NORMAL INTRA-OCULAR PRESSURE*

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INTRA-OCULAR pressure varies from individual to individual, from right eye to left eye, and from time to time. Many manometric studies have been made on experimental animals but observations on human eyes have been few: Wessely (1915, 1916) found an average of 22·5 and 18·5 mm. Hg, and Seidel (1922) one of 20 and 25·5 mm. Hg. Tonometric studies of human eyes, however, have been many; the results range from 12 to 35 mm. Hg (Table I), and the normal average may be taken between 15 to 35 mm. Hg.

TABLE I
TONOMETRIC RECORD OF INTRA-OCULAR PRESSURE (mm. Hg)

Author	Date	No. of Eyes	Minimum Record	Maximum Record
Schiötz ...	1909	—	19	30
Wegner ...	1911	100	17	35
Toczycki ...	1912	70	15·5	30
Gridland ...	1917	1,001	16	28
Gjessing ...	1921	2,180	13	35
Andrezen ...	1928	447	12	35
Present Series	1956	1,000	13	30

Material and Methods

No tonometric studies have previously been made on the eyes of Pakistani subjects and consequently no data is available. Tonometric studies of 1,100 healthy eyes were made, using a Schiötz "X" tonometer, and the results are presented below. Pressures are expressed in mm. Hg, using the Schiötz conversion tables.

The radius of curvature and scleral elasticity vary from eye to eye, and these, plus the weight of the instrument and the mode of application, introduce many inaccuracies in tonometry. To reduce these variables to a minimum, the tests were all done with the same tonometer and by the same tonometrist.

The following aspects of the subject were studied:

(1) **Normal Tension.**—The average of 6-hrly tonometer readings for 2 consecutive days represents the mean tension in each of 1,000 eyes.

*Received for publication November 14, 1955.

(2) **Diurnal Variation in Normal Eyes.**—2-hrly tonometer readings were taken on fifty eyes.

(3) **Effect on Normal Tension of Provocative Tests.**

(a) *Jugular Compression Test* (Schoenberg, 1929).—The pre-compression ocular tension was taken on fifty eyes with a Schiötz "X" tonometer, then the sphygmomanometer cuff was tied round the neck to compress both jugular veins, and the cuff was inflated to 40 mm. Hg for one minute. The ocular tension was taken immediately and again 20 min. after release of the cuff.

(b) *Water-Drinking Test* (Wegner, 1930a, b, 1931).—The 25 individuals studied were kept in bed, and each was given 1,000 ml. water to drink in 5 min. on an empty stomach after emptying the bladder in the morning. Smoking was not allowed. The ocular tension was taken 15 min. before the test started and then every 15 min. for 2 hrs. Urine was collected every 30 min. for 3 hrs to study diuresis, and 2 ml. venous blood was collected in a dry oxalated vial before the test and then every 30 min. for 3 hrs to study changes in haemoglobin percentage (Salhi's technique) and plasma proteins (copper sulphate specific gravity method).

Results

(1) **Average Normal Tension.**—Out of a total of 1,000 eyes investigated (669 male and 331 female), the average tension was 19 mm. Hg (Table II).

TABLE II
INTRA-OCULAR PRESSURE IN VARIOUS AGE GROUPS

Ocular Tension (mm. Hg)	Number of Eyes												
	Total			Age Group (yrs)									
	Male	Female	Total	11-20		21-30		31-40		41-50		51-60	
				Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
13	11	9	20	—	—	11	9	—	—	—	—	—	—
14	24	16	40	18	12	6	4	—	—	—	—	—	—
15	48	28	76	21	9	15	11	12	8	—	—	—	—
16	72	26	98	24	10	17	6	10	5	12	3	9	2
17	110	37	147	33	12	21	9	20	7	21	6	15	3
18	139	52	191	30	12	32	15	15	6	33	10	29	9
19	76	20	96	16	4	11	4	13	3	18	4	18	5
20	59	20	79	9	5	7	2	14	4	16	4	13	5
21	44	25	69	5	3	6	4	9	5	11	6	13	7
22	27	15	42	2	—	4	1	7	3	7	5	7	6
23	21	17	38	2	1	2	2	5	3	5	5	7	6
24	19	18	37	1	1	2	1	3	2	6	6	7	8
25	12	15	27	—	—	1	1	2	3	4	5	5	6
26	4	17	21	—	—	1	1	1	3	1	6	1	7
27	1	8	9	—	—	—	—	—	1	1	2	—	5
28	2	4	6	—	—	—	—	—	—	1	1	1	3
29	—	2	2	—	—	—	—	—	—	—	2	—	—
30	—	2	2	—	—	—	—	—	—	—	—	—	2
Average Tension	18	20	19	17	17	17	17	19	19	19	22	19	22

A tension below 15 mm. Hg was found in 6 per cent., all below 30 years of age; 4 per cent. (mostly females over 40 years of age) showed a tension between 26 and 30 mm Hg; 69 per cent. showed a tension between 15 and 20 mm. Hg; and 21 per cent. a tension between 21 and 25 mm. Hg. 48 per cent. showed equal tension in the right and left eyes, and most of the remainder (42 per cent.) a higher tension in the left eye than in the right (Table III), the greatest difference being 3 mm. Hg (Schiötz)

TABLE III
DIFFERENCE IN TENSION BETWEEN RIGHT AND LEFT EYE

Paired Eyes	Per Centage	Tension	Difference (mm. Hg)
209	48	Same right and left	—
183	42	Higher in left eye	1 to 3
43	10	Higher in right eye	1 to 3

(2) **Diurnal Variation.**—Two types of diurnal variation in intra-ocular pressure were noted:

(a) '*Typical*' (Maslenikow, 1904).—The tension is usually highest in the early morning before rising and lowest in the evening between 6 to 8 p.m. It falls in two steps after rising in the morning; a sharp fall within 2 hours and a slow fall until late in the evening. During the night it rises again in two steps: a slow gradual rise until 2 a.m. and then a sharp rise to a maximum before getting up.

(b) '*Reversed*' (Hagen, 1925).—Very rarely the tension is highest in the evening and lowest in the morning (4 per cent.).

The typical diurnal variation (Fig. 1), was seen in 48 eyes (96 per cent.) and the reversed in two eyes (4 per cent.). The range of diurnal variation was between 2 and 5 mm. Hg (Schiötz).

FIG. 1.—Diurnal variation in intra-ocular pressure.

FIG. 2.—Intra-ocular pressure after ingestion of 1,000 ml. water.

(3) Provocative Tests

(a) *Jugular Compression Test*.—Four types of results were obtained, the first three being similar to those of Schoenberg (1929) and Agarwal and Sharma (1953):

- (i) No change (four eyes).
- (ii) Rise during compression and gradual fall to the initial level within 20 min. of release of sphygmomanometer cuff (eighteen eyes).
- (iii) Rise during compression and fall to a point below the initial level within 20 min. of release of cuff (sixteen eyes).
- (iv) Rise during compression and slow fall to a point above the initial level (twelve eyes).

78 per cent. showed a rise in ocular tension of between 2 and 6 mm. Hg Schiötz; 14 per cent. (mostly females over 40 years) showed a rise of between 7 and 10 mm. Hg (Table IV). The final position was between 2 and 3 mm. Hg. above or below the initial level.

TABLE IV
EFFECTS OF PROVOCATIVE TESTS ON INTRA-OCULAR PRESSURE

Jugular Compression Test			Water Drinking Test		
No. of Eyes	Rise in Ocular Tension (mm. Hg)	Per Cent.	No. of Eyes	Rise in Ocular Tension (mm. Hg)	Per Cent.
4	No change	8	—	—	—
39	2 to 6	78	44	2 to 6	88
7	7 to 10	14	6	7 to 10	12

(b) *Water-Drinking Test*.—All cases showed a rise in ocular tension after the water-drinking test, 88 per cent. of between 2 and 6mm. Hg Schiötz, and 12 per cent. of between 7 and 10 mm. Hg (Table IV). The greatest rise in ocular tension occurred 30 to 45 min. after drinking the water, and the tension gradually fell to the initial level in 2 to 3 hrs (Fig. 2).

Tests with less than 500 ml. water gave negative results, although positive results have been obtained by giving as little as 250 ml. (Agarwal and Sharma, 1953) and even 50 ml. (Schmidt, 1931) in glaucomatous patients. Results obtained with the water-drinking test by various workers in normal eyes are given in Table V.

TABLE V
RESULTS OF WATER-DRINKING TESTS IN HEALTHY EYES

Author	Date	No. of Eyes	Rise in Tension (mm. Hg)			
			2 to 6		7 to 10	
			No.	Per Cent.	No.	Per Cent.
Present series ...	1956	50	44	88	6	12
Agarwal and Sharma	1953	50	49	98	1	2
Sugar ...	1948	143	9 eyes (5 per cent.) gave positive results.			

Diuresis.—This started within 30 min. of drinking the water, reached its peak within 2 hrs, and then declined. Leydhecker (1950) classified diuresis as “high” or “delayed” as follows:

- (i) *High.*—More than nine-tenths of the water taken is excreted within 2 hrs or more, and the total amount is excreted within 3 hrs.
- (ii) *Delayed.*—Less than six-tenths is excreted within 2 hrs, or less than eight-tenths within 3 hrs.

The incidence of “high” and “delayed” diuresis (Table VI) was similar to that recorded by Campbell, Gloster, and Tonks (1955). No direct relationship was found between the rate and degree of diuresis and the rise in ocular tension.

TABLE VI
DIURESIS IN WATER-DRINKING TESTS (NORMAL SUBJECTS)

Author	Date	No. of Subjects Tested	Diuresis			
			High		Delayed	
			No.	Per Cent.	No.	Per Cent.
Campbell, Gloster, and Tonks	1955	20	10	50	4	20
Present series	1956	50	27	54	9	18

Blood.—The plasma proteins and haemoglobin showed a slight immediate fall after the water-drinking test and returned to normal values within 2 hrs in most cases; 16 per cent. however showed no change in plasma proteins or haemoglobin, and in 32 per cent. the fall was negligible, while in 52 per cent. it was only slight (Table VII). No relationship was found between these blood changes and the rise in ocular tension.

TABLE VII
CHANGES IN PLASMA PROTEINS AND HAEMOGLOBIN (mg. per cent.)
AFTER WATER DRINKING (NORMAL SUBJECTS)

No. of Subjects	Before		After $\frac{1}{2}$ Hr		After 1 Hr		After 2 Hrs		Average Change (per cent.)
	Proteins	Haemoglobin	Proteins	Haemoglobin	Proteins	Haemoglobin	Proteins	Haemoglobin	
8	6.12	85	6.11	84	6.12	85	6.12	85	None
12	5.86	80	5.78	77	5.83	80	5.93	81	0.1
14	6.33	90	6.14	84	6.26	87	6.32	89	0.2
16	5.48	75	5.19	64	5.36	68	5.44	73	0.3
Average	5.95	83	5.81	77	5.89	78	5.96	82	0.1

Discussion

Average Normal Tension.—The estimate of Schiötz (1909) and Cridland (1917) of the average normal ocular tension as 20 mm. Hg is in general agreement with the average of the present series.

A tension above 30 mm. Hg gives rise to a suspicion of glaucoma; and a tension above 35 mm. Hg is definitely pathological, since an eye cannot bear such a high tension long without disturbance of functions. In spite of the

above generalization, a simple record of raised tension is of little value in subjects of glaucoma age in the absence of any other signs or symptoms of glaucoma, since the normal maximum intra-ocular pressure is known to be as high as 35 mm. Hg (Wegner, 1911; Andrezen, 1928; Müller, 1931). Cases showing ocular tension between 26 to 30 mm. Hg were subjected to repeated ophthalmoscopic and perimetric examinations, and provocative tests for a period of 2 years for any evidence of glaucoma. The results of these tests were negative, and these individuals had no other symptoms suggestive of glaucoma. It is also true that cases of fully-developed glaucoma may show ocular tensions below 30 mm. Hg.

Effect of Age and Sex.—Tension tends to increase slightly with age, especially after 40 years in females (Table II). This is probably due to many factors, including increased rigidity of the sclera, neuro-vegetative changes, and endocrine instability, which are also important predisposing factors for glaucoma.

Diurnal Variation.—96 per cent. of our series showed diurnal variations up to 3 mm. Hg, and only 4 per cent. showed variations up to 5 mm. Hg. This in general confirms the results obtained by Maslenikow (1904), Hagen (1925) and Sallmann and Deutsch (1930), but Cordes (1937) gives a figure of normal variation up to 9 mm. Hg.

The difference of tension between the right and left eyes (Table III), and especially a higher tension in the left eye is not well understood, though perhaps as the left eye is more directly in the path of circulation, it may be more subject to the influence of general vaso-motor changes.

Provocative Tests

Jugular Compression.—The results so far obtained do not lead to any useful conclusion. This test has been declared useless except by Agarwal and Sharma (1953), who found it simple and reliable for the diagnosis of glaucoma, and believe that a rise of more than 6 mm. Hg is pathological. In the present series, rises of even 10 mm. Hg were observed in normal eyes (Table IV).

Water-Drinking.—Complete rest in bed and prohibition of smoking and stimulating drinks are pre-requisite to the water-drinking test, especially in the tropics, for otherwise it is likely to give negative results.

Blood.—The ingestion of water brings about a slight dilution of the plasma and a slight increase in plasma volume, as shown by a fall in haemoglobin and total proteins (Table V). Haemodilution causes a decrease in crystalloid osmotic pressure and an increase in capillary permeability which facilitates the flow of water out of the blood vessels. Consequently, there is increased flow of aqueous and a temporary rise in intra-ocular pressure. This returns to the initial level in about 2 hrs (Fig. 2) through immediate compensatory diuresis and distribution of water throughout the extracellular and intracellular fluids. The whole process, which appears so simple, is controlled by complex hormonal and neuro-vegetative factors.

Blood Pressure.—This is not affected by the water-drinking test either in healthy subjects as observed in the present series, or in glaucomatous individuals (Agarwal and Sharma, 1953); it is therefore improbable that it is a factor in the rise of ocular tension. In glaucomatous eyes, the abnormal rise of ocular tension in the water-drinking test can be explained by the greater increase in capillary permeability of the uvea and defective drainage of the aqueous.

Diuresis.—No direct relationship between “high” or “delayed” diuresis and rise in ocular tension has been found by other workers or in the present series. Diuresis is largely due to decreased secretion of the antidiuretic hormone of the posterior pituitary. The osmoreceptors lying in the distribution of the internal carotid artery are extremely sensitive to changes in the crystalloid osmotic pressure; any decrease in the osmotic pressure that might be caused by the water-drinking test inhibits secretion of the antidiuretic hormone by impulses carried through the hypothalamus to the posterior pituitary (Verney, 1929, 1947).

Summary

Tonometric records of intra-ocular pressure in 1,000 healthy eyes showed that the ocular tension ranged from 13 to 30 mm. Hg Schiötz (average 19 mm. Hg).

Diurnal variations in normal intra-ocular pressure and the effects of the jugular compression and water-drinking test on the normal intra-ocular pressure were also studied in view of their importance in the diagnosis of glaucoma.

I wish to thank Lt. Gen. W. A. Burki, C.B.E., Director General of Medical Services, and Major General M. N. Mahmood, Director of Medical Services, for their permission to publish these statistics, Lt. Col. M. Ayib Khan and Lt. Col. H. K. Khalil for their encouragement, and the medical officers and nursing staff of the Eye Department for their help and co-operation.

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