CYCLODIALYSIS STUDIED BY MANOMETRIC TECHNIQUES IN THE MONKEY*†‡

BY

JAMES P. GILLS,§ CHRISTOPHER A. PATERSON,||
AND M. ELIZABETH PATERSON||

*From the Wilmer Institute, Johns Hopkins Hospital and
Johns Hopkins University School of Medicine, Baltimore, Maryland, U.S.A.*

VARIOUS theories have been proposed to explain the mechanism of cyclodialysis. Decreased aqueous formation with detachment of the ciliary body is a recognized finding (Barkan, Boyle, and Maisler, 1936; Barkan, 1950; Chandler and Maumenee, 1961; Goldmann, 1951; and O'Brien, 1935). Goldmann, who studied four eyes after cyclodialysis using his fluorescein method, noted suppression of aqueous formation for a few months after surgery. He felt that his data also indicated an increase in outflow facility after several months, probably by way of the choroidal vessels.

Previous animal experiments to study the mode of action of cyclodialysis have not been successful (Elschnig, 1932; Krauss, 1907; Wernicke, 1908). In animals, cicatrix formed in the area of the cyclodialysis, particularly when foreign bodies were used to hold open the cleft (Wernicke, 1908; Krauss, 1907). Since the event of plastic materials intra-ocular prostheses have been used in man with minimal reaction (LaRocca, 1962; Richards, 1965; and Gills, 1966). The present experiments were designed to study the mechanism of cyclodialysis, using intra-ocular manometric techniques in the monkey.

Methods

Sixteen Rhesus monkey (*Macaca mulatta*) eyes were operated upon, utilizing one of three types of cyclodialysis: A, B, or C. The operations were performed under a cataleptic dose of phencyclidine (*Sernyl*, Parke-Davis and Co.; 1–2 mg./kg. body weight) and pentobarbital sodium (*Nembutal*; 5–10 mg./kg.) anaesthesia. All three types of cyclodialysis used a prosthesis of 1 mm. plastic tubing (teflon or polyethylene) (Fig. 1, overleaf).

Type A.—A 12 mm. long U-shaped tube was used, the arms of which held open the cyclodialysis, the bent part being on the outside of the sclera (Fig. 1A). This type of cyclodialysis is similar to the procedure described by LaRocca (1962) and Richards (1965); but in the procedure performed in this study a larger area was dialysed, and the tubes did not protrude into the anterior chamber.

Type B.—The same tube prosthesis was used but it was sutured in the cyclodialysis cleft with no opening into the subconjunctival space (Fig. 1B). We will refer to this procedure as the subcleral cyclodialysis.

Type C.—A straight piece of plastic tubing, 9 mm. long, was sutured into a blind cleft between the choroid and sclera (Fig. 1C). There was no entrance into the anterior chamber with this cyclodialysis.

* Received for publication September 13, 1965.

† This work was supported in part by the N.I.H. Training Grant 5T 1NB5217-06 (J.P.G.) and also by PHS Grant NB 02591 (C.A.P.) from the National Institute of Neurological Diseases and Blindness.

‡ Address for reprints: C. A. Paterson, Dept. of Physiology, Institute of Ophthalmology, Judd Street, London, W.C.1.

§ Now at the Department of Ophthalmology, Duke University, Durham, North Carolina, U.S.A.

|| Now at the Department of Physiology, Institute of Ophthalmology, Judd Street, London, England.

(A) U-shaped implant extending subconjunctivally. (B) U-shaped implant sutured into the cyclodialysis cleft. (C) Suprachoroidal implant (closed cyclodialysis) not opening into the anterior chamber.

FIG. 1.—Cyclodialysis implants.

The animals were carefully observed after surgery. At 8 and 10 months after surgery, intra-ocular manometric studies were performed to determine the steady-state intra-ocular pressure and the outflow facility of aqueous humour. The manometric procedures were performed under the same mode of anaesthesia used for the surgical procedures. Outflow facility was determined by the analysis of pressure-decay curves at 8 and 10 months, and verified by steady-state infusion studies at 10 months. The manometric techniques and analysis of pressure-decay curves in the monkey have been described in detail by Paterson and Paterson (1965). No attempt was made to measure the rate of aqueous formation directly but pressure-recovery curves provided a convenient means of comparison between normal and operated eyes. Pressure-recovery curves were recorded by lowering the intra-ocular pressure a few mm. Hg below the steady-state pressure by means of the saline reservoir, and measuring the rate at which the pressure returned towards its initial value. Fig. 2 (opposite) compares a normal recovery curve with that from an experimental animal. Indirect ophthalmoscopy and gonioscopy were performed after the manometric procedures. Histological examination of the eyes was also performed.

Results

Paterson and Paterson (1965) showed that normal monkeys exhibited variable intra-ocular pressures and outflow facilities, but there was no significant difference between the eyes of an individual animal. The mean normal intra-ocular pressure was 10.0 ± 0.6 mm. Hg, and outflow facility determined from the analysis of pressure-decay curves was 0.47 ± 0.04 $\mu\text{l./min./mm. Hg}$ (arithmetic mean $\pm$ standard error from twenty eyes). Outflow facility determined by steady-state infusion studies was 0.41 ± 0.04 $\mu\text{l./min./mm. Hg}$, and it was shown that there was no significant difference between the values of facility determined by the two methods. For these reasons, each eye will be compared with its fellow eye in this study. The Table (opposite) summarizes the results of studies on the sixteen eyes.

FIG. 2.—Pressure-recovery curves recorded from a normal monkey eye (upper trace) and from an operated eye (lower trace).

P_o is the steady-state intra-ocular pressure towards which the pressure is returning.

TABLE
RESULTS OF MANOMETRIC STUDIES FOLLOWING CYCLODIALYSIS IN THE MONKEY

Animal No.	Side	Type of Operation	Intra-ocular Pressure (mm. Hg)		Facility of Outflow (μ l./min./mm. Hg)		
			8 Mths	10 Mths	By Pressure Decay Analysis		By Steady-State Infusions
					8 Mths	10 Mths	
1	Right	B	7.5	6.0	.49	*	.42
		A	8.5	7.0	.38	*	.22
2	Right	B	9.0	10.0	.23	.25	.30
		A	**				
3	Right	B	12.0	10.0	.15	.17	.14
		A	9.0	8.0	.45	.37	.36
4	Right	C	7.5	9.5	.42	.51	.24
		A	7.5	9.5	.40	.51	.18
5	Right	C	*	8.0	*	.23	.15
		A	*	7.0	*	.32	.20
6	Right	C	15.0	*	.32	*	*
		A	15.0	*	.32	*	*
7	Right	C	7.0	*	.40	*	*
		B	7.0	*	.18	*	*
8	Right	C	9.5	10.0	.20	***	.34
		B	9.0	12.0	.26	***	.17

* No recordings ** Proteinous aqueous due to cannulation procedure *** Decay curves abnormal due to light anaesthesia

Monkey 1.—A subscleral cyclodialysis (Type B) was performed on the right eye but gonioscopically and histologically the cleft was closed to the anterior chamber. The eye

maintained a low pressure, normal facility of outflow, and slow recovery curve. Histology also revealed the plastic tube posteriorly over the *pars plana* with minimal reaction.

The left eye had a Type A cyclodialysis and exhibited a low pressure and normal outflow facility. Gonioscopically a large cleft could be seen with minimal reaction. Histologically the left eye showed scarring and chronic inflammation around the implant. The lens of the left eye was cataractous.

Comparison of findings from these two eyes suggests that entrance of the cleft into the anterior chamber (or internal filtration) is not a significant factor in the production of the desired effect of cyclodialysis. Post-operative reaction also appeared to be less when the cleft did not open into the anterior chamber.

Monkey 2.—A subsccleral procedure (Type B) was performed on the right eye. The eye exhibited a normal pressure, a low normal facility of outflow, and a slow recovery curve. Protein in the anterior chamber of the left eye because of the cannulation procedure prevented valid determinations. Histologically, the right eye had mild chronic cyclitis near the tube. The left eye showed mild chronic iritis and scleritis.

Monkey 3.—A cicatrix formed over the area of the cyclodialysis in the left eye (Type A). The intra-ocular pressure was below the mean normal, the increase of pressure was slow, and outflow facility was normal. Histologically, the left eye showed no reaction.

A subsccleral cyclodialysis (Type B) was performed on the right eye. The pressure in this eye was normal, but the outflow facility was well below normal. Histological examination showed a peripheral anterior synechia in front of the tube in the right eye, which may have accounted for the low outflow facility.

Monkey 4.—A closed cyclodialysis (Type C) was performed on the right eye and a Type A procedure on the left eye. The results of intra-ocular manometric studies were essentially the same in both eyes. The intra-ocular pressures were below the mean normal, outflow facility was normal, and slow recovery curves were recorded. Histologically, the right eye showed atrophy of the ciliary body and ciliary processes above the tube. The left eye showed minimal inflammation, with the tube in good position. Apparently, no benefit was derived from the cyclodialysis opening into the anterior chamber in the left eye.

Monkey 5.—A closed cyclodialysis (Type C) was performed on the right eye and a Type A cyclodialysis on the left eye. Both eyes showed pressures below the mean normal, low normal outflow facilities, and slow recovery curves. Histologically, the tube in the right eye was surrounded by a fine capsule without inflammation.

Monkey 6.—A closed cyclodialysis (Type C) was performed on the right eye and a Type A cyclodialysis on the left eye. The manometric investigation in the eighth month showed similar results in both eyes. The intra-ocular pressures were above the mean normal, and outflow facilities were low normal. The animal died of pulmonary tuberculosis before the tenth month.

Monkey 7.—A closed cyclodialysis (Type C) was performed on the right eye and a subsccleral cyclodialysis (Type B) on the left eye. Both eyes exhibited a low pressure. The facility of outflow in the right eye was normal and in the left eye below normal. The animal was killed because of tuberculosis after the eighth month recording. (This animal was the cage mate of Monkey 6, which also died of pulmonary tuberculosis.) No histological findings were available for either of these diseased animals.

Monkey 8.—A closed dialysis (Type C) was performed on the right eye and a subsccleral dialysis (Type B) on the left eye. The pressure and facility of outflow were low normal in both eyes; slow recovery curves were recorded from both eyes. Histologically, the tube in the right eye was posterior, over the *pars plana*, with a fibrous capsule around the tube. In the left eye there was no inflammation around the tube.

As is shown in Fig. 3, the rate at which the pressure returns toward its steady-state value was greatly reduced in all operated eyes. The recovery curves for the normal monkey eyes were obtained from a group of animals of the same species, weight, and age as those used for the surgical procedures. The mean intra-ocular pressure in the experimental eyes was below normal, but the facility of outflow was not increased above normal by any of the procedures.

FIG. 3a.—Pressure-recovery curves recorded from normal monkey eyes.

3b.—Pressure-recovery curves recorded from operated monkey eyes.

Discussion

Previous experimental studies on cyclodialysis have led to suggestions that the procedure works by reducing aqueous formation or by internal filtration *via* the choroidal vessels, or by a combination of the two. However, these suggestions have not been based on the results of direct intra-ocular measurements in the primate, as were performed in this study. Determination of outflow facility by the technique of pressure-decay curve analysis has been used successfully in the rabbit and was shown by Paterson and Paterson (1965) to be a useful technique in the monkey.

The results of the manometric studies show that there was no increase in outflow facility following cyclodialysis procedures in which the cleft opened into the anterior chamber. This would suggest that any resultant internal filtration is not a significant factor in reducing the intra-ocular pressure. Outflow facility following the closed cyclodialysis (Type C) was virtually the same as that found following the other procedures. Thus, in the monkey eye, it would appear that cyclodialysis has little or no effect upon outflow facility.

Pressure-recovery curves were found to be slower than normal and essentially the same in all operated eyes. This finding suggests that the reduction in intra-ocular pressure following cyclodialysis is mainly due to decreased aqueous formation. The most likely cause of the decrease in formation is atrophy of the ciliary body about the implant. A more direct study of aqueous humour formation following cyclodialysis is obviously necessary.

Histologically, there was only minimal post-operative reaction in eyes in which the tube was buried and the cyclodialysis cleft did not open into the anterior chamber.

With the cyclodialysis cleft open to the anterior chamber, reaction comparable to that seen with the conventional cyclodialysis was observed. Since closed cyclodialysis reduced intra-ocular pressure as effectively as the open-cleft procedure, and produced less tissue-reaction, closed cyclodialysis is presumably the procedure of choice.

Clinical Correlation

Procedures similar to Type A cyclodialysis have been performed on at least 95 human eyes: 31 by LaRocca (1965), 12 by Richards (1965), 40 by Gills (1966), and 12 by Bietti (1965). The results have been better than those seen with the conventional cyclodialysis (McPherson, 1946) and the filtering procedures on the Negro (Iliff, 1944). Gills (1966) analysed the facility of outflow pre- and post-operatively and found no significant difference, and concluded that decreased aqueous formation was the primary mechanism of the cyclodialysis. In the modification of the LaRocca procedure described in this paper, a larger area of cyclodialysis is achieved; and the tube holding open the cleft does not protrude into the anterior chamber. The tube is referred to as a *cyclodialysis implant* (Fig. 4, opposite). This procedure has been successful so far, but further follow-up and evaluation is necessary.

Closed cyclodialysis prosthetic procedures (Type C) not entering the anterior chamber have been performed on a total of twelve eyes: by Alpers (1966), Leopold (1965), and Maumenee (1966). Minimal post-operative reaction occurred (although fixation was a problem in one of the cases). The longest follow-up has been 4 years, during which there has been good control of intra-ocular pressure despite little or no change in outflow facility as measured by tonography.

Summary

Three different types of cyclodialysis procedures were performed on sixteen monkey eyes. The results suggest that:

- (1) the LaRocca type procedure works by cyclodialysis;
- (2) decreased aqueous formation is the primary mode of action of the cyclodialysis;
- (3) internal filtration is not an essential factor in the cyclodialysis;
- (4) separation of the ciliary body at the scleral spur and entrance into the anterior chamber is not necessary to produce decreased aqueous formation, and does not result in any significant increase in outflow facility.

REFERENCES

- ALPERS, M. G. (1966). *Amer. J. Ophthalm.*, **61**, 1490.
 BARKAN, O. (1950). *Arch. Ophthalm. (Chicago)*, **43**, 793.
 ——— BOYLE, S. F., and MAISLER, S. (1936). *Amer. J. Ophthalm.*, **19**, 21.
 BIETTI, G. B. (1965). Personal communication.
 CHANDLER, P. A., and MAUMENEE, A. E. (1961). *Amer. J. Ophthalm.*, **52**, 609.
 ELSCHNIG, A. (1932). *Ber. dtsch. ophthalm. Ges.*, **49**, 277.
 GILLS, J. P. (1966). *Amer. J. Ophthalm.*, **61**, 841.
 ———, PATERSON, C. A., and PATERSON, M. E. (1967). *Exp. Eye Res.*, **6**, in press.
 GOLDMANN, H. (1951). *Ophthalmologica (Basel)*, **121**, 94.
 ILIFF, C. E. (1944). *Amer. J. Ophthalm.*, **27**, 731.
 KRAUSS, W. (1907). *Z. Augenheilk.*, **17**, 318.
 LARocca, V. (1962). *Brit. J. Ophthalm.*, **46**, 404.
 ——— (1965). Personal communication.
 LEOPOLD, I. H. (1965). Personal communication.

FIG. 4.—Operative technique of cyclodialysis implant.

- McPHERSON, S. D., Jr. (1946). *Amer. J. Ophthalm.*, **29**, 848.
 MAUMENEE, A. E. (1966). Personal communication.
 O'BRIEN, C. S. (1935). *Arch. Ophthalm. (Chicago)*, **14**, 527.
 PATERSON, C. A., and PATERSON, M. E. (1965). *Exp. Eye Res.*, **4**, 196.
 RICHARDS, R. D. (1965). *Eye Ear Nose Thr. Mthly*, **44** (Aug.), p. 54.
 WERNICKE, G. (1908). *Klin. Mbl. Augenheilk.*, **46** (2), 579.

ADDENDUM

Since this paper was accepted for publication intra-ocular manometric procedures have been performed on several human eyes before and after conventional cyclodialysis (Galin, unpublished) and cyclodialysis with an implant (Gills, Paterson, and Paterson, 1967; Gills, unpublished). Both decreased aqueous formation and increased outflow facility were observed.