AGE CHANGES IN PERIMETRY

In a patient with 6/6 vision, the 1/1 object on the Goldmann perimeter disappears completely in the 70's and the 1/2 object disappears in the 80's provided there are no lens opacities to accelerate the process. The 0/1 disappears much earlier. With the 1/2 it was found that there was much variation between people and the mean isopter was around 28°. In some it reached 40° but in others it was only just outside the blind spot. In persons aged between 60 and 69, with dilated pupils and 6/6 vision, the mean isopter to the 1/2 was only just outside the blind spot but, as this was a mean reading, there were many with the isopter inside the blind spot so that under certain circumstances baring of the blind spot occurred in this age group without glaucomatous change. Baring of the blind spot occurs sometimes below but usually above the blind spot. Refractive errors must always be corrected when investigating the central field, particularly when using hemispherical perimeters.

Value of tonometry and tonography in the diagnosis of glaucoma

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The value of a technique in the diagnosis of disease depends on its ability to give a measure of the disease process. Tonometry and tonography attempt to give this measure in glaucoma by a number notation. We shall confine our attention to chronic simple glaucoma since it is in this disease that both tonometry and tonography have been most widely used together. The great disadvantage of both techniques is that they measure a feature related perhaps only remotely to the disease process. Furthermore, while tonometry at least measures a typical physical sign of glaucoma, tonography purports to measure a factor which causes only one of the physical signs of the disease, namely raised intraocular pressure.

The choice between their relative merits, therefore, is a difficult one. Tonometry, the direct measure of intraocular pressure, is notoriously variable in the disease, and at one time the reading may be representative, while at another it may have a value indistinguishable from that found in a normal eye. Tonography, on the other hand, as a measure of outflow through the trabecular meshwork, estimates a quantity which shows wide variation between normal subjects and is not constant if determined on the same patient on several occasions. Both techniques, when related to chronic simple glaucoma in a group of patients, thus show about an equal correlation with the disease process (Fisher, Carpenter, and Wheeler, 1970). This fact throws considerable doubt on the value of a single outflow facility measurement in diagnosing early cases.

Apart from their relationship to the disease, the accuracy of measurement in both tonography and tonometry is of paramount importance if either is to be of value. Tono-

metry, which developed as a numerical measure of the finger palpation technique for assessing the hardness of the globe, was in its early history subjected to much criticism as a true estimate of intraocular pressure in terms of a definite unit (mm.Hg). Priestley Smith (1915), for example, stated that "pressure could only be expressed in terms of the scale reading of the tonometer".

This criticism of the initial indentation and calibration technique arose from the fact that the enucleated eye was examined by means of the tonometer as a closed elastic container after intraocular pressure had been measured by a manometer. In this method the variable elastic properties of the whole globe, together with those of the indented cornea, simultaneously affected the relationship between intraocular pressure and the final scale reading. This problem has been overcome in tonometry by the applanation method of measuring pressure. This method avoids indentation of the cornea and elastic distention of the globe. The variables are thus reduced to one, namely, the bending moment at the corneal surface, while even this is compensated for by the small positive pressure induced by the surface tension of fluid around the applanating surface in contact with the cornea. In tonography, the problem of distension of the whole eye remains, since an indentation tonometer must be employed to estimate changes in volume of the globe. Thus the accuracy of pressure measurement in Schiötz tonometry and of volume measurement in tonography are very closely related and depend for their measurement on the precise relationship between the volume changes produced by pressure in the globe.

Changes in volume of the globe with pressure

Friedenwald (1937) showed that, as the pressure was raised, the globe became less distensible, and that this property was particularly marked over the pressure range from 10 to 45 mm.Hg. Thereafter, however, distensibility became practically constant with pressure. Intraocular volume strain when related to pressure could therefore be expressed only by a simple constant (ocular rigidity) when the logarithm of pressure was plotted against volume strain. This finding has been used as a basis of subsequent tonographic estimations. This increased resistance to distension of the globe as pressure rises is very unusual, since most biological substances, even when complex, for example lens substance, show an initial linear elastic strain, and a subsequent permanent set when stressed beyond the elastic limit (Fisher, 1971a). The most likely cause of this peculiarity of the pressure volume strain characteristics of the globe is that the choroid is compressed much more than the sclera is stretched in the early portion of the pressure/volume curve, and in consequence blood is expressed from the eye *via* the vortex veins. To investigate this possibility more precisely, Fisher (1971b) examined the strain pressure relationship of the inner scleral surface of the globe (Fig. 1, overleaf), and found that volume strain and pressure almost obeyed a linear relationship until viscoelastic failure of the specimen occurred.

It is apparent that, as intraocular volume strain is so much greater than intrascleral strain, expulsion of blood from the choroid must occur to accommodate the experimental increased volume of fluid injected into the globe in the intraocular volume strain experiments. A comparison of these two types of strain at every pressure makes this measurement of blood ejection from the choroid possible.

Ejection of blood from the choroid

In Fig. 2 changes in choroidal blood volume are shown in relation to pressure together with the two curves from which the choroidal blood volume was obtained. The two curves

FIG. 1 Differences of pressure and volume strain between the sclera and the intact human eyeball

Upper left hand. Schematic diagram of apparatus for measuring volume strain of posterior half of scleral globe by vacuum technique (Fisher, 1971b)

Lower left hand. Schematic diagram of apparatus for measuring volume strain of intact globe by intra-aqueous injection technique (Friedenwald, 1937)

Upper right hand. Pressure and volume strain of inner scleral surface of globe

Lower right hand. Pressure and volume strain of inner retinal surface of globe

intersect at a pressure of about 50 mm.Hg, and this indicates that thereafter no further expulsion of blood from the choroid occurs. Furthermore, if the blood expelled from the choroid by a rise in intraocular pressure is divided by this change, a coefficient is produced termed "the ocular blood expulsion coefficient". It represents the amount of blood expelled per mm.Hg rise in pressure.

Does this theoretical concept based on the comparison of two experimental curves have any validity in practice? Ytteborg (1960) has performed the only series of blood expulsion experiments in living human eyes and has compared his results with the volume of corneal indentation produced by the Schiötz tonometer. Fig. 3 (opposite) shows his experimental results expressed in terms of the ocular blood expulsion coefficient and the corresponding values obtained from an equation derived from applanation and Schiötz tonometer readings of the same eyes (Fisher, 1971b).

The results of two eyes were excluded from the graphs since these showed no change in blood expulsion with pressure, possibly because they contained large intraocular tumours. The remaining values were calculated for the findings within the mid and physiological range of pressures, and it will be seen that the experimental results and the values derived from the tonometric methods are in good agreement. It must now be asked what influence changes in ocular blood expulsion during tonometry can have on the subsequent outflow facility measurement made by tonography.

FIG. 2 Changes in choroidal blood volume with intraocular pressure

————	Intraocular pressure volume curve	V_o	= Intraocular volume at pressure P_t (μ L)
-----	Intrascleral pressure volume curve	V_s	= Intrascleral volume at pressure P_t (μ L)
————	Choroidal pressure volume curve	V_{ch}	= Choroidal volume at pressure P_t (μ L)

Note Scleral and intraocular volumes at pressures below 10 mm.Hg would indicate in theory that blood would have to be pumped into the choroid to produce the required distension of the globe. Experimentally, this cannot occur in the enucleated eye, so the globe has to be distended to almost 10 mm.Hg before reproducible pressure and volume strain recordings are obtained

FIG. 3 Comparison of observed and calculated blood ejection coefficients obtained on six human eyes in vivo
Note Coefficients calculated from Ytteborg (1960)

Tonography and the blood ejection coefficient

Fisher (1971b) found that blood ejection from the choroid was related to outflow facility when measured at the same time and on the same eye. The relationship, however, depended very much on the magnitude of the outflow facility which was subsequently found. If the outflow was good, little blood appeared to be ejected from the choroid as the tonometer was applied, but if the outflow was poor, a much greater volume of blood was ejected initially.

In low outflow facilities which occur in glaucomatous eyes, when the eye is indented by a tonometer, both blood and aqueous flow from it, and this gives an apparently larger

outflow facility—the tonographic outflow facility—than the true aqueous outflow. Therefore, as there are two separate exit channels from the eye and the tonographic procedure can only give an indication of their combined effect, it is hardly surprising that good outflow occurs in many obviously glaucomatous eyes. The value of tonography thus becomes severely limited if blood and aqueous outflow are truly independent properties of the glaucomatous eye. Fisher (1971b) suggests that this is not so, and the increased blood outflow from the choroid in glaucomatous eyes may be as important a physical property of the eye as is impaired aqueous outflow facility. With these new facts a comparison of tonometry and tonography in chronic simple glaucoma can now be made.

Comparison of tonometry and tonography

When used as the sole test of a glaucomatous eye, both tonometry and tonography often fail as a guide to the diagnosis of early chronic simple glaucoma. Fisher and others (1970) found that, even when a large number of cases were considered together, the correlation of tonography with the disease was no better than that of pressure. This was because tonography, which should measure a constant resistance, has a similar variability to that of pressure when three successive tests are performed, at different times, on the same eye. Furthermore, the variability of both pressure and outflow were found to correlate with the size of the pupil. In the case of tonography, the probable reason is that the true flow of aqueous is not measured in the glaucomatous eye. Fisher (1971b) has found that, when 5.5 g. and 7.5 g. weights were used successively on different occasions on the same eye, the proportions of the flow of blood and aqueous could be measured separately. This examination was performed on ten glaucomatous eyes and the true average aqueous outflow from the exit channels of the eye was found to be 0.1 $\mu\text{L./min./mm.Hg}$, whereas the outflow facilities recorded by tonography were 0.21 and 0.13 respectively. Thus, on many occasions, 50 per cent of the tonographically measured outflow facility is in fact made up by a flow of blood from the choroid.

The real difficulty is that outflow facility and intraocular pressure are so intimately associated that an estimate of either does not further the assessment of optic nerve damage. On the other hand, the blood supply of the choroid is vital to the nourishment of both the retina and the optic nerve. Any biophysical measurement of the choroid therefore, if it is appreciably altered in the disease, would be a very good index of the disease process. From a preliminary study of normal and glaucomatous populations, it would seem that the choroid of the glaucomatous eye is much less able to withstand a rise in intraocular pressure than a normal eye.

Although tonometry and tonography, especially if measured on many occasions in the same individual, serve as useful parameters of the disease, they are both related to it only indirectly. With the advent of applanation tonometry, the former, so far as accuracy of measurement is concerned, has become very precise, while the latter, although developed to measure a constant property of the eye, has failed in this respect since by the nature of the test both aqueous and blood are squeezed out in variable proportions.

However, the very ability of the indentation tonometer to squeeze blood from the eye as soon as it is applied, while negating an accurate estimate of aqueous flow, may now be utilized in assessing the biophysical properties of the posterior rather than the anterior half of the eye.

This latter region is just where most of the damage to sight occurs in chronic simple glaucoma.