EPISCLERAL VENOUS PRESSURE IN TONOGRAPHY*†

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DURING the 11 years in which the clinical measurement of facility of outflow by means of tonography has been practised, various workers have sought to elucidate and correct the sources of error inherent in this method.

One of the assumptions originally made concerning tonography was that the episcleral venous pressure was not disturbed during the measurement. Friedenwald (Grant, 1951) and Becker and Friedenwald (1953) drew attention to the possibility that changes in the episcleral venous pressure might constitute a source of error, and estimated that the weight of the tonometer might raise the intra-orbital pressure by almost 10 mm. Hg. The subsequent congestion of the orbital veins would then bring about a rise in the episcleral venous pressure, with consequent diminution of the pressure gradient from the anterior chamber to the episcleral veins. Failure to allow for this effect would cause the facility of outflow to be underestimated.

The episcleral venous pressure in the normal eye has been measured by several workers and has been found to be in the region of 10 or 11 mm. Hg (Goldmann, 1950, 1951; Linnér, 1955a; Linnér, Rickenbach, and Werner, 1950; Löhlein and Weigelin, 1949; Rickenbach and Werner, 1950). The first measurement of the disturbance in episcleral venous pressure due to the application of the tonometer to the eye was reported by Linnér (1955b). He measured the episcleral venous pressure before, during, and after the application of the tonometer to the eyes of recumbent subjects, and found that the application of the tonometer provoked a mean rise of 1.25 mm. Hg in the episcleral venous pressure. Linnér suggested that allowance could be made for this by modifying Grant's formula for facility of outflow

$$C = \frac{\Delta V}{T(P_{t \text{ av.}} - P_o)}$$

to

$$C = \frac{\Delta V}{T(P_{t \text{ av.}} - P_o - \Delta P_v)},$$

where ΔP_v was 1.25 mm. Hg.

Linnér found that ΔP_v was independent of P_t and was the same in normal and glaucomatous eyes. His report did not, however, state the length of time that the tonometer had been applied before the episcleral venous pressure was measured.

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In Fig. 1 the standard electrical symbol for resistance has been used to illustrate diagrammatically the various resistances encountered by the aqueous as it flows from the anterior chamber through an aqueous vein to the episcleral venous system. Perfusion experiments on enucleated human eyes

FIG. 1.—Diagram of resistances to aqueous outflow.

R_t — resistance to flow through trabecular meshwork
 R_s — resistance to flow through intra-scleral channel
 R_a — resistance to flow through aqueous vein

(Grant, 1958; Leith, 1963) suggest that the main resistance to the outflow of aqueous is in the trabeculae. If the increased resistance in open-angle glaucoma is also in the trabeculae, then it is the trabecular resistance which should be measured by means of tonography. In order to measure the trabecular resistance with the greatest possible accuracy, one should, therefore, take the canal of Schlemm as the zero point for the aqueous outflow system.

This means that one must attempt to measure ΔP_v as close to the canal of Schlemm as possible, and the nearest practicable site is at the point of emergence of an aqueous vein. Goldmann (1959) took measurements of the intra-ocular pressure and the pressure in a large aqueous vein in four cases while applying pressure to the eye. He found that the increase in pressure in these veins varied from eye to eye, but was proportional, in a given eye, to the value of P_i . He concluded that no

single constant could be used to correct for this effect in all eyes. At the point of measurement used by Goldmann, ΔP_v has two components:

- (1) The rise in episcleral venous pressure due to orbital stasis;
- (2) The increased pressure gradient across R_a caused by the increase in outflow resulting from the rise in intra-ocular pressure from P_o to P_i .

The presence of the second component probably explains Goldmann's finding that P_v varied with P_i . At any given point in a particular eye this second component would depend not only upon the values of P_o and P_i but also upon the values of the various resistances. As the anatomical arrangements which determine R_s and R_a vary widely from vessel to vessel and from eye to eye, it is hardly surprising that Goldmann found variations from case to case.

As the volume of aqueous entering the episcleral vessels is small compared with the flow of blood in these vessels, changes in aqueous outflow would not be expected to alter the episcleral venous pressure significantly. ΔP_v of the episcleral veins consists essentially of component (1). Linnér's work showed

that this component was relatively constant from eye to eye and, therefore, that it might be feasible to apply a standard correction for this in all cases.

To sum up, in order to measure R_i as accurately as possible by means of tonography, the zero point for aqueous outflow should be chosen as close to Schlemm's canal as possible. At this point, however, ΔP_o is so variable that it would have to be measured in every case. This is not practicable on a clinical basis. For routine clinical tonography, therefore, a zero point must be chosen which allows a reasonably reproducible ΔP_o from eye to eye, so that a constant value may be used to correct for ΔP_o in the computation of C . Linnér's findings have suggested that the episcleral veins may be used as a suitable zero point. In this case R_s and R_a are being included in the measurement of the resistance to outflow, and one must accept the fact that the measurement of R_i is diluted by their presence.

It is common practice to determine P_o by means of the Goldmann applanation tonometer. Whenever this is done, there is a further episcleral venous pressure change which must be considered. The Goldmann tonometer is used with the patient sitting, whereas tonography is performed with the patient recumbent. The change from the sitting to the recumbent position is associated with a rise in episcleral venous pressure, an effect which has been investigated by Linnér and others (1950) and also by Stepanik (1956). Linnér and others (1950) found that the pressure change involved was of the order of 1 mm. Hg; but Stepanik found a mean value of 6.7 mm. Hg for the change in episcleral venous pressure associated with the change from sitting to lying. In 25 cases he found values ranging from 0.2 to 13.4 mm. Hg. The exact value of the rise in episcleral venous pressure resulting from the change from the sitting to the recumbent position is of some importance, as it must be added to the value obtained with the Goldmann applanation tonometer in order to determine the value of P_o in the lying position.

In the present study measurements of episcleral venous pressure were made throughout the entire period of 4-minute tonographies. The episcleral venous pressure and intra-ocular pressure variations associated with postural changes were also investigated.

Procedure

The method employed was based upon the pressure-chamber technique described by Seidel (1923) and since used by others. The pressure-chambers used were made of Perspex approximately 5 mm. long $\times$ 3 mm. diameter (Fig. 2, overleaf). The open end was covered with a hemispherical membrane; initially a latex membrane was used, but this was replaced by a plastic membrane which was found to be thinner, more flexible, and more transparent. The entire system was filled with air and the pressure controlled by means of a bronze bellows actuated by a foot pedal. The pressure was recorded on a double manometer unit, each manometer being fitted with a magnetic valve which permitted its reading to be held. The valves were individually controlled by means of a push-button mounted on the Zeiss operating microscope which was used for illumination and observation. The light source on

FIG. 2.—Pressure-chamber.

the microscope was fitted with a diaphragm with a small aperture so that a circle of light just large enough to illuminate the pressure-chamber was projected on to the eye. The push-button system permitted all measurements to be made in duplicate without the operator having to take his attention from the field of observation.

All measurements were made on medium to large-size episcleral vessels, usually about 4 to 6 mm. from the limbus. No measurements were made on eyes which showed any sign of unusual congestion of the vessels in response to the topical anaesthetic, for it was found that in such eyes the venous pressure was invariably elevated and showed considerable pulsation. All eyes were prepared in the manner used for routine tonography with the Schwarzer tonometer, using the 7.5 g. weight. Novesine was used for anaesthesia before applanation tonometry and Amethocaine before the tonography itself. In each eye episcleral venous pressure readings were taken 1 min. before the beginning of the tonography and 30 sec. and 1, 2, and 4 min. after tonography was begun. All patients were recumbent on an examining table.

It was found that the application of the tonometer displaced the globe posteriorly, necessitating refocusing of the microscope after starting tonography. The time involved in refocusing and in positioning the pressure-chamber over the vessel made it difficult to obtain a reading earlier than 30 sec. after the beginning of tonography, although a 15-sec. reading would have been desirable.

It appears that most workers who have measured the episcleral venous pressure in the past have measured the pressure necessary to collapse the vessel completely and to obliterate the blood column. This does not give an accurate measurement of pressure at the point under observation, for when flow ceases there is no longer a pressure gradient along the vessel. The pressure measured then becomes that of the nearest distal branching point of the vessel. It was decided, therefore, to attempt to measure the pressure at the instant when the vessel wall was first observed to yield to the externally applied force. A magnification $\times 25$ was used to observe the vessels, and with practice it was found possible to obtain good reproducibility of measurements. Paired readings taken at any given point on a vessel seldom differed by more than 0.25 mm. Hg, and all measurements were made to the nearest 0.50 mm. Hg.

Investigation of the effects of postural changes was carried out with the patient sitting in a dental chair, thus permitting the change from the sitting to the supine position to be effected without the need for physical exertion on the part of the patient. Episcleral venous pressure measurements were carried out in the usual manner. In making intra-ocular pressure measurements it was considered desirable to use a technique which did not require the assumption of abnormal positions, such as hyperextension of the neck. This meant that the tonometer to be used would have to be capable of working in two different positions. As the Schiötz tonometer depends upon gravity for its operation, it was not possible to use it on patients in the sitting position. The earlier model of the applanation tonometer, as fitted to the Model 360 Haag-Streit slit lamp, works by means of a spring, and it was found possible to modify the instrument for use in two positions. The tonometer was mounted upon the Zeiss operating microscope so that the measurements could be made with the patients sitting or recumbent simply by rotating the microscope through an angle of 90°. Precise alignment of the tonometer was obtained in either position by means of spirit levels attached to the body of the instrument. A counterweight was clipped on to the prism lever of the applanation tonometer when it was rotated into the horizontal position in order to restore the static balance of the lever assembly. The calibration of the instrument in this position was checked by means of a sensitive torsion balance and was found to be correct. Episcleral venous pressure and intra-ocular pressure measurements were made with the patient sitting; the chair was then lowered and after 2 min. the measurements were repeated with the patient supine. The chair was then returned to its upright position and the cycle repeated.

Results

An initial series of measurements was made on sitting patients in order to permit comparison of the results obtained by this method with those obtained by other workers (Table I). No significant difference was found between glaucomatous and non-glaucomatous eyes, and the mean value obtained is in good agreement with the findings of other investigators.

TABLE I
EPISCLERAL VENOUS PRESSURE IN SITTING SUBJECTS

Eyes	Type	Normal	Glaucomatous
	No.	20	20
Episcleral Venous Pressure (mm. Hg)		10.45 ±0.212	10.95 ±0.274
Intra-ocular Pressure (mm. Hg)		16.00 ±0.705	23.36 ±1.425

Measurements were made on 101 eyes during tonography (Table II). Although there was a substantial rise in episcleral venous pressure after 30 sec., this was not sustained and the episcleral venous pressure slowly fell during tonography until at the end of the 4th minute it was almost back to the pre-tonography level.

TABLE II
RISE IN EPISCLERAL VENOUS PRESSURE DURING TONOGRAPHY IN 101 CASES

Time (min. after start of tonography)	0.5	1	2	3	4
Rise in Episcleral Venous Pressure (mm. Hg)	0.61 ±0.146	0.56 ±0.103	0.52 ±0.099	0.28 ±0.102	0.19 ±0.102

Measurements to determine the effect of postural changes upon the intra-ocular pressure and episcleral venous pressure were made on twelve subjects (Table III). A difference between the sitting and lying position of approximately 1 mm. Hg was found in both the intra-ocular pressure and the episcleral venous pressure.

TABLE III
EFFECT OF POSTURAL CHANGES ON INTRA-OCULAR AND
EPISCLERAL VENOUS PRESSURE IN TWELVE SUBJECTS

Posture	Sitting	Lying
Intra-ocular Pressure (mm. Hg)	15.50 ±1.362	16.60 ±1.370
Episcleral Venous Pressure (mm. Hg)	10.46 ±0.316	11.42 ±0.398

Discussion

The measurements on sitting patients confirm the finding by others that there is no significant difference in the episcleral venous pressure in normal and glaucomatous eyes. This is in accordance with the concept that episcleral venous pressure is controlled by episcleral blood flow and not by aqueous outflow. There would appear to be no abnormality of episcleral venous pressure in chronic simple glaucoma. In view of the fact that all pressure readings were taken at the point where collapse of the vessel was initiated rather than completed, it might have been anticipated that the pressure readings obtained in this series would be significantly lower than those obtained by others who measured the pressure necessary to collapse the vein completely. This is not the case, however. When measurements were made on the same vessel comparing these two different end-points, it was found that the difference between them ranged from 0.25 to 2.0 mm. Hg.

In cases in which a large number of anastomoses bypassed the point under observation, the difference between the two end-points was minimal because there was no damming up. The pressure difference between the two end-points was greater in solitary vessels in which there was no opportunity for the blood flow to bypass the point under observation.

In the tonography series, a mean value of 11.66 mm. Hg was obtained for the episcleral venous pressure in 101 recumbent patients immediately before starting tonography. The mean value for the intra-ocular pressure, measured by means of the Goldmann applanation tonometer with the patients in the sitting position, was 18.36 mm. Hg. There was no correlation between these two variables, the r value being less than 0.01.

Fig. 3 shows the data of Table II graphically. The distribution obtained suggests that even higher pressures may have prevailed during the first 30 sec. of tonography. The average value for ΔP_v during the 4-minute period is 0.44 mm. Hg.

FIG. 3.—Rise in episcleral venous pressure during tonography.

The reason for the fall observed in venous pressure is not immediately apparent. It may be that some vascular reaction counteracts the orbital venous stasis induced by the weight of the applied tonometer. It is also possible that a simple physical process is involved, somewhat analogous to tonography itself, in which blood is being forced out of the orbital venous plexus until a new equilibrium is reached between the orbital venous pressure and the orbital venous outflow channels. Some observers have found an initial steep fall in intra-ocular pressure during the first minute or two of tonography, and it is possible that the rather rapid fall in episcleral venous pressure seen in certain cases during the present study may contribute to the production of such tonographic tracings. This effect would largely be avoided by those who practise the technique of 6- or 7-minute tonographies, utilizing the last 4 minutes of the recording for their calculation of C . In this case, the ΔP_v correction would become so small that it could almost be ignored. In the case of an ordinary 4-minute tonography, performed on an eye with a normal rigidity, a P_o of 20, and a facility of outflow of 0.25, the

application of the ΔP_o correction of 0.44 mm. Hg increases the value of C by approximately 4.5 per cent.

The results of the investigations into the effects of postural changes are in good agreement with the findings of Linnér and others (1950) regarding episcleral venous pressure, and of Maurice (1958) regarding the effects of postural change on the intra-ocular pressure. The change from the sitting to the lying position is associated with a rise of approximately 1 mm. Hg in both the episcleral venous pressure and the intra-ocular pressure. Presumably the rise in intra-ocular pressure results from the rise in episcleral venous pressure. The Goldmann applanation tonometer reading taken before tonography should therefore be augmented by 1 mm Hg to obtain the true value of P_o in the lying position.

Summary

The episcleral venous pressure was measured in forty eyes in sitting subjects. The mean value found was 10.7 mm. Hg and no significant difference was seen between normal and glaucomatous eyes.

The episcleral venous pressure was followed throughout tonography in 101 eyes. The rise in episcleral venous pressure was found to be greatest during the first half of tonography and to have returned almost to the pre-tonography level by the end of tonography. The mean value for ΔP_o during this period was 0.44 mm. Hg.

The change from the sitting to the lying position was found to be associated with a rise of approximately 1 mm. Hg in both the episcleral venous pressure and the intra-ocular pressure. This correction should be added to the Goldmann applanation tonometer reading whenever this instrument is used to measure P_o for tonography or for rigidity determinations.

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