USE OF ARGON LASER ENERGY TO PRODUCE IRIDOTOMIES*

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INTRODUCTION

THE USE OF LASERS† IN MEDICINE IS A FAIRLY RECENT DEVELOPMENT, AND EMployment of radiant energy to create a nonsurgical iridotomy for the treatment of angle-closure glaucoma is an important contribution to ophthalmology. The scientific method is reminiscent of the experiment by Boerhave who, in the 18th century, used a magnifying glass to concentrate the sun's rays and quickly burned a hole through a piece of darkened paper.[1]

Many years later, in a related experiment, Meyer-Schwickerath produced iridotomies using the Zeiss xenon photocoagulator as an energy source.[2] With a maximum luminance of 2.3×10^{-9} cd/m^2, the light of the xenon photocoagulator could be focused on the iris using repeated exposures of 0.5 to 1.5 seconds (sec) to produce an iridotomy. However, light photocoagulation produced by either a xenon or copper-covered carbon arc was often followed by corneal and lenticular opacities, and the use of radiant energy was mainly limited to the treatment of aphakic eyes.[3-6]

Ruby laser energy, on the other hand, was found to produce iris and retinal burns with shorter delivery time and with much less total energy delivered to the eye than was possible with xenon photocoagulation; and it caused little or no damage to the ocular media.[7,8] Recognizing this, Flocks, Zweng and co-workers attempted to penetrate the iris by ruby laser using 0.1 joule (j) delivered in a 300-milliseconds (msec) pulse. Although they failed to produce a permanent iridotomy, they did recognize the potential capability of coherent radiation to produce iris holes.[8,9] Snyder[10] produced iridotomies with 95% success in Dutch chinchilla rabbits after 3 weekly treatments using ruby laser energy levels of up to 0.3 j. This was often accompanied by retinal lesions. No retinal lesions occurred when the

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†Acronym for light amplification by stimulated emission of radiation.

energy was decreased to 0.15 j, although the success rate dropped to 20%.

The ruby laser has been employed in brown-iris human and rabbit eyes to produce iridotomies using energy levels of 0.2 to 2.0 j with a single burst of 500 to 630 microseconds (μsec). In many cases the treatment had to be repeated, either because the hole was not completed on the first trial or it subsequently closed,[11-15] but the results were encouraging. Beckman was successful using a more-powerful ruby laser with energy levels of 3 to 4 j and pulses of 6 msec. In persons with brown irides, he was able to penetrate the iris with a single pulse, but the results in patients with blue irides were less consistent and required energy levels twice as great.[16,17]

Following adaptation of the continuous-wave (c-w) argon laser to the slit lamp[18] and the pioneering work of Zweng, L'Esperance and Patz, the argon laser soon became available in most centers of ophthalmic research, mainly for treatment of retinal disease.[18-22] Having a wavelength of 4,545 to 5,145 A, the blue-green beam was transmitted by the optical system of the eye with relatively low absorption. The quality of its burn, like that of the ruby laser, was dependent on the presence of pigment and melanin. Its focusing quality made it well-suited not only for treatment of retinal vascular disease and retinal detachment, but also for production of iridotomies.

Using the c-w argon laser, iridotomies were successfully performed in monkeys,[15] Dutch rabbits,[23] and in humans.[24-27] Spot sizes of 50 microns (μ)[25-27] to 200 μ[26] with energy levels up to 2 watts (w) were employed for 0.2 to 0.5 sec to perforate the iris. In some cases the iridotomy was achieved instantaneously[26] or after a series of burns at the same site,[27] whereas in some cases the iridotomy site did not open for one to three weeks after treatment.[25] Retreatment was sometimes required, either because of failure to complete the iridotomy on the first procedure or because of its subsequent closure.

A major disadvantage of c-w argon lasers was that the long pulse (0.2 to 0.5 sec) produced a pronounced thermal effect at the site of energy absorption and a thermal insult to the cornea and lens. With shorter pulses, there occurred a corresponding reduction in heat loss from the target site to the other tissues. This resulted in greater focal rise in temperature and vaporization of the target tissue.[28] Although the pulsed ruby laser utilized these advantages and was very effective in vaporizing a hole in the brown iris, its weaker effect in the blue iris left something to be desired. For this reason, there developed increased interest in a pulsed argon laser that was introduced as a tool not only to treat retinal disease, but also to produce iridotomies with less thermal spread.[29]

Early in our experience it became apparent that certain problems and factors had to be dealt with before laser iridotomy could become a

generally-accepted method for the treatment of angle-closure glaucoma. Those aspects include the following:

(1) A wide range of targets, energy levels, and exposures are currently used with the c-w argon laser to attain the same goal: a permanent, complete peripheral irodotomy. The number of patient visits required to achieve this, the total energy required per treatment session, the frequency of subsequent iris closure, and the overall success rate vary widely at various medical centers. The current study seeks to investigate the possible factors that can give rise to these differences and to provide a more clearly-defined approach.

(2) The pulsed argon laser has been introduced as an instrument that should, on a theoretical basis, vaporize an iris hole with minimal thermal conduction to the surrounding and underlying tissues. This study seeks to impart our experience with this laser.

(3) The hazards and complications of laser iridotomy have been defined by many investigators. This study provides further findings on the definite and suspected complications by means of histologic study and iris angiography.

(4) The effects of pigment dispersion resulting from the treatment remain unexplored. An attempt is made herein to study the early effects of pigment dispersion on aqueous humor dynamics.

(5) This report seeks also to evaluate the role that laser iridotomy can be expected to play in the diagnosis and treatment of angle-closure glaucoma.

CONTINUOUS-WAVE ARGON LASER

MATERIALS

During the past four years laser iridotomy has been performed on some 300 eyes with angle closure glaucoma, 215 of which are included in this report. All of the patients were white. Two c-w argon lasers (Coherent Radiation Laboratory models #800 and #900) connected to a Zeiss slit-lamp were used to treat 169 of the eyes. One of these instruments (model #900) was equipped with a high-powered research laser having a maximum energy output of 5.5 w, whereas the other had a maximum output of 3.0 w. Both instruments were conveniently adapted for treatment of the anterior segment utilizing a weaker argon focusing beam that was parfocal with the focal length of the biomicroscope.

Fluorescein iris angiography was performed in eight eyes at six to 36 months after the last treatment. A Zeiss photo-slit-lamp with a Zeiss external illuminator and camera having the capability of taking pictures every 1.5 sec was used following intravenous injection of 5 ml of 10% sodium fluorescein solution. Color photographs of the same iris with high-power views of the iridotomy were taken during the same examination.

A modified Goldmann fundus contact lens, coated to prevent reflection of the laser beam, was used for part of the study. A small plano-convex button lens having a focal length of 15 mm was bonded onto the anterior surface of the lens (Fig 1).*

METHODS

Each volunteer patient in the study was given a personal explanation of the treatment and required to sign a consent form. Prior to laser treatment each patient was asked to continue whatever glaucoma medication he was using until the iridotomy remained open four to six weeks or, when applicable, until all studies regarding the effect of the iridotomy on aqueous humor dynamics were completed. If the eye was not already being treated with miotics, 1% pilocarpine was instilled within four hours before treat-

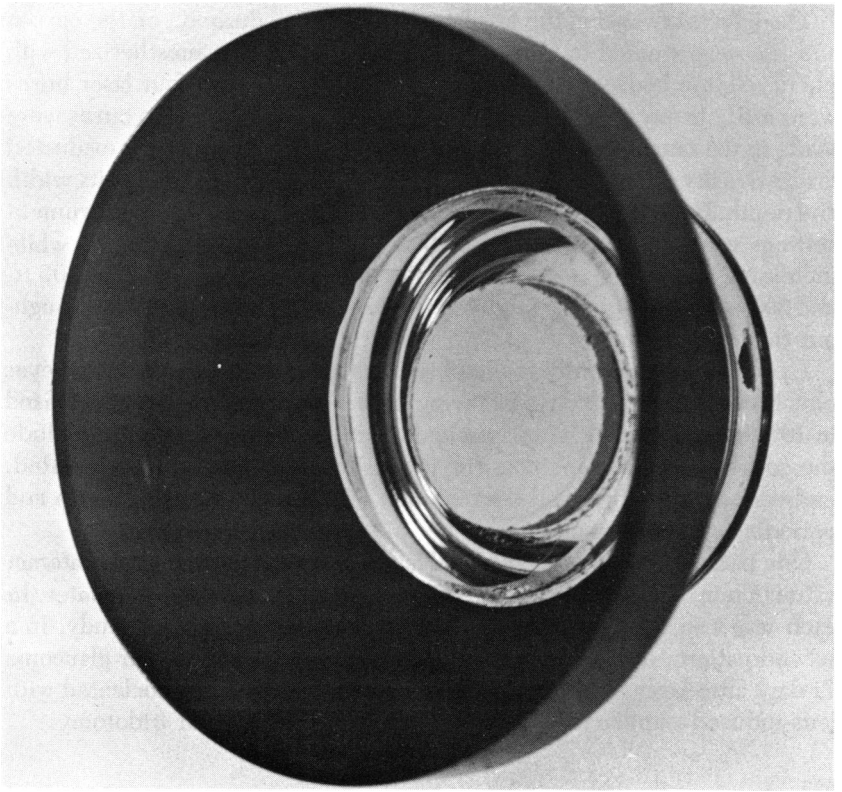


FIGURE 1

Specially-designed Goldmann fundus contact lens used in most cases. Lens was coated to prevent reflections, and a small plano-convex button was bonded to its anterior surface.

*Provided by Coherent Radiation Laboratory.

ment. After instillation of one drop of proparacaine the modified Goldmann fundus contact lens with gonioscopic fluid (Burton, Parsons) was applied to the eye. No contact lens was used in 85 of the 169 eyes.

A laser iridotomy was made in 77 consecutive eyes employing energy levels of 500 to 2000 milliwatts (mw) for 0.1 to 0.5 sec and using a 50 to 200 μ spot (Fig 2). Each eye was followed at weekly intervals, during which time the laser iridotomies were observed by biomicroscopy for closure of the defect with pigment. When the opening was judged to be 50% closed, the pigment was dislodged with low energy levels of 200 to 1000 mw.

After each treatment session one drop of prednisolone acetate 1% was instilled into the conjunctival cul-de-sac, and this same medication was prescribed every two hours during the day of treatment and four times daily for the following three days.

The effects of varying the laser power and pulse duration on the cornea and iris were studied in four cynomolgus monkey eyes anesthetized with phencyclidine hydrochloride (2.3 mg/kg). No more than four laser burns were made in any single quadrant of cornea or iris, and no two burns were made in the same or contiguous locations. The corneal burn was evaluated for its density and width, whereas the iris lesion was judged for its width and depth. Both were graded on a scale of four. The sequence of instrument settings was as follows: 0.01 to 0.20 sec in a stepwise progression while increasing from 1 to 5 w. Similar studies were made with the 50 μ, 100 μ, and 200 μ laser spots. The modified fundus contact lens was used throughout this experiment.

Histologic studies were made of two rabbit eyes and two monkey eyes enucleated seven to 21 days following laser iridotomy. The eyes were fixed in 10% formalin for 48 hours, washed overnight, and sectioned to include the cornea, iris, and lens near the iridotomy. Sections were dehydrated, embedded in paraffin, and later stained with hematoxylin and eosin and periodic acid-Schiff stains.

One patient underwent a bilateral laser iridotomy followed by a cataract extraction in one eye 24 hours later and in the second eye five days later. In each case a sector iridectomy included the laser iridotomy for study. In a second patient, one eye was enucleated because of neovascular glaucoma 71 days after laser iridotomy. In a third case, the eye was enucleated with lens-induced pupillary-block glaucoma 12 days after laser iridotomy.

RESULTS

Most of the patients were referred for this study because of poorly-controlled intraocular pressures in eyes suspected of having chronic angle-closure glaucoma (Table I). A second group was referred specifically

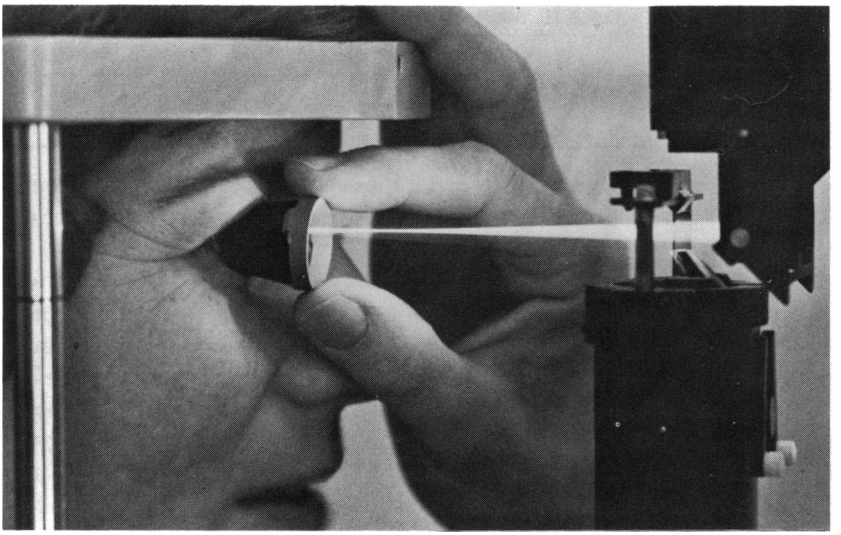


FIGURE 2
Convergent laser beam was brought to sharp focus on iris.

for laser iridotomy rather than a surgical procedure, because of a history of complications that had occurred when a surgical peripheral iridectomy had been performed on the fellow eye. These complications included retrobulbar, intraocular, and expulsive hemorrhage; rapid postoperative cataract formation; wound dehiscence and malignant glaucoma.

Follow-up data on 148 eyes that were followed for a minimum of one year and a maximum of four years are summarized in Table II. A laser iridotomy was successfully performed in 95% of the cases. However, in seven eyes the

TABLE I: REASONS FOR PATIENT REFERRAL FOR LASER IRIDOTOMY

Chronic angle-closure or combined* glaucoma	103
Acute or subacute angle-closure**	36
Complications after operation# in fellow eye	17
Concern because only one functioning eye	12
Refused surgical iridectomy	5
Secondary pupillary block	
a) Iridovitreal block	2
b) Lens block	2
c) Occluded pupil (posterior synechiae)	2
Total number of patients	179

*Previous history of open angle that narrowed (5 cases).
**In laser-treated or fellow eye.
#Peripheral iridectomy or filtering operation.

TABLE II: SUCCESS RATE OF LASER IRIDOTOMY

YEARS FOLLOWED	1-2	2-3	3-4	TOTAL
Successful	44 (95%)	53 (96%)	44 (94%)	141 (95%)
Unsuccessful	2 (5%)	2 (4%)	3 (6%)	7 (5%)

iridotomy could not be completed and these patients underwent a successful surgical peripheral iridectomy (4), trabeculectomy (2), or cataract extraction (1).

A laser iridotomy was made in 77 consecutive eyes, and each was carefully followed at weekly intervals for 12 weeks and then at six-month intervals for up to four years. In 51 cases (66%) the iris opening remained patent after the first treatment (Table III). In 26 of the 77 cases the defect became at least 50% closed with pigment. In these eyes, partial or complete closure of the iridotomy with pigment always occurred during the first six weeks (Fig 3). One case was lost to follow-up between the 5th and 12th week when partial closure was first observed and is not included in this analysis.

In each case of partial or complete closure, the iridotomy was reopened with 200-400 mw for 0.2 sec using a 50-100 μ spot. In no case did closure occur between six weeks and the maximum of four years follow-up. Usually, the smaller the iridotomy, the more likely it was to occlude.

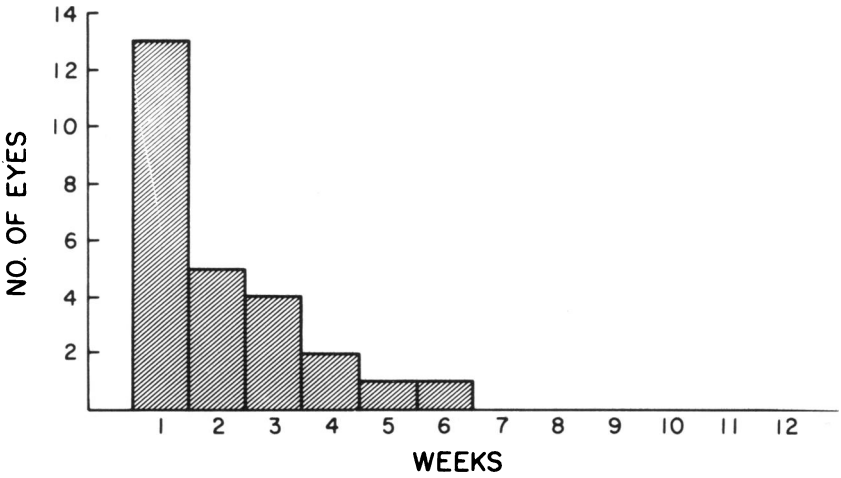


FIGURE 3

In 26 of 77 eyes followed weekly for three months, iridotomy became at least 50% closed with pigment. Nearly all cases of partial or complete closure of iridotomy occurred within four weeks, and none closed after six weeks. Each closed iridotomy was re-opened, and in no case did closure occur between six weeks and up to four years after treatment.

TABLE III: FATE OF IRIS HOLE FOLLOWING LASER IRIDOTOMY

Remained patent	51 (66%)
More than 50%-closed by pigment	26 (34%)
Total number of eyes	77

In 94% of cases the holes were made between the 9:00 and 11:00 o'clock meridians and between the 1:00 and 3:00 o'clock meridians. Both the iris stroma and pigment epithelium were most responsive to the 50 μ or 100 μ spots. The 200 to 500 μ spot sizes required increased energy levels to achieve a similar iris char, and for this reason were only rarely used. Energy levels between 700 and 1500 mw were most frequently used, although levels as high as 2500 mw were employed on rare occasion.

The ease with which each iridotomy could be produced varied from eye to eye, and even from site to site within the same eye. Frequently a poor response of the iris to repeated laser treatment at one site was followed by achievement of a prompt and complete iridotomy in a nearby site on the same iris and with the same instrument settings.

To test the possibility that vaporization of an iris hole could be more effectively performed with a higher energy level and shorter exposure time, we used a c-w argon laser model #900, having a maximum energy output of 5.5 w and exposure time as short as 0.01 sec. Using a 50 μ spot, the first perceptible iris lesion occurred with 1.0 w and a 0.05 sec pulse, whereas the earliest superficial corneal burn occurred with 3.0 w for 0.10 sec (Table IV). The best iris char having no associated visible corneal burn took place at energy levels of 1.0 to 2.0 w for 0.2 sec. Combinations of 4.0 to 5.0 w with shorter pulses (approximately 0.4 j) failed to yield deeper iris lesions but they consistently caused a corneal burn. In most trials, as the energy level and exposure time were increased, so did the likelihood of a corneal burn. Similar results occurred using the 100 μ spot. Use of the 200 μ spot showed little difference in iris effect when compared to the results obtained with smaller spots, although the corneal burns were more frequent and more pronounced (Table V).

On 12 occasions, corneal endothelial burns occurred—particularly, although not always, in eyes with extremely shallow anterior chambers and brown irides. Usually this was overcome by moving to another, and more central, corneal location and decreasing the energy level. However, on two occasions energy levels as low as 700 mw for 0.2 sec repeatedly produced endothelial burns without significant charring of the iris. Each of these patients underwent a successful surgical peripheral iridectomy.

TABLE IV: EFFECT OF VARIOUS ARGON LASER SETTINGS ON THE CYNOMOLGUS MONKEY CORNEA AND IRIS USING A 50 μ SPOT

	5 WATTS		4 WATTS		3 WATTS		2 WATTS		1 WATT	
SECONDS	CORNEA*	IRIS**	CORNEA	IRIS	CORNEA	IRIS	CORNEA	IRIS	CORNEA	IRIS
.01	trace	1+	0	1+	0	trace	0	trace	0	0
.05	1+	2+	1+	2+	0	1+	0	1+	0	trace
.10	2+	3+	2+	3+	1+	2+	0	2+	0	1+
.20	4+	4+	3+	4+	2+	3+	0	3+	0	3+

*Size and density of white corneal burn.
**Size and depth of crater.

TABLE V: EFFECT OF VARIOUS ARGON LASER SETTINGS ON THE CYNOMOLGUS MONKEY CORNEA AND IRIS USING A 200 μ SPOT

	5 WATTS		4 WATTS		3 WATTS		2 WATTS		1 WATT	
SECONDS	CORNEA*	IRIS**	CORNEA	IRIS	CORNEA	IRIS	CORNEA	IRIS	CORNEA	IRIS
.01	1+	1+	0	1+	0	1+	0	trace	0	trace
.05	2+	2+	1+	1+	1+	2+	0	1+	0	1+
.10	3+	2+	2+	2+	2+	3+	0	2+	0	2+
.20	4+	3+	4+	3+	3+	4+	trace	4+	0	3+

*Size and density of white corneal burn.
**Size and depth of crater.

Endothelial burns lasted longer than the superficial corneal burns, and in two eyes they have persisted for more than three years. They were not associated with visible thickening of the cornea, and because of their very small size and peripheral location they have not affected the visual acuity or the visual field.

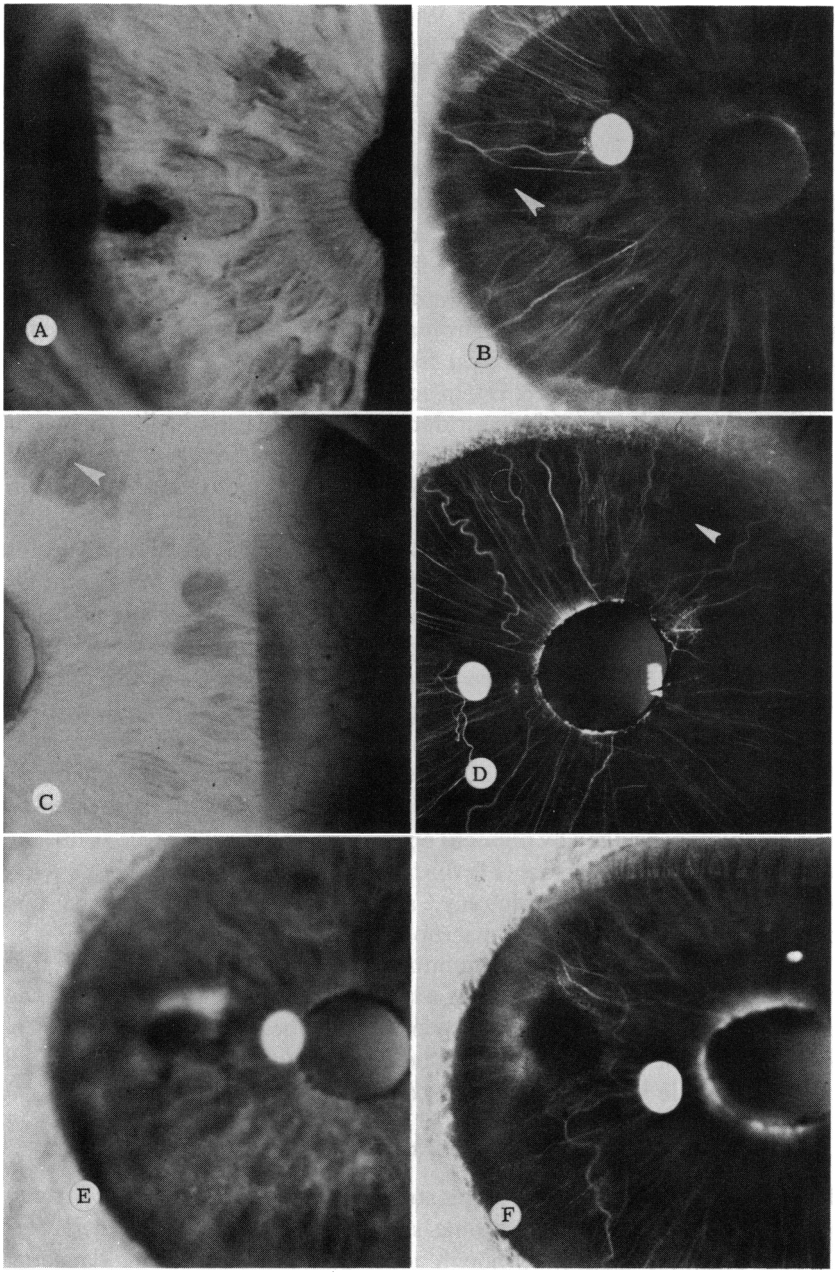
In each of eight eyes in which fluorescein angiography was performed, the color photographs were examined in conjunction with the iris angiograms (Fig 4, A-F). In each case the vessels in the atrophic zone surrounding the iridotomy failed to fill or leak fluorescein. Furthermore, even when the surrounding atrophic iris showed absence of pigment epithelium on retroillumination, and definite stromal thinning and atrophy, the iris did not permit passage of fluorescein from the posterior chamber into the anterior chamber (Fig 4, C & D). In one case a puff of fluorescein appeared at the superior border of the iridotomy, and this gradually expanded upward (Fig 4, E). In another case, fluorescein appeared at the margin of the iridotomy by the second dye transit and was similar to the accumulation of fluorescein-stained aqueous at the pupillary margin (Fig 4, F).

During the first week after laser iridotomy, the rabbit and monkey irides showed edema and necrosis in the adjacent stroma similar to previously-described cases.[10,27] There was migration of pigment-laden macrophages into the stroma and loss of pigment epithelium. Within a few weeks, most of the edema subsided. Three months after treatment, there was definite atrophy in the iris stroma surrounding the iridotomy, loss of melanocytes, and presence of many pigment-laden macrophages. In both monkey and rabbit eyes there were occasional cases in which pigment epithelium partly or completely bridged the iridotomy (Fig 5). In one patient, the iridotomy was completely bridged by pigment epithelium and there was also a fibrous membrane across the defect (Fig 6). In another, posterior synechiae were visible adjacent to the iridotomy, and the overlying iris stroma was crowded with pigment-laden macrophages (Fig 7).

In one case we were able to examine histologically the lens opacity that occurred in the process of creating a laser iridotomy (Fig 8). Although the capsule remained intact, fragmentation of lens fibers and partial atrophy of lens epithelium occurred. Within the cellular debris were several small round refractile bodies, suggesting calcific change.

DISCUSSION

The great majority of patients in this study were referred because of chronic angle-closure glaucoma or chronic simple glaucoma with suspiciously-narrow chamber angles. Although most patients with acute glaucoma undergo surgical iridectomy with a very high rate of success, a small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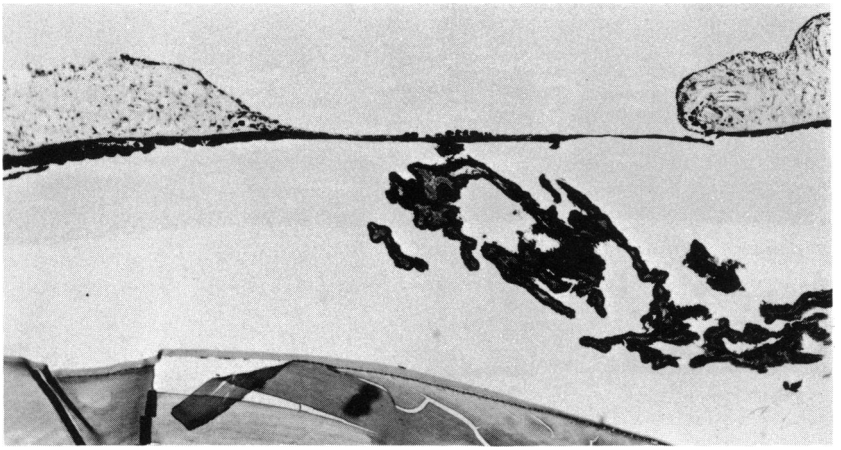

FIGURE 5
Pigment epithelium bridging laser iridotomy made 3 months earlier in Dutch pigmented rabbit (hematoxylin-eosin, ×50).

number of cases are complicated by postoperative hemorrhage, wound dehiscence, infection, and rapid cataract formation. Many such patients were referred for laser iridotomy in the fellow eye, and they represented a surprisingly large part (9%) of the study population.

Performing a laser iridotomy following an acute attack of glaucoma is feasible after the corneal edema has cleared. However, there is a large element of risk that the laser iridotomy will not be completed during the first treatment session and thus the eye will be temporarily in jeopardy. For this reason the surgeon may choose to treat the eye that suffered an acute attack by a surgical iridectomy and, during the same hospitalization, perform a laser iridotomy on the fellow eye.

Any enthusiasm for producing a laser iridotomy is limited by a major restraining consideration: the importance of causing minimal thermal damage to the cornea and lens. On the one hand, the surgeon faces the constraint to use less laser energy and a small spot size to make a smaller hole, in order to minimize pigment dispersion, secondary iritis and increased intraocular pressure. On the other hand, it is desirable to use more

FIGURE 4
Fluorescein angiograms (B, D) were examined in conjuncton with photographs (A, C) and revealed no leakage in area around hole (arrow). B, D: When surrounding area was thin and atrophic with loss of pigment epithelium, it did not permit passage of fluorescein from posterior to anterior chamber. E: A puff of fluorescein appeared at superior border of one iridotomy and gradually expanded upward. F: Fluorescein appeared at margin of iridotomy and pupil at same time, by second dye transit.

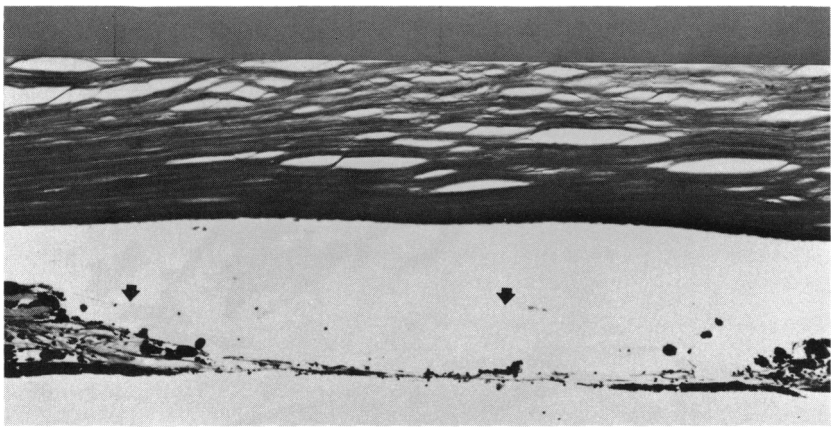

FIGURE 6
Complete bridge of pigment epithelium 12 days after laser iridotomy in blind human eye enucleated with phacomorphic pupillary-block glaucoma. Note fine fibrous membrane over iridotomy (arrow) (PAS, ×160).

energy to vaporize a hole of ample diameter and lessen the chance for subsequent closure. It is indeed fortunate that hemorrhage is not an additional problem, it being eliminated by the laser's coagulative effect.

To minimize the side effects that occur with laser iridotomy, one searches for the most direct technique to perform a rapid iridotomy with the least amount of laser energy. One should focus upon several technical considerations that will now be considered.

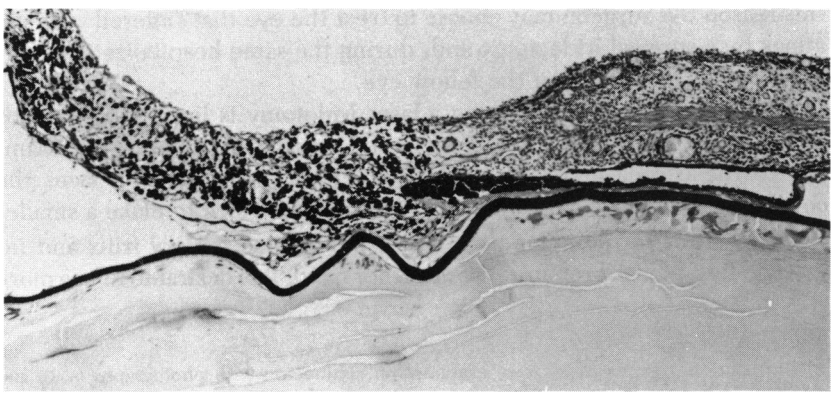

FIGURE 7
Posterior synechia with fibrovascular tissue between iris and lens at margin of laser iridotomy. Overlying stroma reveals proximity to iridotomy by abundance of pigment-laden macrophages. Eye was enucleated because of neovascular glaucoma (hematoxylin-eosin, ×60).

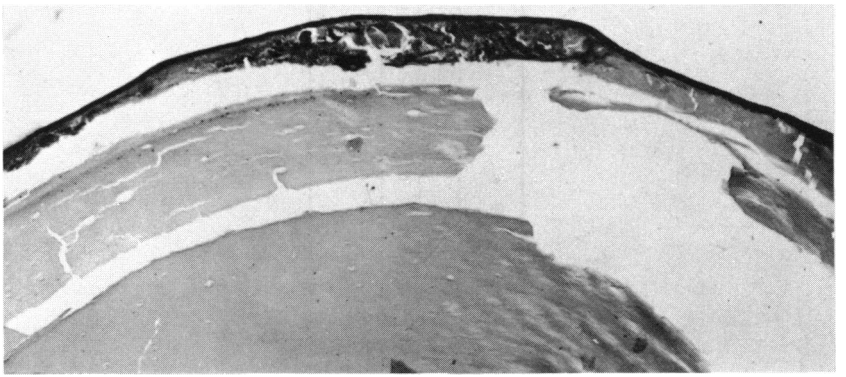

FIGURE 8
Histologic section through human lens with localized opacity produced during laser iridotomy. Lesion is entirely subcapsular and consists of fragmented lens fibers and partial atrophy of lens epithelium (hematoxylin-eosin, ×200).

IRIS COLOR

Our previous experience has suggested that both blue and brown irides respond well to the c-w argon laser, and has confirmed the observations of others that it is slightly more difficult to produce an iridotomy with the argon laser in the brown eye than in the blue.[25,27] This is certainly different from the results obtained with the ruby laser, which produces an iridotomy easily in the brown iris and poorly in the blue.[15,16] At the same time, it is well-known that some blue irides also respond poorly to the argon laser.[30] Our experience indicates that there is a wide range of iris color variation that appears to be susceptible to the argon laser. It is clear that the gray, green, hazel, and light-brown irides are easy to treat. Whereas most of the iris tissue pigment is in the pigment epithelium, there is also a variable amount of stromal pigment. This is distributed in melanocytes throughout the stroma and can be seen in greater concentration in darker eyes in the anterior limiting layer.[31,32] At one end of this color spectrum is the very light-blue iris that is nearly devoid of stromal pigment; while at the other end, is the thick, dark-brown velvety iris that is laden with melanocytes. In the light-blue iris, pigment epithelium is sometimes shattered by the laser energy with very little destruction to the overyling stroma. Repeated attempts to complete the iridotomy may be unsuccessful. Similarly, some dark-brown velvety irides appear to be resistant to the laser energy, and respond with hardly more than a superficial char. Fortunately, the great majority of patients have irides that fall between these two extremes and are readily treatable. In difficult cases, especially in eyes with blue irides, it is often easier to penetrate the stroma on retreatment one to two weeks

TABLE VI: EFFECT OF VARYING THE PULSES PER SECOND IN SIX HUMAN EYES WITH BROWN IRIDES USING A 50 μ SPOT WITH 3 WATTS

		200 PPS		400 PPS		500 PPS		600 PPS	
EXPOSURE (SEC)	POWER (J)	CORNEA*	IRIS**	CORNEA	IRIS	CORNEA	IRIS	CORNEA	IRIS
0.20	0.60	0	0	0	trace	trace	1+	2+	3+
0.10	0.30	0	0	0	0	0	trace	1+	2+
0.01	0.03	0	0	0	0	0	0	trace	trace

*Size and density of white corneal burn.
**Size and depth of crater.

after the first treatment session. This may be due to the enhanced absorption of energy by the stroma after it has become infiltrated by pigment-laden macrophages following the first laser application.[27]

There are many reasons for the variable success rate that is encountered in the many medical centers where laser iridotomy is being used. Technical experience is a significant factor. Not only must one gain experience in use of the laser itself, but one must also become proficient in evaluating the iris response and be prepared to alter one's approach accordingly. The initial four or five iris burns should serve as an indicator of the tissue's reaction to the laser energy at this site. If the laser penetrates the iris well and produces a small but definite pit into the iris stroma, then one proceeds with a subsequent series of burns directed into the same spot. If a satisfactory initial pit is not produced, one simply moves to another site until a more favorable iris response is obtained. We have encountered many situations in which the iris cannot be penetrated despite 40 or 50 burns in one site, whereas a short distance away the iridotomy can be completed after five or 10 burns.

TREATMENT SITE

It is preferable to make the iridotomy under the upper eyelid to minimize the likelihood of visual disturbance from light leak. In one patient an iridotomy at the 5:00 o'clock meridian in the left eye caused monocular diplopia on occasion.

The great majority of iridotomies in this study were made either nasally or temporally between the 9:00 and 11:00 o'clock position and between the 1:00 and 3:00 o'clock position. This is an especially convenient region to treat because it is easily viewed with the biomicroscope through a contact lens. Also, the patient's ocular fixation can be moved nasally or temporally to direct the laser beam away from the posterior pole. This becomes slightly more difficult when a superior site is chosen. While the patient's gaze can be directed upward to avoid the posterior pole, the contact lens meets resistance from the upper eyelid and orbital rim. An added disadvantage to the superior location is that vaporization bubbles cannot rise, and they tend to accumulate over the treatment site. Nevertheless, 20% of our iridotomies were made between the 11:00 and 1:00 o'clock meridian.

A peripheral location is particularly desirable for several reasons: (1) If a corneal or lenticular opacity occurs it will not impair central vision. (2) There is less chance that the laser beam will be directed to the posterior pole, but rather to the peripheral retina. (3) There is a greater separation between the posterior iris surface and anterior lens capsule in the area peripheral to the anterior lens curvature. One prefers to direct the laser

inside the limbal arcus when it is present, yet remain as far peripherally as possible.

In most cases, one can simply approach a suitable site and proceed with the iridotomy. Occasionally, in blue irides the dilator muscle contracts in response to the laser energy, causing the iris to thicken and the pupil to deflect toward the burn. In our experience the best approach then is simply to move to another site, and create a circle of weak 200 mw burns, each of which tends to thicken the iris at that point, leaving a central thin area. One can then proceed to drill a hole in the center of the taut circle with higher energy levels in the usual manner.[27] An alternate approach is to place four weak burns at the corners of a square in order to produce a hump. One then proceeds to create the iridotomy in the center of this elevation.[23,26] This has the advantage of decreasing the chance for thermal conduction to the underlying lens, because of the increased depth of the posterior chamber at this point. However, the iris elevation immediately disappears after the first few burns in its center, thus negating its usefulness. It is actually unnecessary to use either a circle or a hump in most cases.

SPOT SIZE, EXPOSURE, ENERGY

Irradiation by an argon laser pulse of long duration and with a large beam radius augments the damage to the iris stroma because of its thermal effect, whereas a short exposure time with a small beam radius augments the damage to the pigment epithelium.[28] However, larger beam diameters of 200 μ or more may require higher levels of energy to produce the same char, and they cause a more pronounced corneal burn. The most effective burns occur with a 50 μ or 100 μ spot.

Because of potential damage to the cornea and lens, the amount of laser power employed in each burn must be limited. Very high levels of energy must be coupled with shorter exposure times, whereas lower levels of energy can be used with longer exposure times. A review of the data shows that the maximum well-tolerated power was 0.3-0.4 j. Higher powers (0.5 to 0.6 j) routinely and consistently produced corneal and lenticular burns.

One of our c-w argon lasers had the capability of producing energy levels of up to 5.5 w. It was hoped that we could combine this high energy output (4-5 w) with short pulses of 0.01-0.05 sec (.04-.25 j). However, this was simply insufficient energy to produce a satisfactory effect on the iris, and yet it nearly always caused a corneal burn (Table IV). The best results were obtained with energy levels of 2 w or less for 0.2 sec. At these levels, one could produce a satisfactory iris lesion with little or no damage to the cornea.

There is a theoretical advantage to using shorter exposures combined

TABLE VII: EFFECT OF PIGMENT DISPERSION ON FACILITY OF AQUEOUS OUTFLOW IN RABBITS AS DETERMINED BY TONOGRAPHY

	BEFORE DISPERSION		AFTER DISPERSION		%ΔC	C
RABBIT	TREATED*	CONTROL*	TREATED	CONTROL	TREATED	CONTROL
1	.14	.10	.09	.09	−36	−10
2	.12	.13	.19	.13	+58	0
3	.19	.22	.13	.17	−32	−23
4	.17	.13	.16	.17	−6	+31
5	.18	.19	.16	.21	−11	+11
6	.14	.14	.13	.14	−7	0
7	.14	.13	.14	.15	0	0
			Mean	=	−4.9	+3.4
			Std. Dev.	=	20.9	17.6
			p	=	0.3	

*ml/per min × mm Hg^{-1}.

with high levels of energy. Whereas longer exposures allow the laser energy to spread from the treatment site to produce a larger thermal burn in the iris stroma, short exposures conserve the energy and produce vaporization of a hole. However, our experiments failed to demonstrate an advantage with high levels of energy. This could, in part, be due to the loss of energy in the cornea where a superficial burn usually occurred. Our best results occurred with pulses of 0.1 to 0.2 sec, but the increased thermal effect of the 0.2 setting proved a definite advantage. Still longer pulses of 0.5 sec caused excessive thermal damage to the adjacent iris tissue and

TABLE VIII: SIMULTANEOUS INTRAOCULAR PERFUSION IN RABBIT EYES AFTER MULTIPLE LASER IRIDOTOMIES

RABBIT#	DAYS AFTER IRIDOTOMIES	CONTROL*	TREATED*	%DIFFERENCE
27	2	.23	.26	+13
28	2	.30	.25	−17
34	8	.63	.68	+8
24	14	.16	.11	−31
19	19	.66	.72	+9
22	19	.54	.36	−33
20	21	.28	.21	−25
29	21	.30	.27	−10
8	108	.23	.24	+4
9	127	.33	.36	+9
10	127	.41	.35	−15
11	135	.38	.41	+8
14	135	.52	.47	−10
15	135	.27	.24	−11
		Mean	=	−7
		Std. Dev.	=	15.8
		p	=	>.05

*ul/min × mm Hg^{-1}.

greatly increased the likelihood of producing a corneal burn and excessive uveitis. Therefore, 0.2 sec has proved to be the most desirable exposure time in these experiments.

CLOSURE OF THE HOLE

In the ideal situation a laser iridotomy can be produced during the first visit, with a short series of burns and with no subsequent closure of the defect. However, in a large number of cases pigment gradually closes over the hole within a few weeks. Rarely does the hole close after being open for four weeks, and in no case has it closed after six weeks. Therefore, it is important to follow these patients and to dislodge the occluding pigment with low levels of laser energy when necessary. In all of our cases, once the hole remained open without treatment for four to six weeks, it remained permanently patent during the follow-up period of up to four years.

In rare cases a barely-visible fibrous bridge can be seen to have developed over the iridotomy (Fig 6). This, too, must be disrupted by further treatment in order to maintain patency of the iridotomy.

Still another hazard is the formation of posterior synechiae around the margin of the laser iridotomy (Fig 7). Detection of this complication is very difficult because the iridotomy, itself, may appear open and anterior lens capsule may be clearly visible through the hole.

Confirmation of patency is generally assured by a clear view of the lens capsule; absence of posterior synechiae, or pigmentary or fibrous bridges; and, gonioscopically, widening of the anterior-chamber angle. It is there-

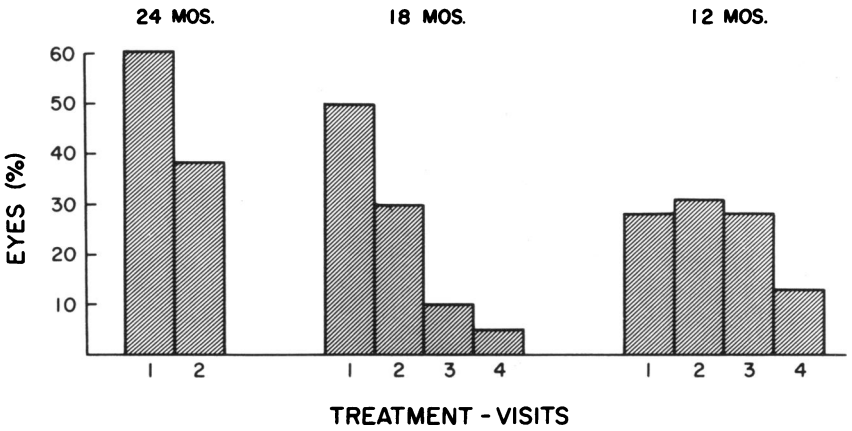

FIGURE 9

With experience, laser side-effects were reduced by using lower power and shorter exposures, although this required more treatment visits to achieve permanent iridotomy.

fore important to make a careful gonioscopic examination both before and after completing the iridotomy.

TREATMENT VISITS

In our earliest cases a permanent peripheral iridotomy was achieved in all cases during the first or second visit. However, it became apparent that fewer side effects—such as blurred vision, corneal edema, uveitis, and increased IOP—were obtained with lower levels of energy and shorter exposures. We therefore decreased the laser time from 0.5 to 0.2 sec and decreased the energy levels from 2 w to a range of 0.7 to 1.5 w. Although the patients required more visits before a permanent iridotomy was achieved, they were able to drive home with minimal ocular side-effects after the treatment (Fig 9). There was less iris destruction and atrophy surrounding the hole, less severe uveitis and little or no subsequent rise of the IOP. Furthermore, this approach caused minimal blurring of vision and allowed us to treat both eyes during the same visit.

THE CORNEAL BURN

The cornea is about 78% water and, with the tear film, it is bounded posteriorly by aqeuous humor and anteriorly by the tear film and air. Thus its anterior surface may be considered relatively impermeable to heat, because the thermal conductivity of water is so much greater than that of air.[28] The rise in corneal temperature in laser procedures is a function of the incident laser energy, exposure time, and beam radius; and, as already shown, a superficial corneal burn is more likely to occur with high energies and small spot sizes. The superficial corneal burn is transient and disappears in 1 to 7 days. These findings are consistent with those seen after irradiation with the ruby laser, and histochemical studies have shown reversible changes in the quantity and disposition of glycogen in rabbit corneas.[33]

Protection against the superficial corneal burn can be provided by instillation of glycerine into the conjunctival sac before irradiation,[34] or by use of a contact lens.[25] Not only does the contact lens, with its gonioscopic lens solution, provide a heat sink but it also provides lid retraction and helps to control ocular movements. Another adjunct is provided by the small plano-convex button lens that is cemented onto the coated Goldmann contact lens (Fig 1). It converges the beam to a slightly smaller spot to increase the power density and, at the same time, provides additional magnification of the target site.

The corneal endothelial burn, on the other hand, probably occurs as a result of thermal conduction from the iris surface.[16,28] The degree of this

burn is also a function of laser energy, exposure time and beam size, but the depth of the anterior chamber and amount of iris pigmentation are also factors influencing the likelihood of excessive thermal conduction to the cornea. The potential for endothelial damage in these eyes is especially great because of the shallowness of the anterior chamber. To avoid corneal burns—both epithelial and endothelial—it is important to reduce the thermal effect by shortening the exposure time and using weaker energy levels and larger beams. On the other hand, vaporization of the iris hole can be more quickly achieved with higher energy levels and smaller spots. We are therefore striving for a delicate balance between these factors, and this plays a major role in determining the success rate.

THE LENTICULAR BURN

The proximity of healthy iris to the anterior lens surface varies from 1 mm in the periphery to less than 1 μ at the pupil. At the moment the laser beam is about to penetrate the iris, the pigment epithelium may absorb the laser energy with little transmission and an immediate sharp rise in local temperature. With sufficient energy this thermal insult to the underlying lens may produce a cataract.[16,28] The lens opacity thus produced is localized immediately behind the iridotomy and has shown no tendency to spread. The opacity represents subcapsular cellular debris resulting from thermal destruction of lens epithelium and fibers (Fig 8).

The wavelength of argon laser light is in the range that is almost completely transmitted by the ocular media. However, the yellowing and aging lens shows evidence of greater laser energy absorption, particularly for larger beams.[28] Since many patients with angle-closure glaucoma have some degree of nuclear sclerosis and laser energy absorption by the lens for this wavelength, one must consider the possibility that the laser treatment may hasten the development of a cataract. A long-term controlled prospective study of cataract formation in eyes treated with argon laser irradiation has not yet been done.

THE RETINAL LESION

The iris pigment epithelium serves as an effective barrier that allows less than 1% transmission of ruby laser light by the pigmented rabbit iris, and only 4.2% by the albino rabbit iris.[28] Transmission by the iris should be even less with the argon laser, because of its shorter wavelength. However, as soon as the pigment epithelium is penetrated the laser energy will be transmitted through the ocular media, with threat of absorption by the retinal pigment epithelium. This is particularly so if one continues laser application after the iridotomy has been completed, in an attempt either to

widen the opening or burn away residual cord-like stromal or pigment-epithelial bridges. For this reason, care must be taken to direct the laser beam toward the retinal periphery. Although we have observed retinal scars from the laser, in no case were they apparent to the patient.[27]

IRIS ANGIOGRAPHY

The process of laser iridotomy also creates a surrounding zone of atrophy, along with fragmentation and shattering of the contiguous pigment epithelium. This results both from thermal conduction to the surrounding tissue and from misdirected applications. This tissue destruction may cause acute iritis and secondary glaucoma, but the long-term effects are mainly unknown. Concern for this tissue destruction has raised two specific questions: (1) What effect does dispersion of iris pigment and debris have on aqueous humor dynamics (see below). (2) Does creation of a zone of atrophy around the iridotomy adversely affect the eye? One way to investigate the latter question is to study this region by fluorescein angiography.

In the normal mouse and human iris a blood-iris barrier has been demonstrated using electron microscopy[35,36] and fluorescein angiography.[37,38] Similar observations were made in this study, and even in the presence of a laser iridotomy there was no fluorescein leakage during the first dye transit. Furthermore, the results show no evidence of fluorescein leakage in the atrophic area surrounding the hole within two minutes of injection. This vascular non-leakage is consistent with the histopathology, in which one sees necrosis with vessel occlusion in this region. In the eight cases we studied, the remainder of the iris also maintained its integrity, with no apparent disturbance of the blood-aqueous barrier. These observations are similar to those of Unger, who found no disturbance to the blood-aqueous barrier after treatment with the ruby or argon lasers.[39]

In some cases the region surrounding the iris hole transilluminates well because of loss of pigment epithelium, while the overlying atrophic iris stroma has remained intact. It almost appears possible for aqueous to percolate through this thinned stroma, even though a definite hole cannot be completed. With fluorescein angiography, however, the region fails to permit passage of fluorescein from the posterior to the anterior chamber, even after the fluorescent aqueous begins to pass through the pupil or through other iridotomies in the same iris.

PULSED ARGON LASER

INTRODUCTION

A major disadvantage of the c-w argon laser is its long pulse, allowing much of the absorbed energy to be lost by conduction to the surrounding and

underlying tissues. The pulsed argon laser, on the other hand, produces a shorter pulse (120 msec) and this should permit less loss of energy by absorption and greater utilization of peak energy within the small cross-section of a 50 μ spot. The absorbed energy then produces an abrupt temperature rise that, by vaporization and chemical breakdown, converts much of the focal absorbing tissue to gaseous products, leaving an iridotomy in its wake. Iridotomies were made in a small group of patients to study the possible advantage of this instrument.

MATERIALS AND METHODS

A pulsed argon laser (Britt Corporation, Prototype of model #152) was employed in the treatment of 46 eyes. With this instrument the laser energy was delivered as a series of 120-msec pulses whose repetition rate could be varied from 1 to 650 pulses per second (pps). The instrument provided a maximum peak power of 30 watts per pulse and a maximum mean of 3 watts, during a pulse train that could be varied from 0.1 sec to "paint," but was usually kept between 0.1 to 0.2 sec. Energy levels of 500 to 2000 mw were used with the 50 μ to 200 μ spot. Each patient was treated in the same manner as those treated with the c-w argon laser and were followed at weekly intervals for 6 weeks.

Iridotomies were made in a smaller series of 6 brown human irides to determine the effect on the cornea and iris by varying the pps and exposure time while keeping the energy level at the maximum of approximately 3 watts. The sequence of settings was as follows: 0.01 to 0.20 sec in a stepwise progression increasing from 200 to 600 pps (Table V). No contact lens was used in this segment of the study.

RESULTS

The optimum pulse repetition rate was determined by varying this rate at the maximum energy level setting provided (3 w). As mentioned, exposures were varied from .01 to 0.2 sec, using a 50 μ spot (Table VI). A barely-visible iris char was first observed with 400 pps (0.6 j). A very nice crater was produced with 600 pps at 0.6 j, but pronounced superficial corneal opacity also occurred, prohibiting further treatment via this site on the cornea. The most desirable iris char occurred with 500 to 600 pps and at energy levels of less than 3 w, producing little or no corneal burn. The most satisfactory results were obtained with 0.7 to 2 w using exposures of 0.2 sec.

DISCUSSION

The pulsed argon laser produces a train of pulses having a maximum average power of 3 w, although each pulse has a maximum peak energy of

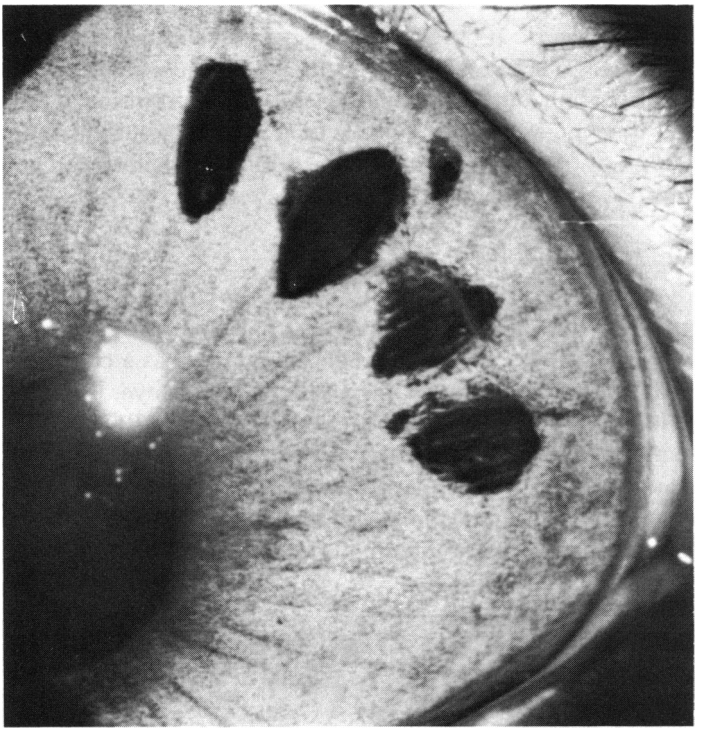

FIGURE 10
To test effect on outflow facility, four large laser iridotomies were made in one eye of each rabbit to cause dispersion of iris pigment and stromal debris to anterior chamber angle.

30 w. Theoretically the pulse duration is so short that there is insufficient time for thermal conduction away from the site, at which point the energy is used to vaporize the iris and produce an iridotomy. Unfortunately, even a maximum power of 3 w was unable to produce a statisfactory iris burn with frequencies below 400 pps, eliminating a major potential advantage for use of the pulsed laser.

The best effect on the iris occurred with high (500-600) rather than low pps, combined with less than 2 w of power. With a high pulse repetition rate, the laser's effect on the iris, its associated side effects, and the ease with which an iridotomy could be produced were similar to those observed using a c-w argon laser.

EFFECT OF LASER-INDUCED PIGMENT DISPERSION ON FACILITY OF AQUEOUS OUTFLOW

INTRODUCTION

When the laser beam vaporizes a hole, iris pigment and debris is dispersed

into the aqueous humor and eventually settles, mainly in the inferior trabecular meshwork. It has been suggested that accumulation of pigment in the meshwork may adversely affect the eye.[40] To estimate the effects of pigment dispersion, outflow facility was studied by perfusion in rabbit eyes at various time intervals after multiple laser iridotomies. In further studies of rabbits and humans, tonography was performed before and after laser iridotomy.

MATERIALS AND METHODS

To study the effects of pigment dispersion on the facility of aqueous outflow (C), four large laser iridotomies were made in one eye of each of seven Dutch Belted rabbits, while the second eye served as a control (Fig 10). Prednisolone acetate 1% was instilled into the treated eye. Using the Alcon Pneumatonograph, three separate measurements of IOP followed by three tonograms were made three to seven days apart and within two weeks before laser treatment. A similar series of measurements were made 12 to 14 weeks after treatment. Estimates of IOP and C were made by averaging each set of three tests. The tonometer was periodically calibrated on an

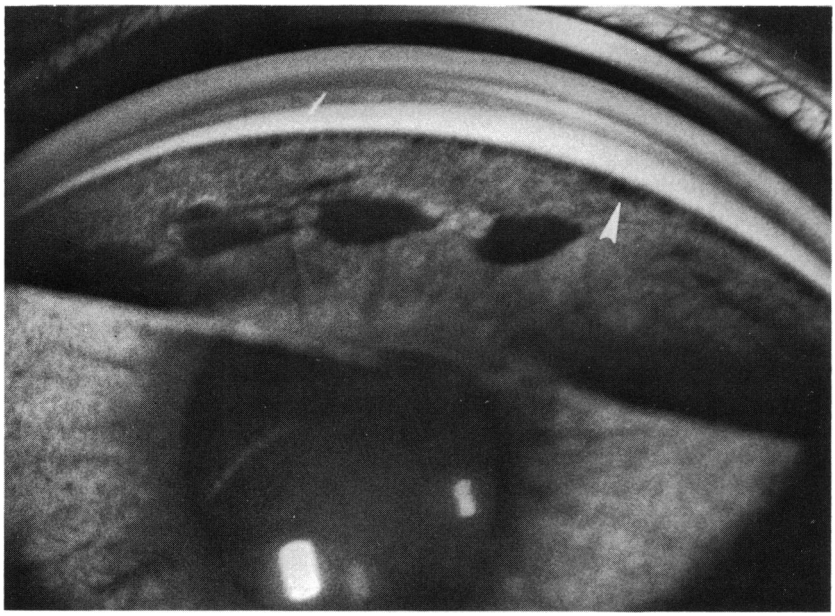

FIGURE 11

In each case a heavy pigment band (arrow) formed in the inferior angle, with much less pigment dispersion superiorly. Photograph taken two weeks after iridotomies were made.

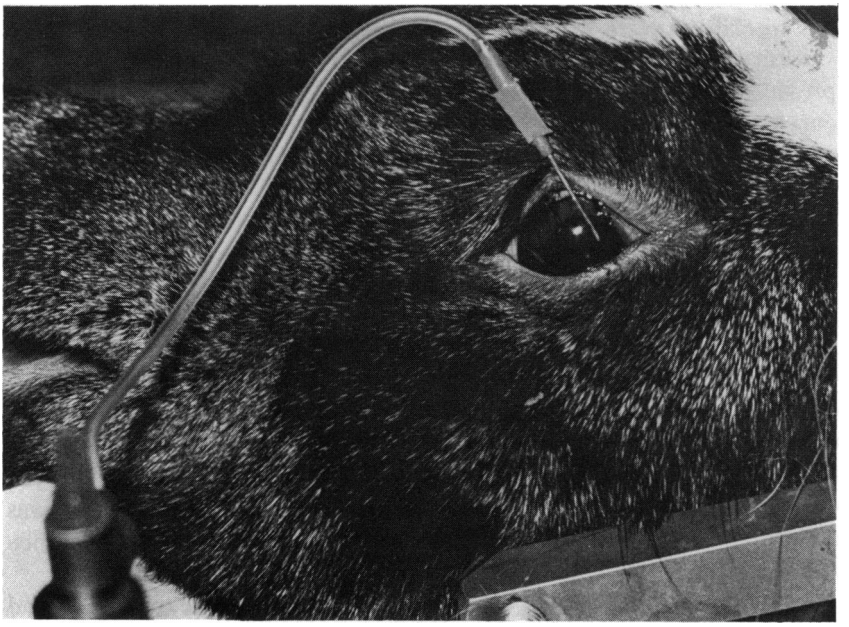

FIGURE 12
Simultaneous perfusion of both eyes of each rabbit was performed. In each case, four laser iridotomies had been performed in one eye two weeks to five months earlier.

enucleated human eye by manometry.

Sixteen Dutch Belted rabbits weighing 2 to 3 kg were tranquilized with chlorpromazine (Thorazine), 5.5 mg/kg, following which four laser iridotomies were made in one eye. The second eye served as a control and remained untreated. Photographs of the anterior chamber angle were taken to record the amount of pigment dispersion (Fig 11). Two weeks to five months later, perfusion studies were carried out after anesthetizing the rabbits with urethane, 1.0 mg/kg, by intraperitoneal injection. The rabbit's head was firmly secured in a clamp. A reservoir of balanced salt solution (BSS) was connected by polyethylene tubing to a Hewlett-Packard 267 BL transducer. This was, in turn, connected to a Hewlett-Packard 301 single-channel carrier amplifier-recorder. An infant infusion set connected to a 25-gauge needle was used to cannulate each eye at the superior limbus. The needle was passed through the cornea into the anterior chamber, taking great care to avoid touching the iris, and was fixed in position with tape to minimize any further manipulation of the eye and prevent the needle from touching either the corneal endothelium or the iris (Fig 12). The eyes were covered with methyl-cellulose solution to prevent evaporation

from the surface. Both eyes were perfused simultaneously, and simultaneous recordings were made.

After determining the steady-state IOP, BBS was infused at an infusion pressure of 40 mm Hg. Then the stopcock was closed and a pressure-decay curve was recorded over a five minute period. At the end of each experiment, an aliquot of aqueous humor was removed from each eye and diluted with an equal volume of 10% trichloracetic acid. The experiment was discarded when the aqueous humor showed excessive protein.

The IOP at every one minute interval was measured from the trace, and the aqueous volume corresponding to each of these pressures was determined by the pressure-volume relation established by Eisenlohr and Langham for the living rabbit eye.[41] For each one minute interval along the decay curve the change in volume (Δv) and average pressure (P_{av}) was calculated. A regression line relating Δv to P_{av} was calculated by the method of linear regression. The slope of this regression line was taken as a numerical estimate of the outflow facility (C).[42] In 86% of regressions the correlation coefficient was greater than 0.90 and in 100% of cases it was greater than 0.87. The Student-t test was used to analyze the difference between the means for C of the treated and control eyes.

Tonography was obtained using the Berkeley electronic tonometer and recorder within one week before making a laser iridotomy in each eye of eight patients. Tonography was repeated four to six weeks later, after the last laser treatment. In each case, all glaucoma medication was continued

TABLE IX: CHANGE IN INTRAOCULAR PRESSURE AND FACILITY OF AQUEOUS OUTFLOW AFTER LASER IRIDOTOMY IN PATIENTS WITH CHRONIC ANGLE-CLOSURE GLAUCOMA

		BEFORE TREATMENT		AFTER TREATMENT		% CHANGE	
PATIENT	EYE	PO	C	PO	C	PO	C
1	R	27	.08	22	.15	−19	+88
	L	25	.08	21	.06	−16	−25
2	R	27	.08	20	.14	−26	+75
	L	24	.08	20	.10	−17	−25
3	R	30	.07	20	.10	−33	+43
	L	24	.12	12	.19	−50	
4	R	25	.16	16	.35	−36	+119
	L	19	.25	16	.31	−16	+24
5	R	20	.07	20	.12	0	+71
	L	24	.08	20	,16	−17	+100
6	R	30	.07	20	.16	−33	+129
	L	23	.10	18	.13	−22	+30
7	R	32	.18	23	.25	−28	+39
	L	34	.19	25	.23	−27	+21
			Mean		=	−24	+57
			Std. Dev.		=	12	43
			p		=	<.01	<.01

without change throughout the entire test procedure and until the second tonogram was completed.

RESULTS

Tonography was performed before, and 12 to 14 weeks after, making multiple laser iridotomies in one eye of each of seven Dutch Belted rabbits. There was a mean fall of 4.9% in C in the treated eye, compared to a 3.4% increase of C in the fellow control eye. This difference was not significant (Table VII).

Perfusion studies were carried out successfully in 14 rabbits treated with multiple laser iridotomies in one eye. Although the mean C for the treated eyes was 7% lower than the control eyes, this difference was not significant (Table VIII).

Eight persons with chronic angle-closure glaucoma underwent bilateral tonography before and after being treated with laser iridotomies. There was a 57% mean increase in C, associated with a 24% fall in IOP (Table IX).

DISCUSSION

During the process of creating a laser iridotomy, destruction of iris stroma and pigment epithelium occurs by a process variously described as "denaturation of tissue" and "vaporization of a hole." The process is accompanied by dispersion of stromal fragments and pigment. In some cases, rather large amounts of pigment cascade from the depths of the iris lesion and settle mainly in the chamber angle inferiorly. There is concern that this pigment dispersion might interfere with aqueous outflow and thus cause a secondary glaucoma, similar to that seen in pigmentary-dispersion syndrome. Pigment granules might clog the trabecular channels and produce a lower C and increased IOP, similar to the mechanical obstruction envisioned as a possible cause for pigmentary glaucoma.[43-46] Such an adverse effect might be particularly dangerous in the early postoperative period, when the pigment is densest and before it is carried away.

The effect of pigment dispersion following multiple laser iridotomies was studied in seven rabbits at 12 to 14 weeks after treatment. There was no

TABLE X: POSSIBLE INDICATIONS FOR LASER IRIDOTOMY

Chronic angle closure
Combined-mechanism glaucoma
Dislocated lens causing pupillary block
Suspected malignant glaucoma
Vitreous (iridovitreal) block
Cilio-lenticular block (before operation)
Fellow eye after complicated surgical iridectomy
Incomplete surgical peripheral iridectomy

significant change in C. However, there was a large standard deviation and the results suggested a trend toward a lowered C in the laser-treated eye. For this reason, perfusion studies were undertaken. Analysis of the perfusion data similarly showed no significant difference between the outflow facilities in the treated and control eyes, and suggested no adverse effect of pigment dispersion within the limitations of this study. These results are still more meaningful when one considers that the amount of tissue destruction and pigment dispersion was far greater in these animals with multiple large iridotomies than is ordinarily produced in humans.

From these results it seems reasonable to conclude that pigment dispersion is unlikely to interfere significantly with C after performing a laser iridotomy in the human eye. A comparable human tonographic study would be highly worthwhile, and would require that one eye of each patient be treated while maintaining the fellow eye as an untreated control. Although that particular plan was not within the scope of this investigation, tonography was performed on a series of 14 eyes (seven patients) with chronic angle-closure glaucoma before and after performing bilateral laser iridotomy. There was a pronounced postoperative fall in the mean IOP, associated with an increased C (Table IX). If any increase in trabecular outflow resistance was caused by pigment dispersion, it was overcome by a more-than-comparable decrease in resistance that occurred when the pupillary block was broken.

There still remains the possibility that residual pigment might, some years after laser iridotomy, produce a delayed glaucoma. It has been shown that erythrocytes are transported by histiocytes and endothelial macrophages out of the eye.[47] In a similar process, eventual incorporation of melanin into the cytoplasm of the trabecular meshwork[48] and distention of the endothelial cells[49] have been demonstrated in the pigmentary dispersion syndrome. The possibility of such a mechanism occurring years after laser iridotomy must be considered as a potential threat to the outflow system, and this is the subject of a separate study now in progress. However, a major difference exists between the acute pigment dispersion that follows laser iridotomy and the continuous dispersion over many years that occurs in pigmentary glaucoma.

THE ROLE OF LASER IRIDOTOMY IN DIAGNOSIS AND TREATMENT OF ANGLE-CLOSURE GLAUCOMA

When compared to the surgical procedure, making an iridotomy with argon laser energy is relatively safe. Even though intraocular hemorrhage, infection, wound dehiscence and iris prolapse are avoided by laser

iridotomy, other complications may occur. These include postoperative inflammation and ocular hypertension, localized lenticular opacity, corneal and retinal scar, and occurrence of an acute glaucoma attack in event of failure to produce and maintain a patent iridotomy.

The ability to produce an iridotomy without opening the eye is, however, a distinct advantage and is the principal justification for its use in these cases. Not infrequently the patient refuses surgical intervention, either because of failure to appreciate the seriousness of the disease or fear of its outcome. Use of the laser to achieve the same end result as surgery offers an alternative. In other situations, surgical intervention may be associated with greater-than-usual risks—as in cases with dislocated lenses, vitreous in the anterior chamber, or a history of ciliary-block glaucoma in the fellow eye (Table X).

An interesting fact is that the laser iridotomy can serve as an important tool for distinguishing certain forms of glaucoma, and helping to arrive at a diagnosis when it is otherwise uncertain. A beneficial effect on the IOP, C, and anterior-chamber angle can be anticipated following laser iridotomy in cases of open-angle glaucoma combined with partial angle closure (combined mechanism glaucoma); whereas, no change will occur from the iridotomy if the correct diagnosis is primary open-angle glaucoma.

Similarly, certain cases of chronic angle-closure glaucoma may be difficult to differentiate from open-angle glaucoma with a narrow angle.[50] All too often the tendency is to treat such patients medically while the disease process progresses unrelentingly from angle apposition to permanent angle closure. This can occur when the ophthalmologist is uncertain of the diagnosis, or he is reluctant to operate on an eye that has none of the classical signs or symptoms of acute angle closure. Here, again, use of the laser to make an iridotomy permits an acceptable resolution of the problem.

The possibility of diagnosing ciliary-block glaucoma by laser iridotomy is intriguing. It requires a high degree of suspicion for this entity in any case of angle closure, especially when the fellow eye has a similar history. Failure of the angle to widen and the pressure to fall following laser iridotomy could establish the absence of pupillary block in certain cases of angle closure that include plateau iris or ciliary-block glaucoma.

During the past several years, laser iridotomy has been performed for virtually every type of pupillary-block angle-closure glaucoma. One can anticipate increasing reliance on the laser as a desirable method to create iridotomies as our experience grows. It is an important tool in both diagnosis and treatment, and it promises to be increasingly popular in the coming years.

CONCLUSIONS

Laser iridotomy with the c-w argon laser and the pulsed argon laser has been performed in some 300 eyes, 261 of which are included in the present investigation. Using instrument settings and techniques described in this study, a laser iridotomy was successfully made in 95% of cases. However, in a series of 77 consecutively treated eyes that were followed at regular intervals for up to four years, 66% of iridotomies remained patent whereas 34% required retreatment. In no case did an iridotomy close if it remained patent for six weeks.

The optimum results were obtained using a specially-designed contact lens and a 50-μ or 100-μ laser spot with energy levels of 1.0 to 2.0 w for 0.2 sec. Larger spots and higher powers, even when combined with shorter pulses, were either less effective or produced more frequent and more pronounced superficial corneal burns.

The ease with which an iridotomy could be made was partly dependent on iris color and thickness, corneal tolerance and deturgescence, depth of the anterior chamber, patient cooperation, and instrument quality. However, success was also considered to depend on the technician's proficiency and experience. The specific iris site selected also influenced the ease of iridotomy, even within the same iris.

A test of patency was the visibility of lens capsule through the iridotomy. Even so, a mistaken estimation of patency could result if there were posterior synechiae around the margin of the iridotomy or if one failed to recognize the presence of a barely-visible fibrous membrane bridging the hole.

Complications that occurred with laser iridotomy included corneal epithelial and endothelial burns, lens opacity behind the iris defect, and retinal burn. The lens opacity was found to be caused by localized fragmentation of lens fibers and atrophy of the lens epithelium. Iris angiography performed six to 36 months after laser iridotomy in human eyes failed to reveal any disturbance in vascular permeability and the blood-aqueous barrier. The effect of pigment dispersed by the laser on the facility of aqueous outflow was studied by tonography and perfusion in rabbits. There was no significant change in C within five months following multiple laser iridotomies.

The pulsed argon laser produced an iridotomy in human eyes with the same degree of ease and the same side effects as that made with the c-w argon laser.

Laser iridotomy was considered the procedure of choice in monocular patients and for treating the fellow eye in persons who have suffered a complicated peripheral iridectomy in one eye. Similarly, laser iridotomy

was preferred for treating pupillary-block glaucoma in eyes having a greater-than-usual risk of complication, including lens-induced glaucoma. The laser played an important role not only in treatment but also in diagnosis of chronic angle-closure and combined-mechanism glaucoma.

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