 automation in krypton laser photocoagulation

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histologic study of lesions produced by krypton red (647.1 nm) and krypton yellow (568.2 nm) laser lights reported here suggests advantages in alternating these two wavelengths in photocoagulation. selection of the best wavelength to be used in a given location on the retina should result from predetermined absorbance conditions in that location. the feasibility of the relative measurement of absorbance in different fundus locations by measurement of the relative reflectance is discussed. instrumentation for these measurements and for switching from one wavelength to the other is described. instrumentation for the possible expansion of krypton laser applications to clinical problems in the anterior segment also is suggested. invest ophthalmol vis sci 25:711-719, 1984

the use of krypton red (647.1 nm) laser light for photocoagulation is currently receiving a good deal of clinical attention, whereas the use of krypton yellow (568.2 nm) appears to be receiving less. this is unfortunate because the red and yellow krypton lights each have their own advantages for photocoagulation, and it seems unlikely that exclusive use of either light will be satisfactory in all clinical situations. we believe that the most effective clinical use of the krypton laser can be obtained by combining the advantageous aspects of both of these laser lights and will demonstrate here the relative merits of red and yellow laser lights in photocoagulation by histologic studies of lesions. we also believe that to increase the safety and efficiency of photocoagulation in ophthalmology some changes, which are described here, must be made in currently used instrumentation.

little has been done to introduce automatic features, available even in inexpensive photographic cameras, into photocoagulators. to our knowledge, only birngruber and his colleagues in west germany have approached this problem. they have been interested, however, in automatically terminating the photocoagulation when the ophthalmoscopic appearance of the lesion shows the goal has been attained. we think that the method of stopping the coagulation by measuring the amount of energy absorbed in the tissue during the photocoagulation is a step toward increasing the efficiency and safety of photocoagulation treatment. we believe, however, that this technique would be more efficient if the right amount of energy to be transferred to the tissue were determined before the irradiation, and if the beam used for this measurement were the actually used coagulating beam.

we also think that the variety of laser wavelengths available for photocoagulation makes the identification of those most suitable for photocoagulation essential. some of the wavelengths, such as the blue ones, are absorbed in xanthophyll. their use, at least in older patients and in the macular area, should be avoided. the blue wavelengths also have a pronounced, objectionable photochemical action on ocular tissues.

this work is based on our histologic study of the effect of red and yellow wavelengths on the ocular tissues in different fundus locations of the owl monkey. the results of these studies were used to demonstrate the specific differences of each of the two wavelengths.

materials and methods

the wavelengths with the most specific effect on ocular tissues are those in the red and green-yellow range. we selected krypton yellow (568.2 nm), an isobestic wavelength (equally well absorbed in oxygenated and reduced blood), because its absorption in blood is much higher than the commonly used argon green (514.5 nm). (the absorption coefficient of krypton yellow in blood is more than twice as high as that of the presently used argon green.) the red, little of which is absorbed in blood, is the other specifically absorbed wavelength. we used the red wavelength of 647.1 nm since it and the yellow (568.2) are both available in our krypton laser. these wavelengths also can be produced by dye lasers.

a problem that arises with the clinical use of krypton yellow is its instability below 50 mW (especially for the aiming beam). we have solved this problem by incorporating an acousto-optic deflector modulator (ADM) into the system. the laser is operated con-
a preset amount (from almost zero to 90%) of the power from zero order into the first-order beam, as commanded by the electronic driver. The delivery system is made coaxial with the first-order beam, which crosses the mirror through an aperture provided ad hoc. The electronic driver can be operated either manually from the switchboard or automatically by signals from the reflectometer.

The ADM, in addition to deflecting into the delivery system a preset percent of the energy contained in the total beam, also can deflect each wavelength from the total (polychromatic) beam separately, at the operator’s choice. The intracavity wavelength selector is replaced by a broad-band mirror, 100% reflective for red and yellow. This makes the krypton laser emit both red and yellow wavelengths together. The ADM electronic driver commands both features, the deflection of the selected wavelength into the delivery system and the fixation of its power.

**Results**

Figure 1 shows the typical ophthalmoscopic appearance of three pairs of lesions produced with krypton red light with spot size of 100 μm. We selected this spot size because it is proportional to the small size of the ocular structure in the owl monkey. Obviously, different spot sizes are appropriate for different...
clinical goals. However, for our purpose of comparing colors, any spot size could be used. Small spot sizes, as well as lower laser beam power, give more characteristic information on the behavior of a given laser beam.) The energy was the same for each pair but varied among pairs. The ophthalmoscopic appearance of lesions among pairs is not the same, nor is it the same within each pair.

Figure 2 shows the histology of lesion 3 from Figure 1, which is a good therapeutic lesion. We consider a good therapeutic lesion to be one that is confined to the pigment epithelium and receptor layer and that leaves the nerve fiber layer and Bruch's membrane intact. Damage to the nerve fiber layer may create an unwanted scotoma and breaks in Bruch's membrane create an entrance to new vascularization. The same kind of lesion is demonstrated in Figure 3, which shows the histologic section of a lesion in a macaque fovea containing xanthophyll. It is this type of lesion that generates enthusiasm about the clinical value of krypton red, especially for panretinal photocoagulation (PRP). In addition, there seem to be fewer postoperative complications when red light is used.1,2,6,8

In Figure 4 the histologic section of lesion 4 from Figure 1 shows deeply penetrating damage into the choroid with a choroidal hemorrhage. Lesions 3 and 4 were produced with the same dosage of krypton red laser light. The reason for this dramatic difference between the two lesions is shown in Figure 5, which presents the ophthalmoscopic appearance of the same fundus in red light. In areas where the inner choroidal
layers are not heavily pigmented, illumination with red light shows the large choroidal vessels in sharp negative contrast. Figure 5 shows that the good therapeutic lesion was produced on a large choroidal vessel with little melanin above it, whereas the lesion that produced choroidal hemorrhage was on a heavily pigmented inner choroid above another large choroidal vessel. This variability of lesions produced with the same dosage of krypton red laser light is the cause of the dissatisfaction noted by some clinicians.

In summary, the same dosage of krypton red irradiation can produce either excellent therapeutic lesions or undesirable damage, depending on its location in the fundus. Clinical use would be much safer if the laser power could be adjusted to the local absorbance conditions.

Figure 6 shows a typical ophthalmoscopic appearance of the three pairs of lesions by krypton yellow. With the exception of lesion 1, they are all very much alike. Small differences in lesion size are due to differences in irradiation dosage between different pairs. Figure 7 shows the histology of lesion 1 in Figure 6. The choroid is entirely destroyed, and an extensive choroidal hemorrhage resulted from the explosion of the large choroidal vessel. The histology of lesion 2 from Figure 6 is shown in Figure 8. Lesion 2 is a good therapeutic lesion. The difference in effect produced by these applications of equal irradiation dosage is explained in Figure 9, which shows the ophthalmoscopic appearance of these lesions in red light. Lesion 1, which produced hemorrhage, was placed on a large choroidal vessel with a lightly pigmented inner choroid. Lesion 2, which was therapeutic, was placed on a heavily pigmented inner choroid. Thus, the unwanted heavy damage produced by krypton yellow and by krypton red light seems to occur in opposite absorbance conditions.

Figure 10 summarizes the damage produced by red and yellow light for both the lightly and heavily pigmented inner choroid. Histologic sections A and C show lesions produced with red and yellow light on lightly pigmented inner choroid. Red light (A) produces a mild, therapeutically useful lesion, whereas yellow light (C), incident almost directly on a large choroidal vessel, produces choroidal hemorrhage. Sections B and D show lesions produced with the same colors and same dosage on a heavily pigmented inner choroid with underlying large choroidal vessel. In this case, red light (B) produces hemorrhage, and yellow light (D) produces good therapeutic lesions. This figure clearly shows that a large choroidal vessel under a lightly pigmented inner choroid is a condition of high risk for yellow light, and a heavily pigmented inner choroid over a large choroidal vessel is a condition where the use of red light could be dangerous.

Discussion

From these results it follows that: (1) The predetermination of absorbance conditions in every target
Fig. 7. Histology section through the center of lesion 1 in Figure 6. Bruch's membrane is broken, and there is a choroidal hemorrhage.

Fig. 8. Histology section through the center of lesion 2 in Figure 6. This is a good therapeutic lesion.
Monochromatic (640 nm) photograph of the same fundus as in Figure 6. Large choroidal vessels are visible in negative contrast through the lightly pigmented inner choroid.

location and the automatic presetting of the irradiation dosage should permit a safer clinical use of both wavelengths. (2) Even better results can be obtained by changing rapidly and automatically from one wavelength to the other, according to the pigmentation of the inner choroid. (3) Automation requires continuous processing of an analog signal from a measuring device to a digital signal to the device that adjusts the dosage. A microprocessor has been built into the system for this purpose.

To estimate the absorbance conditions in every target area and to monitor the formation of the lesion during photocoagulation, we designed the ophthalmoscopic attachment shown in Figure 11. The absorbance is obviously not measurable in vivo. One could, however, obtain a good approximation of absorbance by measuring the power of the coagulating beam at the target location in the retina and the total flux scattered back from retina and choroid in the same location at the retinal surface. We assume that the small amount of light transmitted through all layers in the fundus, including the sclera, is negligible, and varies little throughout the fundus of the same eye. Physically the measurement can be done only at the cornea. The calculation of the corresponding values at the retina requires the knowledge of the unknown transmission losses of the laser beam on its way in, toward the retina, and for the flux scattered back from the retina.

The difficulty in determining these losses, especially in the nonuniformly absorbing and scattering media often found in older patients, makes absolute measurements difficult. By matching the entrance pupil of the reflectometer with the patient’s dilated pupil, we make the measurements at the cornea of the light scattered back from retina and choroid, independent of retinal location, at least in the posterior hemisphere. This enables us to obtain a quantitative comparison of the absorbance conditions in any location of the fundus with those measured in a test location, which is sufficient for our purpose. The measurement in the test location is stored in memory, the measurement in any new location is compared automatically with the stored value, and the dosage is preset accordingly.

An example of the measurement of the relative absorbance of the red and yellow light is shown in Figure 12. The upper trace shows the absorbance (obtained by measuring the reflectance) along a line traced on the fundus by the krypton red aiming beam. The bottom trace shows the absorbance along approximately the same line traced by the krypton yellow aiming beam. The curve for the yellow light is almost flat, showing even absorbance, except for two vessels represented by two peaks, whereas the curve for red light shows irregular absorbance.

Other important information needed in photocoagulation is the melanin concentration in the inner choroidal layer and in the retinal pigment epithelium. This information can be obtained by measuring the reflectance with yellow and red, consecutively, in the same location. A large difference between the two measurements indicates a lightly pigmented inner choroid and a choroidal vessel crossed by the laser beam because the red is absorbed only in melanin and the yellow in melanin and also in the choriocapillaris and the large choroidal vessel. This describes the conditions of high risk for yellow light. A very small difference between the two measurements indicates a heavily pigmented choroid and no large choroidal vessels in the laser beam’s pathway, or, at least, that the pigmentation in the inner choroid is sufficient to absorb either wavelength almost entirely before it reaches the blood vessel. This indicates that either color could be used with a dosage of irradiation sufficiently reduced to prevent a penetration of lesions deep into the choroid with damage to Bruch’s membrane. A sizable difference between measurements would indicate more or less pigmented inner choroid with the large choroidal vessel in the pathway of the laser beam. This difference is due to the absorption of yellow in choriocapillaris and in the large choroidal vessel. This describes a condition of high risk for red light.

Introduction of ADM into the photocoagulator permits rapid switching from one wavelength to the other, and at the same time it solves another important problem. In case of accidental hemorrhage during treatment...
Fig. 10. A histologic analysis of the damage produced by red and yellow light in lightly and heavily pigmented inner choroid.
with the red light, the clinician can switch rapidly from red to yellow and cauterize the bleeding vessel. The arrangement also permits us to start the treatment with one color and continue it with the other. Finally, it permits us to treat with red light all locations with low absorbance in the inner choroid and switch to yellow in locations where the inner choroid is heavily pigmented, thus avoiding the risk of hemorrhage while at the same time taking full advantage of the red light.

The ADM also permits the conversion of the krypton laser from continuous to pulsating mode with selectable frequency from 0–10 MHz. The therapeutic value of short pulses for clinical work in the anterior segment seems to be well established. The possibility of using the krypton laser in either a continuous or a pulsating mode significantly increases the range of its clinical applications.

In conclusion, we think that this laser photocoagulator is flexible enough to be used in almost all clinical cases. It emits two wavelengths that can be used either continuously or in very short pulses. The selection of color depends on absorbance in the fundus. The instrumentation permits rapid switching from one wavelength to another. In addition, all krypton wavelengths can be combined for a burst of 3–4 millijoules in a μsec pulse range.

However, only an extensive study of histologic sections and their relation to predetermined color and irradiation dosage will demonstrate the laser photocoagulator’s reliability. Our hope is that this attempt will provoke more research in this field that will lead to safer and more efficient operation.

Key words: krypton red laser, krypton yellow laser, photocoagulation, instrumentation, histologic study

Acknowledgments

The authors thank Patricia Pearson for the histology and Drs. Noritsu Mukai and Ilene Gipson for helping to interpret the results.

References