove effective in this field.

Second, substantial research into endoscopic surgical techniques may open the orbit and the eye to more microsurgical approaches that will make inroads on existing cut-and-sew technology such as the phakoemulsifier has made inroads into large incision cataract surgery. A significant research effort to explore existing technologies and potential applications would probably go further than the development of any single new laser in increasing laser use in ophthalmology.

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