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ELECTROCOAGULATION OF THE SCLERA*

Reduction in Ocular Volume and Pathologic Changes Produced

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I. Introduction

Although the value of sealing retinal holes in the cure of retinal detachment, pointed out by Gonin,[1-5] (1921-1930), has been confirmed by most subsequent workers in the field of retinal detachment surgery, a significant percentage of surgical failures continues to occur. Numerous techniques and almost every conceivable type of instrument have been employed to seal retinal holes. It therefore seems reasonable to investigate further any supplementary aids which are available to help reduce the number of failures. One of these aids is scleral resection or scleral shortening.

Reduction in volume of the scleral coat by resection was introduced in 1903 by Leopold Müller.[6] Müller mentioned its use in 7 instances all with satisfactory results. His stated aim was to reduce the volume of the sclera to that of its contents. Various reports have since appeared in the literature regarding the use of scleral resection. Müller,[7] 1930, reported results in 19 patients.

In 1934, Lindner[8] reported its use in retinal detachments carrying poor prognoses such as those associated with aphakic eyes, nystagmus, proliferating retinitis, and funnel-shaped detachments with bands following previous retinal detachment surgery. Lindner described his technique in detail.

He was very conservative in estimating his results and advocated doing the procedure only after electrocoagulation had previously been done. Pischel,[9] Borley,[10] Vail,[11] and Bogart[12] have written recently on the subject in our own country. Vail pointed out its value in retinal detachment with equatorial staphyloma.

Shortening of the eyeball or reduction in volume of the sclera has been accomplished by excising a piece of sclera. This can be a technically difficult procedure. There is reason to believe that some reduction in ocular volume can also be produced by electrocoagulation. Albaugh and Dunphy,[13] 1942, first commented upon the marked initial rise in pressure associated with the cyclodiathermy operation. Stocker,[14] 1943, made the same observation. Meyer and Sternberg[15] claimed that the volume of the eyeball is decreased in cyclodiathermy operations because of shrinkage of the sclera. Berens, Pischel, and Thorpe, in discussing a paper by Pischel,[9] stated that electrocoagulation consistently produced rather marked shrinkage of the sclera during retinal detachment operations. One of us (H. G. S.) made similar observations independently which led to the work presented in this paper.

Little is known about the actual changes in volume associated with either electrocoagulation of the sclera or scleral resection. Such knowledge and a comparison of the changes in volume produced by either technique might be of some value. If reduction in ocular volume could be safely produced by electrocoagulation which was comparable in amount to that resulting from scleral resection, a much simpler method of approach might be made available for clinical use. The duration of such changes should also be ascertained. The following experimental work was therefore performed.

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The microscopic slides were prepared by Dr. Larry Calkins and reviewed by Dr. Wilfred E. Fry and Dr. Calkins.

✓ Glaser

II. Purpose of Experiment

The object of the experiments about to be described was:

A. To measure the volume changes occurring in the eye as a result of electrocoagulation of the sclera.

B. To establish the duration of such changes in volume.

C. To compare the changes in volume resulting from electrocoagulation with those of experimental scleral resection.

D. To observe the pathologic changes occurring in eyes so coagulated.

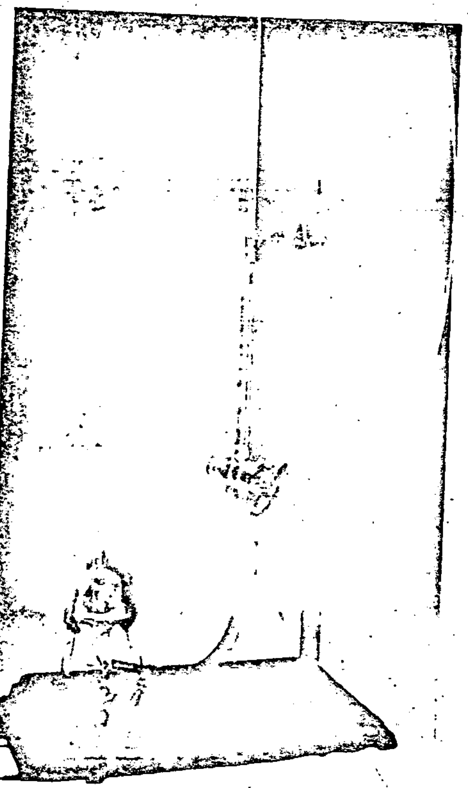

Fig. 1 (Scheie and Jerome). Apparatus for volume measurement, assembled.

III. Techniques and Apparatus

Several methods for measuring the volume of an eyeball and subsequent volume changes suggested themselves. After some trial, a fluid displacement method was decided upon and suitable apparatus devised (figs. 1 and 2). This consisted of a bell-

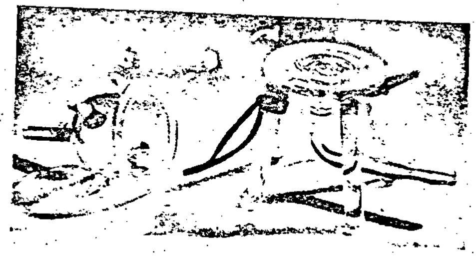

Fig. 2 (Scheie and Jerome). Device for volume measurement. (A) Etched mark indicating level to which device is filled. (B) Ground-glass surfaces on "bell" and base, lightly oiled. (C) Hooks, on which rubber banks from base are fastened. (D) Glass tube to fill device, with etched mark at zero level.

shaped chamber of 15-cc. capacity. The bell, which was open at the bottom, rested upon a base with a flat surface. Their approximating surfaces were of ground glass.

The dome of the bell was surmounted by a cannula that was etched at the level corresponding to 15 cc. when the apparatus was filled. At the center of the base was a small opening communicating with a small cannula which connected through a short piece of heavy rubber tubing to a 10-cc. analytical certified burette calibrated in 0.02-cc. divisions.

A fine film of oil applied to the ground glass surfaces achieved a water-tight union between the base and the bell. This union was given support by the traction of elastic bands.

The eye was debrided of its muscles and all adherent connective tissues and was placed on the center of the base and covered by the bell. Fluid was then allowed to enter the chamber filling it to the mark on the can-

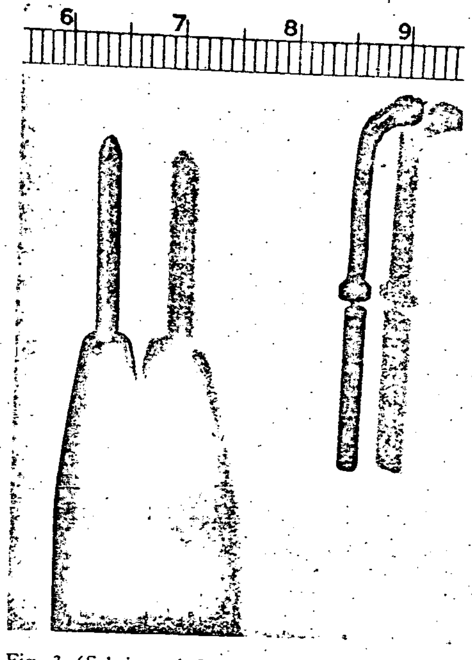

Fig. 3 (Scheie and Jerome). Surface and penetrating electrode employed in experiments.

nula surmounting the bell. The difference between the volume of fluid required to fill the apparatus containing the eye and the volume when empty gave the amount of fluid displaced by the eye, or its volume. Various control measurements were made.

Measurements repeated on the same eye could be duplicated with an average error of 0.01 cc. (Table 1). The eyes were kept at a constant intraocular pressure, for obviously an eye displaces less fluid when soft than when hard. To evaluate this relationship, measurements of five eyes were made with pressures varying from an eye too soft to measure with a Schiøtz tonometer* to 50 mm. Hg (Schiøtz) (Table 2).

The average difference between these two extremes of pressure was 0.48 cc. The difference between 10 mm. Hg and 25 mm. Hg was only 0.02 cc. while that between 25 mm. Hg and 50 mm. Hg (Schiøtz) was 0.1 cc. All volume measurements were subsequently done in these experiments on eyes in which the intraocular pressure was maintained between 15 and 25 mm. Hg because of the small error at that level.

The apparatus used for electrocoagulation was the standard Walker retinal detachment unit. The 1.1-mm. penetrating electrode from the Liebel-Flarsheim retinal detachment kit was used. The surface electrode was made of aluminum and designed to give a contact surface of one square mm. in area (fig. 3).

The technique of electrocoagulation in both enucleated eyes and on living animals was that employed at the hospital of the University of Pennsylvania in clinical retinal detachment surgery both in regard to intensity of current and time of application. A current of approximately 90 ma. was applied for

* All intraocular pressures in these experiments were recorded with a Schiøtz tonometer.

TABLE 1

ACCURACY OF VOLUMETRIC APPARATUS DETERMINED BY REPEATED MEASUREMENTS OF THE SAME DOG EYE (Intraocular Pressure Constant, Schiøtz)

Eye 1	Eye 2	Eye 3	Eye 4	Eye 5	Eye 6	Eye 7	Eye 8
5.32 cc.	5.26 cc.	5.44 cc.	6.10 cc.	6.06 cc.	5.34 cc.	5.71 cc.	5.68 cc.
5.34	5.25	5.42	6.10	6.08	5.34	5.70	5.68
5.32	5.25	5.40	6.08	6.08			
5.31	5.24	5.40	6.08	6.07			
5.35	5.24	5.39	6.08	6.05			
							Average Error Between Successive Measurements = .01 cc.

TABLE 2

VOLUME OF DOG EYES AT VARIOUS INTRAOCULAR PRESSURES, DEMONSTRATING MINIMAL VARIATIONS BETWEEN 10 AND 25 MM. HG (SCHIØTZ)

Eye No.	Too Soft to Register	Vol. Diff.	10 mm. Hg	Vol. Diff.	25 mm. Hg	Vol. Diff.	50 mm. Hg
1	5.57 cc.	.23 cc.	5.80 cc.	.01 cc.	5.79 cc.	.13 cc.	5.92 cc.
2	5.19	.57	5.76	.04	5.80	.07	5.87
3	5.04	.59	5.63	.06	5.69	.09	5.78
4	5.44	.24	5.68	.03	5.71	.06	5.77
5	5.54	.14	5.68	.02	5.70	.14	5.84
	Average Difference	.35		.03		.10	

about two seconds. The factor most variable and difficult to control in applying coagulation was the degree of wetness of the sclera.

Klein[16] has pointed out the importance of keeping the sclera moist because the electrical resistance of dry sclera is so unpredictable that control of the process is impossible and the degree of coagulation is uncertain. Pischel,[9] in discussion following his paper, implies that shrinkage of the sclera is much greater in degree when coagulation is applied to a wet field, but he believes that much of this shrinkage is temporary. Thorpe,[9] in the same discussion, warns that puncture coagulation must be carried out in a dry field or an "hour glass" eyeball will be produced by excessive shrinkage.

In our experience, a dry field would be difficult to maintain because of capillary oozing, even if it were desirable. To obtain uniform results an arbitrary number of applications of the electrodes was used for the purpose of our measurements. Fourteen surface applications were employed because dog eyes seemed to tolerate this number well. Thirty punctures were used in the experiments with penetrating electrocoagulation, a number which we felt did not exceed that used in some retinal detachment operations.

IV. EXPERIMENTAL DATA

A. SELECTION OF SPECIES

The earlier experiments were attempted upon rabbit eyes, but these were found to be entirely unsatisfactory because of the thinness of the sclera. The eyes tolerated electrocoagulation poorly, and the sclera necrosed. Measurements were also difficult because of the constant escape of intraocular fluid through openings in the thin sclera with lowering of intraocular pressure. Dog eyes were then used and found to be quite satisfactory.

TABLE 3

COMPARISON OF VOLUME OF THE RIGHT AND LEFT NORMAL DOG EYES

Intraocular Pressure Right Eye	Intraocular Pressure Left Eye	Volume Right Eye	Volume Left Eye	Difference in Volume between Eyes
10 mm. Hg	10 mm. Hg	5.94 cc.	5.98 cc.	.04 cc.
16	15	5.44	5.43	.01
13	11	5.14	4.89	.25
22	19	4.69	4.65	.04
25	25	5.26	5.26	.00
19	19	4.17	4.19	.02
17	15	4.97	4.97	.00
17	17	5.73	5.72	.01
17	17	5.54	5.53	.01
25	22	5.79	5.80	.01
25	25	5.69	5.71	.02
				Average Difference .037 cc.

TABLE 4

CONTRACTURE OF ISOLATED STRIPS OF SCLERA FROM FRESHLY ENUCLEATED HUMAN EYE FOLLOWING ELECTROCOAGULATION OF ENTIRE EXTERNAL SURFACE

Measurements of Strips Before Electro-coagulation	Measurements of Strips After Electro-coagulation	Percent Shrinkage in Length
19=5 mm.	13×3 mm.	32
43×6	24×3.5	44
21×6	13×3	38
19×6	12×4	37
44×6	24×3	45
25×6	15×3.5	40
25×6	14×3	44
28×5	18×3	36
27×6	19×3	30
		Average 38.4%

The thickness of the sclera lies between that of the rabbit and the human eye.

Experiments upon the living animal required that one eye of each pair be used as a control. Equality of volume of the two eyes had to be determined. The volume of 11 pairs of eyes was measured and compared. The difference in volume between the eyes of 10 of these pairs ranged only from zero to 0.04 of a cc. (Table 3). The 11th pair differed in

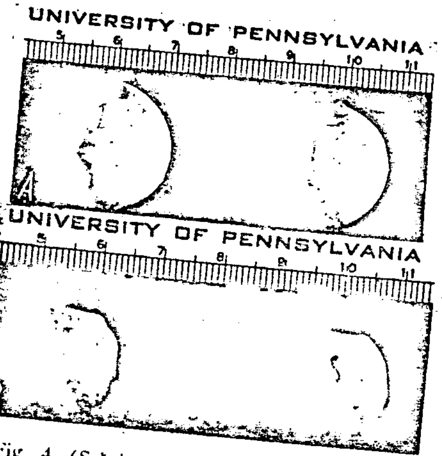

Fig. 4 (Scheie and Jerome). Flattening and puckering of sclera produced by surface coagulation. (Freshly enucleated dog eyes.) (A) Rear view. (B) Side view.

size by 0.25 cc. The average difference between the two eyes of 11 pairs therefore was only 0.037 cc.

B. EFFECT OF SURFACE COAGULATION ON EXCISED STRIPS OF SCLERA

Before proceeding to experiments upon an intact eye, coagulation was performed on isolated strips of sclera from freshly enucleated human eyes. These strips contracted approximately 38 percent in length (Table 4).

C. EFFECT OF ELECTROCOAGULATION UPON INTRAOCULAR PRESSURE OF ENUCLEATED DOG EYES

Before utilizing the living animal, coagulation was carried out upon enucleated dog

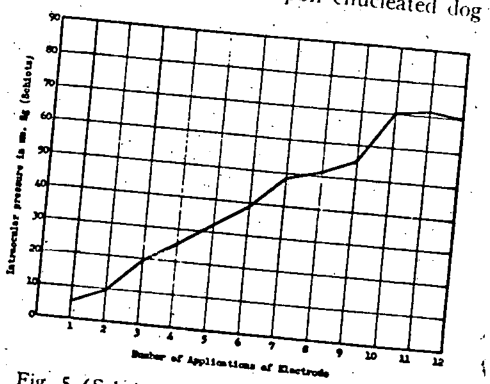

Fig. 5 (Scheie and Jerome). Effect of increasing amounts of surface coagulation upon the intraocular pressure. (Freshly enucleated dog eyes.)

eyes. Penetrating electrocoagulation was unsatisfactory in these experiments because vitreous flowed from the punctures and the eye became so soft as to render volume measurements impossible. Experiments were therefore carried out using surface electrocoagulation.

Marked shrinkage of the sclera with puckering and flattening at the site of application of the surface electrode was seen (fig. 4). The intraocular pressure rose rapidly (fig. 5). After only 4 to 6 applications of the surface electrode, the average intraocular

pressure rose from a level too low to record on a tonometer to 40 mm. Hg. After 9 or 10 applications, the intraocular pressure approached 70 mm. Hg beyond which further increase was impossible because ruptures occurred in the sclera.

These experiments confirmed previous observations regarding contracture of sclera and increase in intraocular pressure following surface coagulation. These observations also demonstrated the necessity of reducing the volume of the ocular contents during electrocoagulation to permit the sclera to contract without the resistance of increasing intraocular pressure. Therefore, in succeeding experiments, in order to maintain the intraocular pressure as nearly as possible between 15 and 25 mm. Hg, aqueous was aspirated by paracentesis with a No. 27 needle inserted through the limbus obliquely.

D. EFFECT OF SURFACE COAGULATION IN REDUCING THE VOLUME OF ENUCLEATED DOG EYES

Reduction in volume following surface electrocoagulation was studied in 11 dog eyes. The usual 14 applications of the surface electrode were used (Table 5). All of the measurements were taken with the tension within the limits noted above. If the eye

TABLE 5

EFFECT OF SURFACE COAGULATION IN REDUCING THE VOLUME OF ENUCLEATED DOG EYES (14 Applications of Electrode)

Volume Before Coagulation	Volume After Coagulation	Reduction in Volume
4.70 cc.	3.89 cc.	.81 cc.
5.28	4.42	.86
5.32	4.52	.80
5.94	4.72	1.22
5.98	4.77	1.21
5.44	4.42	1.02
5.43	4.40	1.03
5.14	3.91	1.23
5.89	3.86	1.03
4.69	4.09	.60
4.65	3.85	.80
		Average Reduction in Volume .96=18.5%

was too soft following coagulation, as a result of excessive paracentesis, saline solution was injected through the same fine needle to elevate the intraocular pressure to a dependable level. The smallest reduction in volume was 0.6 cc., the largest 1.23 cc. An average reduction in volume of 0.96 cc. or 18.5 percent of the volume of the eye resulted.

TABLE 6

EFFECT OF SCLERAL RESECTION (4×22 MM. ELLIPSE) IN REDUCING THE VOLUME OF ENUCLEATED DOG EYES

Volume of Eye Before Resection	Volume of Eye After Resection	Reduction in Volume
4.96 cc.	4.46 cc.	.50 cc.
4.88	3.90	.98
5.11	4.39	.72
4.70	3.66	1.04
5.17	4.44	.73
6.23	5.58	.65
4.86	4.21	.65
6.04	5.55	.49
5.26	4.68	.58
4.97	4.35	.62
		Average Reduction in Volume .7 cc.=13.3%

E. EFFECT OF SCLERAL RESECTION IN REDUCING THE VOLUME OF ENUCLEATED DOG EYES

Scleral resections, consisting of the removal of an ellipse of 4 by 22 mm., were performed on 10 enucleated dog eyes. The technique was the standard one for scleral resection described in some detail by Lindner.[8] The average reduction in volume was 0.7 cc. or 13.3 percent (Table 6) which was less than that occurring with the surface coagulation of enucleated eyes.

F. IMMEDIATE EFFECT OF SURFACE COAGULATION IN REDUCING THE VOLUME OF THE DOG EYE IN THE LIVING ANIMAL

One eye of each of 5 animals was prepared by incision of the conjunctiva and tenotomy of the external rectus muscle to expose the sclera. Cautery was then carried out in a manner similar to that in the experiments on the previously enucleated eyes. Care was taken to avoid electrocoagulation of the ciliary body. Fourteen applications of the surface

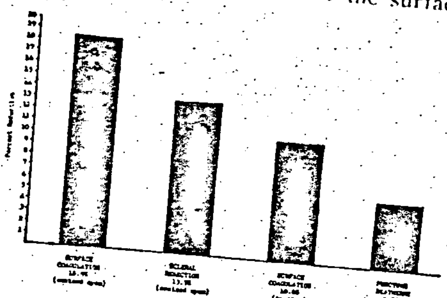

Fig. 6 (Scheie and Jerome). Comparison of reduction in volume in dog eyes produced by various operative procedures.

electrode were made. Paracentesis had to be performed to prevent the rise of intraocular pressure to an extremely high level and to permit reduction in volume. Immediately following the coagulation procedures both eyes were enucleated. The unoperated eye was used as a control for the determination of volume changes.

The average reduction in volume was found to be 0.64 cc. (12.7 percent) which was closely comparable to that obtained by scleral resection. As shown in the table, a rather marked discrepancy in results exists between the operation performed upon eyes previously enucleated and the operations done in the living animal (fig. 6). This can best be explained as due to variations in effectiveness of the electrode.

The eyes already enucleated were coagulated after moistening the area of contact with saline solution which is an excellent conductor. The amount of current delivered and the effect of each application was therefore quite uniform. In the living animal such application is more difficult because of constant oozing of blood into the field of operation and inevitable variation in the delivery of current.

G. Persistence of reduction in volume produced by surface coagulation

Having determined the fact that electrocoagulation of the sclera produced a reduction in volume of the eye in the living animal comparable with that of a scleral resection of a size used clinically, it seemed important to establish the duration of such changes.

To determine this, animals were operated

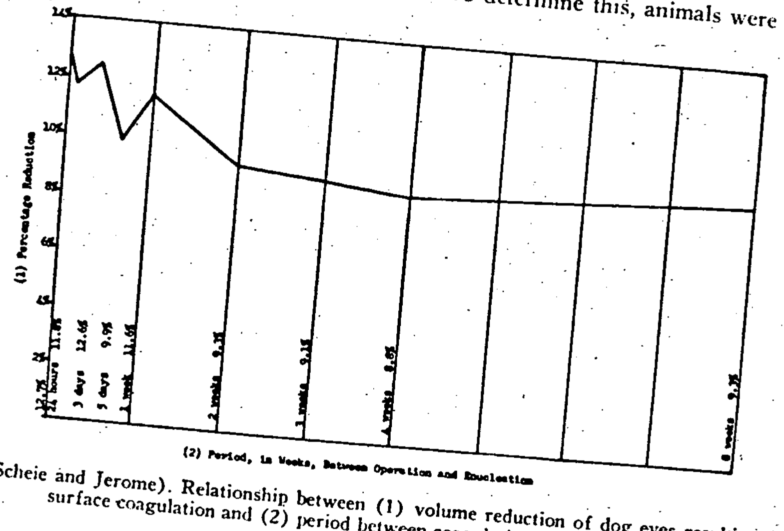

Fig. 7 (Scheie and Jerome). Relationship between (1) volume reduction of dog eyes resulting from surface coagulation and (2) period between coagulation and enucleation.

in the manner just described and the eyes of 5 dogs, were removed and measured at each of the following periods: 24 hours, 3 days, 5 days, 1 week, 2 weeks, 3 weeks, 4 weeks, and 8 weeks (fig. 7).

The reduction in volume fell slowly during the first two weeks when a reduction of approximately 0.5 cc. or 9 percent was reached. Subsequent to the second week the reduction remained unchanged and the operated eye remained smaller than the unoperated eye throughout the period of observation of two months. This was true even though both eyes appeared normal to external examination. The intraocular pressure was normal in each, except in animals subjected to short-term experiments.

H. The effect of penetrating electrocoagulation in reducing the volume of the dog eye in the living animal

Control measurements on enucleated eyes using penetrating diathermy were unsuccessful because of the low intraocular pressure resulting from vitreous loss through the punctures. It was not possible by injecting fluid into the eye to raise the tension to a dependable level (15 to 25 mm. Hg). The fluid escaped as fast as it was injected. The same was true in experiments in the living animal where the eyes were enucleated shortly after operation. The difficulties, however, were obviated by postponing enucleation of the eyes until one week after operation. By this time the punctures had sealed and the eye could be injected so that the intraocular pressure was within the limits satisfactory for volume measurements.

Thirty applications of the penetrating electrode distributed over almost half of the scleral surface behind the ciliary body were made. The average reduction in volume by this technique was 0.26 cc. or 4.9 percent. Eyes of another group of 5 animals were enucleated 4 weeks following operation. A reduction in volume of 0.36 cc. or 6.9 percent was found.

The discrepancy between volume changes of the eyes of these two groups of animals cannot be explained. The essential fact remains that although reduction in volume with this number of applications did occur, the amount was only approximately half that produced by the technique of surface coagulation used in our experiments (fig. 6). This was undoubtedly due to the fact that a smaller area of the sclera was affected by the penetrating technique than by the surface application.

V. Pathology

Previous experimental studies on eyes treated by various perforating techniques—actual cautery (Herzfeld,[17] 1930, Luntz,[18] 1939) perforating diathermy (v. Szily and Machemer,[19] 1933, Cordero,[20] 1934), electrolysis, trephining with application of caustic to the choroid (v. Szily and Machemer[19]), and perforation with a sharp instrument (Weekers[21, 22]) have shown a general agreement as to nature and sequence of pathologic changes in the eyes so treated. Weekers especially emphasizes that the histopathologic picture is essentially the same regardless of the nature of the perforating agent. He conclusively shows that the origin of the fibrous tissue band that holds the retina so firmly in place after perforating wounds is in the episclera, and that this fibrous tissue invades the wound toward the retina in a remarkably short time after the injury.

The first stage in the sequence of the pathologic change referred to is characterized by mechanical adherence of retina to choroid at the operative site (Herzfeld[17]), edema and vascular engorgement of the sclera, choroid, and retina, outpouring of fibrin or blood into the wound, and mild inflammatory changes of the acute type, with polymorphonuclear leukocytes predominating.

These changes are followed in from 1 to 2 weeks by a second phase consisting of subacute inflammation, in which mononuclear cells predominate. The sclera loses its nuclei and begins to look necrotic, but it does not disintegrate. Active connective-tissue proliferation starting from the episclera is seen. The choroid and retina lose their vascular engorgement and pigment rearrangement occurs.

The third stage is characterized by completion of a firm fibrous tissue bridge which extends between episclera and choroid, frequently reaching to or invading the retina. Localized atrophy and thinning of sclera, choroid, and retina are seen. The retina at this stage is very firmly attached to the scar beneath it.

Following surface coagulation, basic histopathologic changes show essentially the same nature and sequence, according to most observers, with the exception that the invasion of the necrotized sclera by scar tissue from the episclera is much slower and is not mentioned by several authors as occurring at all.

Weekers[21,23] emphasizes that broad, fairly firm adhesions form between retina and choroid after surface coagulation, but he does not mention or illustrate fibrocytic invasion of the sclera as occurring with this technique, despite the fact that some of the eyes in his series remained in vivo for 5 weeks after operation.

Pischel[24] obtained less firm but broader retinochoroidal adhesions using surface coagulation than he did with the penetrating technique. He emphasized that changes in sclera, choroid, and retina spread farther from the operative site with surface coagulation. The longest period between operation and enucleation in his series is two weeks; sections of eyes coagulated with the penetrating electrode show marked fibrosis into the scleral wound, but no such change is seen in surface-coagulated eyes.

Cordero's[20] studies of eyes enucleated in periods ranging from 3 to 70 days after surface and penetrating diathermy did not disclose instances of fibrous tissue invasion of the sclera after the former method, but confirmed the similarity of other pathologic changes occurring with each method. He found that the reaction of the uveal tract and retina is more severe to surface coagulation. He based this conclusion on ophthalmoscopic and microscopic evidence.

Bucallosi[25] was able to demonstrate in rabbit eyes that a bridge of fibrous connective tissue connecting episclera to retina is present one month after surface coagulation with caustics or diathermy. He was possibly the only investigator to describe this reaction.

Occasional or frequent concomitant changes with both perforating and surface technique listed by these investigators are: vitreous opacities, corneal edema, cellular deposits within the eye, retinal hemorrhages, retinal folds, detachments, retinal tears, and degeneration of retina and choroid extending well beyond the operative sites. The frequency and intensity of these reactions seems to be directly related to the amount of operative trauma.

A. PATHOLOGIC CHANGES OCCURRING IN EYES COAGULATED WITH SURFACE ELECTRODES (TABLE 7)

Slides for microscopic study were prepared from most of the eyes operated during the conduct of the volume studies. The specimens were fixed in formalin, after which they were embedded in nitrocellulose. Sections were 14 to 20 microns in thickness. They were stained with hematoxylin and eosin and mounted in Canada balsam. We were thus able to follow the histologic changes resulting from electrocoagulation at the same periods of time used for studying the volume changes. The sequence followed, therefore, involved eyes of periods ranging from those enucleated immediately after coagulation to those followed for as long as 8 weeks.

In general, the changes seen confirmed those of previous observers. The histologic changes seen in the episclera were somewhat modified because the episcleral connective-tissue mantle had to be dissected away as completely as possible to permit accuracy of volume measurements. Following removal of

Tenon's capsule and this connective-tissue mantle, the sclera appeared somewhat darkened and thinned at each site where the electrode had been applied. This was true for eyes treated with perforating as well as surface diathermy.

1. Changes in eyes removed immediately after coagulation (fig. 8). Ophthalmoscopic examination revealed white exudative areas at the site of each application of the surface electrode. The media appeared clear.

Only one eye was studied microscopically. The sclera was thickened by edema, severe engorgement of the choroidal vessels was present. Hemorrhagic foci were seen in the choroid. Retinal edema and degeneration with irregularity of the various retinal layers was present. No other pathologic changes were seen.

2. Changes in eyes removed 24 hours after coagulation. Ophthalmoscopic examination of 4 of the 5 eyes removed 24 hours after coagulation revealed the same white areas of retinal exudate at the site of each coagulation point. The fifth eye had a hyphemia preventing a view of the fundus. Two of the eyes had retinal detachment. A large retinal hemorrhage could be seen in one eye in the area of coagulation.

The microscopic changes were much more marked than those which had occurred in the eyes removed immediately. Coagulation necrosis had occurred; edema of the sclera was present; fibrin could be seen on the surface of the sclera; some infiltration with polymorphonuclear cells had occurred. The choroid showed marked vascular engorgement. Many polymorphonuclears were also seen, as well as a few monocytes. Edema of the choroid was present. The retina was edematous. Detachment of the retina had occurred over the coagulated site in 2 of the eyes. Pigment disturbance was present in 1 eye. The retinal vessels were engorged. A few cellular

TABLE 7

SUMMARY OF PATHOLOGIC CHANGES RESULTING FROM SURFACE COAGULATION

Length of time Observed	Ophthalmoscopic	Histopathologic Findings			
		Coagulated Area			Associated Findings
		Sclera	*Choroid*	*Retina*	
Acute to 5 days	White retinal exudates; spotty or confluent, site of coagulation. Retinal hemorrhages in coagulated area. Retinal detachment frequent.	Edema moderate. Coagulation necrosis. Pmns, fibrin, fibroblasts on surface. New vessels occasionally.	Vascular engorgement. Edema increasing. Pmns maximum at 3 days. Occasional hemorrhages.	Edema. Degeneration with irregularity of layers. Vascular engorgement. Detachments frequent. Hemorrhages occasional.	Deposits of granulocytes and pigment on corneal endothelium. Vitreous: clumps of rbc occasional. Papilledema occasional.
1 week to 2 weeks	Retinal exudates absorbing. Retinal hemorrhages. Occasional localized retinal detachment. Vitreous opacities occasional.	Coagulation necrosis. Fibrocytes cover surface. Wbc decreasing. New vessels occasionally.	Vascularity decreasing. Edema subsiding. Pigment dispersed. Hemorrhage occasional.	Atrophy increasing. Detachment frequent. Hemorrhage occasional.	Deposits of wbc plasm cells and pigment. Same type cells in cilioscleral sinus frequently. Vitreous hemorrhage occasional.
3 weeks to 4 weeks	Retinal exudates nearly absorbed. Hemorrhages persist. Occasional retinal detachment. Beginning retinal atrophy coagulated area.	Coagulation necrosis. Fibrocytes invading necrotic region. A few new vessels.	Vascularity decreasing further. Pigment dispersal increasing. Thickening frequent; Thinning occasional.	Atrophy severe. Detachment occasional. Hemorrhage occasional.	Retina: Irregularity of layers near coagulated area occasional Ciliary Body: Plasma cells occasional.
8 weeks	Atrophy coagulated area. Pigment disturbance frequent. Hemorrhage occasionally. Vitreous opacities occasionally.	Coagulation necrosis same as at 4 weeks. Fibrocytes cover surface and invade necrotic region. Pigmentation occasionally seen.	Vascularity same as at 4 weeks. Thinning inconstant.	Atrophy severe. Detachment occasional. Firm adherence between retina and choroid frequent.	Retina: atrophy frequently extends beyond operative site.

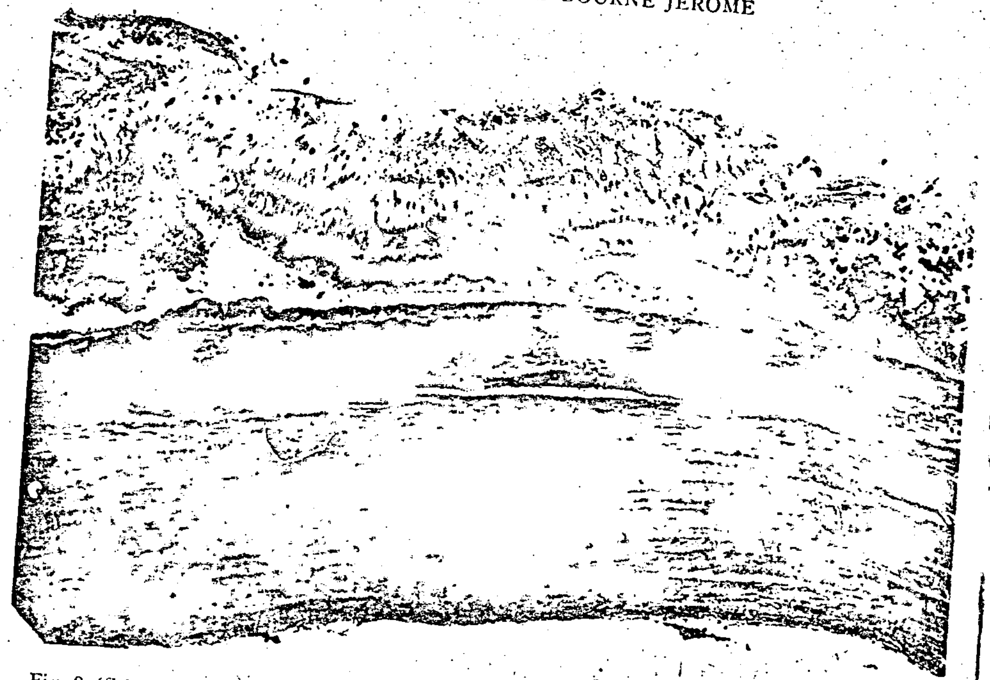

Fig. 8 (Scheie and Jerome). Photomicrograph of section (×160) from an eye removed directly after operation showing edema and density of staining reaction at the scleral operative site, as well as edema, folding, and architectural distortion of the retina.

deposits could be seen on the corneal endothelium of 2 eyes; the iris vessels were engorged; the ciliary body was edematous in 2 of the eyes studied.

3. Changes in eyes removed 72 hours after coagulation. Ophthalmoscopic examination revealed little change from that in the eyes enucleated immediately and at 24 hours. Retinal hemorrhages were more common.

Microscopically, the sclera revealed little change from that in eyes removed at 24 hours. The mantle of connective tissue and cellular infiltrate over the coagulated area was probably more marked. The sclera at the operative sites now appeared slightly necrotic. The choroid was engorged and edematous. The same type of cellular infiltrate was present as at 24 hours. The retina was edematous in all eyes over the coagulated area and the various cellular layers were irregular, as is shown in Figure 9.

One of the 4 eyes examined revealed some cellular deposits on the corneal endothelium. The iris vessels were engorged in 2 of the eyes. The ciliary body was edematous in 3 of the eyes. The choroid was diffusely edematous in 1 eye. Clumps of cells were found in the vitreous of 2 eyes.

4. Changes in eyes removed 5 days after coagulation. White retinal exudate and retinal hemorrhages over the coagulated areas were characteristic by ophthalmoscopic examination.

Three eyes were examined microscopically. The sclera over the coagulated area was edematous and showed necrosis. The fibroblastic mantle could be seen over the coagulated area. This contained many white blood cells and fibroblasts. The choroid in the coagulated area was edematous and hemorrhagic. Rather marked vascular engorgement was present.

The retina over the coagulated area was folded and edematous. Its layers again were irregular. Cellular deposits could be seen in the anterior chamber. The ciliary body was edematous and the iris showed some engorgement. The nervehead of one eye was edematous.

5. Changes in eyes removed one week after coagulation. Ophthalmoscopic examination revealed less retinal exudation than was present in eyes previously described. The retinal hemorrhages remained.

The sclera showed evidence of coagulation necrosis. The fibroblastic mantle was thick and completely covered the operative site. Vascularity of the choroid was decreasing. The retina showed beginning atrophy in all cases. Retinal detachment was present in two of the four eyes examined. The changes elsewhere in the eyes were little different from those recorded in the preceding groups except that one cornea showed what appeared to be an interstitial keratitis near the limbus.

6. Changes in eyes removed 2 weeks after coagulation. Ophthalmoscopic examination revealed absorbing retinal exudates and hemorrhages. Both phenomena were less marked than at one week.

Three eyes of those removed at the end of 2 weeks were examined microscopically. The sclera again showed coagulation necrosis and a connective-tissue mantle more heavily developed. Fibrocytes were beginning to invade the sclera in one eye. The choroid showed dispersion of pigment with dimin-

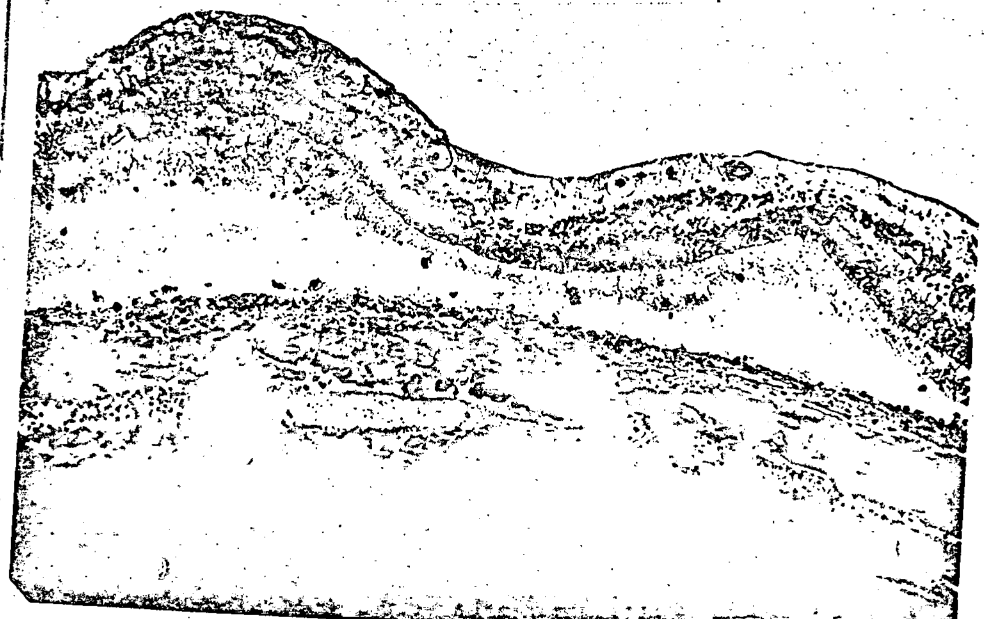

Fig. 9 (Scheie and Jerome). Photomicrograph of section (×160) from an eye removed 72 hours after operation showing coagulation necrosis of the sclera at the operative site; edema, vessel engorgement, and moderate inflammatory reaction in the choroid; fluid retinal detachment and edema and architectural distortion of the retina.

ishing vascular engorgement.

The retina was atrophic over the coagulated area with detachment present in all 3 eyes. One eye was normal outside the coagulated area; 1 showed degenerative change of the ciliary body near the operative site. Apparently a portion of the ciliary body had been coagulated.

7. Changes in eyes removed 3 weeks after coagulation (fig. 10). Ophthalmoscopic examination revealed that the white retinal exudates had nearly absorbed. Retinal hemorrhages were still present. Localized pigment disturbance was common. Localized retinal atrophy over the coagulated area could be seen in 2 of the 6 eyes.

The sclera in all of the eyes still demonstrated coagulation necrosis and formation of a connective-tissue mantle. In 2 of the eyes connective tissue was seen invading the coagulated sclera. The choroid showed less vascular engorgement with some pigment disturbance at the site of the coagulation. The retina was detached in 2 of the eyes at the site of coagulation. Hemorrhagic exudate was present beneath the detachment in each of these eyes.

Retinal atrophy was marked over the coagulated area in 5 of the eyes. The ciliary body showed pigment disturbance and some atrophy in 2 eyes in which the coagulation was near this region. The other eyes were normal elsewhere than at the site of coagulation.

8. Changes in eyes removed 4 weeks after coagulation. Ophthalmoscopically the hemorrhages were less marked and retinal atrophy was much more obvious.

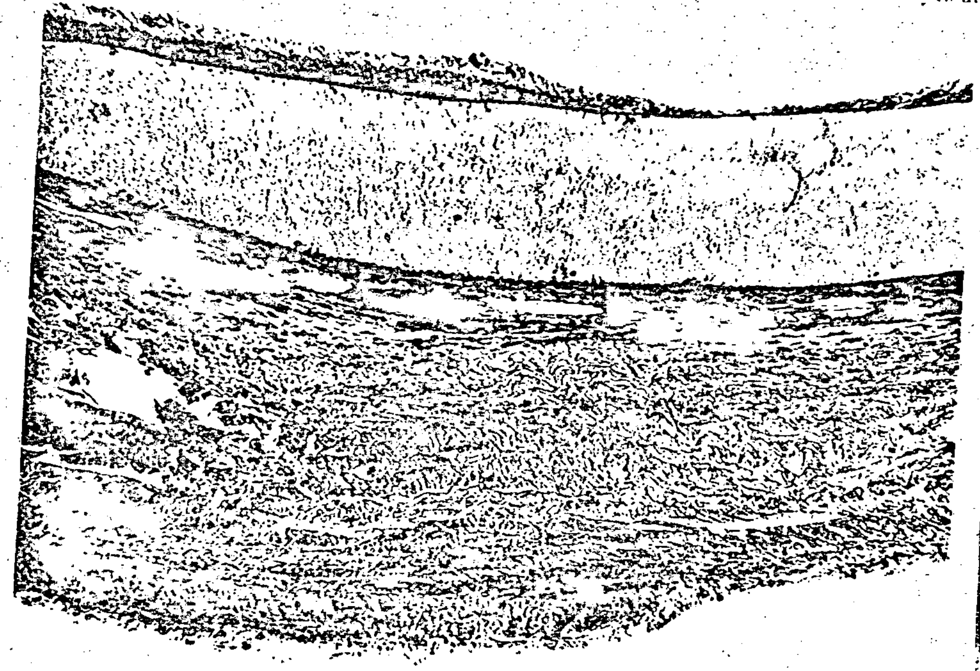

Fig. 10 (Scheie and Jerome). Photomicrograph of section (×80) from an eye removed three weeks after operation showing necrotic scleral operative site; hemorrhagic retinal detachment; and "band type" retinal atrophy immediately under the operative site.

The sclera in all 3 of the eyes examined microscopically showed coagulation necrosis and again the connective-tissue mantle. Fibrous tissue now extended deeply into the necrotic sclera in all 3 eyes. The choroid and retina both showed irregular atrophy over the coagulated area. The eyes were essentially normal otherwise, although the ciliary body adjacent to the site of the coagulation showed some pigment disturbance and probably atrophy.

9. Changes in eyes removed 8 weeks after coagulation (fig. 11). Retinal hemorrhages were seen in but 1 eye ophthalmoscopically. These were small and deep. Retinal atrophy was present.

Microscopically, necrosis of the sclera was still visible. The area of necrosis was covered and deeply invaded by fibrous tissue. The choroid showed diminished vascularity and atrophy over the coagulated sites. The retina was similar. Retinal detachment with subretinal hemorrhagic exudate was seen in 2 of the eyes. A vitreous hemorrhage was found microscopically in 1 of the eyes.

B. Pathologic changes occurring in eyes coagulated with penetrating electrodes (table 8)

A study of these eyes was made in an attempt to prove or disprove the observation of Weekers that fibroblastic tissue from the episclera migrated inward toward the choroid and retina through the puncture holes. From our observations described above, we could well predict that Weekers's observations would be confirmed because one of the earliest phenomena following electrocoagulation of the sclera is the formation of the fibroblastic connective-tissue mantle.

This fibroblastic mantle in the early stages involved only the surface of the sclera. In 1 of 6 eyes at the end of 3 weeks and in all eyes at 4 weeks, it was shown that these fibroblastic cells invaded the necrotic sclera itself. Presumably this invasion would have occurred much more promptly and earlier had openings been provided into which fibroblasts might grow.

In the microscopic study of the eyes coagulated with penetrating diathermy, the

Fig. 11 (Scheie and Jerome). Photomicrograph of section (×160) from an eye removed eight weeks after operation showing advanced cicatrization about the scleral operative site and confluence of the margins of the sclera, sclerotic choroid, and atrophic retina. Note dense episcleral "mantle" of fibrous tissue over necrotic zone of sclera.

same intervals were used as for volumetric measurements; namely, 1 and 4 weeks.

1. Changes in eyes removed one week after penetrating coagulation (fig. 12). Ophthalmoscopic examination. Vitreous opacities were seen in 1 eye of 4 examined. All eyes had soft white retinal exudates surrounding each puncture. Two eyes showed depigmentation near the puncture sites. In 1 eye a small hemorrhage was seen.

Three eyes were examined microscopically. All showed scleral coagulation necrosis at the operative site traversed by a core of fibrous connective tissue which appeared to arise from an episcleral fibrous-tissue mantle and extended almost to the choroid or invaded its substance. Pigment dispersion at the operative site was uniformly present in 1 eye.

The retina under the puncture site in 1 eye was normal; in another it was necrosed and had a small hemorrhage; in a 3rd, fibrosis had extended into its substance from the episclera and through the choroid; small hemorrhagic detachments were present near the operative site in this eye. There were no abnormal findings in the other structures of these eyes.

2. Changes in eyes removed 4 weeks after penetrating coagulation (fig. 13). Ophthalmoscopic examination: Two of 5 eyes had nonfloating vitreous striae over and attached to the coagulated area. In all 5, chorioretinal atrophy was seen around each puncture. In one case the atrophic areas were partially confluent, while, in another, a soft white exudative appearance was superimposed on the atrophy.

All 5 eyes were examined microscopically. All showed scleral coagulation necrosis at the operative site; 3 had a substantial core of fibrous connective tissue reaching from a fibrous episcleral mantle down to choroid or retina. In the 4th eye the sclera at the operative site was thinned, the episcleral fibrous tissue was vascularized and there were only a few fibrocytes in the depth of the sclera. In the 5th eye the episcleral tissue was itself necrotic.

The choroid at the operative site was degenerating or atrophic in all eyes, with decreased vascularity and pigment disturbance the rule. In 1 eye, a small inward proliferation of pigmented tissue from the choroid was seen. In all 5 eyes the retina showed a bandlike atrophy confined to the operative site. In all cases it was in firm apposition with the choroid at these points.

Findings in the other structures of these eyes included pigment disturbance and mild

TABLE 8

Summary of Pathologic Changes Resulting from Penetrating Coagulation

Length of time Observed	Ophthalmoscopic	Histopathologic Findings			
		Coagulated Area			Associated Findings
		Sclera	*Choroid*	*Retina*	
1 week	White retinal exudates sites of coagulation; occasionally confluent. Pigment disturbance at coagulated site occasionally.	Coagulation necrosis at operative sites traversed by core of fibrocytes extending from fibrous mantle on surface deep into sclera. Monocytes in necrotic area.	Moderate pigment chorcid dispersal. Necrosis occasionally. Fibrosis occasionally.	Moderate necrosis or degeneration with irregularity of layers. Occasional hemorrhage. Occasional small detachments.	Essentially normal.
4 weeks	Chorioretinal atrophy at each coagulated site; occasionally confluent. Striated vitreous opacities occasionally. Occasional retinal hemorrhage or persisting exudate.	Coagulation necrosis at operative sites traversed by core of fibrocytes extending down from episcleral fibrous mantle, reaching to choroid or even retina.	Degeneration or atrophy localized to operative sites. Decreased vascularity. Pigment disturbance occasionally.	Localized atrophy. Close adherence to choroid at operative sites.	Ciliary body: Pigment disturbance, irregularity of structure occasionally.

degeneration of the ciliary body when a coagulation was placed near its pars plana. Hyalinosis of the ciliary processes was present in another eye. One eye showed corneal bleb formation, mild degeneration of the ciliary body, and pigment deposits in the anterior chamber. One eye showed keratitis of the anterior third of the corneal stroma. Inexplicably, a small vascularized central corneal staphyloma was seen grossly in another eye.

Fig. 12 (Scheie and Jerome). Photomicrograph of section (×160) removed one week after operation showing well-marked episcleral "mantle" of fibrous tissue and an intermediate stage of healing with penetration of connective tissue core through necrotic sclera to underlying chorioretinal mass which itself shows atrophy and fibrous tissue formation. Note edema and early necrois of surrounding retinal tissue.

VI. Discussion

The work reported herein was undertaken to determine the amount of scleral shrinking which could be produced by electrocoagulation of the sclera and to compare these results with those obtained by experimental scleral resection. A method for measuring the volume of an eye through a fluid-displacement technique was devised and found to be reasonably accurate. The work was done upon the dog eye because the sclera was thicker and more like that of man than was that of the rabbit.

Surface and puncture diathermy were used in different experiments. Surface diathermy produced marked shrinkage and puckering of the sclera at the site of application with rapid rise of intraocular pressure signifying reduction in volume. In enucleated eyes, the tension could be elevated to 70 mm. Hg, beyond which scleral ruptures would occur and the tension would rise no higher. These experiments confirmed the observations of several workers who had

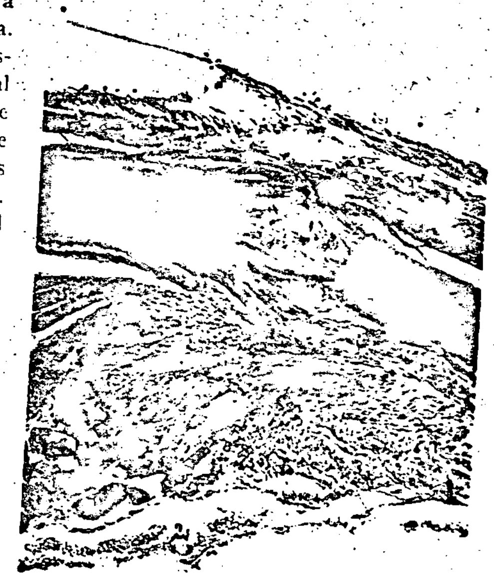

Fig. 13 (Scheie and Jerome). Photomicrograph of section (×160) removed one month after operation showing marked episcleral fibrosis and healed penetrating diathermy wound. There is underlying choroidal and retinal fibrosis and retinal atrophy. Note close adhesion of chorioretinal tissue to scleral scar at the operative site.

noticed a similar rise in intraocular pressure during cyclodiathermy.

To ascertain the amount of volume change which could be produced, paracentesis of the anterior chamber had to be done permitting the sclera to shrink. Fourteen applications of a surface electrode which had a contact surface of one square mm. were used in all surface coagulation experiments. An average reduction of 0.96 cc. or 18.5 percent of the volume resulted in experiments on 10 enucleated dog eyes. This was approximately 0.25 cc. more than that produced by scleral resections of 4 by 22 mm. also performed on enucleated dog eyes. The same amount of coagulation on the living animal was somewhat less effective, the average reduction in volume being 0.64 cc. Subsequent experiments demonstrated that this volume change fell during the first 2 weeks to about 0.5 cc. or 9 percent, after which, during our observation period of 2 months, the volume remained unchanged.

The effect of electrocoagulation with the penetrating electrode was then studied. Thirty applications were used, which was felt to be within the range of at least some operations for the clinical treatment of retinal detachment. These eyes were studied and a reduction of about 6 percent in volume was found, about two thirds that of the reduction obtained by surface coagulation. Because a smaller total area of sclera was coagulated, the reduction in volume by penetrating diathermy was less than that produced by surface diathermy. Even so the amount was not insignificant.

An objection to these observations can immediately be raised, for it is certainly not a common observation that the refraction of an eye operated upon for retinal detachment undergoes a marked change in refraction toward the hyperopic side, as one might expect. This we are unable to rationalize, unless the change in volume results from a flattening of one side of the eye, rather than a shortening of the anteroposterior diameter. It does seem certain, however, that at least some degree of scleral shrinking is produced with every electrocoagulation operation for retinal detachment and suggests that further study ought to be done to devise more effective means of shortening by electrocoagulation. The present experiments tend to explain the advantages claimed for surface coagulation and possibly also serve as an argument for Langdon's[26] thermophore technique.

The pathologic studies carried out, in general, confirm those of previous observers. The sclera, choroid, and retina became edematous and engorged shortly after coagulation. The sclera had a coagulated appearance. Changes of acute inflammation presented, which in from 1 to 2 weeks transformed to a subacute appearance with mononuclear cells. Finally, fibroblasts proliferated throughout the area, and the sclera, choroid, and retina underwent atrophy in varying degrees.

Weckers's[22] work demonstrating a fibroblastic plug growing toward the choroid and retina through the opening in the sclera made by the penetrating electrode was confirmed. This seems of great importance since it causes the retina to adhere firmly to the choroid following such operations. Similar changes tend to occur following surface diathermy but the fibroblasts grow through necrotic sclera and hence the process takes place much more slowly, requiring 1 or 2 months. After using the penetrating technique, the plug can be seen as early as 1 week postoperatively.

The changes which occurred following surface diathermy, where the coagulation was more extensive and intense, were more severe than those following the penetrating technique. The engorgement of the retinal vessels, particularly in the nerve-fiber layer, was more marked. The appearance of these engorged vessels might well explain the common occurrence of preretinal and vitreous hemorrhage, seen clinically, following too heavy coagulation of the sclera.

The changes ensuing after surface diathermy, where the volume changes were marked, were such that one would be hesitant to use this degree of coagulation clinically. Not only was the engorgement of vessels pronounced, but the final retinal atrophy was considerable, and, although the eyes were negative externally, their histologic appearance would counsel caution.

In conclusion, it can be stated that electrocoagulation is capable of producing a high degree of scleral shrinkage manifest by reduction in volume of the eye. This undoubtedly occurs to some degree in every operation for retinal detachment by the electrocoagulation technique.

Experimentally, surface diathermy produces more scleral shrinkage than penetrating diathermy, no doubt because a greater area of the sclera is affected. However, the pathologic changes resulting from surface coagulation are of such a severe nature that clinical application to the same extent would probably be inadvisable.

Further work should be done to devise a technique which would produce scleral shrinkage yet be less destructive to the underlying choroid and retina because there seems sufficient evidence to believe that reduction in volume of the scleral shell is of at least supplementary value in retinal detachment surgery.

VII. Summary

1. The value of scleral resection is discussed.

2. Surface electrocoagulation was found to produce a reduction in ocular volume in enucleated eyes and eyes in the living animal comparable to scleral resections of 4 by 22 mm. Penetrating electrocoagulation produced a smaller reduction in volume.

3. The reduction in ocular volume resulting from electrocoagulation persisted during the period of observation of 2 months.

4. Electrocoagulation of the amount used in these experiments produced pathologic changes of such a nature as to suggest caution in its clinical use.

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Discussion

Dr. Jonas S. Friedenwald (Baltimore, Maryland): I think we are all familiar with the fact that, after successful detachment operations, the area of the fundus that has been cauterized is often visible with a higher plus lens than corresponding areas in other parts of the periphery, but in general the axial refraction is not significantly changed. I would like to ask Dr. Scheie, therefore, whether the contraction that he gets is not rather a flattening of the sclera at the point of cauterization than the general reduction in radius of the eyeball that one gets with the scleral resection.

Dr. Conrad Berens (New York, New York): I should like to ask Dr. Scheie whether he tried the Walker bident using the back part of it, not the points? We have thought that we got better shrinkage of the sclera by using the back of the Walker bident than by using the individual electrodes or the two points in contact with the sclera. It certainly seems to work out in practice that way, although scientifically I cannot say why shrinkage is greater than with two points introduced separately.

Dr. David G. Cogan (Boston, Massachusetts): It is of interest to note that the white opacification of the retina from surface diathermy of the sclera is much more extensive during the diathermy than immediately following it. This suggests that the retinal opacification is not, as generally assumed, one of coagulation. With the diathermy applied to the sclera of an excised and bisected eye, it can be shown that the opacification is due, in some measure at least, to the formation of numerous bubbles in the retina, bubbles which, when massaged out, leave the retina transparent.

Dr. Scheie (closing): The question which Dr. Friedenwald raised occurred to us. We certainly haven't seen a marked degree of hyperopia occurring in our patients with operations for retinal detachment, and the only way to explain it is just as Dr. Friedenwald has. Marked flattening of one side rather than of the anteroposterior diameter of the eye can be seen in the slides of animal eyes.

In reply to Dr. Berens, we have not used the Walker bident.

INTRAOCULAR HEMORRHAGES IN YOUNG RATS ON CHOLINE-DEFICIENT DIETS*

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Best and Huntsman (1932) demonstrated that choline or a precursor was essential in the diet of rats to prevent the accumulation of excess amounts of fat in the liver. Later, Griffith and Wade (1939) reported hemorrhagic degeneration of the kidneys of weanling rats deprived of dietary choline. The renal lesion was usually responsible for the animal's death within two weeks. These authors also noted intraocular hemorrhage in the animals whose kidneys were most severely affected.

Christensen (1940) stated that this intraocular hemorrhage occurred mainly from the blood vessels of the ciliary body and iris. Engel and Salmon (1941) reported that the hemorrhage "appeared to originate in the ciliary vessels and spread into the posterior chamber." They also demonstrated the presence of uremia in the rats by determinations of the levels of the nonprotein nitrogen in the blood, and by the xanthydrol reaction applied to sections of brain. All the foregoing investigators were interested primarily in the renal, rather than the ocular, lesions.

The first investigations concerned mainly with the ocular changes were those of Bellows and Chinn (1943). They found that 10 to 33 percent of their animals showed some type of ocular hemorrhage, usually within the 48 hours preceding death. The most frequent form was a column of blood in Cloquet's canal; the next, was a "hemorrhage apparently arising in the region of the ciliary body, and shortly spreading beyond the crystalline lens." Less commonly, hemorrhages visible to the naked eye appeared as hyphemia.

Microscopically, they noted that the vessels of the eyeball were generally engorged, and that the ciliary processes were swollen and frequently hemorrhagic. They found free blood most often between the anterior limiting membrane of the vitreous and the crystalline lens, and not uncommonly in the anterior chamber. Puppies on the same diet developed fatty livers, but hemorrhagic degeneration of the kidneys, eyes, and other organs did not occur.§

The present paper will deal with further observations regarding the intraocular hemorrhages occurring in weanling rats on diets low in choline, and after nephrectomy. The results are based on observations involving more than 350 albino rats of the Wistar strain.

Methods

Diets

Two diets were used. Diet A (Lucas; 1948) is extremely low in choline and its precursors, but is believed to be adequate in all other respects. Diet B (Lucas; 1948) is somewhat less deficient in lipotropic agents, but is believed to be adequate in all other respects except possibly in certain amino acids. This diet takes 1 to 2 days longer to produce its results in weanling rats than does diet A. The animals were fed these diets at pleasure in each instance.

Examinations of living animals

A small percentage of the hemorrhages were visible to the naked eye in the form

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§ Since this paper was prepared, these findings of Bellows and Chinn have been confirmed by Brückner, R., and Viollier, G.: Helvet. physiol. acta, 6:3, 1948.