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MEASUREMENTS OF THE SAGITTAL AXIS OF THE HUMAN EYE *IN VIVO* DURING APPLANATION OF THE CORNEA*†‡

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PRIJOT and Weekers (1959) measured the so-called coefficient of the scleral rigidity (E) in two human eyes before enucleation, using Friedenwald's differential tonometry and a manometric procedure. There was a surprisingly high difference between the results of the two methods. Prijot (1961) supported this finding by results from a more extensive series of cases; he found that the mean value of E was 0·025 when measured by differential tonometry, and 0·013 by manometry. Discussing the paper of Prijot and Weekers at a meeting of the Ophthalmological Society of Belgium, Goldmann (1959) suggested that this discrepancy might be explained by the following hypothesis:

The Schiötz tonometer resting upon the cornea produces not only an indentation of this tissue but also a flattening of the posterior pole of the eyeball. To estimate the scleral rigidity, both volumes, that of the corneal indentation and that of the deformation of the posterior pole, must be considered. Manometry fulfils this demand, but in differential tonometry only the volume of corneal indentation is known, so that the coefficient E is overestimated.

This hypothesis we have attempted to investigate experimentally. In theory the supposed flattening of the posterior pole in emmetropic, normotensive eyes should cause a shortening of the sagittal axis of about 0·5 mm. We felt, therefore, that we should be able to measure such a difference ultrasonically, as the standard errors of the mean ($S_{\bar{x}}$), calculated from nineteen measurements by our echographic equipment on one eye, were $\pm$0·031 mm. within the anterior chamber, $\pm$0·024 mm. within the lens, and $\pm$0·044 mm. for the section of sagittal axis within the vitreous space.

We endeavoured to measure the sagittal axis of the eyeball by echography before and during a deformation of the cornea by compression in the antero-posterior direction, by the following procedure:

A plexiglass-prism with two parallel and two oblique sides was fixed to the sound probe so that the ultrasonic ray could enter and leave the prism precisely in the vertical direction. The prism was put on the cornea with various pressures, thus producing applanations of the cornea of different degrees. The changes in the sagittal axis of the eye during those applanations were then registered photographically from the echogram screen. Another camera photographed the fluorescein ring around the corneal applanation through the oblique side of the prism. This equipment was arranged upon a Haagstreit slit lamp, model 900. The investigations were performed by two examiners, one of whom pressed the prism against the cornea and observed the curve on the echogram screen, while the other adjusted the camera on the slit lamp to the fluorescein ring. The two cameras, that registering the echogram and that registering the applanation, were released simultaneously.

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From the photographs of the fluorescein rings the diameter of the applanated area was measured. Using the latter, the height of the applanated corneal segment was calculated, paying attention to the radius of the corneal curvature as measured on the ophthalmometer (Javal/Schiötz). In applanations of more than 6 mm. diameter, the decline of the corneal curvature in the corneal periphery was considered (Prijot, Weekers, and Maréchal, 1964; Collingnon-Brach, Papritz, and Prijot, 1966), so that the shortening of the sagittal axis resulting from the applanation of the cornea could be established.

Several echographic measurements were performed on the untouched eye and compared with the echograms obtained during the applanations. The resulting differences were accepted as the consequence of the compression of the eye.*

The results of 39 measurements performed on nine emmetropic eyes have already been published (Stepanik and Ossoinig, 1967). Within the anterior chamber there was an impressively high correlation between the values for the shortening of the sagittal axis as derived from the photographs of applanations on one side and from the echograms on the other side ($r = 0{\cdot}879$; $P = 0{\cdot}001$). Within the remaining section of the eye, however, no change in the sagittal axis could be found to correspond to the corneal applanation ($r = 0{\cdot}11$).

The present report deals with the question how ametropic eyes—especially eyes with myopia of high degree—behave under the same experimental conditions.

Myopic Eyes

Case 1, a woman aged 28 years. The refraction was −31·5 D sph., + 2 D cyl., 20° in the right eye, and −29 D sph. in the left. The average radius of the corneal curvature was 7·9 in the right eye and 8·0 in the left. The thickness of the cornea was 0·5 mm. in each eye. The depth of the anterior chamber was 3·49 mm. in the right eye and 3·37 mm. in the left. The intra-ocular pressure was 19 mm. Hg in the right eye and 20 mm. Hg in the left as measured by Goldmann's applanation tonometer.

The results of fifteen measurements performed on both eyes during applanation of the cornea are presented in Table I (opposite).

The diameter of applanation, '*d*', was 7·1 ± 3·22 mm. and the corresponding mean volume of applanation 15 cu. mm. The height of the corneal segment, X, was 0·864 ± 0·539 mm. and was practically equal to the change in the sagittal axis within the anterior chamber as measured by echography:

$$Y = 0{\cdot}886 \pm 0{\cdot}565 \text{ mm.}$$

As shown in Fig. 1 (opposite), there is a highly significant correlation between the X and Y values, the correlation coefficient, r, being 0·867 ($P < 0{\cdot}001$). This excellent conformity of X and Y is still more remarkable in view of the fact that the photographs (X values) and the echogram curves (Y values) were evaluated independently by two examiners.

Within the lens-vitreous space the echograms indicated a slight increase in the sagittal axis:

$$U = 0{\cdot}319 \pm 0{\cdot}517 \text{ mm.}$$

Using the sign test this was moderately significant ($P < 0{\cdot}05$). There was, however, no correlation between U and X values, r being 0·0429 (Fig. 2, overleaf).

* The echographic equipment of Kretz, Austria ,model 7000, with a frequency of 8 megacycles, was the most convenient for our purpose.

TABLE I
MEASUREMENTS FROM TWO MYOPIC EYES

	Photographs of Applanations (15)		Echograms (15)					
			Anterior Chamber			Lens—Vitreous Space		
	Diameter of Area	Height of Segment	Before Applan.	During Applan.	*a–b*	Before Applan.	During Applan.	*a–b*
	d	*X*	*a*	*b*	*Y*	*a*	*b*	*U*
	5·8	0·54	3·49	2·73	0·76	28·80	29·92	−1·11
	8·2	1·00		2·35	1·14		29·52	−0·72
	11·0	1·60		1·89	1·60		27·97	0·83
	5·2	0·43		3·05	0·44		28·90	−0·10
	0	0		3·55	−0·06		28·80	0
	2·2	0·08		3·32	0·17		29·11	−0·31
	9·2	1·30		1·95	1·54		29·41	−0·61
	9·6	1·30	3·40	1·77	1·63	27·9	28·97	−1·07
	9·6	1·30		2·18	1·22		28·79	−0·89
	10·4	1·50		2·02	1·38		28·11	−0·21
	6·8	0·70		2·73	0·67		27·65	0·25
	10·4	1·50		2·04	1·36		28·38	−0·48
	4·0	0·25		3·23	0·17		27·90	0
	6·2	0·60		2·89	0·51		28·01	−0·11
	7·6	0·85		2·63	0·77		28·16	−0·26
$\bar{x}$	7·1	0·864			0·886			−0·319
s ±	3·22	0·539			0·565			0·517

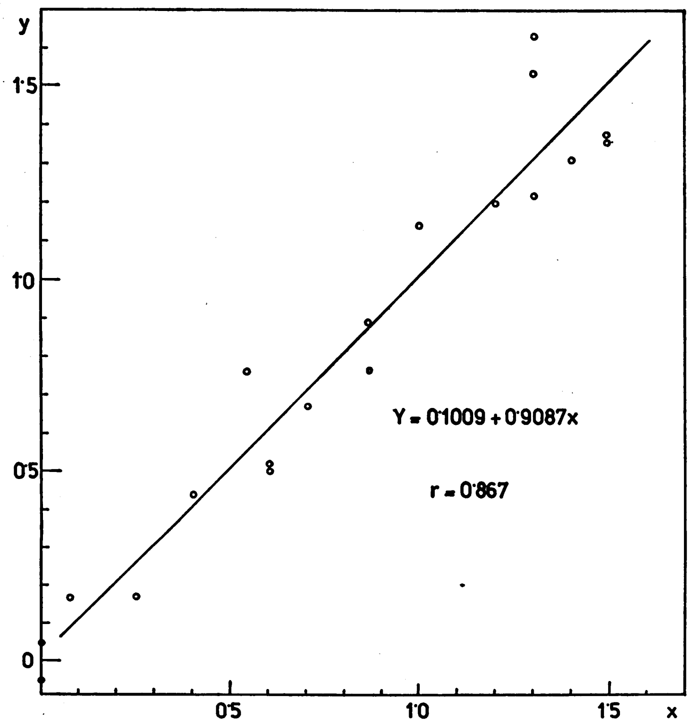

FIG. 1.—Myopic eyes: relationship between height of applanated corneal segment (*X*) and change in sagittal axis within the anterior chamber (*Y*).

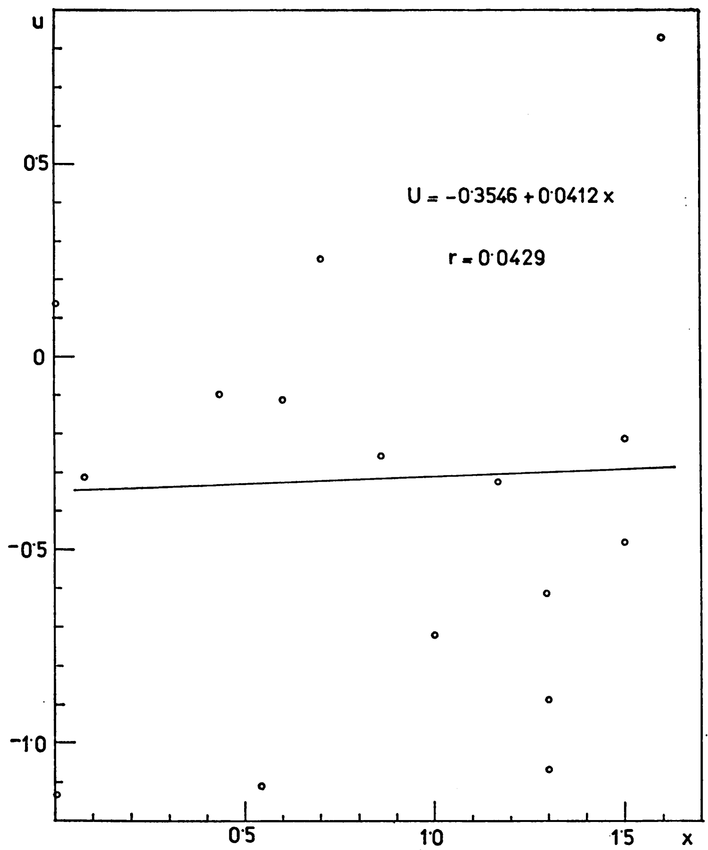

FIG. 2.—Myopic eyes: relationship between height of applanated corneal segment (X) and change in sagittal axis within the lens-vitreous space (U).

Hypermetropic Eyes

Case 2, a man aged 48 years. The refraction was + 7·5 D sph., + 1·75 D cyl., axis 180° in the right eye, and + 9.75 D sph., + 0·5 D cyl., axis 180° in the left. The radius of the corneal curvature was 8·0 mm. in each eye, thus accounting in some part for the hypermetropia. The intra-ocular pressure was 19 mm. Hg in the right eye and 16 mm. Hg in the left (Goldmann applanation).

The results of 21 measurements performed on both eyes during applanation of the cornea are shown in Table II (opposite). The diameter of corneal applanation, 'd', was 6·95 ± 1·95 mm., and the corresponding mean volume of applanation approximately 14 cu. mm. The height of the corneal segment, X, was 0·776 ± 0·34 mm. The echograms indicated a shortening of the sagittal axis within the anterior chamber:

$$Y = 0{\cdot}739 \pm 0{\cdot}364 \text{ mm.}$$

As shown in Fig. 3 (opposite), there was again a highly significant correlation between the X and Y values ($r = 0{\cdot}91$; $P < 0{\cdot}001$).

Within the lens-vitreous space some shortening of the sagittal axis (U) was indicated by the echograms:

$$U = 0{\cdot}234 \pm 0{\cdot}171 \text{ mm.}$$

TABLE II MEASUREMENTS FROM TWO HYPERMETROPIC EYES

	Photographs of Applanations (21)		Echograms (21)					
			Anterior Chamber			Lens—Vitreous Space		
	Diameter of Area	Height of Segment	Before Applan.	During Applan.	*a–b*	Before Applan.	During Applan.	*a–b*
	d	*X*	*a*	*b*	*Y*	*a*	*b*	*U*
	7·0	0·75	3·05	2·12	0·93	17·75	17·76	−0·01
	5·2	0·43		2·65	0·40		17·63	0·12
	7·4	0·82		2·17	0·88		17·90	−0·15
	8·4	1·05		2·12	0·93		17·63	0·12
	8·6	1·10		2·01	1·04		17·62	0·13
	3·6	0·22		2·94	0·11		17·59	0·16
	8·8	1·12		2·10	0·95		17·58	0·17
	8·8	1·12		2·17	0·88		17·47	0·28
	5·4	0·47	3·05	2·58	0·47	17·41	17·24	0·17
	6·2	0·60		2·43	0·62		17·11	0·30
	7·4	0·85		2·22	0·83		17·10	0·31
	8·4	1·05		1·99	1·06		17·23	0·18
	8·4	1·05		1·96	1·09		17·18	0·23
	7·6	0·85		2·14	0·91		17·14	0·27
	3·2	0·16		2·68	0·37		17·44	−0·03
	9·4	1·25		1·71	1·34		17·04	0·37
	8·6	1·10		2·10	0·95		17·13	0·28
	5·2	0·43		3·06	−0·01		16·81	0·60
	6·8	0·72		2·48	0·57		17·00	0·41
	3·6	0·22		2·88	0·17		16·91	0·50
	8·0	0·95		2·02	1·03		17·00	0·41
$\bar{x}$	6·95	0·776			0·739			0·234
s ±	1·95	0·34			0·364			0·171

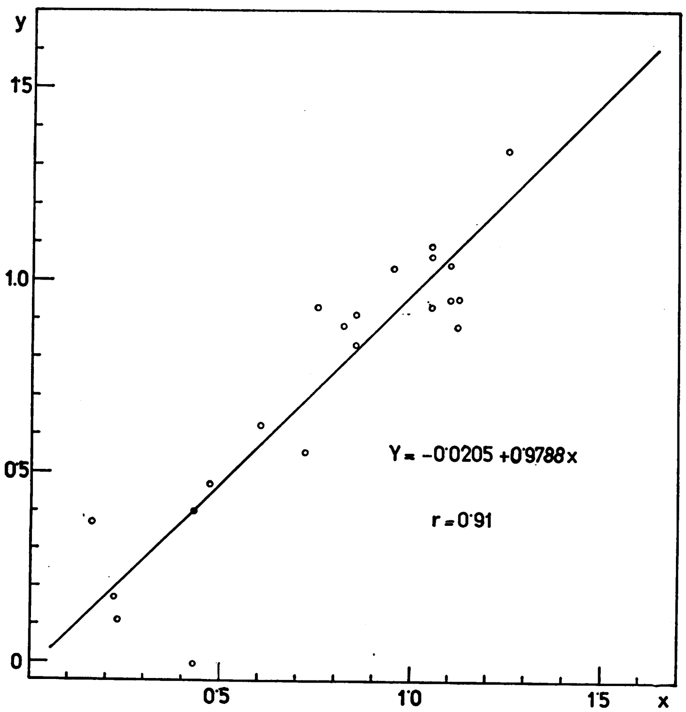

FIG. 3.—Hypermetropic eyes: relationship between height of applanated corneal segment (*X*) and change in sagittal axis within the anterior chamber (*Y*).

Using the sign test this was moderately significant ($P < 0{\cdot}05$). But, again, there was no correlation between the U and X values, r being 0·285 (Fig. 4).

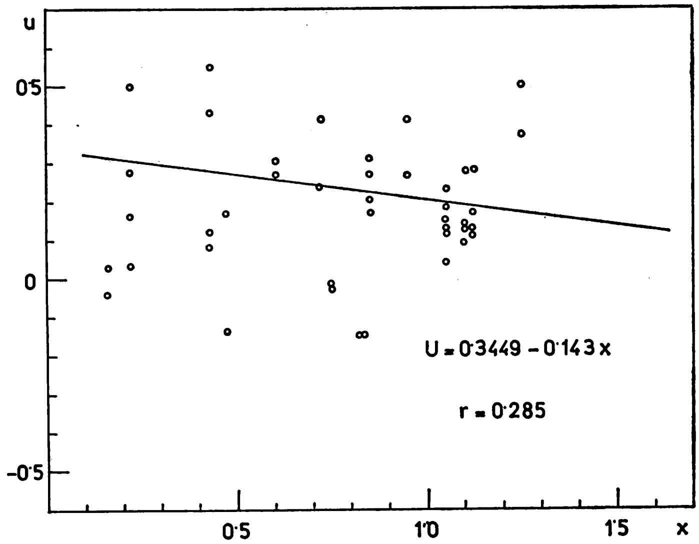

FIG. 4.—Hypermetropic eyes: relationship between height of applanated corneal segment (X) and change in sagittal axis within the lens-vitreous space (U).

Discussion

In human eyes *in vivo*—emmetropic as well as ametropic—pressure against the cornea by a plane surface produces an applanation of the cornea, and the height of the applanated corneal segment is practically identical with the shortening of the sagittal axis within the anterior chamber. This means that, in spite of the "displacement" of the volume of applanation into the anterior chamber, the lens remains *in situ* and is not pushed backwards as might be supposed theoretically. The question then arises: where does the quantity of aqueous corresponding to the applanation-volume go to during the compression of the cornea? Two main possibilities are to be considered: the aqueous may be displaced backwards through the pupil or outwards towards the periphery of the anterior chamber. Our investigations support the latter hypothesis.

From the results of this study, which show that there is no corresponding change in the sagittal axis within the lens-vitreous space when the eyeball is pressed gently into the orbit, it must be concluded that during indentation tonometry no flattening of the posterior pole of the eyeball occurs. This means that another explanation of the findings of Prijot and Weekers must be sought. Instead of a flattening at the posterior pole some deformation of the eye by the oblique muscles may take place during pressure against the cornea. The comparative measurements of the coefficient of scleral rigidity on human eyes *in vivo* using simultaneous indentation tonometry and manometry (Ytteborg, 1960) indicate, on the other hand, that differences between P_o values as measured by applanation tonometry on the one hand or by manometry on the other seem to account for discrepancies in the measurements of scleral rigidity obtained by these two methods. This question thus requires to be further investigated.

Theoretically the myopic eye may change its elliptic towards a more spherical shape and thus shorten the sagittal axis when the intra-ocular volume and pressure are increased. By our measurements a moderate but significant lengthening of the sagittal axis occurred in

myopic eyes during applanation. Thus, with increasing intra-ocular pressure, the wall of the myopic eye, in assuming a more spherical shape, seems to be stretched more at the posterior pole than at the equator.

Summary

In four ametropic eyes, corneal applanations of different extent were performed. During these applanations the sagittal diameter of the eyeball was measured by ultrasonic echograms and the fluorescein rings surrounding the areas of applanation were photographed at the same instant. The height of the flattened corneal segment was calculated from these photographs and this value was then compared with the changes in the sagittal axis within the anterior chamber and also within the lens-vitreous section of the eye as measured by the ultrasound echograms. In a previous study nine emmetropic eyes were examined in the same way. There was a highly significant correlation of the results within the anterior chamber, but none within the lens-vitreous space. The assumption, therefore, that the posterior pole of the eye is flattened when pressure is applied to the cornea could not be confirmed.

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