CYCLODESTRUCTIVE SURGERY FOR GLAUCOMA: PAST, PRESENT, AND FUTURE*

BY *M. Bruce Shields,* MD

INTRODUCTION

ALL SURGICAL PROCEDURES FOR THE TREATMENT OF GLAUCOMA CAN BE DIVIDED into two categories: (1) those with improve the facility of aqueous humor outflow and (2) those which reduce aqueous inflow.

Operations to improve outflow, most notably laser trabeculoplasty, filtering surgery, iridectomies, goniotomy, and trabeculotomy, have a high success rate with most types of glaucoma and are usually the procedures of choice when surgery is required. There are circumstances, however, especially with secondary glaucomas such as neovascular glaucoma, glaucomas in aphakia, and glaucomas associated with inflammation or trauma, in which success with outflow surgery is significantly reduced.

When operations to improve outflow have failed or are felt to be contraindicated, procedures to reduce aqueous inflow offer a useful alternative. The latter group consists primarily of cyclodestructive surgery, in which the function of the ciliary processes is partially eliminated. The purpose of this paper is to survey the literature regarding cyclodestructive surgery, to relate experience at the Duke University Eye Center with two currently used techniques (cyclocryotherapy and transpupillary cyclophotocoagulation), and to consider a new approach to cyclodestructive surgery: intraocular cyclophotocoagulation.

TRANSSCLERAL CYCLODESTRUCTIVE SURGERY

The most commonly used technique for cyclodestructive surgery is the transscleral approach, in which the destructive element must pass through conjunctiva, sclera, and ciliary musculature, before reaching and

*From the Duke University Eye Center, Duke University Medical Center, Durham, North Carolina 27710. This study was supported in part by USPHS grant EY-05164-01.

destroying the ciliary processes. These procedures have the advantages of being noninvasive and relatively quick and easy. Several destructive elements for transscleral cyclodestructive surgery have been evaluated over the years which span the past, present, and future.

PENETRATING CYCLODIATHERMY

Weve[1] introduced the concept of cyclodestructive surgery in 1933, using nonpenetrating diathermy to produce selective destruction of ciliary processes. Vogt[2] modified the technique by using a diathermy probe which penetrated the sclera and Stocker[3] also reported this technique. It was felt by some surgeons that the scleral penetration might create a draining fistula in addition to the cyclodestruction. Early experience with penetrating cyclodiathermy was encouraging,[4,5] and it remained the cyclodestructive procedure of choice for many years. Subsequent evaluation, however, revealed a low success rate and a significant incidence of hypotony,[6] which led to a gradual decline in popularity for the procedure. Results undoubtedly vary with technique, however, and experience with newer instruments, including a one-pole diathermy unit, have been encouraging.[7]

BETA IRRADIATION THERAPY

In 1948, Haik and co-workers[8] reported the experimental application of radium over the ciliary body in rabbit eyes and in one clinical case. Although this was shown to produce a reduction in the vascular supply of the ciliary body, it also caused damage to the lens, and the technique was never adopted for clinical use.

CYCLOELECTROLYSIS

Berens and associates,[9] in 1949, described a concept of cyclodestructive surgery which employed the use of low frequency galvanic current to create a chemical reaction within the ciliary body. This reaction involved the formation of sodium hydroxide, which is caustic to the tissue of the ciliary body. Although this was shown in rabbit studies to produce destruction of the ciliary processes, the procedure did not seem to have significant advantages over penetrating cyclodiathermy and never achieved widespread clinical popularity.[10]

CYCLOCRYOTHERAPY

The use of a freezing source as the cyclodestructive element was suggested by Bietti[11] in 1950. The cryo-injury leads to atrophy of the ciliary processes, primarily by a biphasic mechanism of intracellular ice crystal formation and ischemic necrosis. Cyclocryotherapy is generally felt to be a somewhat more predictable and less destructive procedure than penetrating cyclodiathermy and has gradually replaced the latter technique as the most commonly used cyclodestructive operation. However, the high incidence of complications reported with cyclocryotherapy, while differing somewhat among investigators, has led most surgeons to reserve this technique for situations in which surgical procedures to improve aqueous outflow have failed.

EXPERIENCE WITH CYCLOCRYOTHERAPY

To better understand the value and limitations of cyclocryotherapy, Dr Brindley and I reviewed our experience with this procedure at the Duke Eye Center. We studied a consecutive series of 114 eyes of 102 patients, treated by myself with cyclocryotherapy over a 10-year period. The majority of eyes had neovascular glaucoma (58) or glaucoma in aphakia (33). The technique involved the use of nitrous oxide cryosurgical unit. With the edge of the 2.5 mm probe approximately 1 mm posterior to the limbus, the temperature was reduced to $-80°C$ and maintained for 60 seconds. Four cryolesions were applied per quadrant, and two or three quadrants were treated, using the greater extent of treatment for patients with especially high pressures or of young age. Variables were subjected to analysis by chi-square testing.

Intraocular pressure reduction that was sufficient to avoid further surgical intervention was achieved in 75 eyes (66%), while 14 eyes (12%) developed phthisis. The postoperative visual acuity was worse than the preoperative level in 60% of the eyes. Approximately one-fourth of the eyes required one or more repeat cyclocryotherapy procedures. It was of interest that 13 of 84 eyes receiving only one treatment (15%) developed phthisis, as compared to 1 of 30 (3%) undergoing one or more repeat procedures. Although this did not quite reach statistical significance, it suggests that eyes which withstand the first treatment may have a greater margin of safety regarding subsequent procedures.

Certain factors were found to influence these results, including the type of glaucoma and the age of the patient. Eyes with neovascular glaucoma had the worst results, with intraocular pressure control in 64%, phthisis in 17%, and a postoperative reduction of visual acuity in 69%. On

the other hand, eyes with glaucoma in aphakia, exclusive of those with concomitant neovascular glaucoma, were controlled in 82%, had a 3% incidence of phthisis, and had a reduction of vision after surgery in 52%. The difference in the incidence of phthisis between these two groups was statistically significant ($P = 0.04$), although the difference in percent controlled did not quite reach statistical significance. The mean age among patients grouped according to intraocular pressure response was: (1) controlled after one treatment (56.1 years); (2) not controlled after single treatment (49.7 years); (3) controlled after one or more repeat procedures (42.7 years); and (4) not controlled after multiple procedures (30.2 years). These differences were statistically significant ($P = 0.0157$).

The results of cyclocryotherapy cited above are similar to experience that has been reported by others. Two conditions in which this operation is reported to have particular value are glaucoma after penetrating keratoplasty and open-angle glaucoma in aphakia.[12,13] Cyclocryotherapy has also been advocated by some surgeons for the management of neovascular glaucoma, although others have found that the main benefit in this disease is relief of pain.[14,15] While cyclocryotherapy remains a useful procedure for cases in which other surgical approaches have failed, the unpredictable results with regard to intraocular pressure control and final visual acuity have encouraged many investigators to continue the search for a better cyclodestructive procedure.

TRANSSCERAL CYCLOPHOTOCOAGULATION

Weekers and associates,[16] in 1961, introduced the concept of employing light as the cyclodestructive element. Using the transscleral application of xenon arc photocoagulation over the ciliary body, they were able to demonstrate intraocular pressure reduction in rabbit and human eyes, although they were not able to demonstrate a superiority for this procedure over that of cyclodiathermy. In 1969, the use of laser energy as a transscleral cyclodestructive element was introduced.[17,18] Beckman and associates[19-21] evaluated this approach with both ruby and neodymium lasers and reported a 10-year experience with 241 eyes treated by transscleral ruby laser cyclocoagulation. The overall rate of intraocular pressure control with the ruby laser was 62%, with 86% in eyes with glaucoma in aphakia and 53% in eyes with neovascular glaucoma. Chronic hypotony occurred in 41 eyes, with phthisis in 17 cases, although most eyes retained their preoperative level of vision. Preliminary experience with argon, krypton, and neodymium:YAG laser transscleral cyclophotocoagulation in animals, has also been reported.[22,23]

ULTRASOUND THERAPY

In 1964, Purnell and associates[24] reported the use of focused transscleral ultrasonic radiation to produce localized destruction of the ciliary body in rabbit eyes. Recently, Coleman and co-workers[25,26] reported the use of therapeutic ultrasound in the treatment of rabbit eyes with induced glaucoma, and in 69 patients with uncontrolled glaucoma. In the latter series, intraocular pressure was reduced to less than 25 mm Hg in 83% of the patients.[26] In addition to reducing aqueous inflow by destruction of ciliary epithelium, the authors postulate that this procedure may improve aqueous outflow, by selective thinning of scleral collagen and separation of the ciliary body from the sclera.

EXCISION OF THE CILIARY BODY

In addition to the use of many cyclodestructive elements, as described above, other surgens have sought to reduce aqueous production by removal of a portion of the ciliary body. Freyler and Scheimbauer[27] have reported a 5-year experience with the excision of one quadrant of the pars plicata in 22 eyes with desperate secondary glaucomas. They reported that 12 eyes were subsequently controlled without medication, and 7 more with medical therapy, while the remainder developed phthisis.

TRANSPUPILLARY CYCLOPHOTOCOAGULATION

The primary disadvantages of all transscleral cyclodestructive procedures are (1) the inability to precisely quantitate the amount of destruction of the ciliary processes, and (2) the damage to adjacent tissue, most notably the anterior chamber angle and peripheral retina, leading to the unpredictable results and high complication rate. In an attempt to circumvent these problems, Lee and Pomerantzeff,[28] in 1971, introduced the concept of argon laser cyclophotocoagulation via a transpupillary approach. Histopathologic studies in rabbit[28] and human[29] eyes have confirmed the ability of direct laser application to selectively destroy ciliary processes. However, reports of the clinical value of this technique have been conflicting.[28-33]

EXPERIENCE WITH TRANSPUPILLARY CYCLOPHOTOCOAGULATION

I performed transpupillary cyclophotocoagulation on 16 eyes of 16 patients, who ranged in age from 17 to 82 years, with a mean of 60 years. The types of glaucoma in this series included glaucoma in aphakia (8

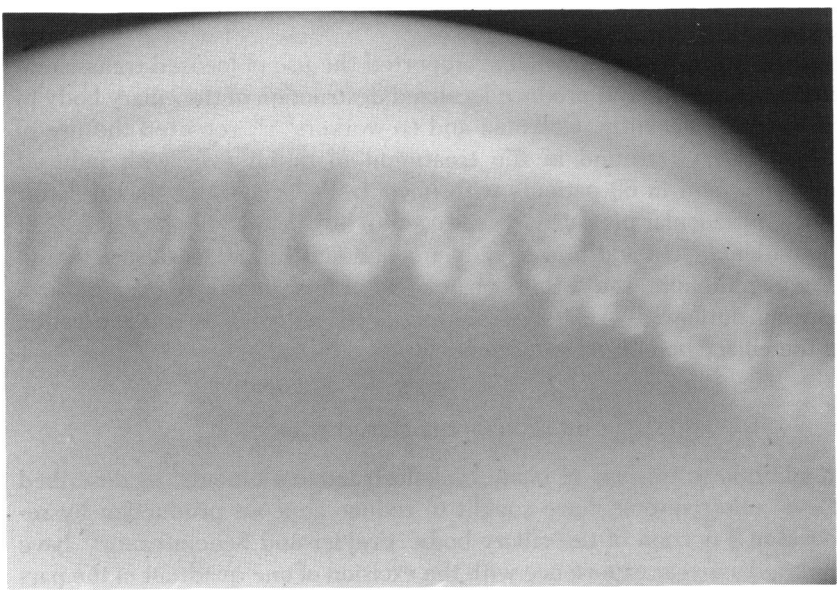

FIGURE 1
Gonioscopic view of ciliary processes in eye with traumatic aniridia in which processes to the right have been treated with transpupillary cyclophotocoagulation.

patients), neovascular glaucoma (4 patients), glaucoma secondary to trauma (2 patients), and open-angle glaucoma with multiple failed filtering procedures (2 patients). The technique involved the use of a continuous-wave argon laser and a Goldmann-type gonioprism, with a scleral depressor to improve visualization of the ciliary processes. With laser settings of 0.1 seconds, 100 μ, and an energy level sufficient to create a pit in the tissue (usually 700 mW), three to five laser exposures were applied to each visible process.

The number of ciliary processes that were visible by gonioscopy, and that were treated, ranged from seven to all processes for 360 degrees, with an average of 26 processes. The means by which these processes were exposed included a sector iridectomy (9 eyes), iris retraction secondary to neovascular glaucoma (5 eyes), two large peripheral iridectomies (1 eye), and traumatic aniridia (1 eye) (Fig 1). Of the 16 eyes treated, the intraocular pressure was controlled in only 4 eyes, which have now been followed for 4 to 10 months.

Failure of transpupillary cyclophotocoagulation may relate, in part, to the number of ciliary processes which can be visualized and treated.[32]

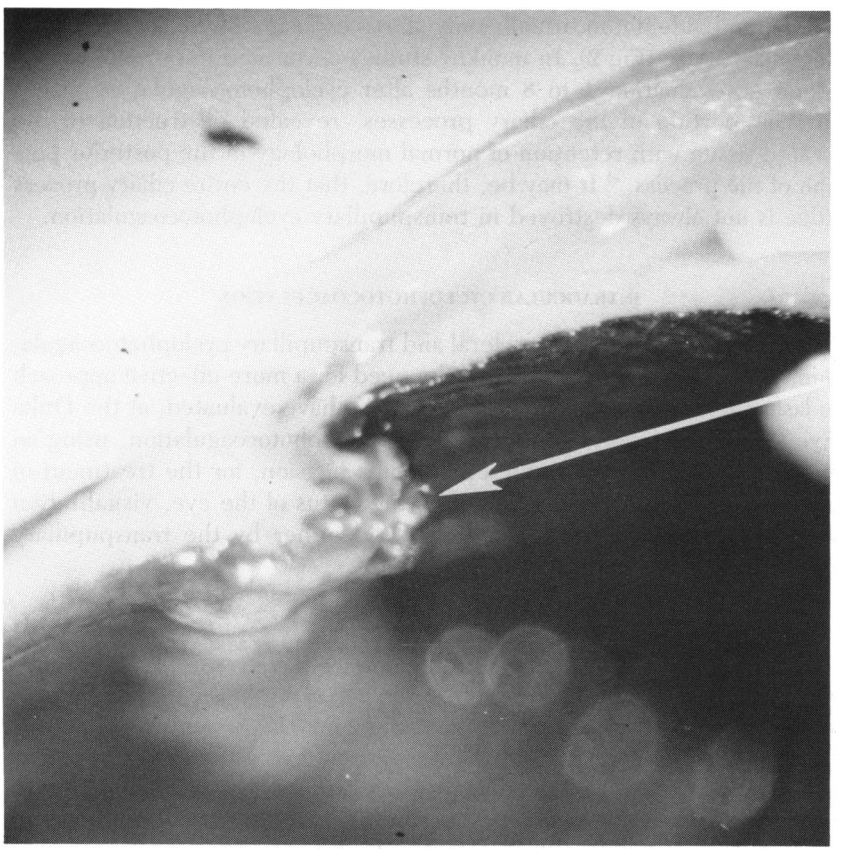

FIGURE 2
Cross-section of human autopsy eye, showing angle of transpupillary visualization of ciliary process ridges (*arrow*), which may be a limiting factor in achieving destruction of entire ridge by transpupillary cyclophotocoagulation.

This does not appear to be the entire explanation, however, since the number of treated processes in the four successful eyes in my series ranged from eight to all processes, which was essentially the same as in the unsuccessful group. Another factor, as pointed out by Lee,[30] is the need for adequate laser burns to the ciliary processes. A white reaction does not always indicate tissue destruction, and the energy level must be increased until a concave brown burn, often with pigment dispersion and/or gas bubbles, is produced. I believe, however, that there is yet another factor which contributes to failure of transpupillary cyclophotocoagulation. The angle of ciliary process visualization by gonioscopy, even

with scleral indentaton, usually only allows exposure of the anterior tip of the ciliary ridge (Fig 2). In monkey studies performed in our laboratory, histologic evaluation 1 to 8 months after cyclophotocoagulation to the anterior portion of the ciliary processes, revealed destruction of the treated tissue with retention of normal morphology in the posterior portion of the process.[34] It may be, therefore, that the entire ciliary process ridge is not always destroyed in transpupillary cyclophotocoagulation.

INTRAOCULAR CYCLOPHOTOCOAGULATION

The limitations of both transscleral and transpupillary cyclophotocoagulation, as described above, indicate the need for a more effective approach to laser therapy of the ciliary processes. We have evaluated, at the Duke Eye Center, the concept of intraocular cyclophotocoagulation, using an endophotocoagulator through a pars plana incision, for the treatment of glaucomas in aphakia. Depending on the status of the eye, visualization with this technique can be accomplished either by the transpupillary route or with an endoscope.

ENDOPHOTOCOAGULATION WITH TRANSPUPILLARY VISUALIZATION

Vitreoretinal surgeons have reported the use of argon laser endophotocoagulation with transpupillary visualizaton for the treatment of retinal disorders.[35-37] During the course of a vitrectomy in an aphakic eye, it is possible to lower the intraocular pressure and use scleral indentation to bring the ciliary processes into transpupillary view, for the purpose of cyclophotocoagulation with the intraocular laser probe.

Our technique with this procedure is to use an intraocular laser probe, which was developed for retinal photocoagulation and has been previously described.[37] After performing an anterior vitrectomy, the vitreous instrument is removed and the endophotocoagulator is inserted through the same cannula. Scleral indentation in the opposite quadrants is then used to bring several ciliary processes into view, and the tip of the laser probe is positioned 2 to 3 mm from the processes (Fig 3). With an exposure time of 0.2 seconds, laser therapy is applied to individual ciliary processes, using an energy level that is sufficient to produce a white reaction and a shallow tissue disruption (usually 1000 mW). Three to five laser exposures are then applied to all processes in the two quadrants opposite the entry site.

Preliminary experience with endophotocoagulation of ciliary processes under transpupillary visualization has been encouraging, although there

FIGURE 3
Intraocular cyclophotocoagulation with transpupillary visualization. Scleral depressor (*black arrow*) brings ciliary processes into view for treatment with endophotocoagulator (*white arrows*).

are limitations with this procedure. To adequately visualize the ciliary processes, the cornea must be relatively clear and the pupil must be well dilated. The latter requirement is frequently not possible in eyes with advanced glaucoma on long-term miotic therapy. In some cases, we have used the vitrectomy instrument to enlarge the pupil, although this is not always desirable.

ENDOSCOPIC CYCLOPHOTOCOAGULATION

When intraocular cyclophotocoagulation cannot be accomplished by

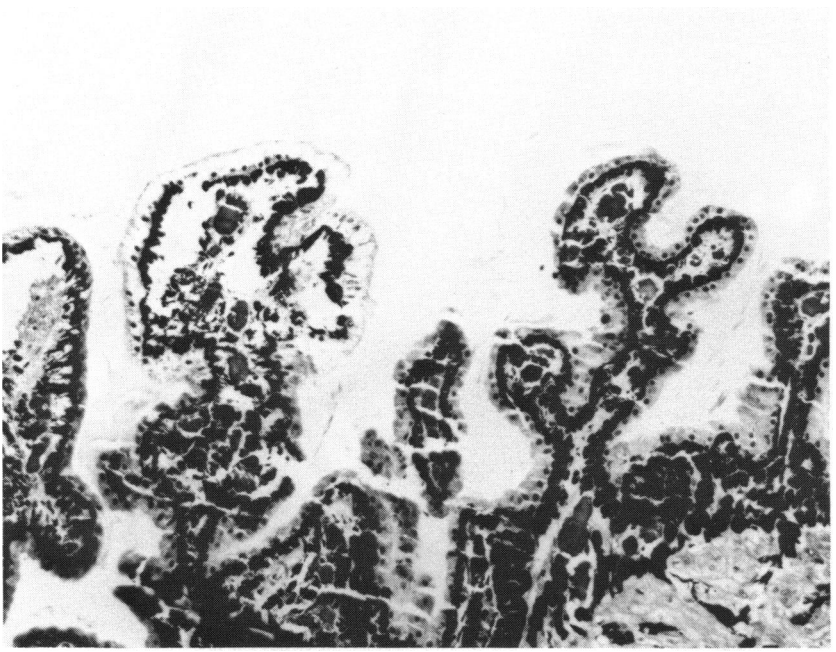

FIGURE 4
Light microscopic view of ciliary processes from eye of rhesus monkey immediately after endoscopic cyclophotocoagulation, showing disruption of both epithelial layers and intrastromal vacuolization of treated process (*left*) with minimal damage to adjacent, untreated process (*right*) (H&E, × 150).

transpupillary visualization, an endoscopic approach offers a possible alternative. Ophthalmologists have used ocular endoscopy for many years. Thorpe[38] introduced the concept in 1934, primarily for the retrieval of intraocular foreign bodies; newer endoscope designs have subsequently been described.[39,40] Norris and co-workers[41,42] reported clinical experience with an ocular endoscope (Needlescope, Dyonics, Inc, Andover, MA) for vitreoretinal procedures and orbital biopsies. The intraocular shaft of the latter instrument is 1.7 mm in diameter and contains a viewing rod lens and a fiberoptic illumination system. We have modified the Needlescope by attaching a laser fiberoptic, connected to a continuous-wave argon laser, to the tip of the instrument.

In preliminary studies with monkeys, a 400 μ laser fiberoptic was attached to the endoscope by a Teflon sleeve.[34] Following the lentectomy and anterior vitrectomy in these animals, the endoscopic photocoagulator

FIGURE 5
Light microscopic view of ciliary processes from eye of rhesus monkey 4 months after endoscopic cyclophotocoagulation, in which processes are largely replaced by fiberoptic mass of pigmented tissue (H&E, × 150).

was inserted through a pars plana incision and, under direct visualization with the endoscope, clusters of individual ciliary processes were photocoagulated at different energy levels. Histopathologic evaluation of the ciliary body from eyes enucleated immediately after therapy, revealed variable degrees of epithelial layer destruction and stromal hemorrhage (Fig 4), while the changes in eyes followed 1 to 8 months postoperatively, ranged from partial ciliary epithelial disruption and intrastromal pigment clumping, to replacement of the processes by a fiberoptic mass (Fig 5). Adjacent, untreated processes and underlying ciliary body tissue were not damaged. The degree of damage to treated processes correlated with the laser energy levels and especially with the immediate, visible tissue response.

A modified endoscopic photocoagulator has been developed for clinical trials, which consists of a shorter endoscope and a 200 μ laser fiberoptic, attached to the tip of the endoscope by a stainless steel sleeve (Fig 6). The

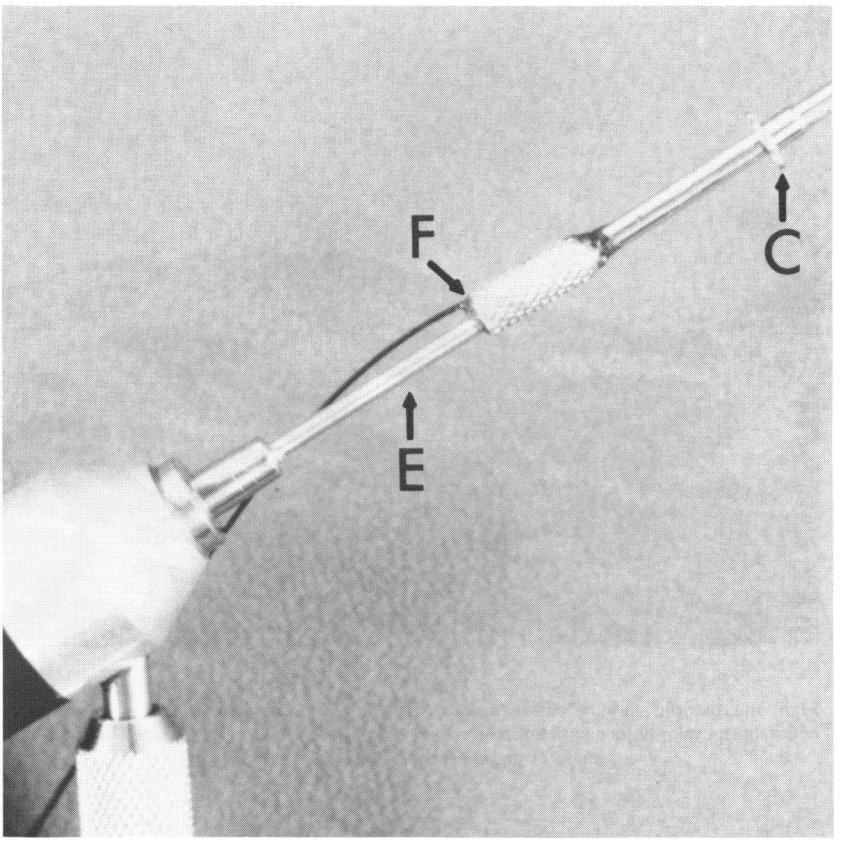

FIGURE 6
Endoscopic photocoagulator for intraocular cyclophotocoagulation. Laser fiberoptic (F) is attached to tip of endoscope (E) with stainless steel sleeve, around which a cannula (C) has been placed.

outer diameter of the entire unit is 2.3 mm, which can be inserted through the same cannula used for the VISC-X. In preliminary studies, this vitreous instrument is used to perform an anterior vitrectomy, and the endoscopic photocoagulator is then inserted through the same cannula to treat all processes in the opposite two quadrants, using the same technique as that described for endophotocoagulation under transpupillary visualization. This procedure is currently being evaluated in eyes, with intractable glaucoma in aphakia without useful vision, for which transpupillary cyclophotocoagulation and endophotocoagulation under transpupillary visualization are not technically possible.

SUMMARY

When surgical attempts to control glaucoma by improving aqueous outflow are not successful, the alternative approach is usually to reduce aqueous inflow by a cyclodestructive procedure. Cyclodestructive elements that have been tried in the past include diathermy, electrolysis, and beta irradiation. Cyclocryotherapy is presently the most commonly used cyclodestructive procedure, although this operation has significant limitations, and newer techniques are being evaluated utilizing laser energy or ultrasonic radiation. Each of these procedures uses a transscleral approach, which has the disadvantages of (1) the inability to precisely quantitate the destruction of the ciliary processes, and (2) damage to adjacent tissue. Transpupillary cyclophotocoagulation minimizes these problems, but is limited to the small number of eyes in which adequate gonioscopic visualization of the ciliary processes can be achieved. An alternative approach for aphakic eyes is intraocular cyclophotocoagulation, utilizing an endophotocoagulator through a pars plana incision. Depending on the status of the eye, visualization for this technique can be accomplished either by the transpupillary route or with an endoscope.

ACKNOWLEDGMENTS

The Needlescopes used for endoscopic cyclophotocoagulation were provided by Cilco, Inc. Mr Dyson Hickingbotham, of the Biophysics Laboratory, Duke Eye Center, developed the endoscopic cyclophotocoagulators. Drs Brooks McCuen and Karl Olsen participated in the intraocular cyclophotocoagulation.

REFERENCES

1. Weve H: Die Zyklodiatermie das Corpus ciliare bei Glaukom. *Zentralbl Ophthalmol* 1933; 29:562-569.
2. Vogt A: Versuche zur intraokularen Druckherabsetzung mittels Diatermieschadigung des Corpus ciliare (Zyklodiatermiestichelung). *Klin Monatsbl Augenheilkd* 1936; 97:672-677.
3. Stocker FW: Response of chronic simple glaucoma to treatment with cyclodiathermy puncture. *Arch Ophthalmol* 1945; 34:181-189.
4. Albaugh CH, Dunphy EB: Cyclodiathermy. *Arch Ophthalmol* 1942; 27:543-557.
5. Voft A: Cyclodiathermypuncture in cases of glaucoma. *Br J Ophthalmol* 1940; 24:288-297.
6. Walton DS, Grant WM: Penetrating cyclodiathermy for filtraton. *Arch Ophthalmol* 1970; 83:47-48.
7. Nesterov AP, Egorov EA: Transconjunctival penetrating cyclodiathermy in glaucoma. *J Ocul Ther Surg* 1983; July-Aug: 216-218.
8. Haik GM, Breffeilh LA, Barbar A: Beta irradiation as a possible therapeutic agent in glaucoma: An experimental study with the report of a clinical case. *Am J Ophthalmol* 1948; 31:945-952.

9. Berens C, Sheppard LB, Duel AB Jr: Cycloelectrolysis for glaucoma. *Trans Am Ophthalmol Soc* 1949; 47:364-380.
10. Sheppared LB: Retrociliary cyclodiathermy versus retrociliary cycloelectrolysis: Effects on the normal rabbit eye. *Am J Ophthalmol* 1958; 46:27-37.
11. Bietti G: Surgical intervention on the ciliary body: New trends for the relief of glaucoma. *JAMA* 1950; 142:889-897.
12. Binder PS, Able R Jr, Kaufman HE: Cyclocryotherapy for glaucoma after penetrating keratoplasty. *Am J Ophthalmol* 1975; 79:489-492.
13. Bellows AR, Grant WM: Cyclocryotherapy of chronic open-angle glaucoma in aphakic eyes. *Am J Ophthalmol* 1978; 85:615-621.
14. Feibel RM, Bigger JF: Rubeosis iridis and neovascular glaucoma: Evaluation of cyclocryotherapy. *Am J Ophthalmol* 1972; 74:862-867.
15. Krupin T, Mitchell KB, Becker B: Cyclocryotherapy in neovascular glaucoma. *Am J Ophthalmol* 1978; 86:24-26.
16. Weekers R, Lavergne G, Watillon M, et al: Effects of photocoagulation of ciliary body upon ocular tension. *Am J Ophthalmol* 1961; 52:156-163.
17. Smith RS, Stein MN: Ocular hazards of transscleral laser radiation: II. Intraocular injury produced by ruby and neodymium lasers. *Am J Ophthalmol* 1969; 67:100-110.
18. Vucicevic ZM, Tsou KZ, Nazarian IH, et al: A cytochemical approach to the laser coagulation of the ciliary body. *Bibl Ophthalmol* 1969; 79:467-478.
19. Beckman H, Kinoshita A, Rota AN, et al: Transscleral ruby laser irradiation of the ciliary body in the treatment of intractable glaucoma. *Trans Am Acad Ophthalmol Otolaryngol* 1972; 46:423-436.
20. Beckman H, Sugar HS: Neodymium laser cyclocoagulation. *Arch Ophthalmol* 1973; 90:27-28.
21. Beckman H, Waeltermann J: Transscleral ruby laser cyclocoagulation. *Am J Ophthalmol* 1984; 98:788-795.
22. Peyman GA, Conway MD, Raichand M, et al: Histopathologic studies on transscleral argon-krypton photocoagulation with an exolaser probe. *Ophthalmic Surg* 1984; 15:496-501.
23. Wilensky JT, Welch D, Mirolovich M: Transscleral cyclocoagulation using a neodymium:YAG laser. *Ophthalmic Surg* 1985; 16:95-98.
24. Purnell EW, Sokollu A, Torchia R, et al: Focal chorioretinitis produced by ultrasound. *Invest Ophthalmol* 1964; 3:657-664.
25. Coleman DJ, Lizzi FL, Driller J, et al: Therapeutic ultrasound in the treatment of glaucoma: I. Experimental model. *Ophthalmology* 1985; 92:339-346.
26. ———: Therapeutic ultrasound in the treatment of glaucoma: II. Clinical applications. *Ophthalmology* 1985; 92:347-353.
27. Freyler H, Scheimbauer I: Excision of the ciliary body (Sauetter procedure) as a last resort in secondary glaucoma. *Klin Monatsbl Augenheilkd* 1981; 179:473-477.
28. Lee P-F, Pomerantzeff O: Transpupillary cyclophotocoagulation of rabbit eyes: An experimental approach to glaucoma surgery. *Am J Ophthalmol* 1971; 71:911-920.
29. Bartl G, Haller BM, Wocheslander E, et al: Light and electron microscopic observations after argon laser photocoagulation of ciliary processes. *Klin Monatsbl Augenheilkd* 1982; 181:414-416.
30. Lee P-F: Argon laser photocoagulation of the ciliary processes in cases of aphakic glaucoma. *Arch Ophthalmol* 1979; 97:2135-2138.
31. Bernard JA, Haut J, Demailly PH, et al: Coagulation of the ciliary processes with the argon laser: Its use in certain types of hypertonia. *Arch Ophtalmol* (Paris) 1974; 34:577-580.
32. Merritt JC: Transpupillary photocoagulation of the ciliary processes. *Ann Ophthalmol* 1976; 8:325-328.
33. Klapper RM, Dodick JM: Transpupillary argon laser cyclophotocoagulation. *Doc Ophthalmol Proc* 1984; 36:197-203.

34. Shields MB, Chandler DB, Hickingbotham D, et al: Histopathologic evaluation of endoscopic cyclophotocoagulation in primates. *Invest Ophthalmol Vis Sci* (Suppl) 1985; 158.
35. Fleishman JA, Schwartz M, Dixon JA: Argon laser endophotocoagulation: An intraoperative trans-par plana technique. *Arch Ophthalmol* 1981; 99:1610-1612.
36. Peyman GA, Salzano TC, Green JL: Argon endolaser. *Arch Ophthalmol* 1981; 99:2037-2038.
37. Landers MB, Trese MT, Stefansson E, et al: Argon laser intraocular photocoagulation. *Ophthalmology* 1982; 89:785-788.
38. Thorpe HE: Ocular endoscope (An instrument for the removal of intravitreous magnetic foreign bodies). *Trans Am Acad Ophthalmol Otolaryngol* 1934; 39:422-424.
39. Butterworth RF, Bignell JL: A new type of eye endoscope. *Br J Ophthalmol* 1952; 36:217-220.
40. Norris J, Cleasby GW: An endoscope for ophthalmology. *Am J Ophthalmol* 1978; 85:420-422.
41. Norris J, Cleasby GW, Nakanishi AS, et al: Intraocular endoscopic surgery. *Am J Ophthalmol* 1981; 91:603-606.
42. Norris J, Stewart WV: Bimanual endoscopic orbital biopsy: An emerging technique. *Ophthalmology* 1985; 92:34-38.

DISCUSSION

Dr Max Forbes. Doctor Shields has presented a thorough comprehensive review of the various cyclodestructive procedures which have been used in the treatment of glaucoma. The ciliary body should not be injured with impunity since its active transport functions are essential to stability of the internal ocular environment. Destruction of the ciliary body should therefore, as Doctor Shields has stated, be restricted to eyes in which operations to improve outflow are either ineffective or contraindicated.

For the past 20 years cyclocryotherapy has been the most widely used cyclodestructive procedure. It is simple, noninvasive, and easily performed on an outpatient basis without need for operating room equipment or personnel. When fractionated into 90-degree sessions using only subconjunctival anesthesia, it is well tolerated by the patient, postoperative inflammation is minimized, and the total amount of destruction can be titrated to the requirement of each individual eye. Although cyclocryotherapy can produce good results one must concede that complications and failures are not infrequent.

Transpupillary argon laser cyclophotocoagulation offers an attractive alternative to the transscleral cyclodestructive procedures. Unfortunately transpupillary access to the ciliary processes is quite limited, even with scleral indentation, and the results have ben unimpressive. Using high technology instruments designed for vitreoretinal surgery Doctor Shields has developed methods for direct endocyclophotocoagulation. Invasive intraocular surgery with anterior vitrectomy is required to provide access to half of the ciliary processes through a single pars plana entry site. I look forward to a future report on the clinical efficacy of these ingenious operative techniques.

Two high technology noninvasive transscleral cyclodestructive procedures are also vying to replace cyclocryotherapy. The first, neodymium:YAG laser cyclophotocoagulation, employs the free-running thermal mode available with the Lasag Microrupter designed by Professor Fankhauser. It produces the same effect as the prototype high-powered ruby laser used by Doctor Beckman, and clinical studies are in progress at several glaucoma centers. The second is therapeutic ultrasound developed and reported by Doctor Coleman and associates. Doctor Coleman has kindly allowed me to perform this procedure on a small series of my own patients using his equipment, facilities, and personnel. I should like to discuss my impressions and preliminary results.

A special transducer system serves as a source of high intensity therapeutic ultrasonic pulses together with an aiming light and diagnostic ultrasound for proper localization and focus. Waterbath immersion is used for fluid transmission of ultrasonic waves from the transducer to the globe. Frequency, intensity, and 5-second pulse duration have been standardized. Six concentric applications are usually focused on the sclera 1.5 mm behind the limbus, but this treatment pattern can be modified at the discretion of the operator. The focal zone of the ultrasonic beam is 0.4 mm wide and 3.0 mm deep. It produces localized thermal disruption of the sclera and underlying ciliary body but leaves the overlying conjunctiva intact. Retrobulbar anesthesia is mandatory to prevent intense pain during each 5-second application. Postoperative pain and inflammation are not severe.

I have performed five therapeutic ultrasound procedures on four eyes, one eye having been retreated after an initial failue. A sixth procedure was aborted because of severe pain despite two retrobulbar injections of lidocaine and total akinesia of the globe. To date, no complications have been encountered in this small series, and three of the four eyes are well controlled with follow-up periods of 4 to 7 months.

Reported complications include uveitis, pressure elevation, scleral thinning, and misdirection of the ultrasonic beam causing damage to the cornea or eyelid. It has been asserted that, in addition to decreased inflow, therapeutic ultrasound also enhances transscleral outflow and uveoscleral outflow. That assertion is currently being studied by tonography and photofluorometry. There was no visible evidence of subconjunctival filtration in any of my patients.

Therapeutic ultrasound seems to cause less inflammation and visual disturbance than cyclocryotherapy. I suspect that it will have a significant place in the future of cyclodestructive surgery for glaucoma. I should like to thank Doctor Coleman for permission to present my experiences with therapeutic ultrasound and Doctor Shields for the privilege of discussing his excellent paper.

Dr David Knox. Since we have the subject of cyclodestructive surgery I would like to speak in defense of what many people consider an archaic procedure, penetrating diathermy. I have found in the group of patients that I have rsponsibility for, chronic uveitis with secondary obstruction of the angle mechanism, not necessarily angle closure but debris and chronic inflammation, penetrating dia-

thermy, two rows of pins, causing some fluid to leak back out through the site, ringing the insertion of two recti muscles, gives control of intraocular pressure in most cases. It may be necessary to do a second procedure. I have not thrown an eye into phthisis, which was one of the fears of the old diathermy procedure applied 180 degrees. I think diathermy is a procedure worth continuing and being given more careful study.

DR RICHARD C. TROUTMAN. Our major use of this technique, and it has been infrequent, is in patients with glaucoma associated with penetrating keratoplasties. I would like to suggest to the author that among the parameters one should include endothelial cell counts. We have found that the operation is a success but the cornea decompensates. Then one has to regraft and the cycle must be repeated.

DR BENJAMIN SHEPPARD. Mr President, Mr Secretary, and friends of the Society, I cannot let this paper go without a little discussion and thank Doctor Shields for reactivating what we have done here for 50 years in our country. You have heard may physicians speak on this topic; Doctors Post, Sir Stuart Duke-Elder, Asher, Kinsey, and Stocker. These procedures we hope to use to help to bring about a balance of the intraocular fluid production and the outflow channels that are still open. Doctor Shields has beautifully brought us up-to-date on this subject this morning. If you will recall, the postoperative histologic slide showed that both the pigmented and nonpigmented epithelium of the ciliary process was affected. This is important.

Soon after World War II, Conrad Berens, who had more ideas than most men, interested me in doing a comparative study on cycloelectrolysis *vs* cyclodiathermy on the normal rabbit eye. This paper has been presented to our society and I want to bring you the conclusions that I drew at that time.

The control study with the comparison of the cycloelectrolysis *vs* cyclodiathermy in 55 normal rabbit eyes were presented in our study demonstrating both gross and histologic changes that the cyclodiathermy using 40 mAmp for 5 seconds appeared less reversible and more likely to lead to rather severe complications than cycloelectrolysis where we used 5 mAmp using the cathode electrode for 5 seconds.

Second, the pathologic effects of cyclodiathermy tended to be localized while those of cycloelectrolysis were more generalized. This was explained on the fact that cyclodiathermy as thermal in its action whereas cycloelectrolysis is chemical.

Third, generally either of these procedures may be considered a temporary antiglaucomatous procedure as the intraocular pressure of the normal eye was found to be initially markedly reduced but only lasted approximately 6 months.

I would like to ask Doctor Shields in conclusion, one question. Where do we place his procedure today as most opportune in treating glaucoma?

DR JOHN LOCKE. Mr Chairman, members and guests: I would just like to be another to put in a word for penetrating cyclodiathermy which I feel has been a

badly maligned operation and one that I have been doing for 33 years with extremely gratifying results.

I learned the technique originally from Doctor Castroviejo. I last met Doctor Castroviejo 3 or 4 years ago, and he was still enthusiastic about it.

It has always seemed to me that the results that I was obtaining with cyclodiathermy were far better than were being reported in the literature for cyclocryotherapy, and better than those I saw my colleagues obtaining with cyclocryotherapy.

An impressive point about cyclodiathermy is that postoperatively, there is generally no pain and minimal iritis. Complications are really few. I must emphasize, however, that it is generally necessary at the end of the procedure to do a paracentesis, because the pressure can go up quite high during the few minutes of the operation—presumably as the result of diathermy-induced scleral shrinkage.

We have heard today that following cyclocryotherapy, 50% of eyes showed a visual acuity loss of two lines; this has not been the case with cyclodiathermy, in my experience. I would not expect to find visual acuity or visual field loss following an uncomplicated procedure. Some years ago, I wrote a paper describing the technique and showing that cyclodiathermy when properly done was particularly useful in patients with small residual fields, and that these tiny fields remained the same afterwards as before.

One particularly gratifying thing about the procedure is that it is generally noncataractogenic. I have not been aware of cataract formation or acceleration of existing cataract following uncomplicated procedures. It is a safe operation, when correctly done. If sympathetic ophthalmitis can occur, it must be very unusual, as one can only find a very rare case reported in the literature.

The only two real problems with cyclodiathermy are either insufficient effect or excessive effect. In the former case, the procedure can be safely repeated. There is fortunately a quite wide margin of safety, but if it is done too enthusiastically, hypotomy leading to phthisis bulbi can, of course, result. In my hands this has occurred only three times and in advanced cases which had already received multiple previous traumas.

There is a strong tendency for the pressure-lowering effectiveness to decrease over the first few weeks, following which it becomes stable, so that the pressure may then be controlled for many years. Furthermore, if the operation has been properly performed, it is usually necessary to continue use of antiglaucomatous medication. This might be considered by some to be a disadvantage.

I feel that the reason that cyclodiathermy did not become universally well received is that too many unsatisfactory variations of the technique were being carried out with adverse results, and that the technique that has given and still gives some of us such satisfying results, as taught to me by Doctor Castroviejo, did not become standardized.

DR M. BRUCE SHIELDS. I am very grateful to all of the discussants. It was a genuine thrill for me to hear the thinking of men who have had these years of invaluable experience and especially to hear Doctor Sheppard's comment on the work he and Doctor Berens did with the cycloelectrolysis. I was also pleased to hear

Doctor Knox and Doctor Locke say that the diathermy concept of cyclodestructive surgery is not dead. It may well be that, with the newer technology coming along, this may be something more of us should reconsider. I appreciate Doctor Troutman pointing out the fact that penetrating keratoplasty is another area where cyclodestructive procedures have been very useful and yet one in which we must exercise caution regarding the complication of endothelial cell loss. I am especially grateful to my dear friend, Max Forbes, for his always kind and wise words. I'm glad that he was able to provide some additonal information regarding ultrasound therapy because this is certainly one of the new and exciting advances in the area of cyclodestructive surgery. Doctor Forbes very rightly pointed out that, with each of these operations, we must be careful not to eliminate too many ciliary processes, because the aqueous is there for more reasons than just keeping the eye inflated. We have to remember that there are also metabolic processes going on. I would like to close with the important question raised by Doctor Sheppard: Where do all of these cyclodestructive procedures lie within our total spectrum of treatment for glaucoma? The answer to this appears to be changing rapidly with each new advance in technology. But as we explore the possibilities, we should look not only at the new operations with lasers and ultrasound but we should also continue to look closely at those procedures that have the benefit of experience from the past.