PROGRESSIVE MYOPIA: A POSSIBLE ETIOLOGIC FACTOR*

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There is some doubt as to when myopia was first recognized. It is known that the word is derived from the Greek, one who squints. Hippocrates did mention squinting of the lids, but, according to Landolt,[1] there is some doubt as to whether he used the term myopia in the same sense as it is used today.

There can, however, be no doubt as to the importance of the condition, affecting as it does millions of individuals. It has been stated by Jackson[2, 3] to be responsible for 4 per cent. of the causes of blindness of both eyes, and in a statistical study in the United States he found that among children between five and ten years of age 8.1 per cent. of the eyes are myopic; at twenty years, 25.7 per cent.; at fifty years, 13.7 per cent.; and after sixty years, 19.1 per cent.

Definition

The term myopia as used here refers particularly to those types that have been evolved, or that have been made to progress, by a stretching of the coats of the posterior pole of the eye. The anteroposterior length of the eye is of importance, especially in myopia of high degree, but it must be remembered that myopia may be conditioned by other factors, *e. g.*, the curvature of the cornea, the refractive index of the lens, etc. Parsons[4] pointed out that in the emmetropic eye the length may vary by as much as 2 mm., and the radius of curvature of the cornea from 7 to 8.5 mm., and that a buphthalmic eye may be as much as 31 mm. in length from

* Candidate's thesis for membership accepted by the Committee on Theses.

the anterior surface of the cornea to the retina, and yet not be myopic.

There are many cases of myopia of low and moderate degree in which the fundi are normal; the fundus changes usually found in progressive high myopia, such as crescents, atrophy of the pigment epithelium, etc., are not found. They are normal eyes, both in appearance and in function, except for the refractive anomaly present, or, as expressed by Parsons[4]: "It would seem certain that from the biologic point of view we should expect to find many examples of permanent low hyperopia, and a few—but perhaps not negligible—of permanent low myopia. Such cases are fundamentally no more pathologically abnormal than short or tall men."

On the other hand, one occasionally sees low hyperopic and low myopic eyes, with definite, even though slight, myopic crescents, which have been brought about by the gradual stretching of the coats of the eye at the posterior pole. Some of these eyes may be considered as potential precursors of progressive myopia. Lipschutz[5] regarded an eye as myopic in the biologic sense if the characteristic changes in the fundus are to be seen, even if the actual refraction is normal.

Randall[6] believed that hyperopia could not be healthfully outgrown, and that to progress from hyperopia to myopia was a pathologic process.

It is stated by Sorsby[7] that the growth of the eye is completed at eight years, and that during this process of growth the organ increases in length by about 8 mm. Unfortunately, in many cases of progressive myopia pathologic elongation of the eye continues after this age. Fuchs,[8] in speaking of the process of elongation of the eyes of young subjects, conceived of myopia as being due essentially to such a disproportion between the elongating force and the resistance offered to it as to render the former unduly predominant; that is, myopia develops either because the elongating force is excessive or

because the resistance offered to it is too weak; in the latter case the coats of the eye at its posterior pole are abnormally distensible. He believed that both factors probably were concerned, but that definite resistance of the eye was the most important factor.

THE EFFECTS OF INCREASED INTRA-OCULAR PRESSURE IN THE YOUNG

A known fact is that the sclera in the eyes of the young is more distensible than in the adult. As age advances it becomes tougher and more unyielding. Witness the effects of prolonged, continuous increased pressure in the eyes of the very young. If the pressure is not relieved, the stretching and enlargement of the globe become extreme; and, assuming that an ectasia of the sclera in young myopes may be produced by an increase in the intra-ocular pressure, the hydrophthalmic eye presents several points of interest. In the first place, if myopia can be produced by an increase in the intra-ocular pressure, why is not cupping of the optic disc present in many of the cases? Like many other questions concerned with myopia, the answer is doubtful, and, without wishing to revive the arguments that myopia and hydrophthalmia represent essentially the same condition, it is known that in many cases of hydrophthalmia cupping of the disc does not appear early, even though the stretching of the corneal and scleral tissues may be marked. Indeed, in many cases in which the cornea is definitely enlarged, the disc may be quite normal in appearance. The assumption has been made by Anderson[9] that the distensibility of the sclera around the entrance of the optic nerve might delay the appearance of the cupping of glaucoma, or, when cupping does appear, it may influence its shape, so that it may resemble a flat funnel instead of the usual cup with parallel or even concave lateral walls. In response to a questionnaire sent out by Anderson, many cases of hydrophthalmia without cupping of the disc were reported, even though definite signs of marked hydroph-

thalmia were present and the age was relatively advanced—in some cases, ten years.

In 1931 Bruckner and Franceschetti[10] reported 25 cases of myopia in children which they considered different from the type which increases during school life. Certain features suggested a similarity between this form of myopia and hydrophthalmia: (1) Two-thirds of the patients were males, and (2) the temporal conus was small, rarely exceeding one-third of the diameter of the disc. These children were about six or seven years of age, and showed myopia of from 3 D. to 25 D. and a myopic astigmatism ranging from 1 D. to 4 D.

In Dettmering's[11] cases of hydrophthalmia, 23 per cent. showed a conus. In spite of certain similarities between myopia and hydrophthalmia, these conditions are not to be regarded as basically similar. The main interest regarding the two, in so far as the present study is concerned, lies in the distensibility of the sclera, which is a common quality of both conditions.

MECHANICAL THEORIES OF MYOPIA

Many experiments have been undertaken and many theories have been presented to explain, on a mechanical basis, the elongation of the anteroposterior diameter of the eyeball in myopia. After reviewing the literature, one is impressed by the many divergent points of view and the many contradictions encountered, but as a result of this interest and theorizing the subject is kept alive and fresh, and eventually a clearer understanding of this condition will ensue.

Ochi[12] (1919) believed that myopia is caused by a compression of the ocular muscles against a weakened sclera. In an experiment on the eyes of young rabbits (twenty-two to thirty days old) this observer attempted to increase the pressure on the globe by inserting cotton balls under the superior rectus muscle above, and between the muscles and the margin of the orbit at the sides and below. Only extremely slight changes in the anteroposterior diameter of the eyes were pro-

duced. On another group of six twenty-five-day-old rabbits Ochi passed a thread around the equator of the eyeball. After six months only three rabbits were living, and of these, both eyes were enucleated. An average increase of 0.4 mm. in the anteroposterior diameter of the eye was produced. Inasmuch as no mention was made as to how tightly the silk thread was drawn, or as to the development of any pathologic changes in the eye, this investigator's conclusions must be accepted with certain reservations.

Dean[13] doubted that a contraction of the extrinsic muscles would cause a bulging of the posterior sclera, since the eye is pulled against a cushion of fat, and he reasoned that if a stretching did occur, it would be at the anterior unsupported part of the eye. He raised the question that if myopia were due to convergence, why would not the condition cease to progress when the eyes fail to converge?

Levinsohn[14] maintained that when the head and body are bent forward the eyeball protrudes, due to gravity, and causes traction on the optic nerve, which, in turn, causes a stretching of the coats of the eye at the posterior pole. This observer was able to produce myopia in monkeys by placing them in cages that were so designed that the animals were forced to look constantly downward. Levinsohn's experiments were repeated by Essed and Soewarno,[15] who obtained similar results. In three control animals, no changes in refraction occurred after one year. The eyes of these experimental animals were examined histologically by Levinsohn,[16] who found typical myopic crescents present.

Edridge-Green[17] held that the primary and essential cause of myopia is an obstruction of the outflow of the posterior lymph channels which empty into the lymph spaces of the optic nerve, and that any effort, *e. g.*, cycling, coughing, lifting heavy weights, that will increase the intra-ocular tension by obstructing the outflow may cause a stretching of the sclera. He did not believe that the use of the eyes for near work was a factor in the production of myopia.

Marlow[18] found muscle imbalance present in a high percentage of his cases of axial myopia, and concluded that this is probably the most important factor in the onset and progress of the condition. He assumed that the resistance of the scleral coat is subnormal in pathologic elongation of the globe, constituting what Poos called "that mysterious tendency toward myopia." Marlow felt that the pressure constantly exerted on an abnormally plastic sclera by tense extrinsic muscles in order to obtain fusion for all distances might serve as a basis for myopia, and this would explain cases of high myopia in those who do not use their eyes excessively for near work.

Comberg[19] also attempted to explain the progressive character of myopia on a mechanical basis. He believed that physiologic variation in growth cannot be the cause of the frequently occurring pathologic changes and the early foci of degeneration. He held that important tendencies in connection with mechanical factors condition the myopic structure of the eyeball (for example, flat foot and pulmonary emphysema). This observer attributed the elongation of the eye to two factors: (1) The vibration of the optic nerve in lateral movements of the eye because of the resistance of the cushion of fat and the underlying recti muscles, and (2) the backward shifting of the eyeball in the orbit at the opening and closing of the lids. He did not accept Levinsohn's theory that the eyeball fell forward when the head was bent and caused a traction on the optic nerve, which in turn caused a stretching of the posterior pole of the eye. As the result of experiments Comberg found that the eye extends forward from 1 to 1.5 mm. only in patients lying down; in those sitting up it extends not more than 0.5 mm., and bending forward of the head exerts no influence at all. He concluded, therefore, that the eyeball can never "hang on the optic nerve." He explained the results of Levinsohn's investigations on monkeys by the difference in the anatomy of the eye of a monkey and by the unnatural position in which their bodies were held.

Lipschutz[5] maintained that the protrusion of the eye can be verified in many instances, but that the eye moves forward *in toto*, without alteration in shape. He observed the eyes of myopic children, both in the upright and in the stooping position, and the only change he found was a difference in the volume of venous pulsation. He believed that the congestion brought about the forward movement of the eyeball leading to compression of the nutrient ciliary vessels entering around the optic disc, thus causing a weakening of the sclera.

Many other theories have been advanced to explain myopia on a mechanical basis.

Holm[20] assumed an interrelation between the activity of the ciliary muscle and the growth of the eyeball. Müller[21] believed that myopia is produced by traction of the inferior oblique, and reported good results following tenotomy of this muscle. According to Favolara,[22] the size and shape of the orbit do not influence the development of the eye. He came to this conclusion after anatomic examination of numerous orbits.

SQUINTING IN MYOPIA

Several other factors that may exert a possible influence in the production of myopia must be considered. Myopes, like all humans, possess certain individual characteristics. For example, some possess the desire to see clearly at a distance, whereas others do not. It is quite common to find cases of myopia of low, or even of moderately high, degree in which there is no desire to see clearly at a distance at all times. Such subjects do not feel it necessary to wear their glasses constantly, but put them on only when real use of their eyes is required, either for distant or for near vision. The fundi in these patients may be perfectly normal, and crescents or other signs of progressive myopia may be entirely absent. It has often been observed that these myopes have not acquired the habit of constantly squeezing their lids together in order to diminish the circles of diffusion and thus see more

clearly; they have accustomed themselves to indistinct vision without glasses. On the other hand, when fully correcting lenses are worn, squinting of the eyelids is not necessary to obtain clear distant vision. Foerster[23] observed that in many persons who had persistently worn overcorrecting lenses from youth the myopia did not progress, and that after ten, twenty, or even thirty years the glasses still overcorrected the myopia. Jackson[2] and others have called attention to the fact that there is less tendency for myopia to progress when fully correcting lenses are worn. Prangen[24] has made a somewhat similar observation regarding the correction of myopia. Patients whose myopia was definitely overcorrected were comfortable and enjoyed good vision and normally functioning eyes developed. Those who received an exact full or slight undercorrection were not so comfortable, complained of blurred distant vision, and the myopia appeared to show a tendency to progress.

Let us examine the myope who possesses a desire to see things clearly at a distance, but who wears lenses that only partially correct the myopia. In order to see more clearly, he squints the lids. If he is a young individual in whom the sclera is easily distensible, and if the squinting becomes habitual, it is assumed that the myopia will progress. One sometimes wonders whether an incomplete correction of the myopia does not, in some instances, cause the condition to increase more rapidly than it would without any correction, for in the latter case the distant vision is so poor that the effort to overcome it by squinting of the lids is abolished, whereas in the former case vision can be made sufficiently distinct by squinting of the lids. It would seem unlikely that a slight undercorrection of the myopia by as much as 0.25 D. or 0.50 D., enough to cause slightly indistinct distant vision, would materially affect the amount of accommodation and convergence required by close work, and yet, as has been stated, in many of these cases the myopia does have a tendency to increase.

Squinting of the eyelids is frequently resorted to by those who possess astigmatic eyes. In many cases of progressive myopia there is an associated astigmatic error. De Schweinitz[25] observed that sometimes the process of elongation of the eye is begun in hyperopic eyes, especially in those with astigmatism. Marlow[18] found that only 3.5 per cent. of myopic eyes were free from astigmatism. Since in both myopia and astigmatism there is the tendency to squint the eyelids, it would be interesting to speculate as to what effect this action by the orbicularis muscle might have on the intra-ocular pressure, thus causing an elongation of the anteroposterior axis of the eyeball. It would be difficult, I believe, to dismiss entirely the action by some mechanical force on the eyeball causing an increase in its length. The eye is a delicate, highly developed, movable organ. In the young, why would not its length be increased by a factor that tended to cause an increase in the intra-ocular pressure, even assuming that in the beginning the sclera is normal? And why would not this force cause a further increase of myopia in later years in those eyes in which the sclera had previously been thinned and stretched by the myopic process?

THE ROLE OF THE ORBICULARIS MUSCLE

The orbicularis is a sphincter muscle and, according to Whitnall,[26] acts as a whole on forced occlusion of the lids. In partial closure of the lids the lacrimal portion of the palpebral margins come in contact over the lacus lacrimalis so that the whole palpebral opening is reduced in both vertical and horizontal directions.

The action of the orbicularis is more complicated than that of merely closing the lids. In the living subject it can readily be seen that the palpebral portion of the muscle is so curved that it corresponds to the curved contour of the anterior aspect of the globe from before backward and from side to side. Due to this anatomic position and to its sphincteric action, the muscle undoubtedly compresses the globe, tempo-

rarily raising the intra-ocular pressure. This action by the muscle is respected by the ophthalmic surgeon, as, for example, during cataract operations, when squeezing may cause damage to the eye. Such accidents are much less common today than formerly, since the muscle is usually temporarily paralyzed before operation.

(*a*) *Clinical Testing of the Strength of the Orbicularis Muscle.*—With these facts in mind, it is interesting to note the amount of force that can be exerted by forcible contraction of the orbicularis. Comberg[19] measured the amount of backward push on the eyeball in opening and closing the lids. The push at blinking was intercepted in an apparatus used for the purpose, and was found to correspond to an average weight of from 15 to 16 gm.—in full opening and closing of the lids it measured from 35 to 40 gm. This investigator felt that the blinking influenced the posterior pole as contre coup, and at the same time caused a jerk of the optic nerve.

To measure the amount of constrictive pressure which the orbicularis exerts on the globe is not a simple procedure. Two methods of indirectly testing this action of the muscle were employed. First the actual pull of the muscle in patients was measured. For this purpose a dynamometer was devised (fig. 1). The instrument is in reality a squint hook, the hook and handle being indirectly connected by means of a spring inside of the handle. The shaft of the hook is graduated in millimeters, so that each millimeter represents a pull of one gram. In testing the upper lid the hook of the instrument was placed under the lid and the handle inclined so as to form a right angle to the anterosuperior surface of the globe, that part of the eyeball which is covered by the lid. The subject was instructed to relax his lids, and at the same time the lid was gently drawn away from the globe. He was then told to squeeze the lids forcibly, after which the pull exerted on the hook was read on the scale. The hook was then placed under the lower lid with the handle at right angles to the antero-inferior surface of the globe, and the pull of the lower

lid was measured. The pull exerted by the upper lid usually measured from 50 to 70 gm., whereas that of the lower lid was somewhat less, averaging from 40 to 50 gm. These results were quite constant in 25 patients of various ages and in different refractive conditions. The figures heretofore given are believed to be reasonably accurate, but it is not assumed that they are exact. They do, however, give some indication as to the amount of force that can be applied to the globe by forcible contraction of the orbicularis. Then, too, under ordinary conditions the cushion of the orbital fat, against which the globe rests, might yield enough to prevent the full compressing action of the orbicularis to be felt.

(*b*) *Effect on Intra-ocular Pressure.*—The effect exerted on intra-ocular pressure by the orbicularis was measured on rabbits which had been anesthetized by the use of "Nembutal" administered intravenously. The normal intra-ocular pressure of the rabbit's eye, as measured by the Schiötz tonometer, was found to average approximately 20 mm. Hg. When the lids were tightened, and the palpebral fissure narrowed by placing the thumb over each canthus and stretching the lids, the intra-ocular pressure could be increased to 40 mm. Hg or more with comparative ease.

EXPERIMENTAL PRODUCTION OF AXIAL MYOPIA

In order to determine, if possible, the degree of elasticity of the sclera in rabbits, 15 animals were selected. They were then divided into three groups—small, medium, and large—which corresponded to the respective ages. It was believed that if a constricting band or suture could be applied around the equator of the eyes, producing an increase in the intra-ocular pressure, an increase in the length of the antero-posterior diameter of the eyes could be produced, and that in the younger animals this elongation would be more marked than in the older rabbits. It was also considered that the length of time the increased pressure was sustained would influence the amount of stretching. Several tests were neces-

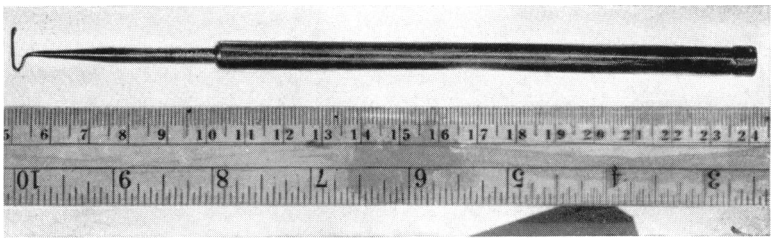

Fig. 1.—Dynamometer hook.

Fig. 2.—Eye showing only slight reaction following application of wire.

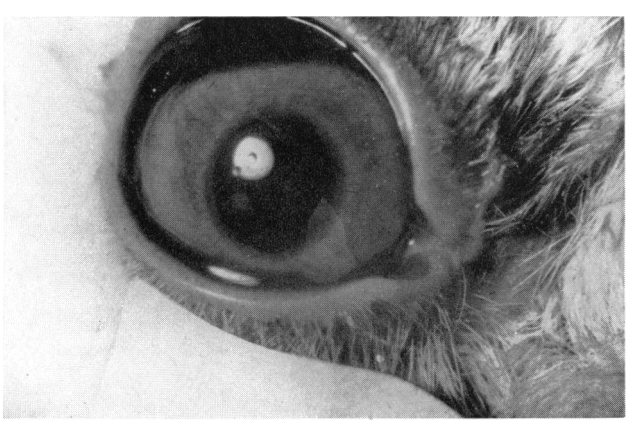

Fig. 3.—Eye showing a dilated pupil, edema of cornea and ecchymosis of conjunctiva.

sary to determine the most practical method of producing the desired effect. A 5 mm. silver band was tried, and was found very effective in producing a rise in the pressure. Difficulties were, however, encountered, for example, it was difficult to tighten the band to the exact degree required, and it caused considerable irritation and would sometimes slip off. A purse-string suture of braided silk seemed satisfactory, but this would sometimes slip forward to the insertions of the muscles. Finally, a 22-gauge stainless steel wire was selected. A loop of the wire was placed around the equator of the globe, and the ends gradually twisted with forceps until the intra-ocular pressure rose to the desired height. The twisted ends were then cut off somewhat close to the globe, and bent to the side, so that a minimal amount of irritation would be caused. In these animals the right eye was subjected to the experiment, the left eye serving as a control. Anesthesia was produced by intravenously given Nembutal, injected into a vein of the ear. The wire was twisted moderately tight to prevent it from slipping either anteriorly or posteriorly. The Schiötz tonometer was placed on the cornea, and the wire further tightened until the intra-ocular pressure was raised to the desired height—75 to 100 mm. Hg. Mercury bichloride ointment (1:5000) was then placed in the culdesac. The cornea became hazy, and the pupil dilated immediately. On the day following the experiment a definite band of ecchymotic conjunctiva anterior to the wire was present (figs. 2 and 3). The marked clouding of the cornea remained. The pupil was moderately dilated, and the blood-vessels of the iris were grossly congested. The pressure of the eye fell rapidly from the initial high to approximately 40 mm. Hg within an hour, but remained moderately elevated—to about 35 mm. Hg—until the end of the experiment (two to two and one-half days). At the completion of the experiment the animals were sacrificed, and both eyes were removed and placed in formalin. After hardening, paraffin sections from anterior to posterior pole were made and mounted. The

anteroposterior diameters of the eyes were measured, under magnification, from greatly enlarged photographs of figures 4 and 5. Because of the thickening of the cornea in some of the eyes, measurements were made from the posterior surface of the cornea to the inner surface of the sclera. Since the microscopic sections did not retain the same form as the original eye, measurement of these sections would have been inaccurate.

TABLE 1.—RABBIT EYES SUBJECTED TO PRESSURE BY THE APPLICATION OF A WIRE BAND

Number and Size of Experimental Animal	*Intra-ocular Pressure, mm. Hg*		*Pressure After Application of Wire, Right Eye*	*Duration of Pressure, Right Eye*	*Anteroposterior Length in mm. at end of Experiment*		*Gain in Length, Right Eye, mm.*
	Right Eye	*Left Eye*			*Right Eye*	*Left Eye*	
2, small.....	22	23	100	48 hrs.	14.7	13.3	1.4
3, large.....	17	19	75	48 hrs.	17.1	14.3	2.8
4, medium....	25	25	75	48 hrs. (wire slipped off)	13.3	13.5	−0.2
5, small.....	22	19	75	48 hrs.	14.7	12.3	1.4
6, large.....	22	18	75.5	24 hrs.	15.2	15.2	0
7, small.....	24	15	75	24 hrs.	14.7	13.1	1.6
8, small.....	18	15	75	24 hrs.	13.8	13.3	0.5
10, medium....	20	20	110	60 hrs.	15.4	13.8	1.6
11, medium....	22	20	110	60 hrs.	14.2	13.8	0.4
12, large.....	20	15	110	60 hrs.	16.6	15.5	1.1
13, medium....	16	16	110	60 hrs.	15.2	13.3	1.9
14, large.....	18	18	110	60 hrs. (wire slipped off)	15.0	15.0	0
15, large.....	10	12	110	60 hrs.	17.3	17.3	0
16, medium....	22	22	110	60 hrs.	16.6	15.2	1.4
17, medium....	18	18	110	60 hrs.	16.4	15.2	1.2

In the three groups of rabbits the average increase in length of the experimental eye was as follows: Small, 1.25 mm.; medium, 1.30 mm.; large, 0.97 mm. Although the increase in the two former groups was approximately the same, it will be noted that the increase for the large group was much less. There was also less average gain in length in those eyes

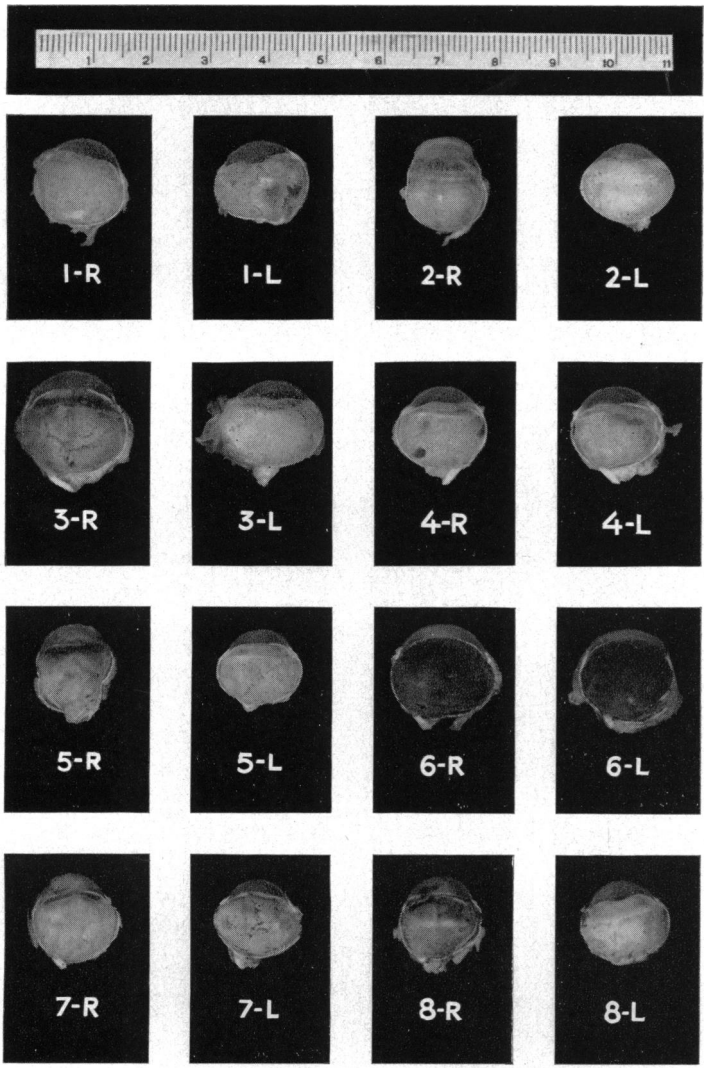

Fig. 4.—Eyes illustrating the increase in the anteroposterior diameter. See table for corresponding numbers.

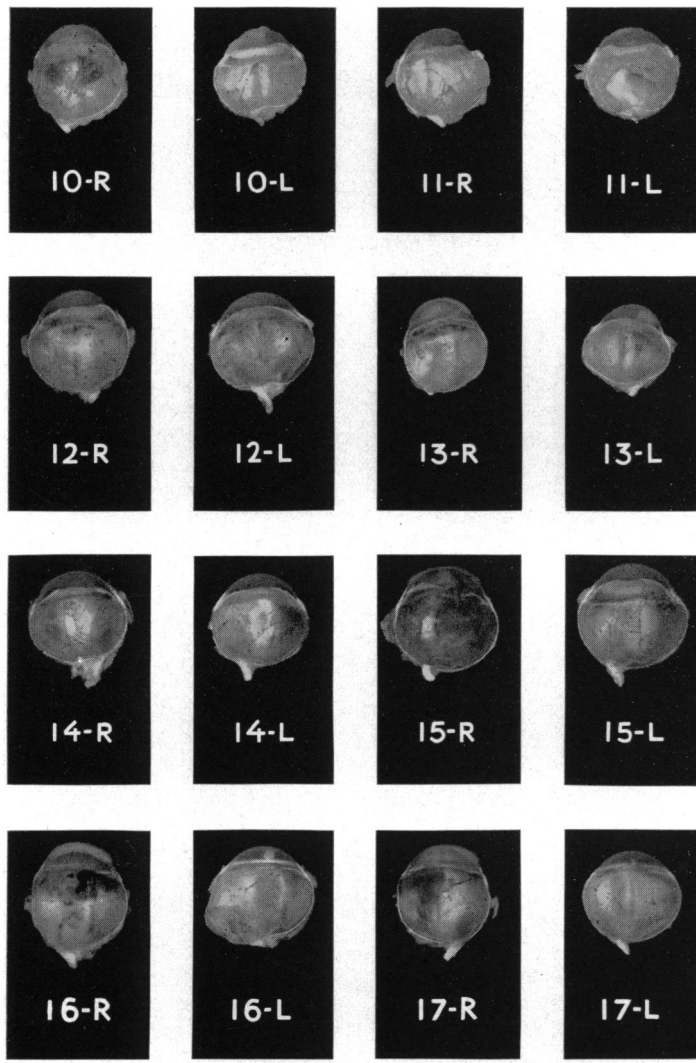

Fig. 5.—Eyes illustrating the increase in the anteroposterior diameter. See table for corresponding numbers.

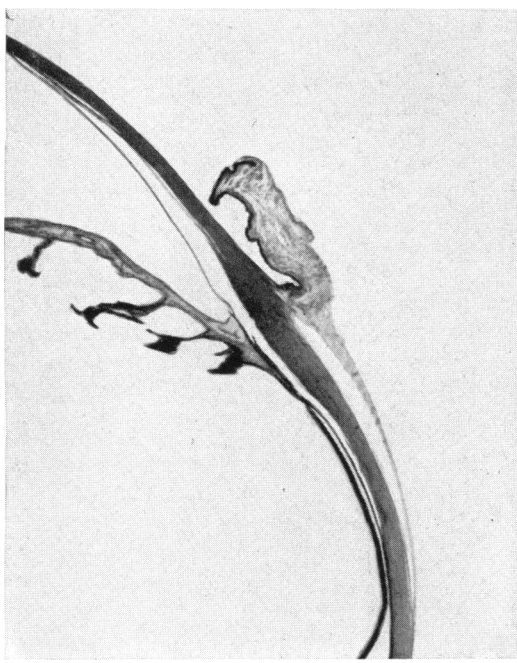

Fig. 6.—Section of normal control eye.

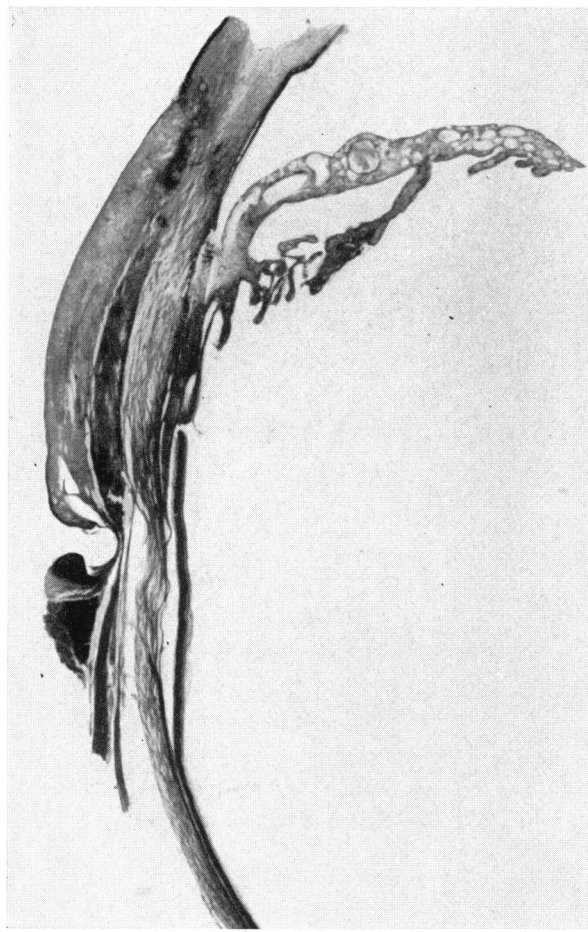

Fig. 7.—Section of experimental eye. Note the deep furrow in the thickened conjunctiva caused by the wire.

which were subjected to the pressure for twenty-four hours than in the eyes in which the pressure was maintained for longer periods. The group of animals is admittedly small (15), but, taken as a whole, there was a gain in length of each eye subjected to the experiment, except two, 6 and 15. These were adult rabbits, and possessed, it is believed, a less yielding sclera. (See Table.)

In two rabbits, 4 and 14, from the eyes of which the wire had slipped, there was no change in the length of the experimental eyes at the end of the observation period.

The eyes of rabbit No. 1 (fig. 4) were not considered satisfactory specimens. They are, therefore, not recorded in Table 1.

Microscopic study of slides (figs. 6 and 7) of the experimental eyes showed marked congestion of the blood-vessels of the conjunctiva anterior to the point of application of the wire. The blood channels at the limbus and the vessels of the iris and ciliary body were likewise greatly engorged. The cornea was swollen to a varying degree and contained dilated lymph spaces. The histologic structure of the globe posterior to the point of pressure by the wire was regarded by Dr. Kindred to be essentially normal.*

CONCLUSIONS

1. Myopes who are undercorrected or who wear no correction at all frequently resort to the habit of squeezing the eyelids together in order to make the diffusion circles smaller, thus enabling them to see more clearly at a distance.

2. When the myopia is fully corrected, distant vision is distinct, and there is less tendency to squeeze the eyelids together. Myopia which is fully corrected seems to show less tendency to progress than when it is only partially corrected.

3. Contraction of the orbicularis muscle probably causes

* My thanks are due to Dr. Floyd Boys, of the Surgical Research Laboratory, University of Virginia, for the use of the facilities of his laboratory, and to Dr. J. E. Kindred, of the Department of Histology and Embryology, University of Virginia, for preparing the sections.

an increase in the intra-ocular pressure, which, if maintained over a long period of time, may cause a stretching of the sclera in the young, and in older individuals, if the sclera is already weakened.

4. Elongation of the anteroposterior diameter of the eyes of rabbits can be produced by increasing the intra-ocular pressure.

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