TONOMETRY as an aid in the diagnosis of eye diseases is not of much avail in the absence of information regarding the range of variations of normal eye tension. The measurement of normal eye tension in Europeans (Gjessing, 1905), in Chinese (Pao-Hua, 1932), and in Japanese (Kanda and So, 1933) indicates that the variations are wide. Curiously the highest figure for the normal intra-ocular tension is the same for Chinese, Europeans and Americans; but the lowest is found among Chinese. While the average for Chinese is low, for the Japanese it is the same as that for the Westerners. Corresponding figures are not available for Indians. A reference to literature reveals that extensive investigations have been carried out elsewhere, but not in India, to show the relation between blood pressure and eye tension in some of the clinical conditions where one of them, either blood pressure or eye tension, is altered. The results of clinical research on the relation between osmosis, blood pressure and eye tension show no correlation between blood pressure and eye tension (Weichmann, 1930). Further the observations on the osmotic pressure of the aqueous humour in epidemic dropsy glaucoma (Kirwan and Mukerjee, 1938) and the investigations on the etiology of glaucoma (Weinstein, 1939) conclusively establish that the variation in blood pressure is not the causative factor in the production of hypertonia in these conditions. But so long as the aqueous humour is considered a dialysate of blood plasma, it is probable that in altered physiological conditions, like pregnancy, the fall in eye tension (Ferrari, 1932) is secondary to the fall in blood pressure (Burwell et al., 1938). On the suggestion of Professor A. Subba Rau the present investigation was undertaken to ascertain the range of variation of eye tension in normal eyes of healthy men and women, and the interrelationship between the blood pressure and the eye tension in men, in normal and in pregnant women living in Mysore.

Persons attending the Ophthalmic Out-Patient Department of the Krishnarajendra Hospital for correction of refractive errors and pregnant
women attending the ante-natal clinic of the Vani Vilas Maternity Hospital (now Cheluvamba Hospital for Women), were the subjects of the present investigation. Care was exercised not to include subjects, who showed signs of suffering either from general diseases like nephritis, hyperpiesia, diabetes, and anaemia or from eye diseases like iritis, cyclitis, ulcer and leucoma of the cornea, which are likely to influence either the blood pressure or the eye tension.

The Sehitz tonometer with 5.5 gm. weight was used to record the eye tension after the initial smarting of the 1% holocaine solution had passed off. The blood pressure was measured in the recumbent posture by the auscultatory method, using the Tycos aneroid sphygmomanometer.

The results of the investigation are represented in histograms 1 to 6 and Tables I and II. From the values of the statistics $g_1$ and $g_2$ and their respective standard deviations, it can be inferred that the tension of the healthy eye is a normally distributed variate in both sexes between 10 and 65 years of age. Of the 210 pairs of eyes examined in healthy men and women, in 41 pairs (emmetropic 38 pairs, myopic 2 pairs, and hypermetropic 1 pair) a difference in the eye tension between the two eyes exceeding 2 mm. of Hg was recorded. The maximum difference observed was 4 mm. of Hg in only one subject, the tension in the left eye (22 mm. of Hg) being the lower.

Figs. 1 and 2 indicate that the average value of the blood pressure is the lowest for the group of subjects below 15 years of age, the highest above 55 years, and between 15 and 55 years shows minor fluctuations with a tendency for it to be higher in the decade between 25 and 35 years than in any other decade in that period. This tendency is pronounced in women,
and particularly well shown in the diastolic pressure. The average value of the eye tension on the other hand is highest before 15 years, and tends to be lower than that value after 55 years in both men and women. In the interval between 15 and 55 years, in both sexes, the fluctuations in the eye tension are opposite to those of the blood pressure (except in women between 45 and 55 years, when the eye tension also rises with the blood pressure) in the corresponding decades of life, but more pronounced in women than in men.
Histogram 1
Normal Healthy Men
\( n = 340 \); mean = 19.12 mm. of Hg;
Std. devn. = 2.90 mm. of Hg.
\( g_1 = 0.3026 \pm 0.2202 \); \( g_2 = 0.3290 \pm 0.2712 \); \( Q_1 = 16.04 \) & \( Q_2 = 20.46 \) mm. of Hg.

Histogram 2
Normal Healthy Women
\( n = 80 \); mean = 18.65 mm. of Hg;
Std. devn. = 2.70 mm. of Hg.
\( g_1 = 0.4550 \pm 0.2700 \); \( g_2 = 0.2105 \pm 0.5317 \); \( Q_1 = 16.23 \) & \( Q_2 = 20.38 \) mm. of Hg.

Histogram 3
Pregnant Women during the 8th and 9th months of gestation
\( n = 200 \); mean = 18.5 mm. of Hg;
and Std. devn. = 2.32 mm. of Hg.

Histogram 4
Pregnant Women during the 3rd, 4th, 5th, 6th and 7th months of gestation
\( n = 204 \); mean = 15.48 mm. of Hg;
Std. devn. = 2.77 mm. of Hg.

Histogram 5
Pregnant Women in all the months of gestation
\( n = 416 \); mean = 16.3 mm. of Hg;
gestation Std. devn. = 2.91 mm. of Hg.

Histogram 6
Curve of Relative Frequencies
\( n = 420 \).
In women, during pregnancy the frequency distribution of eye tension is altered. When pregnant women irrespective of the period of gestation are grouped, the number of subjects whose eye tension is 15 mm. of Hg is smaller than the number of subjects, whose eye tension is either 13 mm. or 17 mm. of Hg (Histogram 5). At the approach of full term, this notch disappears (Histogram 3). Therefore it is only during the early months of pregnancy the reduction in eye tension is very marked (Histogram 4) with a tendency for the mode to be on the left of the mean. During pregnancy the mean of the eye tension is 16.3 mm. of Hg with a standard deviation of 2.91 mm. of Hg, as against 18.65 mm. of Hg ± 2.70 mm. of Hg in normal women. Fig. 2 shows that the eye tension during pregnancy is lower than in normal women in all the corresponding age periods. The blood pressure is also lower than in normal women in the corresponding age periods, except in the case of those pregnant women, who were below 15 years of age. No definite conclusions can be drawn from the above, because of the paucity of numbers in some age periods. The above statements are recorded as indicative of the probable relationship between the variations of eye tension and blood pressure.

**TABLE I**

*Analysis of eye tension with respect to the incidence of refractive errors*

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Sex</th>
<th>No. of eyes</th>
<th>Average eye tension in mm. of Hg</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypermetropia</td>
<td>Male</td>
<td>10</td>
<td>17.6</td>
<td>Of the 207 pairs of eyes examined 5 pairs were anisometropic. One eye in each of the 5 pairs was emmetropic and with respect to the other eye one was hypermetropic in one pair and myopic in four pairs. In two myopic eyes of the 4 pairs the tension differed from the emmetropic eye (higher in one and lower in the other by 2 mm. or more of Hg).</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>4</td>
<td>20.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>280</td>
<td>19.3</td>
<td></td>
</tr>
<tr>
<td>Emmetropia</td>
<td>Female</td>
<td>65</td>
<td>17.4</td>
<td>In the case of 33 men (1 hypermetrope, 30 emmetropes, and 2 myopes) and 8 women (all emmetropes) the tension in one eye exceeded that in the other by 2 mm. or more of Hg.</td>
</tr>
<tr>
<td>Myopia</td>
<td>Male</td>
<td>44</td>
<td>20.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>11</td>
<td>19.7</td>
<td></td>
</tr>
</tbody>
</table>

Table II gives the coefficients of correlation between the eye tension and the blood pressure in the several classes. The coefficient is positive in all classes, except in the case of pregnant women nearing term. The mean blood pressure (diastolic + 1/3 pulse pressure) has a higher correlation, probably because the intra-capillary pressure varies with the mean pressure (Wiggers,
### Table II
Significance of the variations in the coefficients of correlation between eye tension and blood pressure in the several classes

<table>
<thead>
<tr>
<th>Class of subjects</th>
<th>No. in each class (n)</th>
<th>Coefficient of correlation (r) between eye tension and</th>
<th>$Z = \frac{1}{2} \log_e \frac{1 + r}{1 - r}$ for eye tension and</th>
<th>Between eye tension, mean blood pressure and diastolic blood pressure</th>
<th>$\cdot \sqrt{\frac{\sum z_1 - \sum z_2}{n_1 - 3} + \frac{1}{n_2 - 3}}$</th>
<th>Mean blood pressure</th>
<th>Diastolic blood pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean blood pressure</td>
<td>Diastolic blood pressure</td>
<td>Mean blood pressure</td>
<td>Diastolic blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adjusted for grouping</td>
<td>Not adjusted</td>
<td>Adjusted for grouping</td>
<td>Not adjusted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Normal men</td>
<td>125</td>
<td>0.09735</td>
<td>0.09389</td>
<td>0.04673</td>
<td>0.04493</td>
<td>0.09409</td>
<td>0.04493</td>
</tr>
<tr>
<td>2. Normal women</td>
<td>34</td>
<td>0.08530</td>
<td>0.08325</td>
<td>0.04201</td>
<td>0.04091</td>
<td>0.08345</td>
<td>0.04091</td>
</tr>
<tr>
<td>3. Pregnant women</td>
<td>208</td>
<td>0.06778</td>
<td>0.06418</td>
<td>0.07633</td>
<td>0.07356</td>
<td>0.06428</td>
<td>0.07376</td>
</tr>
<tr>
<td>4. Pregnant women</td>
<td>103</td>
<td>0.1629</td>
<td>0.1574</td>
<td>0.1545</td>
<td>0.1517</td>
<td>0.15875</td>
<td>0.15289</td>
</tr>
<tr>
<td>5. Pregnant women</td>
<td>98</td>
<td>-0.06747</td>
<td>-0.06474</td>
<td>-0.07659</td>
<td>-0.07335</td>
<td>-0.06484</td>
<td>-0.07345</td>
</tr>
</tbody>
</table>

* $n_1$ and $n_2$, $Z_1$ and $Z_2$ refer to the first and second in the following groups under the class of subjects: 1 and 2, 2 and 3, 3 and 1, 4 and 5.
The Range of Variation of Normal Eye Tension

1937) with the eye tension than the diastolic pressure in all the classes, except in the case of pregnant women when grouped irrespective of the period of gestation. In the earlier months of pregnancy (up to the 7th month) the blood pressure shows a much closer positive correlation with eye tension than in normal health. These variations in the coefficients of correlation amongst the several classes are not statistically significant, because in no case the difference $Z_1 - Z_2$ exceeds twice the standard deviation of the difference (last column, Table II).

The average normal ocular tension in the present investigation is definitely lower than the figures reported by Shoji (quoted by Kanda and So, 1933) for the Japanese (24.21 mm. of Hg), which the author says is equivalent to that of Europeans. Müller's (1931) curve of relative frequencies based on the 2000 figures of eye tension reported by Gjessing (1905) and the Histogram 6 are similar to each other but with the difference that the limits in the present investigation are 10 mm. of Hg and 30 mm. of Hg as against 12 mm. of Hg and 36 mm. of Hg given by Gjessing. Pao-Hua (1932) reports that the highest normal tension is 33 mm. of Hg and the lowest 13 mm. of Hg, and that although the highest normal intra-ocular tension among the Chinese is the same as that of Europeans and Americans, the lowest figure is much lower and the average is 4 mm. of Hg lower than those of European and American authors. The average normal eye tension among the subjects of the present investigation appears to be about 1 mm. of Hg lower than that of the Chinese, and the range of variation is also shifted to the left by 3 mm. of Hg. From the evidences in Table I giving the analysis of the figures for eye tension with respect to the incidence of refractive errors, one can infer that the eye tension is not influenced by the refractive condition of the eye. The low tension of high myopic eyes in most cases is concomitant with the myopic lesions (Caso, 1931). The average figure for the eye tension during pregnancy (16.3 mm. of Hg) in the present investigation is also lower than Farrari's (1932) figure (17.3 mm. of Hg) for pregnant women. These differences are only apparent, because the Schiötz tonometer measures only the impressibility of the cornea, and according to Shope (1932) any given Schiötz tonometer reading may be produced by any of a considerable number of intra-ocular pressures, and different Schiötz tonometers in good repair often give different readings when applied to the same eye. Since the same Schiötz tonometer was used throughout the present investigation, it may be concluded that during pregnancy, the eye tension as measured by the Schiötz tonometer registers a definite hypotony. Fig. 3 shows that this hypotony is very pronounced about the middle of pregnancy. The blood pressure also follows a parallel curve, and is lowest about the
same period. The following observations which corroborate the above, are recorded in the present investigation. In 19 pregnant women, the eye tension and blood pressure were recorded on more than two occasions at intervals of 4 weeks. 7 of them were in the middle months (from 3rd to 7th) and 12 were in the last three months of gestation. Amongst the former the eye tension registered a constant level in one and a fall in 6 subjects, whereas the blood pressure registered a constant level in 2 and a fall in 5 subjects. Amongst the latter, the eye tension registered a constant level in 4, a rise in 4, and a fall in 4 (the average rise being 3 mm. of Hg per month, and the fall 1.5 mm. of Hg per month), whereas the blood pressure registered a constant level in 3, a rise in 6 and a fall in 3 subjects.

The hypotony in pregnant women lasts only during pregnancy, for it was observed from 94 tonometric readings during puerperium (subjects being the In-Patients of the Vani Vilas Hospital) that during the first 3 days after delivery the average eye tension was 14.8 mm. of Hg, rising to 14.95 mm. of Hg during the subsequent 4 days and by the end of about 10-14 days registering a further rise up to 15.75 mm. of Hg. The observations could not be carried out further to ascertain the time it would take on an average for the eye tension to recover from the hypotony induced as a result of pregnancy, as the patients were being discharged on the 10th day.

Discussion

The ocular pressure is an extremely changeable one influenced by many causes like emotion, effort, muscular contractions, all the reflexes of organic life and cardiac oscillations (Bailliart, 1931). “The normal intra-ocular pressure may be taken to be that evolved as the optimum at which the eye is rendered optically rigid and at which its circulation and metabolism of its tissues can at the same time proceed without disturbance” (Duke-Elder, 1934). The maintenance and the regulation of the normal intra-ocular pressure is governed by one or more of the following factors: the efficiency of (1) the pressure circulation through the canal of Schlemm (Duke-Elder and Duke-Elder, 1932); (2) the drainage of the aqueous through the substance of the cornea via the filtration angle (Ridley, 1930); (3) the secretory activity of the ciliary body (Robertson, 1937); and (4) a neuro-humoral mechanism (Elwyn, 1938). Whatever be the mechanism that regulates and maintains the normal intra-ocular pressure, it is not disputed that (besides other factors like the volume of the contents of the globe, the elasticity of the coats of the eye, the colloid content of plasma, and the permeability of the capillaries) the intra-capillary pressure is one of the chief factors responsible for the origin and variations of the intra-ocular pressure.
By the use of Herzog's skin capillary measurement apparatus, evidences are adduced towards the existence of raised intra-capillary pressure in glaucomatous individuals; in general the pressure in the ciliary vessels is found to vary with the pressure in the central artery of the retina, the diastolic pressure in which artery is half of that in the brachial artery under normal conditions; and possibly an automatic mechanism regulates in other conditions, the central retinal arterial pressure causing it to rise seemingly passively with the rise in eye tension; but the slight differences in the blood pressure findings of glaucomatous and non-glaucomatous subjects are not suggestive of hypertonia in the former (Weinstein, 1939).

While the normal blood pressure in pregnant women undergoes no important variations, the central retinal arterial pressure suffers a reduction which loses any significance, when compared with the fall in the eye tension (Ferrari, 1932) (probably because of the automatic mechanism). In contradiction to the above, the pressure in the central retinal artery is reported to be higher than normal and the intra-ocular pressure normal in the late stages of pregnancy (Baratta, 1937). But the systemic diastolic pressure exhibits a definite fall during pregnancy (Burwell and others, 1938). It is therefore doubtful whether the fall in the systemic blood pressure reflected in the retinal arteries indirectly causes a reduction in the eye tension or whether the reduction in eye tension is independent of the variations in the blood pressure during pregnancy.

The low coefficients of correlation between the blood pressure and eye tension probably account for the findings, that indicate the absence of correlation between the eye tension and the blood pressure (Weichmann, 1930), and the want of a definite interrelationship between the intra-ocular tension and the blood pressure of opium addicts, who are vagotonics (Kanda and So, 1933). But Spadavecchia (1937) concludes that the intra-ocular pressure depends on the condition of the arterial bed and that there is a limit of separation between the general arterial pressure and the intra-ocular pressure, which he calls the "Threshold of intra-ocular pressure" or the endocular threshold, the high physiological level being capable of alteration by the various morbid and premorbid local conditions, especially those associated with the arterial system.

Kirwan and Mukerjee (1938) believe that the increase of intra-ocular pressure during epidemic dropsy is probably due to altered permeability of the capillaries. In nephritis with low blood protein the eye tension is normal and in nephrosis the eye tension is found to remain constant during recovery, when blood proteins are being restored to the original level, but the intravenous administration of hypertonic saline (30%) brings about a prolonged
depression of the intra-ocular pressure (Robertson, 1939). In pernicious anæmia, the decrease in the intra-ocular tension seems to bear a closer relationship to the hæmoglobin and red cell count rather than to colour index and white cell count (Suker, 1934).

From the evidences presented above, it seems very likely that, whereas variations in the blood pressure influence the eye tension to little extent, conditions which bring about an alteration in the composition of the blood, have a greater effect on the eye tension. It is probably because of the variations in the blood composition in the different age periods that the variations in the normal eye tension in the corresponding age groups, are opposite to those of the blood pressure (Figs. 1 and 2), in spite of the positive correlation between the two variates (Table II). The significance of the positive correlation therefore seems to lie in the fact that the blood composition remaining unchanged, the variations in the eye tension follow the variations in the blood pressure. If the partial coefficient of correlation between eye tension and blood pressure be determined, eliminating the influence of the changes in the blood composition, the volume of the contents of the globe and the elasticity of the coats of the eye (all of which are very labile) the correlation obtained would be much closer. Therefore it is to be expected, that in the same individual under identical conditions of blood composition, volume of the contents of the globe and elasticity of the coats of the eye, any change in the blood pressure influences the eye tension in the same direction. Such conditions are obtained only during the changes in the blood pressure resulting from the beats of the pulse and the movements of the respiration. The observations of Duke-Elder and Duke-Elder (1931) that the intra-ocular pressure faithfully follows variations in the blood pressure, due to respiratory excursions and pulse beats, even the dicrotic notch being represented in the variations of the intra-ocular pressure, support such inferences.

The explanation for the hypotony of the eye during pregnancy, is therefore to be sought in the altered composition of the blood. Ferrari (1932) believes that the changes in the blood chemistry, slight acidosis, and hyper-cholestræmia, possibly explain the hypotension during pregnancy. Ferraris (1933) attributes the cause of the lowered intra-ocular pressure in pregnant women to any or all the changes in the blood, like hyper-glycaemia and increase of certain hormones in blood. The tendency for both eye tension and blood pressure to return to original levels in the last months of pregnancy, is in conformity with the observations of Cohen and Thomson (1939), that whereas the blood volume, velocity of blood flow, and the cardiac output are increased up to 9th month and decreased prior to
delivery; the haemoglobin, red cell count, haematocrite reading and viscosity of blood are decreased up to 9th month and increased prior to delivery.

Other things remaining the same the fall in blood pressure alone can bring about the above changes in the blood and its circulation. The capillary pressure is lowered as a result of the general fall in diastolic pressure, resulting in an alteration in equilibrium between the tissues and the blood, so that less fluid transudes from the capillaries into the tissues. This increase in blood volume results in the dilution of the blood constituents like haemoglobin and red cell count, thus lowering the viscosity of the blood, and increasing the cardiac output and velocity of blood flow. A return of the blood pressure to original levels in the last months of pregnancy brings about a reversal of all the above changes. Therefore the nature of the changes in the blood and its circulation during pregnancy are probably to an extent secondary to the variations in the blood pressure arising from the altered physiology of pregnancy.

Therefore the higher coefficients of correlation obtained in the present investigation between the eye tension and the blood pressure in the earlier months of pregnancy than in normal health—though statistically not significant—are due probably to the indirect influence of blood pressure on eye tension through the changes in the blood composition.

Whereas in the early months of pregnancy up to 7th month, the basal metabolic rate is increased just in proportion to the mass of the growing foetus, in the later months (the mass of the foetus being considerable) the basal metabolic rate is increased probably by the overactivity of the thyroid (Wiggers, 1937). Therefore the endocrine activity during the last months of pregnancy is likely to be different from the rest of the period. Consequently the changes in blood composition are also likely to be different and are very likely to alter the eye tension. The rise in blood pressure in the last months of pregnancy should result in an elevation of the eye tension, indirectly by its influence on the blood composition. The combined effect of the rise in blood pressure and the altered endocrine activity in the last months of pregnancy is either to augment or prevent the proportional rise in eye tension with the rise in blood pressure. The negative coefficient of correlation in the last months of pregnancy indicates that the rise in eye tension is not in proportion to the rise in blood pressure. It can therefore be summed up that the altered endocrine activity during the last months of pregnancy has opposite effects on eye tension and blood pressure, tending to depress the former and elevate the latter.
The observations, that in women between 45 and 55 years (in the first half of which decade there is the incidence of climacteric (Wiggers, 1937) usually associated with endocrine disturbances), the eye tension follows the rise in blood pressure in contrast to that obtained in other age periods and in men; as also the finding of a negative correlation between the two, in the last months of pregnancy seem to lend support to the humoral control of the maintenance and regulation of the normal intra-ocular pressure.

Summary

(a) The Schiötz tonometer and the Tycos aneroid sphygmomanometer are used to record the eye tension and the blood pressure of 465 subjects consisting of 170 healthy men, 40 healthy women, 208 pregnant women and 47 women after parturition. The results of the investigation are analysed to ascertain

(1) the range of variation of normal eye tension in healthy men and women (average for men = 19.12 mm. of Hg, \( \sigma = \pm 2.90 \) mm. of Hg and for women = 18.65 mm. of Hg, \( \sigma = \pm 2.70 \) mm. of Hg the range being 10 mm. to 30 mm. of Hg);

(2) the influence of age on the variations in eye tension and blood pressure, and their interrelationship;

(3) the relation of the hypotony in pregnancy to the reduction in the systemic blood pressure.

(b) The following observations and conclusions are drawn regarding (2) and (3):

(i) The variations in the eye tension are opposite to those of the blood pressure in all age periods in both sexes, except in women between the ages 45 and 55 years—probably because of the endocrine disturbances accompanying the climacteric.

(ii) The eye tension and blood pressure are the lowest about the middle of pregnancy, both varying in a parallel manner from the start to the termination of pregnancy.

(iii) The factors influencing the eye tension and blood pressure in the last months of pregnancy have a greater depressing effect on the eye tension than on the blood pressure.

(c) The bearing of (i), (ii) and (iii) on the humoral control of the maintenance and regulation of the normal intra-ocular pressure is discussed.

Acknowledgment

I wish to record here my thanks to the University of Mysore for the grant of a research scholarship, to Professor A. Subba Rau for his helpful
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