Laser in Clinical Ophthalmology: Possible Applications, Limitations, and Hazards

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Since the development of the ruby laser by Maiman in 1959, two major questions have been raised with regard to ophthalmology:

1. What is the feasibility for its clinical use as a therapeutic device?
2. What are the hazards of accidental exposures among personnel working with lasers in industry, research, and military installations; how to counteract them?

After clinical light coagulation for various ocular lesions had been included in the therapeutic armamentarium, the introduction of the laser for similar purposes was obvious, and has been accepted with enthusiasm by various groups of clinical investigators. Since, at present, the ruby laser is only used for ophthalmological purposes, the basic principles of its action are briefly reviewed.

Fundamentals of Laser Action

When a photon is absorbed by an atom, the energy of the photon is converted to internal energy of the atom. The atom is then raised to an "excited" quantum state. Later it may radiate this energy spontaneously, emitting a photon and reverting to the ground state or to some state in between.

In such an excited state the atom can be stimulated to emit a photon, if it is struck by another photon having precisely the energy of the one that would otherwise be emitted spontaneously. As a result, the incoming photon, or wave, is augmented by the one given up by the excited atom. More important, the wave, upon release, falls precisely in phase with the wave that triggered its release. There must be an excess of excited atoms to enable stimulated emission to predominate over absorption.

In the ruby laser (aluminum oxide poisoned with a few chromium atoms —Maiman used .05% by wt of chromium), light in the green and yellow bands is absorbed, while blue and red are allowed to pass through. The absorbed light raises the chromium atoms to the excited state from which two steps are required to carry them back to the ground state.

First, they give up some of their energy to the crystal lattice and land temporarily in a metastable state. If not subjected to stimulation, their stay at this level lasts a few msec while they drop at random to the ground state.

Photons emitted during this final drop have a wavelength of 6,943 Å (at room temperature). In the laser, however, the first few photons released stimulate the still excited chromium atoms to give up photons and return to the ground state much faster. If a great number of atoms are excited, the ruby merely emits a burst of its typical red fluorescence, spread over the usual decay period for the excited atoms. But above a critical level, in which more than 50% of the total atoms are brought in the excited state, the atoms return to the ground state at the very same moment. They last approximately 200 to 500 μsec, during which time an intense monochromatic light beam flashes from the laser crystal. The beam is almost parallel if produced at threshold levels. With greater energies increasing divergence occurs.

From the foregoing it becomes obvious that the characteristics of laser radiation are different in several as-

pects from the clinical light coagulator used before. The most important differences are:

1) The spectral distribution of the light source, and

2) The exposure time for production of chorioretinal "burns."

While the conventional Zeiss light coagulator utilizes a xenon high pressure lamp with a spectral range throughout the visible spectrum, the ruby laser beam is monochromatic and produces light at a wavelength of 6,943 Å only. Moreover, the light coagulator allows the ophthalmologist to control the exposure time by pressing a button situated on the ophthalmoscope handle; thus the exposure time is determined under direct vision of the developing tissue response. On the other hand, the exposure time with the use of the laser is inherent within the instrument, and is not controllable during the exposure. Thus, while the light coagulator exposures usually range from about 0.1 sec to 1 sec, ruby laser exposure times are in the neighborhood of 500 μsec.

These two factors—wavelength and exposure time—however, are of fundamental importance with regard to tissue reaction. During recent years absorption characteristics of the human and the rabbit eye have been studied, especially with respect to absorption distribution in the pigmented layers of the ocular fundus. The data were compared with reflection measurements from the ocular fundus, and with light energies required to produce ophthalmoscopic visible minimal lesions. Moreover, the influence of blood flow on the development of ocular thermal effect has been investigated. More recently, a histological and histochemical comparison of ocular lesions produced with light coagulation with those produced with a ruby laser has been described. In later studies exposure times for light coagulation were 30 msec and 175 μsec, while laser exposures were achieved with 200 μsec for "pulsed" and 30 μsec for "q-switched" laser action (Geeraets *et al.*, 1960, 1962a and b, 1963, and 1965; Ham *et al.*, 1963).

Clinical Considerations

Initial Promise and Present Limitations

The Zeiss light coagulator has been used for over a decade to treat such ocular lesions as retinal detachment, vascular lesions of the retina and choroid, inflammatory chorioretinal conditions, iris lesions, etc. As soon as the laser was introduced, several of its features seemed more advantageous relative to this conventional light coagulator:

1) The price of the instrument was expected to be considerably lower than that of the Zeiss light coagulator.

2) The instrument promised to be quite light so that it could easily be carried to the patient's bedside, instead of having to bring the patient to the instrument.

3) The very short exposure times were regarded as beneficial, since with these exposure times the patient would not be able to move his eye, thus eliminating the need for retrobulbar anesthesia.

4) The dim red light of the laser beam (λ = 6,943 Å) will not produce photophobia, another reason for eliminating anesthesia.

5) The short-time, high-intensity exposures would allow much smaller lesions than those produced by light coagulation.

However, after several years of clinical and laboratory experimentation, these anticipated advantages appear at present not as obvious or as convincing as a number of investigators had initially expected. Moreover, it is quite certain today that the laser has not broadened clinical indications nor has it opened new fields for therapeutic application of high intensity light.

Several instruments utilizing the pulsed ruby laser are now commercially available. With the desire to develop a therapeutic device having as many safeguards as possible against possible overexposures, the price and weight of the instruments have both increased and are still rising; thus the expected advantages outlined above under 1) and 2) seem not to be warranted. It is true, however, that the short exposure time and the dim red light do not necessitate retrobulbar anesthesia of the patient's eye. This minor advantage is contradicted by the dangers of short-time exposures. When the instrument is triggered, the degree and severity of the chorioretinal lesion is decided upon. Even if the surgeon has followed instructions and started with low instrument settings—i.e., low energy output which does not cause any lesions—and has slowly increased the laser beam intensity, the exposures are not without danger. The energy output of the laser varies from shot to shot in a random fashion unless special precautions are taken. Moreover, the energy control settings of the instruments have only a very small range between therapeutically desirable intensities, and those which will produce severe overexposures. With this narrow range, and the possible fluctuations from one exposure to another, the usefulness of the instruments presently available is limited. Beside these inherent limitations, the irregularities in pigment distribution of the ocular fundus add to the potential hazards which might be encountered. Examination of a number of eyes treated elsewhere with lasers, for various etiological reasons, revealed lesions which were too severe and well above optimal therapeutic levels. Many of the lesions showed centrally located retinal holes with small hemorrhages and pigment clumps extending into the vitreous.

There may be an advantage in producing chorioretinal coagulations with very short exposure times when the exposure has to be made in a region where injury to the nerve fiber layer may result in a large scotoma. Here, the short exposure times allow for the coagulation effect to be restricted to the choroid and outer retinal layers, thus sparing the inner layers of the retina and the nerve fibers passing over the lesion. This observation, made in numerous experiments (Geeraets, Burkhart, and Guerry, 1963), can be explained by the absence of tissue damage due to thermal conduction during actual exposure time, if the exposure times are sufficiently short, i.e., in μsec. The lesions thus produced must be very mild as heat conduction, continuing from the site of coagulation after the exposure has terminated, might be sufficient to cause coagulation of all retinal layers.

The statement that smaller retinal lesions can be produced with a laser is true, but is of little clinical impor-

tance. I have never observed a clinical situation in which a lesion smaller than that producible with the common light coagulator was desired.

Use in Retinal Tumors

Retinal tumors have been mentioned as another indication for laser treatment. Here, too, the same rules can be applied that have been established for treatment of tumors with light coagulation. One might even speculate that the more extensive coagulation effect using common light coagulation techniques may be more destructive to tumor cells than the laser beam. But the very restricted indications for coagulation treatment of ocular neoplasm remains the same for both methods.

Experimental data obtained on tumor transplants within the suprachoroidal space have shown some of the restrictions one has to observe in such attempts of treatment (Geeraets, Ghosh, and Guerry, 1962; Chan *et al.*, 1963). In cases of retinal angiomata, the red light of the ruby is reflected to a great extent, thus unnecessarily increasing the incident total light energy applied to the ocular media and other ocular structures.

Accidental Laser Exposures

With the very powerful devices developed for industrial, military, and research use, accidental exposures of the human retina have presented a true hazard. Not only the direct exposure to the laser beam, but also laser light from any reflecting surface may result in permanent ocular injury. Since light of the ruby laser (λ = 6,943 Å) is dim red, and light from the neodymium laser (λ = 1,060 Å) is completely outside the visible spectrum, the potential hazard to the eye is greatly enhanced as no immediate discomfort is experienced by the victim. If the ocular lesion is mild and located in the periphery of the retina, the victim may not even be aware of the accident. I have seen such lesions on routine examination where there was no doubt as to the etiology of the lesion. If exposures occur to the fovea or macular area, as in cases where the patient is "fixing" the laser source along the axis of the laser beam or a reflecting spot, the lesion may be of serious consequence, even with mild retinal lesions. And if both eyes are involved, which most likely will happen if the patient is "fixing" on the bright light, the developing macular lesions may produce permanent visual loss.

In case of high-intensity exposures, for instance, as with the giant pulse laser, central as well as peripheral fundus lesions may lead to an explosion-like disruption of the retina and choroid, with massive hemorrhages into the vitreous, resulting in permanent loss of one or both eyes.

These accidental possibilities have necessitated extensive precautions in most installations and laboratories where laser devices are used. Warning signs have been placed in most locations during actual laser operation. Laboratory facilities and equipment have been painted with dark and dull colors to reduce reflection. Special goggles with hardened lenses and color filters have been developed for eye protection. But in spite of these precautions, accidental exposures are not infrequent. Bright flashes of white light produce photophobia and hence constantly bring the danger of exposure to the persons working with these light sources. With the dark red laser beam or the invisible neodymium beam this reminder is absent, possibly explaining the observed negligence by laboratory personnel involved. For legal reasons it has been recommended that any prospective employee to work with, or in the vicinity of, laser devices be given a very thorough eye examination by a qualified ophthalmologist to record all possible existing fundus pathology or anomalies before the person begins work. Routine follow-up examinations should be performed within reasonable periods to insure that no accidental fundus exposures have occurred without the person's knowledge. All reported possible exposures should get immediate medical attention, since laser lesions are more accurately determined the sooner they are examined after exposure. After longer periods of time, scar formation may not be differentiated from other preexisting inflammatory lesions.

According to Tebrock, Young, and Machle (1963), the principles of controlling environmental laser hazards are:

1) Avoidance of the principal beam and its reflections.

2) Proper education of personnel involved.

3) General information given those who might be casually exposed.

4) Use of warning devices to indicate laser is in operation.

5) Policing and clearing of area for long range operation.

6) Use of proper antilaser eye shields on any observer likely to be exposed.

7) Use of count-downs with persons closing eyes or looking away from pulsed, high-power beam.

8) Reporting of all persistent afterimages to medical department.

9) Funduscopic and slit-lamp examination of all people involved in laser operations.

Conclusions

In spite of the limitations and potential hazards involved in ophthalmic application of laser energy at its present status of development, further clinical investigation is necessary. It should be restricted to a few centers, experienced in this type of work, and aware of the fundamental physical and biological mechanisms involved. In reality, this practice is not always followed, thus increasing the potential danger of the clinical use of lasers. Although some of the available instruments are beautifully designed and engineered, these attributes alone do not justify their therapeutic use. In my opinion, arrangements to make the present existing laser coagulators commercially available to all clinical ophthalmologists are irresponsible, to say the least. Some of the ophthalmologists are misled by erroneous advertisement and receive their instruction from overzealous sales personnel lacking adequate knowledge of the physical principles of laser, or of the biological, optical, and functional characteristics of the eye.

Summary

The present status of laser application in clinical ophthalmology is discussed. The differences between conventional light coagulator characteristics and those of presently available ruby lasers for clinical use are compared. The limitations and hazards of laser therapy are stressed.

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