BETA RADIATION THERAPY IN OPHTHALMOLOGY

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THE GOOD RESULTS obtained in the treatment of certain ocular conditions with beta radiation have been described previously (1). On the other hand, some clinics avoid the use of beta therapy for fear of undesirable effects on the structures of the anterior ocular segment (2). Although the availability of radon for ophthalmic applicators has restricted the use of beta radiation to a relatively few large medical centers in the past, the more recently introduced radium D-E and strontium^{90}-yttrium^{90} applicators will permit many physicians to administer this type of radiation therapy. It becomes more important therefore that the ophthalmologist be aware of the rationale, indications, contraindications, dosages, and dangers of beta therapy. Moreover, the physical characteristics, quality and quantity of output of the several new ophthalmic applicators must be known in order to obtain satisfactory results in the treatment of suitable conditions.

The purpose of this thesis is to describe the sources and characteristics of beta particles and to reevaluate the results obtained at the University of Illinois and by the author utilizing beta from a radon source, with special attention to the selection of cases and undesirable reactions.

SOURCES OF BETA RADIATION

The sources of beta radiation for ophthalmic use at present are derived from radium and its derivatives or radioactive strontium^{90}. The characteristics of the emanations from radium are enumerated in Table 1. The clinical effectiveness of both radium and radon applicators is due to the emanations from radium B

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TABLE 1. DISINTEGRATION OF RADIUM

	SUBSTANCE	EMANATION	ENERGY OF BETA (Mev)		HALF LIFE
			Maximum	*Average*	
	Radium	Alpha	—	—	1,600 yrs.
Equilibrium in 4 Hrs. "Radon Applicator"	Radon	Gas alpha	—	—	3.83 days
	Ra. A	Alpha	—	—	3 min.
	Ra. B	Beta & Gamma	0.65	0.23	2.7 min.
	Ra. C	Alpha, Beta & Gamma	3.15	0.65	20 min.
"Radium D Applicator"	Ra. D	Beta	very weak		22 yrs.
	Ra. E	Beta	1.17	0.34	5 days
	Ra. F	Alpha	—	—	140 days
	Lead	—	—	—	—

and radium C. The effective beta particles of the radium D applicator come from radium E with which it is in equilibrium. Whereas radium and radium D applicators, utilizing the metal itself, are semipermanent applicators, the half-life of radon gas is only 3.83 days. Therefore, radon applicators are necessarily of temporary nature and must be renewed every week or two. Because the energy of the beta particles from radium C is greater than of radium E, the penetrating power of the emanations from radium and radon applicators is greater than that from the radium D-E applicator. Radioactive strontium^{90} yields weak beta particles of maximum energy of 0.65 Mev and average energy of 0.2 Mev. However, it is in equilibrium with yttrium^{90} which yields a beta particle of maximum energy 2.16 Mev, and an average energy of 0.8 Mev, which is slightly greater than that from radium C. The Strontium Ophthalmic Applicator is also of a permanent type, having a half-life of 25 years.

Radium Applicator. The Radium Ophthalmic Applicator, described by Iliff (3) and manufactured by the Radium Chemical Company, contains 50 mg. of radium salt, and has a flat rectangular active surface (6 x 12 mm.) consisting of 0.1 mm. "monel" metal. It has the advantage of permanency with a half-life of 1,600 years and a sufficiently energetic beta particle to accomplish ef-

fective therapy; the cost is approximately $1,000. As stated previously, the effective emanations arise from radium B and C, which is in equilibrium with gaseous radon accumulating over the radium metal within the applicator. In common with all applicators utilizing a metallic source, some of the beta particles are absorbed by the metallic mass itself, which reduces the clinically effective output markedly. Since the gamma rays are not greatly impeded, the beta:gamma ratio of the output is correspondingly decreased when more prolonged treatment times are used to obtain adequate beta output (approximately 8 times that of the radon applicator to obtain similar results per unit area).

Radon Applicators. Radon gas is collected in a vacuum glass tube from a solution of radium chloride. After 4 hours, equilibrium is obtained with its disintegration products, radium A, B, and C. The alpha particles are completely absorbed by the thin layer of glass surrounding the radon, and therefore are without effect in the use of the ordinary glass bulb or capillary-tube radon applicator. The beta particles or electrons penetrate through the glass tubing and emerge from the open end of the treatment surface of the applicator. These electrons are absorbed completely by 1 mm. of silver or lead or 1.3 mm. of brass. Therefore, ophthalmic applicators made with walls of these materials permit an accurate localization of beta radiation to a certain area. Only 3.5 percent of the ionizing effects from radon are caused by the gamma rays, approximately 2.5 r for a treatment dose of one gram second (gm. sec.). These rays are comparable to 1.8 million electron volt (Mev) X-rays, and accordingly penetrate very deeply through tissues, with relatively little superficial absorption. Because of the relatively small amount of gamma radiation in comparison to the beta particles which emerge from radon, it is possible to utilize the therapeutic effects of beta without undue gamma absorption in the deeper structures of the eye.

Certain radon technicians complain of the technical difficulty of making a single glass bulb to enclose the radon, such as that devised by Burnam and Neill (4) and in use at the Wilmer Institute. Because of this, an applicator was devised[1] to use ordinary

[1] With the cooperation of Mr. John Hissong and the Radium Chemical Company.

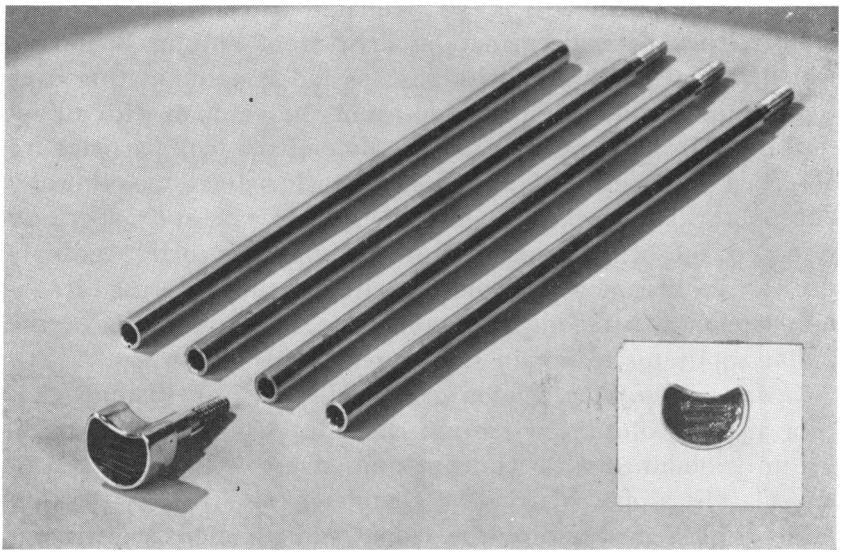


FIGURE 1. RADON OPHTHALMIC APPLICATOR UTILIZING CAPILLARY GLASS TUBES

capillary glass tubes employed in making radon implantation needles (Fig. 1). The open end of the applicator is kidney-shaped, the concave side fitting both the curvature of the limbus and the curvature of the globe. The treatment surface area is about 60 sq. mm., roughly 5 mm. in greatest width and 12 mm. in greatest length. The radon is collected in three or four capillary glass tubes which are laid in parallel rows on the surface of the applicator located about 1 mm. below the edges of the bottom treatment surface. The capillary glass tubes are glued onto the bottom surface by means of ordinary Duco Household Cement. When the needles must be removed for replacement with fresh radon needles, the Duco cement is dissolved by means of acetone. The technical advantages of this applicator include: (*a*) greater ease in the collection of radon within capillary glass tubing compared to a single glass bulb; (*b*) a good fit to the curvature of the globe, permitting more accurate localization of the treatment area; (*c*) a curvature which readily fits most types of areas to be treated, for example, a sector of the scleral portion of the limbus without

treating the cornea, the curvature of the everted lids, and other lesions; and (*d*) almost direct contact of the glass needles with the tissue surface over a relatively large area. This permits a high beta:gamma ratio, the use of relatively small quantities of radon and fewer applications to cover a given area. The greatest effect of the radon covers an area roughly that underlying the needles: about 4 x 6 mm. In case a smaller area is required, a 1 mm. silver filter with a central round hole can be placed over the end of the applicator, although with this filter it is necessary that approximately twice the usual dose be employed.

In general, radon applicators have the advantage of a high output of energetic beta particles, which reduces the treatment time to practical limits depending upon the amount of radon which can be obtained. The major disadvantages of such applicators are that a radon producing plant must be available, the cost is somewhat high if radon must be obtained commercially (about $1.25 per mc.), and the half-life of the applicator is relatively short. In addition, Krohmer (5) recently found considerable variability of the output of a radon applicator on which he made several readings with a modified ionization chamber. To some extent clinically, we have noted apparent variation in the reactivity and effect of the applicator from week to week, but this has not been of significant practical importance. This variability might possibly be related to the thickness of the glass and the position of the needles on the surface of the applicator. The presence of gamma radiation requires that the applicator be stored in a lead container (Fig. 2) with walls at least 1 inch in thickness, and the operator of the applicator should limit himself to approximately 12 treatment areas per day or 70 per week in order to avoid undue exposure.

Radium D-E Applicator. Since 1948, the Radium D-E Applicator[2] has been widely advertised (6). The original applicator contained 10 mc. of radium D, and had an active treatment surface of 6.8 mm. diameter and composed of either 0.05 mm. of aluminum or 0.1 mm. of magnesium. Radium D-E Applicators are now manufactured which contain 15 or 20 mc. of radium D.

[2] Produced by the Canadian Radium and Uranium Corporation; cost of $750 for the 10 mc. applicator and $1350 for the 20 mc. applicator.

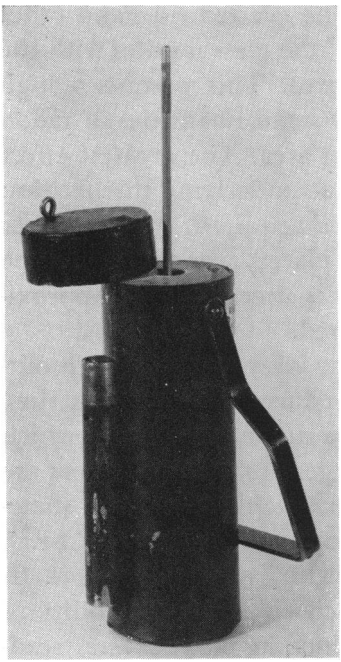


FIGURE 2. LEAD CARRYING CASE FOR RADON APPLICATOR

However, the addition of 10 mc. to the original 10 mc. applicator is stated to result in only a 50 percent increase in the effective output because of even greater self-absorption of the beta particles within the increased radium D mass. This applicator has the advantages of permanency, and the absence of any clinically significant gamma radiation except for "Bremsstrahlung", secondary X-rays formed by the collisions of electrons with the walls of the applicator (about 0.16 r per treatment of 4 gm. secs.). The disadvantages include a relatively low output because of absorption of the beta particles by the radium D mass itself, a less penetrating beta particle which is of some importance in the treatment of deep corneal vascularization, and the lack of official certification of the output of each individual applicator.

Radioactive Strontium^{90}*-Yttrium*^{90} *Applicator.* In 1950, Friedell, Thomas and Krohmer (7) reported the use of a laboratory model Beta Applicator utilizing radioactive strontium^{90}. The energetic beta particle useful in therapy is produced by its equili-

brium product, yttrium^{90}, and no significant gamma emanations are produced. The half-life is 25 years. Since then, a commercial model has been produced (8) which has a flat circular surface of 12.7 mm. diameter, and an active surface of 7.8 mm. diameter. The active face of the applicator consists of 2 mils of stainless steel and 10 mils of aluminum. About 25 mc. of strontium^{90} is spread uniformly on the back of the contact surface. This applicator has the advantages of being permanent, emitting an energetic beta particle, no gamma emanations, and a relatively low cost ($300). Disadvantages include the large size of the applicator, the rather prolonged treatment times necessary, and as yet the absence of adequate clinical information concerning the effectiveness of the applicator and possible dangers to the lens in view of the slightly greater depth dose compared to radon (see below).

For a more complete review of various beta applicators used previously, the reader is referred to an article by Wilson (9).

DOSAGE RATES OF APPLICATORS

Gram Seconds. The strength of radium and radon ophthalmic applicators is determined by means of an ionization chamber which measures the amount of gamma emanation and thereby indicates the number of milligrams of radium or corresponding number of millicuries of radon in the applicator. The unit of dose considering the strength of the source and time has been given most conveniently for ophthalmic purposes in "gram seconds" which has the following conversion equivalents:

1 gram second = 1000 millicurie seconds = 16.7 millicurie minutes = 0.28 millicurie hours.

In calculating the dose for treatment with radon, one must consider that 50 percent of the radon deteriorates every 3.83 days, or a loss of approximately 16 percent effective dose per day after the radon has been collected. The calculation of the dose should therefore be made on this revised figure.

$$\text{number of secs. application} = \frac{\text{number of gram seconds desired} \times 1000}{\text{number of milligrams radium or of millicuries radon}}$$

In the past, the quantity of beta particles emerging from the surface of radium and radon applicators has not been measured directly, and, even now, the accurate measurement of the beta output from these applicators represents a research problem. Applicators have been manufactured according to standard specifications in order that the output of similar instruments will be approximately the same. Some of the factors which can vary the quality or quantity of output include: composition of the walls; composition, thickness and area of the active surface; thickness and evenness with which the radioactive material is layered upon the back surface of the treatment area; and the avoidance of leakage of radioactive material from inside the applicator. A rough estimation of the evenness of the distribution of radioactive material can be determined by exposing X-ray film. Leakage of the applicator can be detected by: (*a*) the so-called "wipe test," in which the face of the applicator is rubbed on the surface of a piece of paper at least six times, and the paper is surveyed with a Geiger tube type instrument; (*b*) restandardization of the output by means of special ionization chambers; or (*c*) animal standardization. The output of the applicator is of course related to the amount or load of radioactive material present, and the factors of filtration both within the radioactive mass itself and the treatment surface affect both the quality and quantity of output. Naturally, the radiation from a localized source will differ from that of a larger area, and the output of the applicator will be greatly affected by the distance of the radioactive source from the surface treated because of scattering and inverse square law spreading which reduce the effective output (double the distance = one quarter of the output). Because of these many variables, it is obvious that standardization of each individual applicator is advisable either on animal eyes or physically, or preferably both.

The rabbit cornea provides a satisfactory method for the standardization of individual ophthalmic beta applicators (10, 11, 12). Rabbits of comparable age are given general anesthesia, and the eyes are proptosed between the lids in order to obtain good fixation, the lids being clamped behind the proptosed eye. The surface of the applicator to be tested is held steadily in contact with the

center of the cornea by some kind of ring stand arrangement. From three to six eyes are given exposures of identical length, critical differences in exposure times being tested on opposite eyes of the same animal to avoid what may amount to a large amount of individual animal sensitivity. The severity of the lesions produced are graded in a manner similar to that given in Table 2. The most

TABLE 2. GRADING THE SEVERITY OF CORNEAL REACTION

Corneal Lesion	*Maximum No. of Points*
Density of Corneal Opacity:	
Nebular haze = ½	
Definite opacity = 1	
Blurs pattern of iris = 2	
Blurs outline of pupil = 3	
Opaque = 4	
Area of Opacity:	
1 = 1/4 of cornea; entire cornea = 4	
Maximum Value of Corneal Opacity = Density x Area (4 x 4)	16
Edema:	
Detectable with slit lamp = 1	
Visible by focal illumination = 2	3
Anterior bulging = 3	
Ulceration:	
Stains with fluorescein = 1	
Visible by focal illumination = 2	4
Deep = 3	
Perforation = 4 = 100% corneal lesion	
Vascularization:	
(mm. area/20)	7
Total Maximum Response[a]	30 = 100%

[a]To obtain a single value for the maximum reaction to an injurious agent, the maximum values of each sign during the course of observation are added.

critical periods of observation are at two weeks, one month, and two months, after which the severity of the lesion usually diminishes unless secondary complications ensue. Ordinary focal illumination with or without a magnifying loupe is sufficient to grade the severity of the corneal lesions. From these observations

TABLE 3. RELATION OF LOAD IN OPHTHALMIC APPLICATORS TO DURATION OF TREATMENT

TYPE OF REACTION	RADON *50 mc.*	RADIUM *50 mg.*	RADIUM D-E *10 mc.*	RADIUM D-E *20 mc.*	STRONTIUM^{90}-YTTRIUM^{90} *Friedell, et al. 100 mc.*	STRONTIUM^{90}-YTTRIUM^{90} *Tracerlab 23 mc.*
Minimal Inflammatory Dose (Rabbit Cornea)	3.3 min. (W)	?	42 min. (W)	27 min. (Est.)	?	28 min. (W, K)
Vs. Superficial Vascularization (Human)	40–60 sec. (H)	5–7.5 min. (I, Est.)	10 min. (W) Also 3.5 min. every week for 3 weeks (S)	6.6 min. (Est.)	55 sec. every week for 4 weeks. (F)	8.7–10 min. (W)
Vs. Deep Vascularization (Human)	1.3–1.7 min. every 3 weeks for 1–3 doses (H)	10–12.5 min. every 3 weeks for 1–3 doses (I)	?	?	?	? 13.5–17 min. and repeated (Est.)

(W) Wilson (11, 12); (Est.) Estimated; (K) Kahn (13); (H) Hughes' applicator; (I) Iliff (3); (F) Friedell, *et al.* (7); (S) See references (5).

and grading, the percentage of the maximum response can be calculated for each exposure, an average can be obtained of eyes similarly exposed, and the standard error of the means calculated. As a rough approximation, the rabbit cornea is about three times more resistant to beta radiation than the human cornea. Roughly, the minimum inflammatory dose (MID) on the rabbit cornea (consisting of a definite nebular haze visible to oblique focal illumination without magnification) approximates three times the dose used to treat corneal vascularization in humans.

The importance of the quantity or load of radioactive material in ophthalmic applicators in relation to the duration of treatment is tabulated in Table 3. It is obvious that radon applicators which can be made as potent as 500 mc. possess the shortest treatment times. An exception is the preliminary report on the clinical effects of the laboratory model of the strontium^{90} applicator reported by Friedell and his associates in 1950 (7), in which they stated that good effects similar to those obtained by radon resulted from a 55-second application of strontium^{90} (5.4 rep per second) every week for four weeks. As will be pointed out later, such results have not been obtained from larger doses with the more powerful commercial model presently available (12).

In addition to the fact that more radioactive material can be efficiently incorporated in a radon applicator than in other types to reduce treatment times, it requires larger doses or more gram seconds of radium D-E or strontium^{90} to produce lesions of like severity of the rabbit's cornea compared to radon (Table 4). This is undoubtedly due in large part to filtration of the beta particles within the applicator itself.

In summary, the number of gram seconds dosage has no meaning unless the individual applicator is standardized either physically or on animal or human eyes. Not only are the outputs of different types of applicators with similar amounts of radioactive material different, but applicators of similar design and materials may show significant variations.

Roentgen Equivalent Physical ("rep"). With improvement in ionization chambers and techniques, the direct physical measurement of surface beta output has been utilized. It may be necessary

TABLE 4. REACTION OF RABBIT CORNEA TO EXPOSURES OF RADON, RADIUM D-E, AND STRONTIUM^{90} APPLICATORS

SEVERITY OF LESION (*Percent*)	NUMBER OF GRAM SECONDS		
	Radon	*Radium D-E* (*10 mc.*)	*Strontium*^{90} (*23 mc.*)
3	10	25	38
12	15	40	50
22	20	60	65
30	25	..	71
50	30	80	90
56	40	..	100
80	50	..	143+

to define the unit of measurement suitable for beta radiation (13). The roentgen or "r" is a unit applicable to electromagnetic radiations such as X-ray or gamma rays in which the photon energy is dissipated in 1 cc. of standard air, producing ions carrying one electrostatic unit of electricity and expending 83 ergs. per gram of air. This unit "r" gives no information concerning the energy of the photon or the time, so dosage rates for X-ray and gamma radiation are given in r per unit time with data concerning the energy (as voltage or half-value layer). If tissue ionization is produced by any primary radiation other than photons (as alpha, beta, protons or neutrons), then the unit r is not applicable. Instead, if the energy loss by beta particles in producing ionization in the tissues is the same as the energy loss for 1 r of X-ray or gamma absorbed in air (83 ergs per gram of tissue), the dose is spoken of as 1 roentgen equivalent physical ("rep"), or roentgen equivalent beta ("reb"). It is to be noted that 1 r of photons will have different degrees of energy dissipation in various tissues and at various energies; therefore 1 r of photons does not always equal 1 rep. Unfortunately, at the present time there is no method of measuring directly the amount of ionization in tissues; that is, a direct measurement of rep in tissue.

Measurement of the rep output of the radium D-E applicator was originally done by Evans (6) as surface output, and some variability was found between different applicators. He found that the surface dose rate was approximately 3.1 rep per second for the

10 mc. applicator and 4.7 rep per second for the 20 mc. applicator.

The surface output of the early laboratory model of the strontium^{90} applicator used by Friedell, *et al.* (7) was 5.4 rep per second. The individually certified commercial models, "RA-1 Medical Applicator," vary between 18 and 25 rep per second at the surface. Wilson (12) standardized a strontium^{90} applicator (RA-1 No. 29) with a stated output of 22.9 rep per second on the rabbit cornea, and his data are given in Table 5. Kahn (13) has standardized a

TABLE 5. RELATION OF GRAM SECONDS RADON TO REP STRONTIUM^{90} ON THE RABBIT CORNEA[a]

Severity of Corneal Lesion (Percent)	*No. of Gram Seconds radon*	*No. rep Strontium^{90}*	*Approximate No. rep/mc/sec (radon)*
3	10	35,000	3.5
12	15	45,000	3.0
22	20	60,000	3.0
30	25	65,000	2.6
50	30	83,000	2.8
56	40	92,000	2.3
80	50	>130,000	3±

[a]Data from studies by Wilson (11, 12), and Kahn (13).

similar applicator (RA-1 No. 18, with an originally stated output of 24 rep per second but which was later remeasured as producing 15 rep per second) on 17 rabbit eyes with essentially the same results. On the basis of an output of 24 rep per second, no corneal reaction was obtained with 29,000 rep, a minimal inflammatory dose was found to be about 36,000 rep, moderate to marked reactions were produced by 45,000 to 65,000 rep, and severe reactions resulted from exposures to 72,000 to 115,000 rep.

It was mentioned previously that physical measurement of the beta output of our Radon Applicator has not been done. However, in view of the similar depth doses of the particles from radioactive strontium^{90}-yttrium^{90} and radon, it is possible to obtain an approximation of number of rep/mc./sec. of radon by comparing doses of radon which produce corneal lesions of equal severity with known rep doses of strontium^{90} (see Table 5). From this biological comparison, the output of radon in the kidney-shaped applicator

which we have used was found to be approximately 2.5 to 3.5 rep/mc./sec. This would indicate that the usual clinical dose we have used varied between 6,000 and 16,000 rep (2-6 gm. secs.).

Although the number of gram seconds of radium D-E required to produce a corneal lesion in the rabbit equal in severity to that produced by radon is about two and one-half to three times, the actual number of rep of radium D-E necessary to produce an equal corneal lesion is only about one fourth the number of rep required by radon. This is probably due to the fact that there is a more concentrated absorption of the less energetic beta particles from radium D-E in the superficial layers of the cornea, resulting in an apparently more severe but probably more superficial lesion of the cornea.

Depth Dose. The surface dose rate of an applicator does not necessarily indicate the clinical effectiveness of the applicator. The depth dose which is of equal or greater importance depends on several factors: (*a*) the maximum and average energy of the beta particles, the maximum energy being related to the extreme depth to which the particles can penetrate, and the average energy giving information concerning the depth of the heavy ionization in the tissue; (*b*) the construction of the applicator, which may alter the energies of the beta particles by selective absorption or reduction in energy; and (*c*) the thickness of the radioactive source itself. Unfortunately, the true absorption of beta radiation in tissue cannot be measured directly because of the factors of scattering and inverse-square-law spreading. However, measurements with the ionization chamber at various depths in a phantom of pressed wood or lucite (which has similar absorptive powers as tissue) reveals the percentage of the surface dose which penetrates to various depths.

As stated previously, radium D-E produces a beta particle of lower energy than that from radon or strontium^{90}-yttrium^{90}, and therefore would be expected to result in more superficial absorption. This was found to be the case clinically. Available data suggests that strontium^{90} has slightly greater penetrability than radon (Table 6). Since the anterior surface of the lens is about 4 mm. back of the anterior surface of the cornea, the penetrability of the beta particles beyond 4 mm. might endanger the lens in eyes which re-

TABLE 6. DEPTH DOSES IN TISSUE PHANTOM (LUCITE) OF BETA OPHTHALMIC APPLICATORS[a]

	Radon	*Radium*	*Radium D-E*	Sr^{90}-Y^{90}	Ru^{106}-Rh^{106}
Content (mc.)	103–365	25 mg.	10	18.6	10
Diameter (mm.)	5	6–8	6–8	6–8	6–8
Inherent filtration	0.1 mm. glass	0.1 Mg.	0.05 Al or 0.1 Mg.	0.001 in. steel	0.25 Al
mg./cm².	30	17.4	13.5 or 17.4	20	67
Surface output (rep/sec.)	0.41 rep/sec./mc. (0.15–0.53)	40	9 (Al), 16 (Mg.)	32	6
	100%	100%	100%	100%	100%
1 mm.	20–50%	17%	10%	41%	55%
2 mm.	6–25%	8%	1%	19%	30%
3 mm.	3–10%	4%		9%	17%
4 mm.	2–5%	2%		4%	10%
5 mm.	0.8–3%	1%		1.2%	6%

[a]Data from Krohmer (5).

quire large doses of beta therapy. This will be discussed further under complications.

Requirements for Beta Radiation Ophthalmic Applicators. Because of the recent availability of beta ophthalmic applicators and the need for standardization and accurate information concerning such applicators, the Subcommittee on Ophthalmic Devices of the Council on Physical Medicine of the American Medical Association has listed several requirements for Beta Radiation Ophthalmic Applicators.

A. Accurate description of the applicator and output, including:
   1) quality of radioactive emanations: (*a*) ratio of beta:gamma; (*b*) energy of beta particles (maximum Mev, average Mev, and depth dosages);
   2) certification by the U. S. Bureau of Standards or by a qualified laboratory of the quantitative output for each individual applicator in rep surface output.
B. Adequate clinical and experimental trial to determine:
   1) corroboration of the output;
   2) clinical practicability: (*a*) technical ease of application; (*b*) therapeutic effect; (*c*) undesirable effects.

C. Advertising to include:
   1) information listed under A and B;
   2) no misleading statements;
   3) statements indicating that discrimination and caution are necessary in the use of beta radiation of the eye as for radiation therapy elsewhere in the body.

COMPARISON OF BETA RADIATION AND X-RAY

Raper (15) recently stated that

"it has long been assumed that beta rays would produce in biologic material effects similar or identical to those produced by X-rays or gamma rays, since these electromagnetic radiations expend their energy by the ejection from the atoms of the absorbing material of high speed electrons identical to the primary particles of beta radiation. Recent and as yet unpublished work performed under the Manhattan District Plutonium Project has shown this to be true, provided the distribution of energy absorption is comparable for the two types of irradiation."

Compared to radon, X-rays of 10-20 kv produce similar results in tissue. The Phillips contact therapy machine (16) which produces X-rays of 44 kv would produce somewhat deeper effects. The Bracke-Seib X-ray machine is capable of producing a range of voltage from 10 to 50 kv and therefore the tissue effects of this machine could be expected to emulate those produced by radon. The ordinary Grenz ray machine produces rays of 8 to 12 kv and therefore the clinical effects are relatively superficial compared to radon.

Compared to the use of X-ray, beta ophthalmic applicators have certain technical advantages. The ophthalmologist himself can apply the beta radiation to the portion of the eye which requires treatment, and can follow carefully the results of such treatments, usually by slit-lamp examination. In addition, ophthalmic applicators allow greater accuracy in the localization of treatment to the desired area without undue exposure of the adjacent tissue. Unless X-ray voltages of 10-20 kv are available, treatment of such conditions as corneal vascularization by X-ray might lead to undue exposure of the lens in order to obtain the desired superficial effects.

GENERAL INDICATIONS FOR BETA RADIATION

The indications for beta radiation are the same as for any other type of radiation such as X-ray. The effects of irradiation should be considered as essentially destructive, and there must be a differential sensitivity between the pathologic cells which are to be destroyed and the normal cells of the adjacent tissue. The relative sensitivity of the various cells has been determined previously by Desjardins (17) in the following order of decreasing sensitivity: lymphoid cells, polymorphonuclears, eosinophils, epithelium (conjunctiva, cornea, ciliary, lens), endothelium (vessels, cornea), connective tissue including the cells of the corneal stroma, muscle, bone, and nerve which includes the neural elements of the retina. Other factors which increase the sensitivity of cells include undifferentiation, immaturity, premitotic stage, active metabolism, and a large blood supply. Although the main indications for irradiation involve the differential destruction of pathologic tissue, infectious processes including pyogenic infections respond favorably to very low doses of all types of irradiation. This might be explainable by the production of immune bodies or possibly vasodilatation secondary to the irradiation. It is also well known that larger doses of irradiation have the adverse effect of inhibiting the reticuloendothelial system, resulting in fewer immune bodies and a detrimental effect on the improvement of the inflammatory condition.

GENERAL DOSAGES AND TECHNIQUE OF APPLICATION OF BETA RADIATION

The dosages recommended by other authors for the use of radium D-E and strontium^{90} have been listed in Table 3. Our experience has been limited to the use of a radon applicator, with which the following general dosages have been used. If the source of beta is in direct contact with the surface of the tissue, that is, if the glass needles are in direct contact with the eye or lids, the following doses are used as a guide: inflammatory lesions = 1 gm. sec.; initial dose and treatment for children = 3 gm. sec.; and corneal vascularization, tumors or vernal catarrh = 4 to 5 gm. sec. If the source of beta radiation is 1 to 2 mm. away from the tissue during treatment, an additional 1 gm. sec. may be added to the above dosage rates. The

effect of irradiation continues for approximately 2 to 3 weeks after treatment, and therefore any two treatments given within this interval produce cumulative effects. The usual interval between treatments is three to six weeks.

With the patient lying down, the eye is anesthetized with 0.5 percent pontocaine or perhaps better, 4 percent cocaine. A lid speculum is then inserted, and the patient is instructed to fix the eye in proper position to expose the treatment area which has previously been selected by slit-lamp examination. The applicator is then placed in direct contact with the portion of the eye or lid to be treated, and as little movement of the applicator or eye as possible is desired in order to avoid undue mechanical trauma. The majority of patients prefer that pontocaine ointment be instilled and the eye be covered for the first 24 hours after treatment, but this is not necessary in all cases. Cold compresses often aid the post-treatment discomfort. Beta radiation does not interfere with any other treatment which may be given concurrently.

Sterilization of the applicator is probably unnecessary in view of the concentrated ionizing effects of the radon. Zephiran and to a less extent alcohol loosen the adherence of the glass needles to the Duco cement.

CLINICAL USES OF BETA RADIATION

In 1948, a special beta radiation clinic was started at the Research and Educational Hospitals of the University of Illinois, in which Doctors Fred G. Cox, Fred M. Wilson, Carroll W. Browning, Albert C. Biegel, William H. Middleton, James E. McDonald, and I have participated. In addition, private patients are included who have been referred to the author by other ophthalmologists. From these sources, a total of 235 eyes in 196 patients treated with beta radon have been collected. The only cases which have been eliminated are those with inadequate observation, inadequate follow-up, or difficulty in evaluation of the case either because of inadequate beta therapy or important accessory therapy which might conceivably have had an important bearing on the outcome of the case. The cases are listed topographically without implication that the results in the first groups are better than those described later.

Within each separate anatomical location, however, the conditions which respond best to beta radiation are described first. The "total dose" is given in gm. sec.

OCULAR ADNEXA AND TUMORS OF CONJUNCTIVA

Eighteen patients were treated for various conditions of the lids and conjunctiva such as granulation tissue, papillomas, vascular dermoids, and basal cell carcinomas (Table 7).

Granulation Tissue. Three cases of exuberant granulation tissue appearing at the orifices of the Meibomian glands were treated satisfactorily with small doses of beta. Although granulation tissue is very sensitive to irradiation, the undesirable cosmetic defect of epilation especially of the upper lashes should be considered in the treatment of these conditions. Either the lashes should be avoided, the treatment limited to 1 or 2 gm. secs., or other cauterization methods should be employed.

Hemangiomas. Three subconjunctival hemangiomas were treated effectively. The great sensitivity of this type of tumor to radiation is illustrated in Figure 3; the tumor disappeared within three

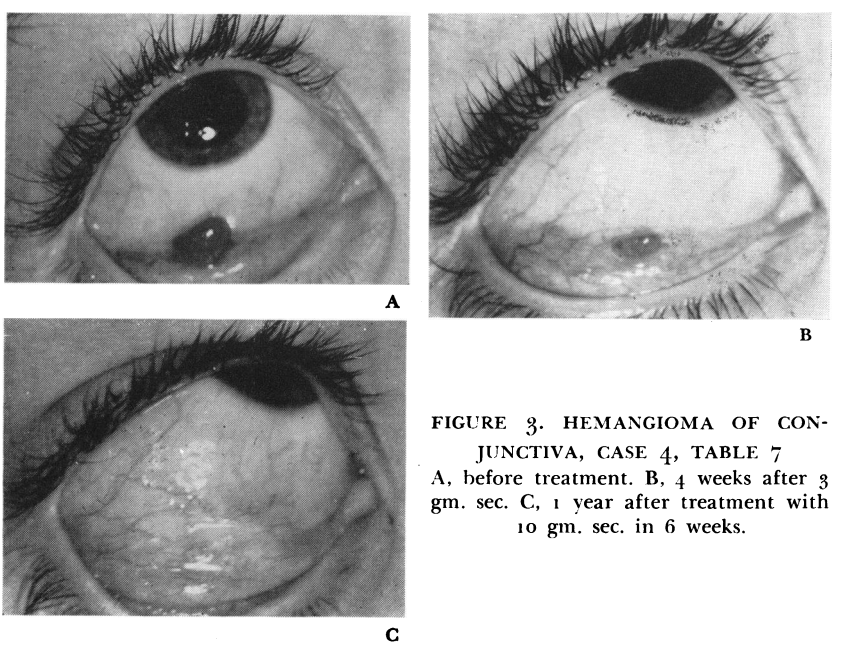


FIGURE 3. HEMANGIOMA OF CONJUNCTIVA, CASE 4, TABLE 7
A, before treatment. B, 4 weeks after 3 gm. sec. C, 1 year after treatment with 10 gm. sec. in 6 weeks.

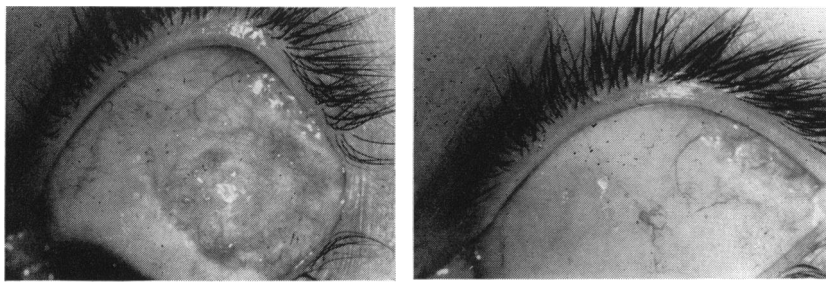
TABLE 7. OCULAR ADNEXA AND TUMORS OF CONJUNCTIVA
(18 CASES)

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		TOTAL DOSE (*Weeks*)	MONTHS FOLLOW-UP	COMMENTS
		Before	*After*	*Before*	*After*			
1 (59)	Chalazion			Granulation tissue, RLL.	Decreased	6 (2)	2	
2 (15)				(Biopsy) Granulation tissue, LUL.	None	12 (5)	4	
3 (45)	2 weeks: styes			Granulation over Meibomian duct.	Fibrous scar	4 (5)	10	
4 (9)	6 weeks			Hemangioma of conjunctiva	None	10 (6)	12	Fig. 3
5 (8 months)				Subconjunctival hemangioma 10×25×5 mm.	None	11 (7)	9	
6 (13)				Hemangioma in lid. 15×20×10 mm.	None	27 conjunctiva, 4 skin (31)	26	
7 (39)	8 years[a]	+	0	Papilloma of caruncle	None	10 (6)	5	
8 (40)	Years			Papilloma lower fornix and caruncle 20×30×20 mm.	None	15 (12)	3	
9 (64)	Also vascular keratitis			Papilloma lower lid near punctum	None	16 (4)	2	

[a] Symptoms: Before, +; After, 0.

10 (40)	Years. Recent growth	Wart, lid margin, 4×3×2 mm.	None	4+ (4)	6	Lashes lost after Rx, but regenerated after 6 months.
11 (15)	Dermoid removed 2 years ago. Recent "spreading."	Vascular dermoid, upper temp. sclera. 12×12 mm.	Pale, little mass.	20 (10)	20	Fig 4
12 (9 mos.)	Dermoid excised 2 months ago.	Residual V.[a] and CO.[b]	Less V.	3−		
13 (58)	1 year	Rodent ulcer inner canthus. 8×12×2 mm.	Healed	30 (24)	31	Fig 5
14 (76)	Biopsy	"Basal cell carcinoma" lower lid	Healed	35 (17)	8	
15 (58)	Biopsy	"Basal cell carcinoma" lower lid 15×10 mm.	None	20 (4)	12	
16 (45)	Incompletely excised. 2 months.	"Basal cell carcinoma" upper lid	None	19 (8)	31	Loss of lashes permanent. Half dose applied to conjunctiva and half to skin.
17 (78)	Removed 2 years. Recurred.	"Basal cell carcinoma" 8×5 mm. upper lid.	Recurred in 26 months.	20 (7) 3 (52)	26	5 months after first Rx—no tumor.
18 (59)	Previous radium Rx without improvement.	"Basal cell" carcinoma. Radium atrophy with edge of recurring tumor.	Persisted and extended into orbit.	29, nasally 34, center 20, temp. (total, 89)	25	Exenteration of orbit performed.

[a] V. = vascularization [b] CO. = corneal opacity



A B

FIGURE 4. VASCULAR DERMOID, CASE 11, TABLE 7
A, before treatment. B, 17 months after treatment with 20 gm. sec. in 10 weeks.

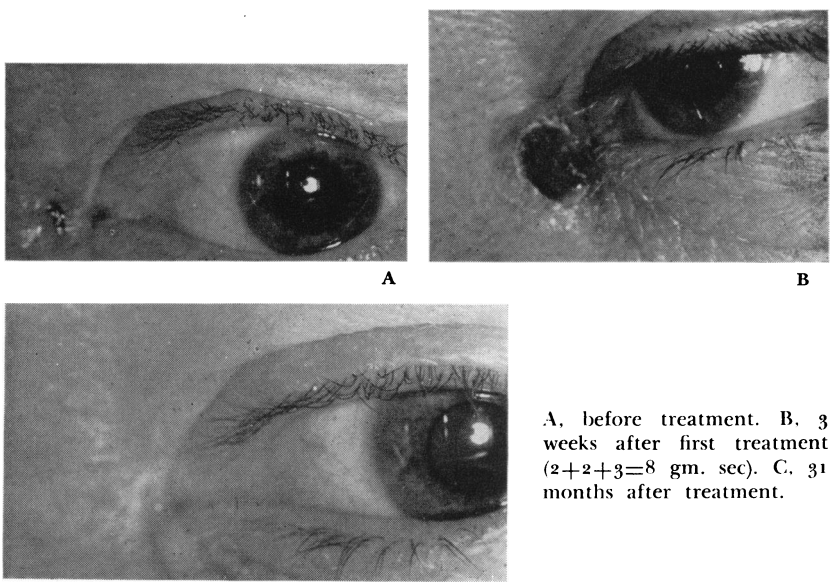
months after beginning therapy with doses of 3,4, and 3 gm. sec. at three week intervals. Objections to the use of radiation for hemangiomas have been raised because of the benign character of these tumors, occasional spontaneous regression, and undesirable post-radiational changes if large doses are necessary. Reese (19) has discussed other methods of treatment such as excision for small hemangiomas, carbon dioxide snow, sclerosing solutions such as 5 percent sodium morrhuate for larger lesions, or irradiation if other methods fail. Port-wine stains are considered to be insensitive to beta (1). If beta therapy is considered for other types of hemangiomas especially of the conjunctiva, only small doses of 2 to 3 gm. sec. should be used, with spacing of several weeks between treatments in order to utilize the minimum effective total dose.

Papillomas of Lid Margin and Conjunctiva. Four papillomas responded rapidly to doses of beta as low as 3 to 4 gm. sec. per area. This may be the treatment of choice for rather diffuse papillomas of the conjunctiva. However, papillomatous-appearing growths on the lid margin may sometimes be carcinomas or nevi. Therefore, in view of the frequent uncertainty of clinical diagnosis and cosmetically undesirable epilation after irradiation, excision and plastic closure is probably the treatment of choice for tumors of the lid margin.

Dermoids. Beta therapy was applied to vascularized areas of two patients from which dermoids had been excised previously (Fig. 4). Although the vascular and to a less extent the epithelial components of these tumors are sensitive to irradiation, much of the

dermoid tissue is not, and therefore primary excision is desirable. It should be remembered that, although persistent vascularity of such tumors can be blanched by irradiation, excessive doses of beta may result in the formation of ugly postradiational vessels a year or two after treatment.

Basal-Cell Carcinomas. Six cases of basal-cell carcinoma of the lid were treated with 19 to 35 gm. sec. of beta. Four cases showed no recurrence after relatively short-term follow-ups, and two recurrent cases again showed recurrences after beta radiation (Fig. 5). From a



A, before treatment. B, 3 weeks after first treatment (2+2+3=8 gm. sec). C, 31 months after treatment.

FIGURE 5. RODENT ULCER, INNER CANTHUS, CASE 13, TABLE 7

consideration of the depth-dose curves of beta applicators (Table 6), it is obvious that radium D-E could not be effective for tumors more than 1 mm. in thickness, radium, radon, and strontium^{90} for tumors more than 2 mm. thick, and Ru^{106}-Rh^{106} for tumors slightly thicker. For small basal-cell carcinomas on the lid margin, it is possible to radiate the entire thickness of the lid and tumor if the beta is applied to both the skin and conjunctival surfaces. Data are unavailable for a dosage schedule of beta adequate for the cure of

TABLE 8. PALPEBRAL VERNAL CATARRH
(15 CASES)

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENTS
		Before	*After*	*Before*	*After*			
1 (18)	Years. Seasonal. Other allergies.	++	0	Cobblestones. D[a]++. Pannus 2 mm.	Flat scars. No recurrence.	23 (10)	20	LE. Fig. 6 (5 months after starting treatment).
	Same as LE	++	0	Same as LE	0	18 (10)	20	RE
2 (14)	1 yr.	+++	++	Several large papillae. 2 mm. pannus. Slight ptosis.	Few papillae	4 lid 2 cornea	30	
3 (22)	16 yrs. 8 mos. ago had 500 r of X-ray and 8 min. radium D-E without improvement.	++++	++	"Pavement stones"++++, pannus 2 mm., punctate erosions of cornea above.	Papillae+++	42 (66) +3 cornea	17	RE. "Bleeding telangiectasis" 4 wks. after 37 gm. sec. in 58 wks.
	16 years, ? X-ray Rx.	++	0	Small papillae	0	9 (5)	17	LE
4 (10)	2 yrs.	++	0	Papillae++, 1 mm. pannus.	Papillae+	10 (4)	17	RE
	2 yrs.	+++	+++	Papillae+++, 1 mm. pannus, limbal vernal, small ulcer.	Papillae++, scarring, cornea clear.	54+ 11 cornea (58)	17	LE
5 (9)		++	0	Papillae++	Papillae 0	29 (21)	13	RE
		++	0	Papillae++	Papillae 0	25(16)	13	LE
6 (11)	Years No allergies	++	0	Papillae+++ D++, Ptosis 1 mm.	Papillae+ D = 0	13 (5)	10	

[a] D = Discharge

7 (22)	Symptoms March-Oct.	+++	o	Papillae++, D+.	o	17 (15)	10	RE
		+++	+	Papillae++, D+	o	17 (15)	10	LE
8 (25)	5 yrs., May-Nov.	+	o	Papillae+	o	12 (6)	17	RE
		++	+	Papillae++	o	25 (12)	17	LE
9 (10)	Years	++	o	Papillae+++	o	34 (20)	18	
10 (13)	2 yrs., Pyribenzamine helped slightly.	+++	+	Papillae+++	Pale and glistening. Papillae o.	35 (11)+ 4 (44)	44	RE
	Same as RE	+++	+	Papillae+++	Same as RE	35 (11)+ 16 (50)	44	LE
11 (14)	Years	++++	+	"Pavement stones" 3 mm. high++++ D+++, Ptosis	Papillae o, streaks of scar, less ptosis.	60 (13)+ 6 (53)	39	RE. Few symptoms summer after Rx.
	Years	++++	+	Same as RE	Same as RE	66 (13)+ 7 (53)	39	LE
12 (15)		++	o	Hyalin, D+. Papillae+.		10 (4)	16	RE
		++	o	Papillae+++, D++, ptosis, central ulcer and V. above.	Papillae flattened, D = o, V = o, CO = ±.	44 lid (24) 16 cornea (10)	16	LE
13 (13)	Onset age 6, Rx X-ray and dry ice.	++++	o	Pavement stones++++, D++++ Ptosis.	Papillae+ D = o, less ptosis	82 (24)	24	RE. Approximately 40 gm. sec. to each area of lid.
	Same as RE	++++	o	Same as RE	Same as RE	83 (24) +6 (36)	24	
14 (25)	No benefit from Cortisone.	++	o	Papillae++	Flattened.	6	3	LE
15 (18)	1+ years, "Electric needle" Rx.	+++	o	Cobblestones, D+.	Flattened.	20 (13)	3	After 11 gm. secs., flattened papillae, no itching.

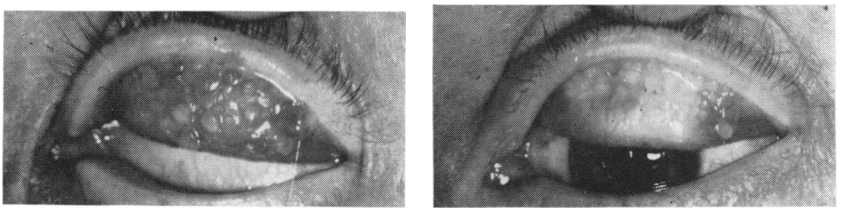
superficial basal-cell carcinomas, and it is difficult to translate the necessary X-ray or gamma-ray dosages for such tumors into terms of beta particles emanating from various applicators. In general, from 3000 to 6000 r of 100-200 Kv X-ray or gamma rays are necessary either in a single dose or within a period of a few weeks (19). The dose of 20 to 30 gm. sec. used in the six cases with our beta-radon applicator would indicate that roughly 6000 to 9000 rep would reach a level of 2 mm. in the tissue, using the data of Table 5. If irradiation is considered desirable for tumors which might extend more than 2 mm. in depth, X-ray or possibly gamma therapy should be instituted with adequate protection of the eye by lead shields.

The cosmetic results of a basal-cell carcinoma of the lid cured by irradiation is not a completely happy one, because of the ischemia produced, some loss of tissue, epilation, and later telangiectases. For tumors involving less than one third of the lid margin, better cosmetic results can be obtained by proper surgical excision and closure utilizing some procedure such as the Wheeler halving operation to prevent notching of the lid margin.

VERNAL CATARRH

In this series, 25 lids with vernal catarrh were treated in 15 patients. Approximately 12 of these had large papillae of "pavement stone" size and some hyalin formation, and in five the thickening of the lid was sufficient to cause some ptosis. Six of those with large excrescences also showed a 1 to 2 mm. superficial pannus at the upper limbus, some with superficial punctate erosions of the corneal epithelium above. Only one case of the palpebral form also had the limbal manifestations. Nine eyes of seven patients showed limbal vernal catarrh.

Palpebral Vernal Catarrh (Table 8). In general, all but possibly two cases responded well both subjectively and objectively to beta therapy. The disappearance of tenacious discharge and improvement of symptoms preceded complete disappearance of all the papillae, especially of the cobble-stone variety. Whereas early papillae disappeared after 5 to 10 gm. secs., large vegetations associated with hyalinization required as much as 40 gm. secs. in each area over a period of more than six months. Such large vegetations



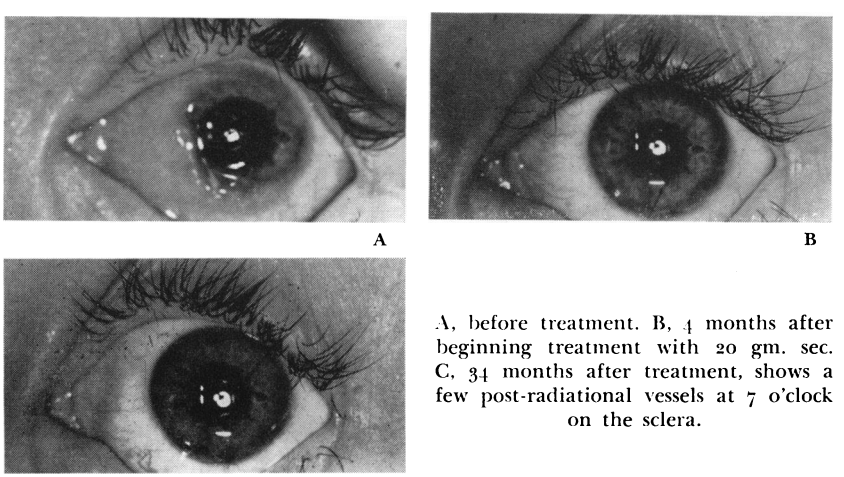
A B

FIGURE 6. CASE 1, TABLE 8

A, before treatment. B, 5 months after first treatment, total dose 23 gm. sec.

gradually became flatter as if the surface were being planed off, and no attempt was made to eliminate them entirely if the symptoms were ameliorated (Fig. 6). Although many of the patients had a history of allergy or an exacerbation of symptoms during hot weather, the recurrence of symptoms the following season after beta therapy was often less severe.

Limbal Form of Vernal Catarrh (Table 9). The gelatinous and sometimes milky tissue of the limbal form of vernal catarrh responded well to relatively small doses of beta radiation (Fig. 7, 8, and 9). After three years in one case (Fig. 7c), a few engorged post-radiational vessels appeared adjacent to the treated area. The cosmetic result of another case (Fig. 9c) was marred by the partial ischemia outlined by a few persisting and enlarged vessels.



A B

C

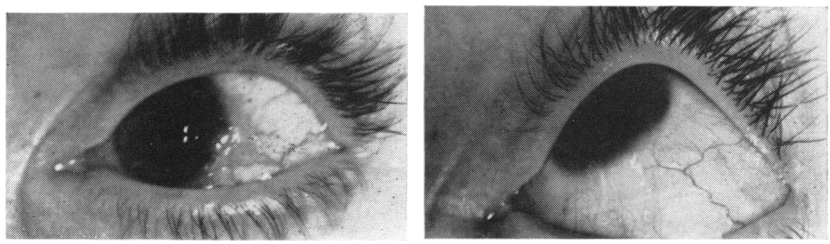
A, before treatment. B, 4 months after beginning treatment with 20 gm. sec. C, 34 months after treatment, shows a few post-radiational vessels at 7 o'clock on the sclera.

FIGURE 7. VERNAL CATARRH OF LIMBUS, L.E., CASE 1, TABLE 9

TABLE 9. LIMBAL VERNAL CATARRH
(7 CASES)

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENTS
		Before	*After*	*Before*	*After*	*Before*	*After*			
1 (16)	7 yrs. Eczema. Sensitivities.	+++	+	Gelatinous.	0 Few late radiational vessels.	50	20	20 (16) LE	36	Fig. 7. RE untreated, and the vernal tissue persisted.
2 (20)	Recurrent. 2 previous radium Rx 8 and 6 wks. ago.	++	0	See Fig. 8a.	0			12+ (4)	33	Fig. 8
3 (48)	6 months.	++	0	Fig. 9a.	Ischemia and post-radiational vessels.	20	25	10 (4)	13	Fig. 9 (RE).
	6 months.	++	0	Same as RE	Same as RE	20	25	10 (4)+ 10 (10)	13	LE
4 (17)	"Followed scarlet fever at age 6."	++	0	Gelatinous tissue from 7–10 o'clock. V. for 2 mm. on cornea.	? Clear			16 (5)	3	Both eyes same appearance, treatment and result.

5 (6)	1 year	++	0	Milky tissue over limbus, 2 mm. above and 1 mm. below.	0	4 (45)	29	One recurrence which responded to treatment.
6 (8)				Milky tissue 2 mm. over limbus.	0	6	31	
7 (57)	9 months	++	+	Milky tissue 5 mm. around entire limbus.	0	34 (9)	11	Irritability of eye after 22 gm. sec. in 6 weeks.

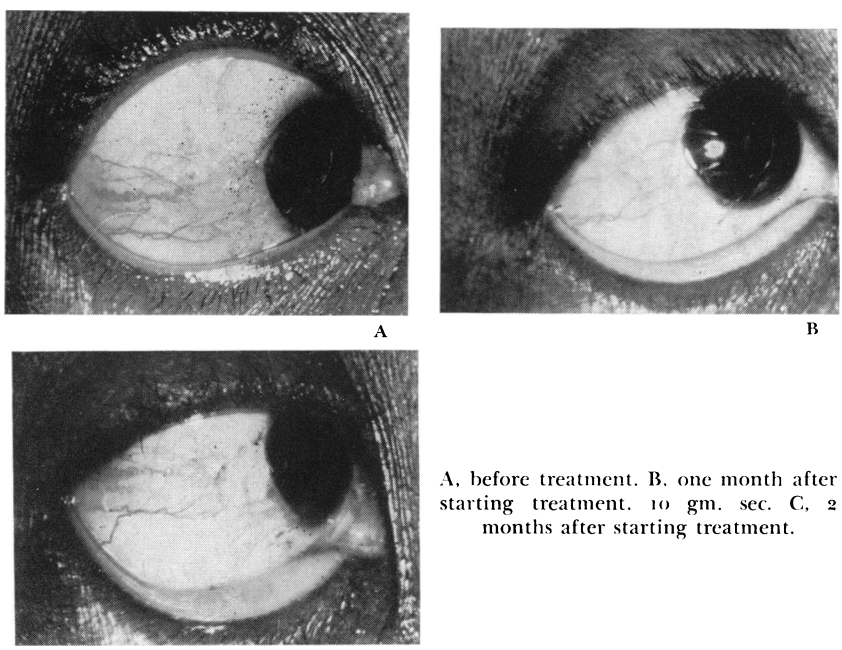


A B

FIGURE 8. VERNAL CATARRH OF LIMBUS, CASE 3, TABLE 9
A, before treatment. B, 3 months after beginning treatment with 12 gm. sec.

TUMORS OF LIMBUS AND CORNEA

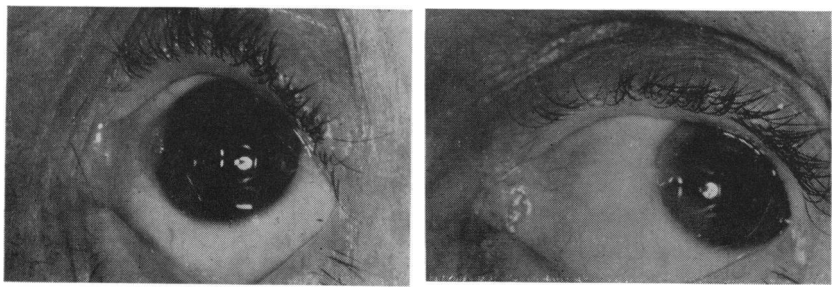
Masses located at the limbus and encroaching over the cornea may require biopsy for diagnosis, and at times mimic the tissue seen in vernal catarrh of the limbus. Nine such tumors of the limbus and cornea are included in this series (Table 10).



A B C

A, before treatment. B, one month after starting treatment. 10 gm. sec. C, 2 months after starting treatment.

FIGURE 9. VERNAL CATARRH OF LIMBUS, CASE 3, TABLE 9



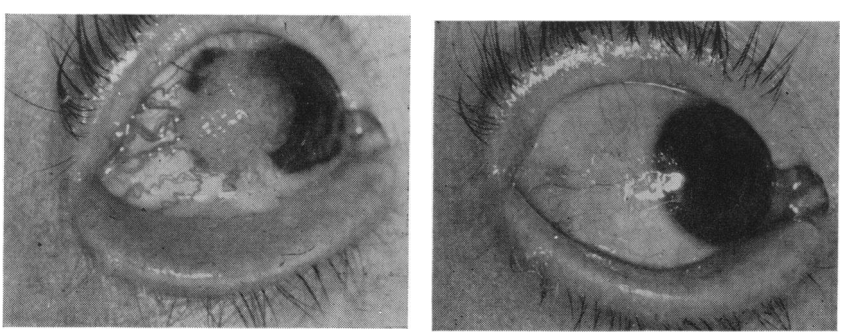
A B

FIGURE 10. BENIGN TUMOR OF LIMBUS, CASE 2, TABLE 10
A, before treatment. B, 5½ months after starting treatment, 16 gm. sec.

Pinguecula. Only one rather vascular pinguecula was treated with beta radiation. Although the small vessels overlying the pinguecula disappeared, there was no change in the underlying mass itself. This might well be expected to be resistant to irradiation because a pinguecula consists of hyalinized material and fibroblastic proliferation. In view of the benign nature of pingueculas, it is doubtful whether they should ever be treated with beta radiation.

One patient presented a rather flat tumor of the limbus which encroached over the cornea and was suggestive of a neoplasm. Biopsy showed a nodular fibroelastic thickening with calcification. Subsequent treatment with beta radiation resulted in its cosmetic disappearance (Fig. 10).

Conjunctival Nevi. Only one nevus located at the limbus and



A B

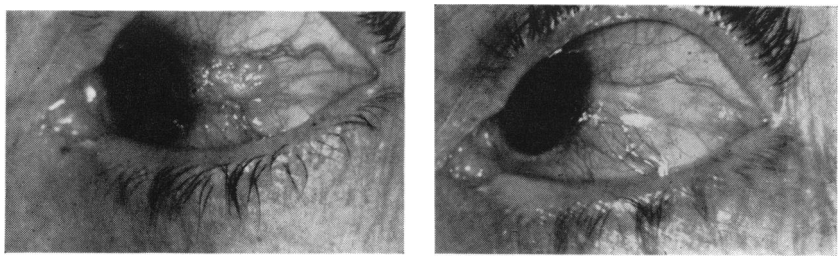
FIGURE 11. CONJUNCTIVAL PAPILLOMA AT LIMBUS, CASE 3, TABLE 10
A, before treatment. B, 5 months after starting treatment, 9 gm. sec.

TABLE 10. TUMORS OF LIMBUS AND CORNEA

(9 CASES)

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENTS
		Before	*After*	*Before*	*After*	*Before*	*After*			
1 (54)				Pinguecula V++	Avascular			6 (4)	3	No effect on pinguecula.
2 (62)	6 months			Nodule adjacent to limbus	Ischemia with dilated vessels around it			16 (12)	31	Biopsy: "nodular fibroelastic thickening with calcification." Fig. 10
3 (79)	6 months	Foreign body sensation		See Fig. 11a.	Site almost avascular, mass gone.			9 (2)	8	Biopsy: conjunctival papilloma. Fig. 11
4	18 months			6×12 mm. spongy red mass	0			58 (13)	6	Biopsy: papilloma
5 (81)				Band-shaped opacity. See Fig. 13a.	Opacity cleared	50	30	7 (3) +18 Radium D–E	37	Biopsy: Bowen's Disease Fig. 13

6	4 months		Milky tumor spreading over cornea (Epithelioma)	0	25	15−	23 (6)	9	Eye markedly irritable 2 mos., slightly irritable for 3 mos.
7 (73)	2 months		6×9 mm. mass	Mass gone; dilated vessels			14 (8)	3	Biopsy: "Epidermoid Neoplasm". Fig. 12
8 (58)	Recurrent growth		Vascular lesion from upper to lower fornix, deeper extension.	Tumor over sclera cleared			66 (22)	5	Biopsy: Squamous cell carcinoma. Also given 7000 r X-ray after beta Rx for deeper extension
9 (74)	Recurrent		2×3×1 mm. frosty white nodule	0			5	29	Biopsy: "Cancer"

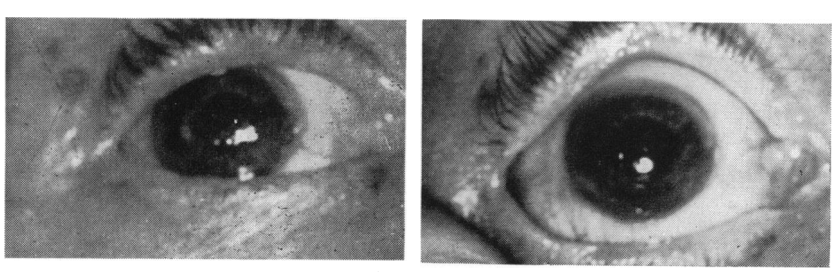


A B

FIGURE 12. EPIDERMOID CARCINOMA OF LIMBUS, CASE 7, TABLE 10
A, before treatment. B, 3 months after starting treatment, 14 gm. sec.

not included in Table 10 was treated. The vascular elements of the nevus disappeared and the pigment of the nevus was scattered somewhat, but there was no clinical evidence that the nevus itself had disappeared. This is in agreement with other reports of the radio resistance of nevi.

Epithelial Tumors of the Limbus. Seven epithelial tumors of the limbus of both benign and locally malignant characteristics were treated with beta radiation (Fig. 11, 12, 13). All responded dramatically, the tumor disappearing in each area treated with 5 or 6 gm. secs. When such superficial tumors disappear after beta therapy, the underlying cornea is clear. Surgical excision usually results in more scarring, and an occasional recurrence which requires further surgery. If X-ray is used for such tumors, care must be taken to avoid dosages which may damage the lens. For these reasons, beta radiation probably represents the treatment of choice in all forms of superficial epithelial tumors of the limbus and cornea.



A B

FIGURE 13. BOWEN'S DISEASE, CASE 5, TABLE 10
A, before treatment. B, 2 months after starting treatment, 7 gm. sec. + 18 gm. sec. Radium D-E.

PTERYGIUM

Beta radiation was used as a primary form of treatment in twenty-seven pterygiums, and as a treatment for pterygiums which had recurred after operation in twenty-five cases. The amount of beta radiation required varied with the number, size and depth of the vessels, actively growing capillaries of recurrent pterygiums being more sensitive.

Primary Treatment of Pterygium (Table 11). A total of 5 to 12 gm. secs. of beta radiation will usually eliminate vessels from the corneal portion of a pterygium. Evidence favors the belief that the actively growing portion of the pterygium consists of the vascular elements of the subconjunctival tissue. To produce complete ischemia of the episcleral and subconjunctival vessels adjacent to the pterygium required total doses up to 30 gm. secs. In a few instances after one to two years, there was a tendency for an encroachment onto the surface of the cornea of a few dilated postradiational vessels above and below the ischemic areas.

The late cosmetic results of the beta radiation treatment of pterygiums as a primary measure was often disappointing. Although the tip of the pterygium usually remained avascular, any residual white tissue, especially in a person with a dark brown iris, was quite noticeable. In addition, an ischemic area at the limbus surrounded by dilated, sausage-shaped, postradiational vessels is certainly unattractive. Therefore, surgical treatment is recommended as a primary measure unless there are strong contraindications such as age or aversion to surgical procedures.

Recurrent Pterygiums. (Table 12). Pterygiums which recur after operation often represent an exasperating problem which may necessitate several operations, resulting in the formation of scar tissue which limits free movements of the eye. The encroachment of a few capillary vessels across the limbus following an operation for pterygium were destroyed by total doses of beta radiation as low as 5 to 12 gm. secs. More fleshy recurrences, especially those which had recurred several times, and in which it was thought desirable to destroy the vascular base of the pterygium, required much higher doses. In such cases, the cosmetic considerations are outweighed by the desirability of preventing a recurrence of the

TABLE 11. PRIMARY TREATMENT OF PTERYGIUM
(19 CASES)

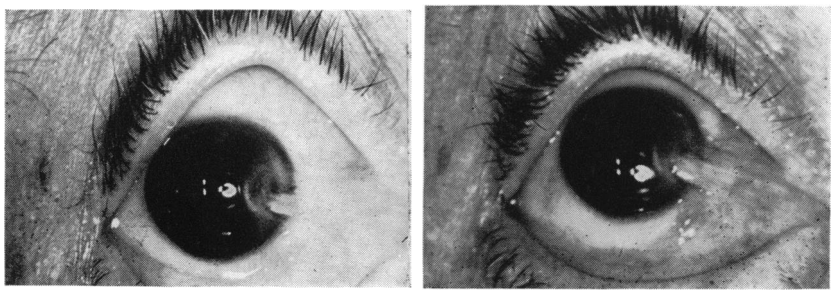
PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENTS
		Before	*After*	*Before*	*After*			
1 (28)				1 mm. V+	Avascular	22 (32)	14	
2 (70)				2.5 mm. V+	Avascular	21 (23)	12	
3 (68)	After repair of of prolapsed iris.			Vascular flap	Avascular	17 (16)	5	Pseudopterygium
4 (57)				4 mm., V+++ E++	Avascular	14 (16)	15	
5 (77)				3 mm., V+++	Avascular on cornea. Hyperemia adjacent	12 (52)	11	RE
6 (33)				2.5 mm., V+++, thick.	Head avascular	8 (3)	5	
7 (77)				2 mm., V+++	Avascular on cornea. Hyperemia adjacent	11 (28)	15	LE
8 (26)	Recent growth		"gritty"	1 mm., V++	Head avascular	10 (16)	6	
9 (41)				2 mm., V++ 3 mm., V++	V+, 1 mm. Constricted VV 1 mm.	12 (20) 12 (20)	14 14	"Pink eye" 5–8 mos. after treatment
10 (41)	15 yrs.			3.5 mm. V++++	Calcified head with cholesterol crystals, dilated scleral VV	17 (15)	23	Cosmetic blemish. Rx, Excision of white scar
11 (66)	10 yrs.			4 mm., V+++	Ischemia	29 (20)	7	RE
				1 mm., V+	Ischemia	17 (8)	3	LE

12 (30)	5 mos.	2 mm., V++	Superficial ischemia, post-radiational VV 2 mm. on cornea	16 (11)	25	Cosmetic blemish
13 (47)		V+++	Ischemia	10 (2)	16	RE. Small residual vessel at 1 year disappeared after 16 mos.
		V++++	1 small capillary	28 (13)	15	
14 (22)		1 mm., V+++	Avascular	5 (6)	4	
15 (15)		1 mm., V++	Flat, no VV.	9 (4)	21	
16 (38)	RE nasally	2 mm., V++	Ischemia	30 (20)	22	? Pseudopterygia.
	RE temp.	2 mm., V++	Ischemia	25 (16)	22	Thread-like material
	LE nasally	2 mm., V++	Capillary twigs	30 (20)	22	under conjunctiva.
	LE temp.	1 mm., V+	Capillary twigs	6	17	After 34 gm. secs. in 10 wks. (17×2 areas each eye), extreme photophobia lasting 2 mos.
17 (29)	RE—1 year	2 mm., V+	Ischemia	5	23	
	LE—3 years	2 mm., V+++	Postradiational vessels	10 (28)	23	LE—Superficial ischemia, and 5 mos. later, sausage-shaped vessels. Cosmetically bad.
18 (57)		4 mm.	8 mos., ischemia 15 mos., post-radiational vessels 2 mm. on cornea	38 (35)	15	Superficial ischemia after 13 gm. sec. Resistant deep vessels after 25 gm. sec.
19 (52)	RE—1 year	2 mm., V+	V±	5	2	Severe reaction lasting several weeks.
	LE—1 year	2 mm., V+	V±	5	2	

TABLE 12. RECURRENT PTERYGIA
(20 CASES)

PATIENT (AGE)	HISTORY PREVIOIS RX	SYMPTOMS		SIGNS		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENTS
		Before	*After*	*Before*	*After*			
1 (75)	Oper. 4 times		0	CO++, A5, V++	Avascular tip	35 (81)	25	Fig. 14
2 (48)	Oper. 3 wks.			1 mm.	Cornea avascular. Loops to limbus.	8 (4)	35	RE
	Oper. 3 mos.			2 mm., V+++	CO+ (4 mm.). Postradiational VV, 1 mm. loops of VV on cornea.	8 (4) 5 (52)	35	LE. Fig. 15
3 (25)	Oper. 2 mos.			V+ (2 mm.)	Avascular tip	18 (29)	32	
4 (57)				V+ (2 mm.)	Ischemia	10 (8)	5	
5 (57)				CO 3 mm., V++	Avascular	4	39	RE
	Oper. 2 times			CO 3 mm., V+++	Avascular	29 (45)	39	LE
6 (64)	Oper. and trichloracetic acid.			2 mm.	Avascular	16 (9)	8	
7 (60)	Oper. 3 mos.				Avascular tip. Few trunk VV on sclera	28 (46)	26	
8				V+ (2 mm.)	V = 0	9 (6)	35	
9	Oper. 10 mos.			V++ (2 mm.)	2 capillary loops 1 mm.	6	12	

10 (31)	Oper. 6 wks. Cauterized 2 times.		V++ (1 mm.)	Ischemia	6	6	RE
	Oper. 6 wks.		V+ (1 mm.)	Ischemia	6	6	LE
11 (31)	Oper. twice.		V+++ (2 mm.)	Ischemia. Dilated VV around area	18 (14)		Irritation 2 wks. after third treatment
12 (33)	Oper. 7 mos.		V++ (2 mm.)	Ischemia except for one long V	12 (8)	10	
13 (55)	Oper. 5 times	+	V++++ (4 mm.)	Yellow plaque at tip. Post-radiational VV lower edge 3 mm.	17 (24)	33	Photophobia for 2 mos. after 13 gm. sec. in 4 weeks. RE irritation in wind after 33 mos.
		+	V++ (2 mm.)	Semi-constricted VV 1.5 mm. Ischemic tip	12 (24)	33	LE
14 (49)	Oper. 3 yrs.		V++ (2 mm.)	Ischemic tip	12 (12)	9	Eye irritable for 3 wks.
15 (44)	Oper. 4 times	±	V+++ (3 mm.) 9 mm. wide	Ischemia	49 (73)	29	Slight persistent blurring
16 (61)	Oper. 8 days		V+ (1 mm.)	Ischemia	7 (5)	36	
17 (50)	Oper. 3 times	?±	V++ (2 mm.)	Ischemic tip	15 (7)	12	Persistent "scum" on eyes. Vision, 20/20
18 (30)	Oper. 3 mos.	0	V+++	Ischemic tip	10 (6)	12	RE
	Oper. 3 mos.	0	V+++	Ischemic tip	20 (28)	12	LE
19 (72)	Oper. 8 mos.		V++ (4 mm.)	2 constricted capillaries (3 mm.)	12 (6)	12	
20	"Excision of benign epithelioma"		V+++ (2 mm.)	Avascular. No recurrence	5	30	Pseudopterygium



A B

FIGURE 14. RECURRENT PTERYGIUM, CASE 1, TABLE 12 (4 OPERATIONS)
A, before treatment. B, 13 months after 35 gm. sec.

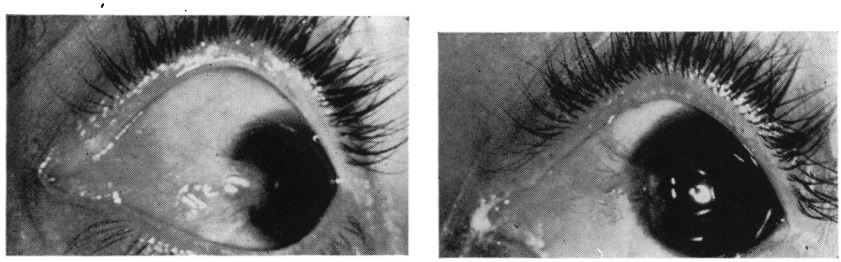
growth, and beta radiation may therefore be preferable to repeated surgical procedures (Figs. 14 and 15).

CONJUNCTIVAL DISEASES

There were 8 patients in this group (Table 13).

Extremely severe *folliculosis* of the lids and globes of one patient was treated with a maximum of 13 gm. secs. to any one area over a period of 10 weeks. This resulted in an elimination of the follicles although a few small papillae remained and the symptoms were improved although not entirely eliminated.

Seven eyes with stage IV trachoma were treated with beta radiation. In one case 5 gm. secs. was applied to produce epilation and relieve the trichiasis. The other four cases (five eyes) received from 16 to 55 gm. secs. total dosage to the corneal and limbal region in an effort to eliminate corneal vascularization and possibly improve



A B

FIGURE 15. RECURRENT PTERYGIUM, CASE 2, TABLE 12
A, before treatment. B, 35 months after 13 gm. sec.

vision. Rather disturbing exacerbations of symptoms occurred in every case. Vision was improved in one eye and became worse in another eye. Otherwise the vision remained the same and the cornea showed little change except for some reduction in the vascularization.

One case of conjunctival shrinkage associated with corneal opacification and *epidermolysis bullosa* obtained little benefit from a total of 25 gm. secs. of beta over a period of 83 weeks. One patient with systemic *pemphigus,* bilateral vascularizing keratitis, and shrinkage of the conjunctiva was treated with a total of over 50 gm. secs. to each eye. Vascularization was at one time eliminated and vision improved from hand motions to counting fingers at 3 feet, but the vascularization partially recurred, the eyes remained irritable, and visual improvement was slight.

CORNEAL VASCULARIZATION

The appearance of corneal vascularization in certain acute inflammatory conditions of the cornea such as interstitial keratitis is often accompanied by a general improvement of the keratitis and resorption of the infiltrates. However there are several undesirable features of corneal vascularization, among which may be mentioned: (*a*) scarring and irregularity of the cornea which not only reduces vision but makes a later keratoplasty more difficult, (*b*) the late development of secondary opacification around the vascular channels, and (*c*) a persistent edema and ocular irritability which may be a direct result of the presence of corneal vascularization. Elimination of corneal vascularization by surgical methods, diathermy, or cauterization frequently results in only temporary benefit, and the vessels once again cross over the cauterized area. On the other hand, the ischemic areas produced by beta radiation are more lasting, and vessels do not readily cross such treated areas. Beta radiation selectively destroys the endothelium of the vascular channels, at first producing petechial hemorrhages in the treated area followed by progressive generalized and localized shrinking of the size of the lumen of the larger vessels and finally complete disappearance of the entire vessel. No shadow vessel can be detected in the cornea by slit-

TABLE 13. CONJUNCTIVAL DISEASES

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENTS
		Before	*After*	*Before*	*After*	*Before*	*After*			
1 (26)	1+ yrs. allergies	++	+	Folliculosis +++ lids and globes	Few papillae			30 (10)	19	RE. 13 gm. sec. maximum in any one area
		++	+	Same as RE	Same as RE			24 (10)	19	LE. Maximum 12 gm. sec. in any one area
2 (50)	Trachoma, stage 4	+++	+++	CO+, V+++	CO+, islands of blood, V++ E[a]++	70[c]	40+	32 (15)	25	Severe photophobia for 5 wks. after 24 gm. sec. in 10 wks.
3 (55)	Trachoma IV	++	++++	CO+, V+++	CO++, V++	60	C.F.	19 (7)	33	Acute flareup 31 mos. after last Rx.
4 (44)	Trachoma, stage 4. Superficial keratectomy 1 wk. ago	+++	+++	CO+++, V+++, U[b]++	CO+++, V+, Calcium++	HM	HM	55 (70)	40	Exacerbations after 15 gm. sec. and after 38 gm. sec. in 22 wks.
	Trachoma IV	+++	+++	CO++, V++	CO+, V+	CF 5′	3/200	15 (12)	21	"Bad reaction" after 15 gm. sec.

5 (64)	Trachoma IV			Trichiasis	Epilation			10	5	"Worse" 4 wks. after treatment
	Trachoma IV			Trichiasis				5	5	Flareup 2 wks. after Rx
6 (50)	Trachoma IV	++	0	V++++ Keratoconus	Avascular in Rx area	300	300	16 (16)	6	"Eye flare-up every time patient has beta," lasting 2 mos. after 16 gm. sec. in 16 wks.
7 (20)	Epidermolysis bullosa			Conjunctival shrinkage CO++++, V+	No change	HM	CF	27 (83)	25	
8 (65)	3 yrs. systemic pemphigus	+++	++	CO+++, V++++, shrinkage of conjunctiva	CO++, V+, E++	HM	CF	39 (32) 20 (15)	24	RE
				Same as RE	Same as RE	HM	HM	51 (32)	24	LE

[a] E = Edema [b] U = Ulceration [c] 70 = 20/70

TABLE 14. ROSACEA KERATITIS WITH ROSACEA DERMATITIS
(11 CASES)

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENTS
		Before	*After*	*Before*	*After*	*Before*	*After*			
1 (54)		++	0	CO+++, A^a5, U+, V++	CO++, V=0 Calcium	30+	20	12 (4)	4	
		+	0	Infiltration 1 mm., V+	Nebular	15	15	6	2	
2 (26)		++	0	Infiltration 2 mm., V 2 mm., velvety lids	Cleared	15	20+	11 (3) +6 to lids	18	
3 (52)	6 yrs., "ulcers"	++	0	CO+++, A6, V+++, U+	CO++, A5, V+ (new 2 mm. loops)	400	80−	30 (26)	18	
4 (64)	Many years allergies	++	±	Infiltration 4 mm., V+++	Healed. Few capillary loops	20	25+	11 (7)	4	Infiltration gone 4 wks. after 6 gm. sec. in 3 wks.
5 (43)	2 attacks	++	0	Infiltration 4 mm., V++	Healed, V = 0	25	25	10 (3)	2	Healed 3 wks. after 4 gm. sec.
6 (50)	8 yrs., allergies	++	0	CO+, A9, V+++	Healed. CO±, V+	30	25−	23 (8)	34	Untreated other eye became worse

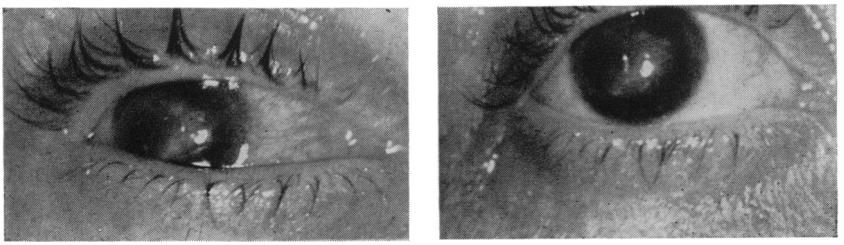
7 (55)	2 yrs.	+++	0	Central CO+++ with lipoid, V++	CO+	100+	60+	34 (27)	38	RE, Fig. 16
	10 yrs.	+++	+	Same as RE	CO++, V = 0	CF	60	25 (46)	16	LE. After beta, penetrating keratoplasty with secondary glaucoma.
8 (47)	7 yrs., ulcers, allergies	++	±	CO+++, A5 V++		40+	40	8	26	
9 (26)	4 yrs.	++	0	CO+, E++, V+ (2 mm. peripherally)	?	200	?	24 (24)	8	
10 (23)	4 yrs.	++	++	CO+++, A3×7 mm. cornea 1/3 normal thickness. Trunk vessel	CO+±, V = 0. E+. Post. synechiae. Tension = 40	60−	CF	18 (16)	28	? Perforation, anterior synechiae and glaucoma. Only limbus treated.
11 (45)	3 yrs. no allergies.	++++	+	CO++, V++++, E++.	CO+, V = 0. E+. Cataract developed 30 mos. after starting Rx, extracted without immediate complication	HM	100− (8 mo.)	44 (18)	36	Blepharospasm ++++ before Rx. Fig. 17

[a] A5 = Area of 5 mm.

lamp examination following successful radiation therapy. Cases which have had extremely marked corneal vascularization may end up with a cornea of reduced thickness after disappearance of the vessels.

Vessels in all layers of the cornea can be reached by beta radiation from radon and presumably from strontium^{90}, and to a less extent with radium D-E. Superficial vessels can usually be eliminated by one or two doses of 4 to 5 gm. secs. each at an interval of 3 to 6 weeks. Deeper vessels or vessels of greater size may require three or four such treatments. No more than two areas can be treated at any one sitting because of the danger of undue reaction. Therefore, to completely eliminate all vessels from a completely vascularized cornea requires about six months. The dosage, interval between treatments, and location of the treatment on the globe and cornea should be governed as much by the slit-lamp appearance three to six weeks after the last treatment as by a prearranged dosage schedule. The severity of the reaction during the first week or two after treatment affords a clue as to the effect of the radiation on the corneal vascularization. Also, a vessel which can be observed under the slit lamp to show beginning constriction, either generalized or localized, may well progress to complete obliteration of the lumen after several months without further radiation. By such observations, the elimination of corneal vascularization can be accomplished with the minimum total dosage. Although at one time I believed that it was preferable to eliminate corneal vascularization by treating the origin of the vessels at the limbus rather than directly over the cornea itself, the corneal stroma appears to be sufficiently more resistant than capillary endothelium to permit the direct application of beta radiation on the cornea. This, of course, does not hold for inflammatory lesions or conditions associated with corneal necrosis if relatively large doses are employed.

Rosacea Keratitis Associated with Rosacea of the Skin (Table 14). Thirteen eyes in 11 patients showed a vascularizing keratitis associated with rosacea of the skin. Although the vascularization, usually in sector configuration, was the most prominent clinical feature, four cases showed small corneal infiltrates, one had central

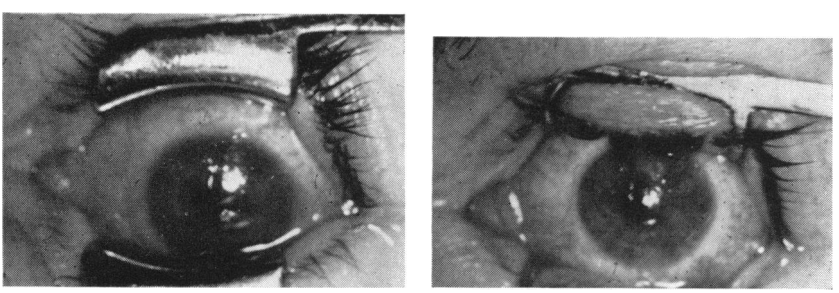


A B

FIGURE 16. ROSACEA KERATITIS, CASE 7, TABLE 14
A, before treatment. B, 3 months after beginning treatment with 22 gm. secs. in 10 weeks.

lipoidal deposits, and one eye showed intense vascularization of all layers of the entire cornea similar to that usually classified as primary vascularizing keratitis..

The results of these cases have been the most gratifying of any of the corneal conditions treated. The symptoms usually disappeared or became very minimal with few or no recurrences, corneal infiltration disappeared within two to four weeks, and corneal vascularization was also eliminated. Clearing of the corneal opacity often included the disappearance of some calcium deposits and improvement in vision (Fig. 16). The only unsuccessful case occurred in a 23-year-old white woman in whom the involved cornea was one third of normal thickness and both the lids and conjunctiva were involved. The immediate response to therapy applied over the limbal region was good. When she returned more



A B

FIGURE 17. ROSACEA KERATITIS, CASE 11, TABLE 4
A, before treatment; vision=H.M. B, 8 months after beginning treatment with 44 gm. secs. in 18 weeks; vision=20/100-.

TABLE 15. VASCULARIZING AND ROSACEA-LIKE KERATITIS WITHOUT DERMATITIS
(20 CASES)

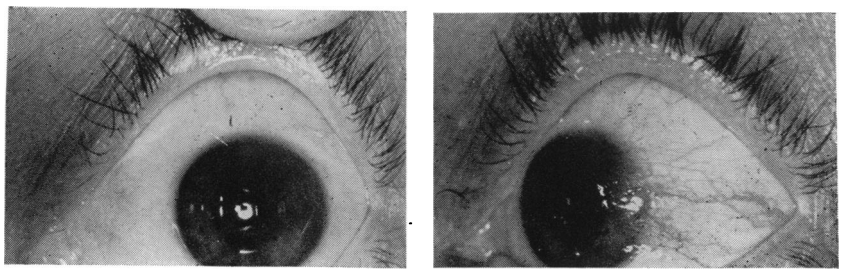
PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENT
		Before	*After*	*Before*	*After*	*Before*	*After*			
1 (42)	6 mos. Associated with menses	++	0	Sector CO+, V+++, E++	CO±, A3, V = 0	50+	15−	10 (15) +10 Rad. D-E	34	Fig. 18. After end of treatment, symptoms worse for 3 wks.
2 (30)	10 yrs. Active for past 11 mos.	++	0	CO++ central, V+, thinning.	CO+, V = 0	40	40	13 (7)	16	RE
	Same as RE	++	0	Same as RE	Same as RE	40	50	10 (6)	16	LE
3 (14)	5 yrs. Recurrent ulcers	++	0	CO+, A5, V++.	Calcified superficial opacity. V = 0	20−	30+	34 (24)	26	RE
	Same as RE	++	0	Same as RE	Same as RE	15	15−	25 (21)	21	LE
4 (43)	6 mos Survey neg.			CO+++, A6, V+++, E++	Thin, golden, asbestos-like opacity. V = 0	25+	20−	9 (3)	24	
5 (40)	6 mos.			Deep infiltrate, V+++	CO++, V = 0	200+	80	19 (17)	31	Postradiational vessels at area receiving 3 gm. sec twice.
6 (37)	29 yrs., recurrent ulcers	+++	+	CO+++, A6, U+, V++++	CO+±, V=0	40	40+	20 (18)	18	Postradiational vessels below ischemia.

7 (30)	12 yrs. ulcers	++	c	CO+++, A5, V++	CO±, V = o	30−	20	23 (12)	22	
8 (50)		++	o	CO+++, A3×6, V++	CO++, crystalline deposits, V = o.	40−	60+	8 (3)	28	Dilated vessels on face. Ulcer adjacent to ischemic limbus 20 mos. after Rx. Healed in 6 days.
9 (17)	10 yrs., recurrent ulcers, allergies	++	o	Calcified scar, trunk vessel, infiltration+.	Lipoid and calcium 2 mm. V = o.	80+	60−	25 (8)	24	Severe reaction of 3 wks. following 15 gm. sec. in 4 weeks.
10 (22)	1 yr., ulcer and iritis, allergy	+	o	Deep capillaries.	Nebula. Shadow VV with some blood	25	20−	18 (9)	7	
11 (52)	3 yrs., ulcers. Florid face.	+++	o	CO+++, A9, E+, calcium and lipoid, V++	CO+, V = o.	40	60	48 (31)	9	
12	5 yrs. Multiple allergies benefitted by Rx.	++	+	CO+++, V+++, A12	CO+, V = o, E+, A3.	80	80	29 (11)	9	Corneal opacity over pupil.
13 (59)	1½ yrs., ulcers.	++	o	CO++, A6, V+++, Infiltration+	CO±, A3, V = o, edema of epithelium.	30−	15	21 (10)	13	

TABLE 15. VASCULARIZING AND ROSACEA-LIKE KERATITIS WITHOUT DERMATITIS—*Continued*

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	
		Before	*After*	*Before*	*After*	*Before*	*After*			
14 (48)	5 yrs., ulcers.	++	0	CO+, V++ (4 mm. around limbus), superficial infiltrates.	V = 0	200	?	42 (24)	8	
15 (72)	3 yrs., ulcers, allergies.	++++	++++	V++++, large trunk vessels.	Enucleated V+++, E++.	10/200	5/200	27 (15)	3	
16 (50)	1 yr. Weeping dermatitis. Allergies.	++	0	Gelatinous tissue and V++ on cornea.	0	40+	15	16 (5)	33	
17 (27)	3 yrs. RE. ? Staph. allergy.	+++	0	CO++, V+++, A12.	V++	10/200	20	30 (9)	7	Rx: also staphylococcus toxoid desensitization.
	Similar but worse than RE.	++++	0	CO+++, V++++, A12.	V++	5/200	50	32 (17)	7	LE
18 (11)	16 mos. ? Staph. allergy.			Active infiltration with V++.	Inactive scar, V = 0.	?	30	10 (7)	5	

19 (64)	2 yrs. Chronic conjunctivitis. Rx: antibiotics.	++	0	V++ with small infiltrates at end of VV.	Inactive scar, V = 0.	40+	20−	25 (18)	17	
20 (39)	RE, 4 yrs. Desensitization Rx. Mother had glaucoma.	+++	±	CO++, V++++, E++.	CO+, V = 0, E+.	70+	20− (1 yr.) 70− (3 yrs.)	39+ 8 Rad.D. (34)	39	Fig. 20. Tonometric tensions elevated after 1 year, no other evidence of glaucoma. No cataract after 39 mos.
	LE, 4 yrs.	++++	+	CO++, V++++, E++.	CO+, V = 0, E+, Aphakia.	6/200	30+ (2 yrs.) 200 (recent aphakic)	51 (16)	44	After 35 months, rapid development of intumescent cataract. Extraction uneventful, small filtering bleb. Tonometric tensions elevated. No other evidence glaucoma Fig. 19



A B

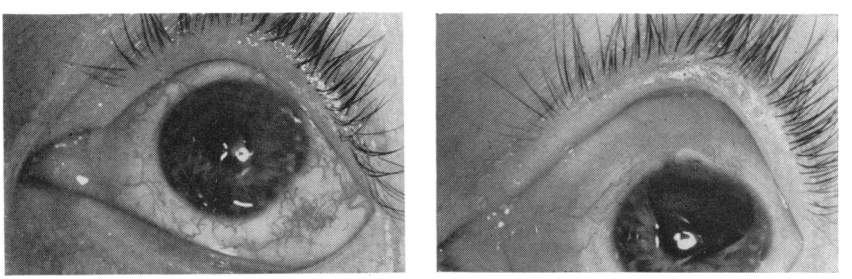
FIGURE 18. ROSACEA KERATITIS, CASE 1, TABLE 15
A, before treatment. B, 31 months after 10 gm. secs. radon and 10 gm. secs. radium D,

than a year later, the rosacea of her lid margins and conjunctiva was much worse. Although the anterior chamber was formed, there was an anterior synechia present near the center of the cornea, indicating a perforation in the area of previously thin cornea. She also had posterior synechias and elevation of tension. This perforation could not be attributed to the direct action of the beta radiation, because the area of perforation was not treated. The other major complication occurred in a 45-year-old white woman who for three years had suffered intensely with an extremely painful, photophobic left eye in which vascularization of all layers of the entire cornea was present (Fig. 17). The blepharospasm and pain were so intense that the patient desired enucleation. Eight months after beginning application of a total dose of 44 gram seconds within a period of 18 weeks, vision improved from hand movements to 20/100—, and blepharospasm became quite minimal, although some photophobia in bright light persisted. Thirty months after starting treatment, the patient developed a cataract which became intumescent within the period of several weeks and was extracted without complications. The problem of cataract formation following beta therapy will be discussed in a subsequent section.

Vascularizing and Rosacea-Like Keratitis without Dermatitis (Table 15). Although vascularization of the cornea may follow any kind of keratitis, at times the degree of vascularization seems to be the most prominent manifestation of the keratitis. Usually the etiology cannot be ascertained, but some of the patients ex-

hibit multiple allergies. Clinically, recurrent and progressive corneal vascularization often covers the entire cornea with superficial vessels of all sizes, and in more severe cases with deeper vascularization. Associated with this, there is usually a large amount of corneal edema, occasionally minor erosions, and much irritability and photophobia, at times of such intensity that the blepharospasm prevents adequate examination of the eye and further hampers the already impaired vision. The pattern of this vascularization is often sector-shaped or involves half of the globe and cannot be differentiated from rosacea keratitis. Accordingly, many of the 24 eyes in 20 patients listed in Table 15 might be considered as roseacea keratitis without dermatitis.

The results of these cases have been equally as gratifying as those described in the previous section where the rosacea keratitis was associated with rosacea of the skin (Fig. 18). At times when the corneal infiltration, edema, and vessels disappeared, a thin asbestos-like opacity was left behind, containing brownish pigment, cholesterol crystals, and calcium. The eye of one 72-year-old man with intense corneal vascularization was enucleated three months after the beginning of beta radiation therapy because of the persistence of marked symptoms. This patient was not given sufficient time for the 27 gm. secs. of beta given in 15 weeks to have its full effect. One of our first patients for beta treatment was a 39-year-old white man with a primary vascularizing keratitis of



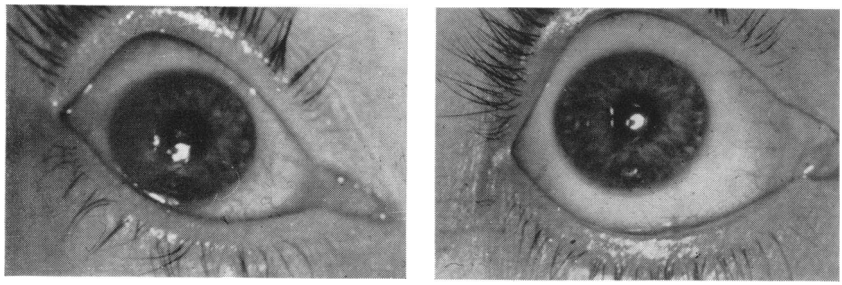
A B

FIGURE 19. PRIMARY VASCULARIZING KERATITIS, L.E., CASE 20, TABLE 15
A, treated with 51 gm. secs. in 16 weeks, showing relatively clear cornea, no vascularization, ischemic areas at limbus and cataract (35 months after beginning treatment). B, following combined extracapsular extraction of cataract. Note small filtering bleb at 12 o'clock.

TABLE 16. STROMAL HERPES
(12 CASES)

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENTS
		Before	*After*	*Before*	*After*	*Before*	*After*			
1 (51)	3 attacks in 2 years. Present duration 6 wks.	++	0	Infiltration 3×6 mm. V+, E++ (stroma).	CO±, V = 0, E = 0. Calcium and Cholesterol.	50+	20−	3	10	
2 (28)	6 wks.	+++	0	CO+++ (2 mm.) E+++ (6 mm.)	Cornea clear.	60+	15	4 (2)	30	Cleared in 3 mos.
3 (47)	7 mos., penicillin, typhoid	+++	0	CO++, A6, E+++, V+, U 2 mm.	CO±, A4, V±	40	20	4 (3)+ 3 spray (4)	8	Much improved 4 weeks. Healed 3 months.
4 (37)	5 wks., iodine, quinine	+++	0	CO+++, A12, E++, U++, V++	CO±, Iridescent crystals. V = 0.	5/200	200	16 + 4 s (12)	21	Vision poor since age 3. After Rx = vision "good as ever." Healed in 6 mos.
5 (49)	Attack 2 yrs. ago. Present 1 mo. Paracentesis.	+++	0	CO++, A7, E+++ (bullae), V+ (edge), U+.	CO±, V = 0	C.F.	30+	9 + 3 s (12)	25	Healed in 4 mos.
6 (43)	? Old trachoma. Pterygium operation preceding attack 5 mos. ago.	+++	0	CO+++, A12, E++, V++.	CO+. Superficial punctate erosions lower half. V = 0.	200	60−	46 (28)	17	Cortisone also used locally. Transitory rise in tension 9 mos. after Rx.

7 (58)	3 attacks. Last onset 6 mos. Iodine, typhoid, aureomycin, Vitamin B.	+++	+ occasionally.	CO+++, A12, E+++, (bulla) V++, ant. synechias.	CO++, E++, (2 small bullae), V+, tension 25. Heavy amber sclerosis of lens. Post. synechia.	C.F.	C.F.	29 + 2 s (12)	28	Transitory rise in tension 16 mos. after Rx. ? Early cataracts.
8 (72)	9 mos.	+++	0	CO++, A6, E++, V+++.	CO++, V+	200	50	18 (94)	23	
9 (57)	2 attacks. 8 mos. duration. Antibiotics.	++	0	CO++++, A9, V++++.	CO++, A7, V = 0.	H.M.	C.F.	64 (36)	17	? Transitory rise in tension. Lens amber sclerosis more than other eye.
10 (54)	Herpes Zoster, 2 ulcers recurred 1 wk. ago.	++	0	CO++, A3, E++, V++.	CO±, A2, V = 0. Cholesterol crystals.	20	20	15 (9)	16	
11 (27)	15 yrs., flare-ups. 7 mos. duration.	++	+	CO++, A9, E+, V++.	CO+, A9, V (deep), punctate erosions.	10/200	"blurred"	5	1	
12 (35)	20 yrs. recurrences, present attack 1 mo. Rx Cortisone, eye worse. 4 vaccinations.	+++	0	CO+++, A9, V+, U++, E+++.	Healed. CO++.	10/200	40	9S (3)	5	



A B

FIGURE 20. PRIMARY VASCULARIZING KERATITIS, RE, CASE 20, TABLE 15
A, untreated. B, 8 months after beginning treatment with 39 gm. sec. radon and 8 gm. sec. radium D-E in 34 weeks.

the entire area of both corneas which reduced his vision to 20/70+ in the right eye (Fig. 20a) and 6/200 in the left eye (Fig. 19a). Intensive beta therapy was applied to the limbus of the left eye, 51 gm. secs. in 16 weeks, and two years later corrected vision in this eye was 20/30+. Thirty-five months after beginning of treatment, the patient rapidly developed a cataract in this eye which became intumescent and was extracted uneventfully. The cornea retained its former clarity, and the wound healed well except for one small area at which a small conjunctival bleb about 2 mm. in diameter persisted (Fig. 19b).

STROMAL HERPES SIMPLEX

Penetration of the herpes simplex virus from an ordinary dendritic keratitis into the corneal stroma produces many forms of deep keratitis characterized essentially by marked edema with relatively little vascularization or ulceration. Twelve such cases of varying degrees of severity were treated with varying amounts of beta radiation (Table 16). In general, the results appeared to be somewhat encouraging, although it is well known that other cases treated by different methods have a relatively good prognosis following a long convalescence. In line with the principle of treating inflammatory conditions with small doses of radiation, the early cases of stromal herpes were treated accordingly. Only in the later stages to eliminate corneal vascularization were larger doses employed.

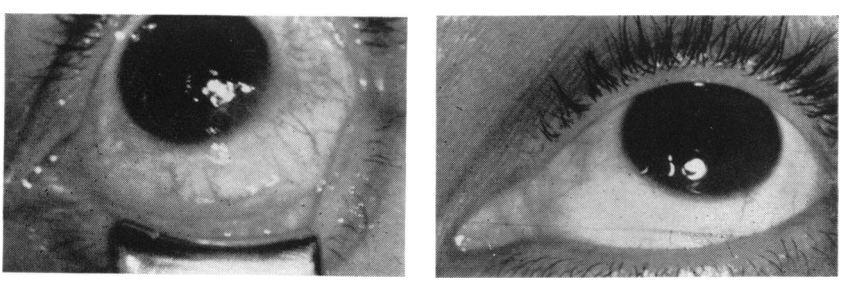
MISCELLANEOUS FORMS OF KERATITIS (TABLE 17)

Other forms of keratitis affected a total of 34 patients.

Phlyctenular Kerato-Conjunctivitis. Satisfactory subjective and objective results were obtained in the treatment of four cases (Patients 1 to 4, Table 17) of phlyctenular kerato-conjunctivitis with a total dose varying from 11 to 30 gm. secs. over periods of 11 to 40 weeks (Fig. 21).

Acute and Subacute Corneal Ulcer and Keratitis. Six cases (Patients 5 to 10, Table 17) are summarized in Table 17 in which the keratitis was characterized by evidence of some activity such as infiltration or ulceration. In general, these patients received from 1 to 3 gm. secs. either contact or spray therapy until the active infiltration or ulceration subsided. In some patients, this was followed by more intense radiation to eliminate corneal vascularization. The effect of radiation upon corneal infiltrations seemed encouraging, and in no instance did the degree of corneal ulceration become more pronounced.

Interstitial Keratitis. One case (Case 11, Table 17) of inactive interstitial keratitis with fine interstitial vascularization was treated with 20 gm. secs. within 18 weeks. Following this, an exacerbation or apparent relapse of the keratitis for three months was associated with transient glaucoma. Both the reaction and glaucoma subsided, corneal vascularization disappeared, and vision improved from 20/200-1 to 20/70-1 twenty-eight months later.



A B

FIGURE 21. RECURRENT PHLYCTENULAR KERATOCONJUNCTIVITIS, CASE 1, TABLE 17

A, before treatment. B, 18 months after beginning treatment with 30 gm. secs. in 40 weeks.

TABLE 17. MISCELLANEOUS FORMS OF KERATITIS
(34 CASES)

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENT
		Before	*After*	*Before*	*After*	*Before*	*After*			
1 (35)	20 yrs. Phylctenular keratoconjunctivitis.	++	0	Limbal CO, V++. Not unlike limbal vernal catarrh. 8 mos. later = episcleritis.	Cornea clear, epithelial edema over treated area.	30	20	30 (40)	18	Fig. 21
2 (48)	"Scrofulous eyes" age 5–12. Recently 8 mos.	++	0	CO+++, A12, E++, V++++.	CO++, V+.	200	100	24 (11)	21	3 mos. after beginning treatment —little effect.
3 (3)	2 mos.	++	0	Two vessels to central CO+++, A3.	CO+, V = 0.	?	200	11 (18)	25	? Phlyctenular K–C.
4 (19)	Recurrent phlyctenular K–C.	++	0	CO+, V++.	Superficial ischemia. Deep VV segmented.	60+	60+	18 (20)+ 6 Rad.D.	6	
5 (71)	3 mos.	++	0	Central ulcer. CO+++, A4, U+, E++.	CO++, E+.	HM	CF	38 (22)	23	

6 (54)	25 yrs. ago foreign body and ulcer. Recurrences, last 6 wks. Rx Strontium^{90} (960 r twice) Cortisone.	++	0	CO+++, A7, U++, V+++.	CO+, V+.	CF	80	5	3	
7 (40)	2 yrs. = 3 ulcers. Rx desensitization to tuberculin.	++	0	Central CO++, A4, V+++, U+, infiltration.	CO±, V+.	30−	20−	19 (7)	4	
8 (40)	Weeks.	++	0	3 mm. infiltration, V++.	CO±, V+, calcium.	20−	20+	8 (3)	3	
9 (61)	10 yrs. ago—ulcer. Recurrence 1 mo.	++	0	CO+++, A4, V+++, healing.	Healed. V+.	CF	?	8 (9)	5	
10 (12)	3 yrs. ago: acute serpiginous ulcer. Recurred.	++	+	CO+++, A6, V+++, Infiltration++.	CO+++, V = 0.	65	100	20 + 2 Spray (79)	24	
11 (24)	Interstitial keratitis 13 years ago.	0	0	Spotty opacities, fine vessels.	Nebular CO, No vessels.	200–1	70–1	20 (18)	28	Flareup after 16 gm. sec. and 20 gm. sec. lasting 3 mos. Transient glaucoma.
12 (19)	2 mos. Neg. survey. Rx: typhoid, streptomycin, aureomycin.	++	++	Deep keratitis, active, CO+++, A8, E+++, V++++	Cornea cleared. Eye still congested.	60	20	13 + 1 (spray) (11)	3	

TABLE 17. MISCELLANEOUS FORMS OF KERATITIS—*Continued*

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENT
		Before	*After*	*Before*	*After*	*Before*	*After*			
13 (68)	4 mos. Neg. survey. Rx: Cortone.	++	+	Deep keratitis, CO++, E++++, V++, iritis.	E++ with bullae.	HM	HM	43 (42)	22	
14 (4)	3 yrs.: "recurrent dendritic ulcers."	++	+	CO+++, V++++.	CO++, small vessels only.	1/200	300	2 + 4 spray (2)	2	
15 (51)	Yrs.: "Sclerosing keratitis".	++	o	CO+++, A8, V+++	"Cornea clear" (?), V+.	40	100	53 (57)	17	Unexplained poor vision after Rx.
16 (60)	6 mos. foreign body and ulcer.	++	o	Pseudoptery-gium, V++++.	Only deep vessels remaining.	60−	40+	23 (16)	6	After 23 gm. secs. in 16 wks., eye remained irritable for 2 weeks.
17 (47)	3 yrs. foreign body and ulcer.	+	o	V+++ (small).	V = o	30	30−	30 (8)	18	Marked reaction for 5 wks. after last Rx.
18 (25)	9 mos. foreign body and ulcer.	o	o	CO++++,A8, V+++.	CO++, A6, ischemia, edema of epithelium in Rx area.	CF	200	49 (75)	21	
19 (44)	10 mos. ago, deep keratitis.	+	o	Inactive CO++++, V++++, A11	CO++, A9, V = o	LP	LP	58 (24)	26	? Elevation of tension.

20 (48)	2 yrs. ulcer.	o	o	Adherent leukoma, A8, V++++	CO+++, A6, V+.	LP	LP	65 (52)	20	
21 (30)	6 mos. ago. Ulcer.	+	o	Elevated scar with V++.	Ischemia.	25	20−	8 (4)	2	
22 (59)	2 yrs. ago: ulcer.	o	o	CO++++, A6, V+++ (large).	CO+++, A5, V = o. Still blood staining 19 mos.later.	20	30+	15 (6)	23	Hemorrhage in cornea with blood staining after Rx.
23 (48)	40 yrs. ago: Erysipelas with irritation of eye since then.	+	±	Heavy vascularized leucoma.	CO+++ (4 mm.), V++ (4 mm.), (returned after Rx).	HM	CF	49 (72)	34	
24 (58)	Vision never good. Cataract extraction 13 mos. ago.	+	+	CO++, A6, V+++.	CO++, A5, V = o. Post-radon vessels around limbus.	5/200	CF	61 (55)	34	RE. 6 gm. sec. of rad. D–E = 2 gm. sec. radon = superficial ischemia. ? Elevated tension 19 mos. after Rx.
	LE: Vision never good. Cataract extraction 1 mo.	+	++	Same as RE	Same as RE	4/200	200	57 (25)	45	Late recurring irritability. ? Elevated tension after 28 mos.
25 (85)	Poor vision since childhood. 5 yrs. cataract extraction with postoperative iritis.	?	o	Large trunk vessels above, peripheral VV below.	CO++, iritis. Tension = 42.	CF	CF	45 + 6 spray (24)	17	

TABLE 17. MISCELLANEOUS FORMS OF KERATITIS—*Continued*

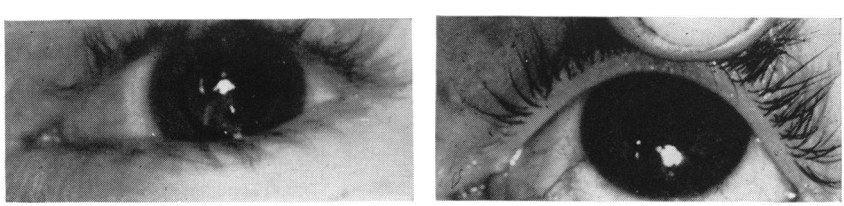
PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	
		Before	*After*	*Before*	*After*	*Before*	*After*			
26 (24)	14 yrs. Keratoconus. 6 mos. = acute hydrops.	+	o	CO+, V++.	Vessels constricted.	30	40+	12 (6)	3	
27 (46)	Years.	+	±	Keratoconus with marginal atrophy. V++ (4 mm.).	Tortuous vessels 2 mm., no growth for 18 mos.	60−	40−	13 (11)	30	RE
	Years.	+	±	Same as RE	Only a few twigs of capillaries.	25	15−	28 (31)	22	LE. Severe reaction after 9 gm. sec. (in 3 wks.) and 24 gm. sec. (in 11 wks.)
28 (24)	Onset 9 yrs.	+	o	Keratoconus with marginal atrophy. V+++.	V = o. Clearer.	60	30−	20 (11)	11	RE. Irritated for for 4 wks. after 20 gm. sec. in 11 weeks.
		+	o	Same as RE	Tortuous VV. 3 mm. (10–2 o'clock).	60	30	34 (29)	20	LE. Severe symptoms for 10 wks. after 30 gm. sec. in 5 wks.
29 (35)	4 yrs., recurrent ulcers.	++	o	Fistula and filtering bleb 4 mm., V++.	Fistula closed, V = o.	60	20−	7 (4)	30	Fig. 22

30 (54)	Interstitial keratitis when a child.	++	0	Salzmann's dystrophy, V++ (small), blotchy stains.	Nebular haze, few punctate stains. V±.	60	25+	9 (4)	19	
31 (54)	45 years of "sore eyes" 20 yrs. of recurrent uveitis. Rx—Cortisone 1 mo.	++	+	Salzmann's dystrophy, lipoid, V+++, ? secondary glaucoma.	V = 0	200	100	18 (10)	12	Intracorneal hemorrhage after beta.
32 (58)	Right esotropia with amblyopia.	0	0	Salzmann's dystrophy, V+++.	V±. No change in nodules.	CF	CF	30 (55)		
33 (50)	10 years. Tatooing.	±	±	CO++++ (central) A7, V++++. Lipoidal dystrophy.	CO+++, A7, V++ (trunks)	HM	CF	41 (20)	23	Optical iridectomy following beta.
34 (57)	6 years	++	0	Lipoidal dystrophy, CO++++, A6, V++++.	V = 0	70	50	22 (9)	40	RE
	6 years	++	0	Same as RE	"Pale and quiet"	70+	40+	43 (22)+ 15 (101)	40	LE

Corneal Scars. Eleven cases of corneal scars from various causes associated with varying amounts of vascularization are described in Table 17. Elimination of the vessels which supplied the corneal scars sometimes seemed to reduce the intensity of the corneal opacity, but the effects were not dramatic. One must realize that clearing of corneal scars occurs for several months or even years after the original injury, especially in young children. Old corneal scars without vascularization were in general not treated in this series. There is no reason to believe that the fibrous tissue comprising the scar is any more sensitive to the effects of beta radiation than the adjacent stromal cells of the normal cornea.

Keratoconus (Cases 26-28, Table 17). The vascularization following acute hydrops in one case of keratoconus was eliminated by beta radiation without any significant effect on the corneal opacity or vision. Four eyes of two patients showed the rather unusual picture of marginal atrophy of the corneas associated with a generalized bulging of the central portions of the cornea. Vessels crossed the marginal gutter to encroach upon the pupillary space. The cautious use of beta radiation at the limbus and to a less extent over the cornea resulted in elimination of the majority of these vessels and improvement of vision without further loss of tissue at the corneal margin. During the course of treatment, however, some severe reactions were obtained which subsided after a few weeks.

Recurrent Fistulizing Corneal Ulcer. One patient (Case 29, Table 17), who had had a recurrent perforating corneal ulcer associated with very little surrounding inflammatory reaction and to which area corneal vascularization had arrived, was treated with beta radiation successfully (Fig. 22). The fistula closed, the cornea



A B

FIGURE 22. RECURRENT FISTULIZING ULCER, CASE 29, TABLE 17
A, before treatment. B, 1 year after 7 gm. secs. in 4 weeks.

in this area became one-third normal thickness, and further breakdown of the fistula did not occur over a follow-up period of two and a half years. The mechanism of this action can only be surmised, whether due to the elimination of the vascularization, or of the epithelium lining the fistula, allowing repair of the defect by the adjacent corneal stroma.

Corneal Dystrophy. Three cases (Cases 30-32) of Salzmann's dystrophy were treated with beta, resulting in an elimination of the vascularization but no apparent effect on the superficial nodules themselves. One man with vascularized leucoma suggestive of lipoidal dystrophy was treated with only slight clearing of the corneal opacity and reduction in the number of vessels. A second patient with bilateral lipoidal dystrophy of the cornea was treated with beta with definite improvement in both symptoms and vision.

SUPERFICIAL KERATECTOMY AND KERATOPLASTY

Four cases of superficial keratectomy (Cases 1-4, Table 18) followed by beta radiation showed disappointing results as far as the intensity of the corneal opacity and visual improvement was concerned. However, by this method vascularization of the cornea was largely prevented. If beta radiation is applied within several days following superficial keratectomy, only small doses such as 2 to 3 gm. secs. will prevent the ingrowth of new capillaries. It should be realized however that the radiation will also inhibit the regeneration of the corneal epithelium, and therefore should be used only when vessels are seen by the slit lamp to be crossing the limbus onto the cornea.

Three cases of penetrating keratoplasty (Cases 5-7, Table 18) complicated by the ingrowth of vessels around and slightly in the graft were treated with beta radiation postoperatively. In general the radiation was confined to an area just outside the margin of the graft in order to avoid exposure of the graft. This technique succeeded in preventing the vascularization of the three grafts.

BURNS

Fourteen cases of burns are summarized in Table 19.

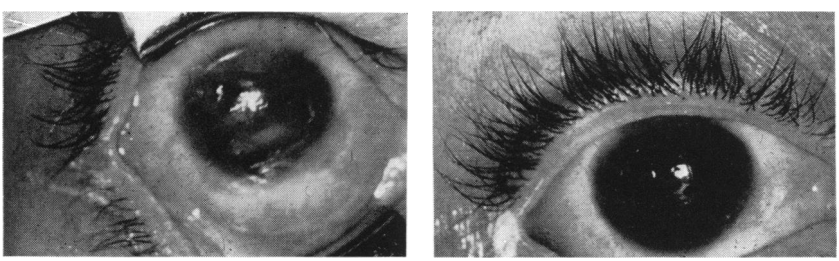
Two cases of severe heat burns of the cornea (Cases 1 and 2)

TABLE 18. SUPERFICIAL KERATECTOMY AND KERATOPLASTY

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENT
		Before	*After*	*Before*	*After*	*Before*	*After*			
1 (40)	SO_2 burn, 6 years, superficial keratectomy, 5 weeks.			Granulation tissue and V+++.	Few vessel loops, 2 mm.	?	CF	31 (9)	31	
2 (9)	8 years ago ulcer and flap. Superficial keratectomy, 10 days. Esotropia.			CO+, A9, V+++.	CO±, V.	HM	CF	39 (26)	15	
3 (63)	Herpes Zoster Ophthalmicus 4 years ago. Superficial keratectomy, 16 days.	++	+	CO++, A9, V++	CO++++, A9, V = 0. Postradiational vessels.	100	CF	63 (29)	25	
4 (45)	Old injury, superficial keratectomy, 1 day.			CO+++, V++ (3 mm.).	CO+, V+.	HM	?	18 (63)	17	

5 (48)	2 years. SO_2 burn. 5 weeks penetrating keratoplasty.	++	++	Vessels around clear graft.	Ischemia. No vessels in graft.	60+	60	23 (19)	11	Rx around graft only.
6 (46)	25 years ulcer. 2 mos. penetrating keratoplasty. Anterior synechiotomy.	0	0	Vessels 1 mm. in graft.	Temporal 2/3 of graft clear. Capillary 1 mm. in graft.	HM	200	4	33	
7 (79)	Penetrating keratoplasty, 4 mos.			Vessels invading graft 1 mm.	Graft hazy. No vessels.			21 (10)	5	1st 2 treatments (11 gm. sec. in 3 weeks) over graft.

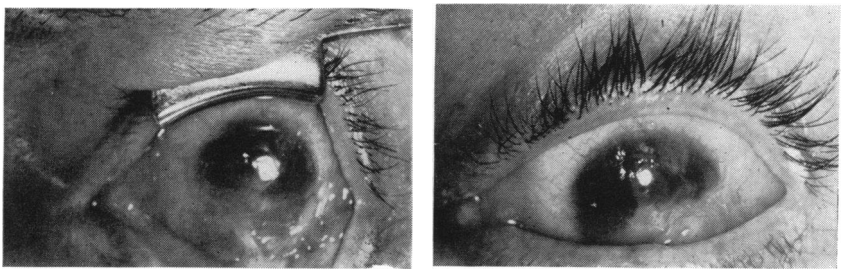
treated several months later with large doses of beta radiation did not produce very satisfactory results. One tear-gas burn (Case 3) associated with corneal vascularization responded well both subjectively and visually to elimination of the vascularization. One recent acid burn seemed to do well on 9 gm. secs. of beta. Three old acid burns did not show any visual improvement after rather intensive beta therapy. Two eyes of one patient burned with sulphur dioxide showed conflicting results. The eye which improved was given beta less intensively, but symptoms in both eyes persisted. One recent sodium bichromate burn responded well to beta and cortisone therapy. One recent lye burn responded well and two moderately recent lye burns showed no improvement following radiation. Two old lye burns responded little. One patient (Case 14) burned in both eyes with ammonia and sulphur dioxide showed some clearing of both corneas following the elimination of vascularization by beta (Figs. 23 and 24).



A B

FIGURE 23. AMMONIA AND SULPHUR DIOXIDE BURN, CASE 14, TABLE 19
A, before treatment. B, 4 months after beginning treatment with 28 gm. sec. in 16 weeks.

On several occasions during the past few years, Iliff, Wilson, and I have made attempts to prevent vascularization of the cornea which follows severe chemical injury (1). Experimentally on rabbit eyes it was impossible to prevent completely the ingrowth of blood vessels soon after the injury without producing deeper ulceration, probably as a result of an undue amount of added damage to the already necrotized corneal stroma. Therefore, it is probably desirable to wait after a chemical burn until the initial healing of the cornea has taken place. Then, the vascularization can be systemati-



A B C

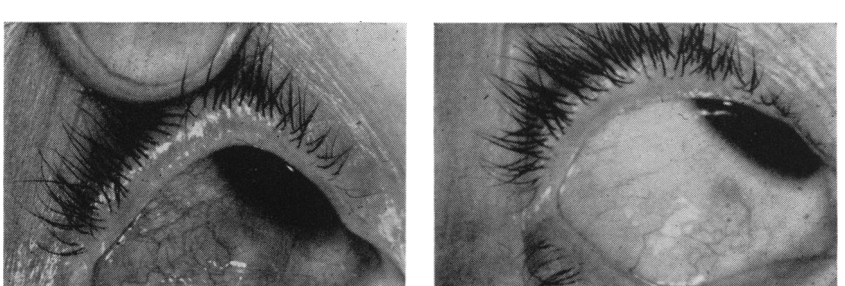
A, before treatment. B, 4 months after beginning treatment with 19 gm. sec. in 16 weeks. C, 4 months after B.

FIGURE 24. AMMONIA AND SULPHUR DIOXIDE BURN, CASE 14, TABLE 19

cally eliminated without danger of accentuating the amount of corneal damage.

EPISCLERITIS AND SCLERITIS (Table 20)

Small doses of beta radiation apparently had a beneficial effect on two cases of acute nodular episcleritis (Fig. 25). Because it is well known that acute nodular episcleritis and scleritis usually



A B

FIGURE 25. NODULAR EPISCLERITIS, CASE 1, TABLE 19

A, untreated. B, 3 months after starting treatment with 4 gm. secs. in 4 weeks.

TABLE 19. BURNS (14 CASES)

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENT
		Before	*After*	*Before*	*After*	*Before*	*After*			
1 (23)	4 mos. molten iron. 1 mo. ago dissected pseudopterygium.	+	0	CO++++, A9, V+++. Pseudopterygium.	CO++. Postradiational vessels 1 mm. on cornea.	200−	200	41 (52)	20	Some regrowth of vessels
2 (50)	7 mos. Heat. Mucous membrane graft.	++	+	CO+++, A10, V++++ (trunks).	CO+++, A9, frosty-glass appearance, V++ (2 mm.).	LP	HM	36 (31)	33	Some regrowth of vessels.
3 (28)	3 mos. Tear gas. Rx.—flap.	+++	+	CO+++, A6, V+++, E++.	CO+, A4, V = 0, E+	100	30+	42 (42)	27	
4 (50)	21 yrs.: sulphuric acid. 5 operations. 16 yrs. ago = 5 radium Rx.	++	+	CO++++, A5, V++++.	Postradiational vessels 1 mm. over limbus.	50+	60+	22 (40)	18	
5 (53)	4 mos. acid.	+	0	CO++++, A5, V+++.	CO++, V+ (2 mm.)	100	40+ (?)	9 (4)	5	
6 (68)	27 yrs. acetic anhydride, O.U.	0	0	CO++++, A12, V++++, symblepharon.	CO++++, A12, V = 0.	LP	LP	35 (20)	5	RE
				Same as RE	Same as RE	LP	LP	48 (16)	5	LE

7 (30)	6 mos. SO_2	++	+++?	CO+, V++ (3 mm.)	CO+, V+, E+.	40	100	24 (4)	19	RE. Symptoms apparently became worse.
		+++	+	Similar to RE	CO±, V+ (1 mm.)	200	30−	34 (25)	28	LE
8 (51)	4 mos. Sodium Bichromate. Rx Cortisone.			CO±, V++.	CO±, V = deep only.	60	40+	15 (18)	9	
9 (32)	2 mos. lye	++	+	CO++, A12, V+++	CO±, A9, pseudopterygium, 3 mm. Postradiational vessels.	100	30	40 (23)	39	
10 (57)	Age 5: Lye irritation past 2 years.	++	o	CO+++, V+++, E++.	CO+++, V+.	5/200	5/200	40 (23)	39	After 34 gm. sec. in 13 wks. = acute conjunctivitis for 4 wks.
11 (27)	17 yrs. Lye.	+	o	Heavy vascular leukoma and symblepharon.	Still some deep vessels.	HM	CF	59 (52)	13	
12 (42)	8 mos. Lye. Rx: Cortone.			Symblepharon to center of cornea. V++.	V = o, E++.	CF	CF	35 (20)	25	
13 (55)	5 mos. Lye.			Vascularized leukoma and ? glaucoma	Only deep VV. Absolute glaucoma.	?	No LP	8 (6)	35	
14 (36)	1 yr. Ammonia and SO_2	++	+	See Figs. V++	See Fig. 23. V = o	CF	5/200	47 (33) 5 (36)	18	RE
	Same	++	+	See Figs.	See Fig. 24	CF	4/200	19 (16) 5 (45)	18	LE

TABLE 20. SCLERITIS

PATIENT (AGE)	HISTORY PREVIOUS RX	SYMPTOMS		SIGNS		VISION		TOTAL DOSE (WEEKS)	MONTHS FOLLOW-UP	COMMENT
		Before	*After*	*Before*	*After*	*Before*	*After*			
1 (61)	10 days	+++	0	Acute nodular episcleritis.	Inactive	40	15−	4 (4)	29	Fig. 25 Improved in 14 days, atrophy sclera in 6 wks.
2 (61)	4 mos. Red eye Asthma. Neg. survey. Rx Cortisone locally.	++	+++	3 areas nodular episcleritis. 5 mos. = marginal corneal ulcer. 1 yr. = uveitis with secondary glaucoma.	Scleral perforation at 18 mos. Enucleation at 22 mos. = "Tuberculosis".	40	CF	17 (28)	22	One treated area cleared in 5 wks, 2 control areas no clearing.

clear up spontaneously during the course of a few weeks, the next patient with three separate nodules of episcleritis in one eye received treatment only to the worst area, which responded well, the two untreated areas remaining unchanged. This eye subsequently developed recurrence of the episcleritis and scleritis, a marginal corneal ulcer, uveitis, secondary glaucoma, and then a localized necrosis of the sclera in one of the areas of inflammation, suggesting the picture of scleromalacia perforans. The eye was enucleated because of pain, and on examination was found to be tuberculous.

Although some of the cases of deep keratitis reported in this series may possibly have been tuberculous, insufficient evidence was obtained to make a presumptive diagnosis of tuberculous sclerokeratitis. Woods (21) reported that of 72 eyes with anterior ocular tuberculosis treated with beta radiation, 53 percent remained healed for at least one year, 39 percent were improved, and 8 percent were unimproved. Improvement in vision of at least two lines occurred in 42 percent of the cases, but no effect was noted on the recurrences of the attack. These results suggest that beta radiation was of some beneficial effect, but exact statistical comparison with a comparable control series is not available.

OTHER CONDITIONS WHICH DO NOT RESPOND TO BETA RADIATION

In addition to the type of cases discussed in the tables above, some mention should be made of certain conditions which have not been found by others to be affected favorably by beta radiation. Cases of Fuchs' endothelial-epithelial dystrophy do not respond. Although several English investigators have reported favorable results following the use of radiation for superficial punctate keratitis, the experience of Iliff and others has not shown any dramatic results. Epithelial downgrowth into the anterior chamber following cataract extraction is not amenable to beta radiation because of the relatively superficial penetration.

UNDESIRABLE REACTIONS AFTER BETA RADIATION

An estimation of the value of beta radiation therapy in ophthalmology must not only consider the rather dramatic effects obtained in several conditions, but also any early undesirable reactions or

later complications of therapy. In view of the maximum follow-up of a little over three years, no information is obtainable in this series as to the possibility of very late complications. However, there are certain immediate and relatively short-term reactions which have presented themselves and which might be avoided in future therapy by proper precautions.

Ocular Irritation Immediately Following Treatment. Within a few hours after treatment, the patient usually develops symptoms of minor irritability similar to that experienced when a foreign body is in the eye. This usually subsides within a few hours or, at the longest, a few days. This may be related at least partially to trauma caused by the applicator.

Persistent or Delayed Irritation. In this series, about 10 percent of the patients developed symptoms of irritation, tearing, and photophobia of at least two weeks' duration at some time during the treatment with beta. Although the average duration of these symptoms was two or three weeks, they persisted for two or three months in a few patients. Examination revealed photophobia, mild diffuse conjunctival injection, occasionally superficial punctate erosions of the cornea, or persistent epithelial edema where large doses had been applied directly to the corneal surface. All symptoms and signs eventually subsided spontaneously, and no really effective treatment was found to relieve the condition. Dark glasses, cold compresses, and the local instillation of cortisone drops have been used.

These reactions undoubtedly represent conjunctivitis and superficial keratitis due to the radiation, although at first some of the cases were treated with anti-bacterial agents without appreciable effect. As seen in Table 21, there is a definite relation between the dosage rate of treatment and the incidence of development of ocular irritability. Any average dose rate of 1 gm. sec. per week or more resulted in some cases of this complication. Except for two cases of trachoma which reacted unduly to single treatments with 5 to 6 gm. secs. respectively, it usually required a total dose of at least 15 gm. secs. to produce this complication. It should be mentioned that these total doses were not necessarily applied in any one area; usually not more than two or three applications totaling

TABLE 21. RELATION OF DOSAGE SCHEDULE TO UNDESIRABLE OCULAR REACTIONS

DOSE/TIME *Gm. Secs./ Weeks*	NUMBER OF CASES	PERCENT WITH OCULAR IRRITABILITY LASTING OVER 2 WEEKS	INDIVIDUAL TOTAL DOSES		OTHER COMPLICATIONS (*Total Doses*)
			Without Ocular Irritability	*With Ocular Irritability*	
15	1	100		4, 4 (and after 1 wk.) 3, 4	
6	2	100		30, 24	
5	1	0	10		
4.5	2	0	9, 58 (papilloma)		
4.0	3	100		23, 25, 30	
3.5	6	50	11, 14, 31	34, 34, 34	
3.0	16	13			Cataract after 3 years (51)
2.5	10	10			Cataract after 2½ years (44) Transitory glaucoma and(?)early cataract (30) Intracorneal hemorrhage (15)
2.0	45	9			Intracorneal hemorrhage (18) (?)Transitory glaucoma (57, 63, 64) Nuclear sclerosis (64)
1.5	18	5			
1.0	55	5			(?) Glaucoma 19 months (61)
0.5 or less	18	0			

12 to 18 gm. secs. were ever given in any one area. Application of radon to the globe appeared to result in this complication more frequently than when it was applied to the conjunctival surface of the lids, in vernal catarrh, for example.

Hemorrhage. Two cases were encountered in which telangiectases following moderately large doses to vernal catarrh of the upper lids resulted in some bleeding externally, but this subsided

spontaneously. Two cases developed intracorneal hemorrhages during the constrictive and fragmentation stage in the corneal vessels. Blood-staining of the cornea resulted in these localized areas.

Formation of Postradiational Vessels. A distinctly undesirable cosmetic blemish often results a year after treatment in areas surrounding ischemia produced by radiation. These vessels are dilated, tortuous, at times partially constricted in the form of sausages, and contain a very sluggish flow of blood. In general, such vessels show little tendency for growth over the ischemic area or onto the cornea; but, in a few instances, after two or three years such an extension occurred. These are particularly undesirable cosmetically when the treatment is carried out within the palpebral fissure, as for pterygiums.

Epilation. In one case, epilation resulted from 2 gm. secs. treatment which was repeated after four weeks. However, six months later, the lashes had regenerated normally. The exact single epilation dose is uncertain but probably ranges from 4 to 6 gm. secs.

Late Corneal Ulceration. In none of our cases did the application of radon appear to accentuate the degree of ulceration. This may be because great care was taken to apply not more than 1 gm. sec. over an area of active corneal ulceration or infiltration, although this dose was repeated in some instances after intervals of one or two weeks. One case in our series and another case treated elsewhere developed a shallow corneal ulcer adjacent to an area of the limbus rendered ischemic by the radiation. The ulcer in our series was also accompanied by bacterial infection and cleared rapidly on antibiotic therapy within six days. The other case showed greater chronicity of several months and a conjunctival flap was recommended. In view of the rather large numbers of cases which had at least partial ischemia of the limbal region, this extremely low incidence of ulceration implies that complete integrity of the limbal circulation is unnecessary for the immediately adjacent cornea. Vascularization has been eliminated from areas of marginal atrophy of the cornea without further thinning of the corneal substance.

Epidermalization of Conjunctiva. Others have reported a condition of epidermalization of the conjunctiva of the lids resulting in

chronic irritability of the eyes. This complication has not been observed in our series, perhaps because of the tendency to avoid sufficient dosage to completely eliminate all the cobblestone papillas of chronic vernal catarrh and rather to flatten them out and eliminate the discharge sufficiently to improve symptoms. It appears quite reasonable to assume that the systematic and complete elimination of all the mucous glands of the conjunctiva might result in undesirable epidermalization of the conjunctiva. However, it should be remembered that advanced forms of vernal catarrh in which there is a deposition of much hyalin material do not resolve themselves spontaneously leaving a normal conjunctiva, but rather some scarring and pathologic change which should not be interpreted as radiational in type.

Glaucoma Following Beta Radiation. Because radiational glaucoma has been described after other forms of radiation, and because superficial aqueous veins are undoubtedly destroyed by beta therapy which renders the limbal region ischemic, glaucoma has been looked for in our cases. The problem of diagnosing glaucoma in most of these cases which have received large amounts of radiation at the limbus is made difficult because of the unreliability of tonometric readings on such heavily scarred and irregular corneas. In a few eyes in which the tactile tension appeared to corroborate the elevated tonometric tension, it was difficult to attribute any increase of pressure to the effects of the irradiation alone in view of the changes present within the anterior ocular segment due to the disease process or an exacerbation of the inflammatory element of the disease itself. A few of these patients who appeared to have elevated tensions apparently became normal spontaneously after several weeks or months. One patient with bilateral vascularizing primary keratitis (Figs. 19 and 20) who received approximately 42 gm. secs. in 34 weeks over the limbal region in one eye and 51 gm. secs. within 16 weeks in the other eye ran tonometric tensions ranging from 25 to 45 for over a year. However, there is, as yet, insufficient evidence of disc and field changes to warrant the diagnosis of glaucoma in view of the possible unreliability of the tonometric tensions.

It is noteworthy that all the patients in whom glaucoma was

suspected had large total doses of beta (average 53 gm. secs.), usually over a prolonged period of time.

Cataracts Following Beta Radiation. Definite cataracts developed in two patients who received relatively large doses of beta-radon over a relatively short period of time (Figs. 17, 19, and 20): Both cases were treated for intense primary vascularizing keratitis, the greatest amount of radiation being applied over the limbal region: in one case 44 gm. secs. in 18 weeks and the second case 51 gm. secs. in 16 weeks. Evidence of cataract appeared at 30 and 35 months respectively after beginning radiation therapy. Although the exact details of the morphology of the cataracts could not be studied because of the moderate haziness of the cornea, the first thing noted was an increase in the amber-colored nuclear haze, followed within several weeks by rapid development of an intumescent cataract. Both lenses were extracted uneventfully, one by the extracapsular route and one by the intracapsular route. The anterior chambers formed readily and the wounds appeared to heal satisfactorily although in one case a small 2 mm. conjunctival filtering bleb developed. The residual clarity of the corneas was not appreciably affected by the operation. No other definite cataracts have been observed, although in two other cases there appeared to be some increase in nuclear sclerosis. It is possible in other cases receiving large doses of beta-radon that cataracts have been concealed behind dense leucomas, and in other cases insufficient time has elapsed for cataracts to develop. No other reports in the literature were found of cataracts forming following the use of beta-radon in other types of applicators. It is possible, of course, that cataract formation in these two eyes might have been mere coincidence, but the monocular character of the opacities, the large dosage rate of beta given, and the rapid development of intumescence are certainly suggestive of an etiologic relationship.

The tolerance of the human lens to X-ray or gamma radiation has not been determined, cataracts having been reported after total doses of 1000 to 3000 r, varying widely because of different energies, regimes of treatment, and so on. In view of the almost complete lack of information concerning the tolerance of the lens for beta particles, it might be interesting to speculate about the possible

TABLE 22. INDICATIONS FOR BETA-RADON THERAPY

Indications	*Condition*
Treatment of Choice	Epithelial tumors of limbus and cornea
	Vernal catarrh, palpebral or bulbar forms, associated with severe symptoms
	Rosacea keratitis
	Primary vascularizing keratitis
	Recurrent pterygium
	Vascularization complicating keratectomy and keratoplasty
Favorable Results (Low Doses)	Phlyctenular kerato-conjunctivitis
	Inflammatory infiltrates in cornea
	Papillomas and hemangiomas of conjunctiva
	Nodular episcleritis
	Granulation tissue
Uncertain Results	Stromal herpes simplex
	Basal cell carcinoma of lid margin
	Chemical burns (not recent)
	Tuberculous sclero-keratitis
	Interstitial keratitis
	Trachoma, IV
	Salzmann's dystrophy of cornea with vascularization
	Lipoidal dystrophy of cornea with vascularization
	Old vascularized corneal scars
	Superficial punctate keratitis
Not Indicated Because of Undesirable Features, Better Treatment Available, or No Effect	Primary treatment of pterygium
	Corneal scars without vascularization
	Fuchs' endothelial-epithelial dystrophy
	Epithelial downgrowth into anterior chamber
	Acute chemical burns
	Large does for inflammatory lesions
	Cicatrizing conjunctival disease (e.g., pemphigus)
	Nevi
	Pinguecula
	Tumors of lid margin

dosage of radiation which reached the lenses in the two patients described previously. Using Krohmer's data (5) and that of Table 5, the output of our radon applicator might be thought to range between 0.5-3 rep/mc./sec. At a depth of 4 mm. at the anterior surface of the lens, a range of values from 440 rep to 7,650 rep might be expected in these two cases. At 5 mm. below the corneal surface or 1 mm. within the lens, a dosage of 220 to 1530 rep might be expected considering a 1 per cent penetration to this level. The extreme upper limits of these gross estimations, therefore, would seem to be within cataractogenic ranges.

SUMMARY OF INDICATIONS FOR BETA RADIATION THERAPY

Ocular diseases which have been treated with beta-radon therapy have been classified in Table 22, considering the degree of response to radiation, the possibility of undesirable reactions, and the comparison of beta radiation therapy to other measures. Beta radiation should be as good or better than other recognized treatment and relatively free of undesirable reactions in order to provide an indication for its use.

SUMMARY

The characteristics of beta radiation from various ophthalmic applicators are described, including a new radon applicator which utilizes radon in capillary glass tubes. The results of treatment of various ocular conditions in 235 eyes with beta-radon during the past three and a half years are reported, including several undesirable reactions and complications which were encountered. From these studies, tentative indications for beta therapy in ophthalmology are listed.

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