rise, electroretinogram, extracellular potassium, subretinal space, pigment epithelium, photoreceptors

REFERENCES


Retinal vessel photoocoagulation: a quantitative comparison of argon and krypton laser effects. Michael Wieder, Oleg Pomerantzef, and Juliane Schneider.

Retinal arteries of owl monkeys were photoocoagulated with single exposures to argon laser green light (514 nm), krypton laser green light (531 nm), and krypton laser yellow light (568 nm). The distribution of damage along the vessel in different retinal layers was characterized geometrically after serial sectioning of the histopathologic material. Krypton laser radiation (green and, to an even greater extent, yellow) produced measurably greater effects on retinal vessels and adjacent structures than on deeper retinal levels; argon laser radiation (green) produced greater effects on the pigment epithelium. Krypton yellow produced the greatest total effect. The location of damage to the retinal arteries and pigment epithelium differed, with the peak of the damage around the arteries being farther from the optic disc than was the peak of the pigment epithelial damage.

The absorption maxima for oxyhemoglobin (542 and 577 nm) are closer to the krypton laser green (531 nm) and yellow (568 nm) wavelengths than to the argon laser green (514 nm) wavelength. We compared the efficacy of the krypton and argon laser wavelengths in photoocoagulating retinal vessels.

The krypton red line, which is effective in photoocoagulating the outer retina and choroid, was not included in this study because of its poor absorption by hemoglobin. The blue argon wavelength (488 nm) was also excluded because of (1) its preferential scattering by the ocular media, (2) its absorption by xanthophyll in the macula and the yellow pigment in older crystalline lenses, and (3) the relative susceptibility of the retina to photochemical damage from shorter wavelength radiation.

Materials and methods. Fourteen owl monkeys, each weighing 800 to 1200 gm, were anesthetized with an intramuscular injection of sodium pentobarbital. The pupils were dilated with 10% phenylephrine hydrochloride and 0.3% scopolamine hydrobromide, and a modified LO-VAC...
Fig. 1. A, Schematic summary of damage assessment. 1. Serial sectioning of specimens perpendicular to vessel axis. 2. Measurement of cross-sectional area of vacuolization around vessel, vacuolization in photoreceptor layer, and vessel on all affected sections. 3. Plotting of these three area measurements vs. their relative position along the vessel axis. (Papilla = optic disc.) B and C, Fluorescein angiograms taken about 2 hr after treatment. B, Fluorescence of three arterial (numbered 1, 2, 3) and three control lesions about 1 min after injection. C, About 2 min after injection, staining of lesions 1 and 2 has almost disappeared. Histologic examination showed pigment epithelium damage and vessel damage in lesion 3 but no pigment epithelium damage in lesions 1 or 2.
Fig. 2. Sections of photocoagulated retina. (Hematoxylin and eosin; bar = 50 μm.) A, On the right is an example of damage at all retinal levels (produced by 531 nm krypton light). Unaffected vein is seen at left. B, Higher magnification of the damaged vessel in A. C, This burn (produced by 568 nm krypton light) shows no appreciable pigment epithelium damage on any section. D, Note fragmentation and necrosis in the vessel wall (produced by 568 nm krypton light). Artery is empty owing to systemic perfusion.
Fig. 3. A and B, Two sections from one burn. B, Approximately 50 μm downstream from A, exhibits little damage in the outer retinal layers but much more destruction in and around the artery than does A. (Hematoxylin and eosin; bar = 50 μm.) C, Schematic longitudinal sections through vascular burns to illustrate the influence of heat convection and obliquity of the laser beam (solid line) on the location of the vessel damage. Arrows, Direction of the blood flow; dashed line, normal to the retina.
formed. Approximately 3 hr after treatment, the animals underwent systemic perfusion with a solution of 1% glutaraldehyde and 2.5% formalin in 0.2M phosphate buffer; the eyes were then enucleated and fixed for 3 days in 10% formalin. Serial 6 μm sections cut perpendicular to the vessel axis were prepared for light microscopy (Fig. 1). The cross-sectional areas of (1) the vessel, (2) the vacuoles around the vessel, and (3) the vacuoles in the photoreceptor layer were measured on 50 histologic sections with a microscope stage micrometer and an electronic digitizing table.

**Results.** Lesions produced by light of all three colors had a similar histologic appearance; they varied only in the extent of the damage to the different retinal tissues (Fig. 2). Arterial walls showed some loss of structure at the site of the greatest laser beam interaction, but holes were never observed. Vacuole formation around the vessel and reduction in vessel diameter were both greatest in the center of the lesion and smallest at its periphery. Vacuoles similar to those around vessels characterized the damage to the receptor layers. The pigment epithelium was detached and partially dispersed. The extent of damage to the outer nuclear layer appeared to be related to the amount of damage to the vessel and/or the pigment epithelium. The choriocapillaris appeared to be compressed locally by the vacuoles in the receptor layer, but deeper choroidal structures were not affected.

In Fig. 1, A, the areas of the vessel, the outer vacuole, and the inner vacuole measured on various sections are plotted against the relative position of the sections along the vessel axis.

Fluorescein angiography showed leakage only in burns with pigment epithelium defects (Fig. 1, B and C). If the lesion was confined to the artery and the adjacent structures, only the vessel wall stained, and this staining disappeared in late phases of the dye transit. Thus fluorescein dye did not penetrate into the vacuoles that surrounded the vessel (Fig. 1, B).

In all experiments, the peak of damage around the arteries was always more peripheral (i.e., farther from the optic disc) than that of the damage at the pigment epithelium (Fig. 3). This peripheral shift of the vascular damage varied between 10 and 90 μm at all wavelengths and was generally larger than the shift resulting from the oblique incidence

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Fig. 4. A, Distribution of vacuolization. Each data point represents one burn. Inner retinal damage is defined as the total volume of vacuolization around the vessel, outer retinal damage, as the volume of vacuolization at the level of the photoreceptors. Volume of vacuoles was computed from vacuole area on each section. Burns in shaded area had extensive damage both around the vessel and at the level of the photoreceptors. B, Relationship between reduction of vessel lumen and inner retinal vacuolization. The vessel lumen decreases as the size of the vacuoles around the vessel increases.
of the laser beam. To assess the possible influence of heat convection by the moving blood, we coagulated retinal veins and found that the inner retinal damage was much less shifted toward the periphery than it was in the case of arteries; in some burns, the damage was even shifted toward the optic disc (Fig. 3, C).

The measurements of the volume of affected tissue permitted a quantitative comparison of the effects of the wavelengths investigated. Both wavelengths of krypton laser light tended to produce more vacuolization around the vessel and less in the outer retinal layers than did the argon green. Krypton yellow produced the greatest total effect.

Fig. 4, A, shows the relationship between inner and outer retinal damage. Any reduction of the vessel lumen was directly related to the size of the inner vacuoles; the vessel lumen decreased as the size of the vacuoles around the vessel increased (Fig. 4, B).

Discussion. Various factors affect the distribution of damage in a vascular lesion produced by photocoagulation. The damage to the outer retinal layer varies with the vessel diameter; such damage is more extensive when smaller vessels are treated. With small vessels, less energy is absorbed by the blood and more is transmitted to the outer retina. In our experiments, arterial diameters ranged from 45 to 100 μm, with an average of about 65 μm. The distribution of vessel diameters for the three wavelengths investigated was not significantly different.

Furthermore, owing to variations in power, working distance, and astigmatism introduced by the contact lens, retinal energy density may vary by a factor of 2 in either direction even under ideal conditions. Since the computed energy density in our experiments was approximately 255 J/cm² (ocular transmission not taken into account), actual energy density probably varied between 170 and 340 J/cm², which caused a relatively large variation in the distribution of damage. It is reasonable to assume, however, that these variations affected the results with all three laser wavelengths similarly.

In some burns, extensive damage was present at both the inner and the outer retinal level (shaded area, Fig. 4, A). In these burns, the energy density appears to have been higher than average because of a combination of the factors mentioned above. These results do not exhibit any significant wavelength dependency. With increasing power, however, not only does the difference between the argon and krypton wavelengths become less appreciable but also the range of clinically safe applications is exceeded.

In the remaining lesions (unshaded area, Fig. 4, A), which represent the average and low range of the energy variation, the damage pattern varied with wavelength. Krypton green and yellow light produced measurably greater effects on the arteries and adjacent structures than on deeper retinal levels; argon green light produced greater effects on the pigment epithelium.

Our findings also suggest that the location of the damage in and around the vessel is determined by the angle of the coagulating beam incidence as well as by the direction (and probably rate) of the blood flow.

We conclude that in many cases of diabetic retinopathy, branch-vein occlusion, sickle cell anemia, and other retinal vascular conditions where direct coagulation of retinal vessels is appropriate, treatment with the krypton green and yellow wavelengths should be more successful than conventional argon laser treatment.

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