PRESSURE IN THE CANAL OF SCHLEMM*

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THE pressure relationships in the anterior chamber, the canal of Schlemm, and the episcleral venous plexus are of obvious importance to the understanding of the drainage of aqueous humour. Episcleral venous pressures have been estimated by several workers (Thomassen, 1947 ; Linner, 1954 ; Bain, 1954), but so far no direct measurements of the pressure in the canal of Schlemm have been attempted. The only comparable measurement in the literature is that of Duke-Elder (1926) who measured the pressure in the veins of the circle of Hovius in the dog and found the pressure to be slightly higher than the intra-ocular pressure. It was, therefore, considered worthwhile to attempt direct measurement of the pressure relationships of the canal of Schlemm and the anterior chamber in the eye of the living Rhesus monkey, in which the anatomical arrangements are very similar to those found in man.

Experimental Methods

The monkeys were anaesthetized with ether followed by chloralose 100 mg./kg. body-weight intravenously. The head was held steady by means of a brass rod screwed to the skull. The lids were retracted with sutures and the eye rotated downwards by a superior rectus suture.

A small segment of limbus was then carefully dissected by removing slices of corneo-scleral tissue until only a thin covering of sclera remained over the roof of Schlemm's canal. In the first eye used the canal could be identified by the presence of blood in it, but in two other animals it was necessary to inject Evans blue into the anterior chamber to show up the canal. In later experiments, leakage of aqueous from small collector channels guided the dissection to the canal. A needle was then introduced into the anterior chamber and connected to a manometer filled with saline and the pressure maintained at 25 cm. saline.

A small slit was now made into the canal and a narrow glass tube drawn out to about 0.3 mm. in diameter at one end inserted into the canal with a micro-manipulator. This glass tube was also connected to a saline manometer. It was thus possible to vary the intra-ocular pressure by means of the manometer connected to the anterior chamber and to measure the pressure in the canal either by means of a bubble in the wider part of the cannula or by means of our usual membrane manometer and recording camera (Greaves and Perkins, 1952).

Experiment 1.—The cannula was successfully introduced into the canal of Schlemm in the right eye and the intra-ocular pressure varied by raising and lowering the saline reservoir. The pressure in the canal was measured by introducing a bubble into the wider part of the cannula and moving the saline reservoir attached to the cannula until

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TABLE I
RESULTS OF EXPERIMENT 1

Eye	Pressure (cm. saline)	
	Anterior Chamber	Schlemm's Canal
Right	25	24.3
	25	23.9
	50	48.2
Left	25	23.2
	35	33.3
	45	43.9
	55	53.8
	65	63.6
	55	54.8
	45	44
	35	32.4
	25	23.7

the bubble remained stationary. A few readings only were possible in the right eye before eye movements enlarged the entrance hole into the canal to such an extent that leakage of fluid took place round the cannula. The readings are shown in Table I.

In the left eye the experiment was repeated more successfully and a range of readings at different pressure levels was obtained. Repeated readings at each intra-ocular pressure gave results varying only by 1 or 2 cm. saline (Table I).

Examination of these eyes under a dissecting microscope showed that the trabeculae were intact in both.

TABLE II
RESULTS OF EXPERIMENT 8

Pressure (cm. saline)	
Anterior Chamber	Schlemm's Canal
20	18
30	27
40	35
50	44
60	53

Experiment 8.—The canal of Schlemm was exposed and the glass cannula successfully inserted, after connecting the anterior chamber to the membrane manometer to give a continuous recording of the intra-ocular pressure (Table II).

The cannula was also connected to a recording manometer so that a photographic tracing of the pressures in the anterior chamber and canal of Schlemm could be obtained. The pressure in the anterior chamber was now raised in steps of 10 cm. at a time. The resultant tracing is shown in the Figure.

FIGURE.—Recording of blood pressure, and pressures in anterior chamber and canal of Schlemm of a monkey during artificial raising of intra-ocular pressure.

Results

The experiment was attempted in eight eyes altogether but only three of these were considered to be completely satisfactory from a technical point of view. In two of the discarded results the canal was opened too widely and the aqueous leaked out round the cannula; in one the trabeculae were found to be ruptured on subsequent examination; in the remaining two eyes, although the trabecula appeared intact under a dissecting microscope, the pressure in the canal equilibrated with the pressure in the anterior chamber rather rapidly, suggesting a slight leak into the canal.

It must be admitted at once that the conditions of these experiments are rather artificial and the technical difficulties of exposing the canal and introducing the cannula are great. For example, the canal may be opened too widely to admit of adequate sealing by the cannula with resultant leakage of aqueous. The cannula may penetrate the trabecula—a complication which is immediately recognizable by the rapid equilibration of the pressure recorded from the cannula with that of the anterior chamber. It is impossible to be sure that even in the experiments in which subsequent examination of the trabecula showed no apparent injury some stretching of this structure without actual rupture did not allow an easier passage from the anterior chamber to the canal than normal.

The accuracy of the membrane manometers must also be taken into account. These manometers will reliably show pressure changes of 2 cm. saline, but in order to calculate absolute values from the records they have to be calibrated against known pressures. When this is done in steps of 5 cm. saline up to and down from 65 cm. saline, it is found that the descending calibration differs by as much as 3 or 4 cm. saline from the ascending readings. In experiments in which relative changes only are required an average of the two readings is used, but in these experiments records taken during the rise of intra-ocular pressure have been calibrated on the ascending scale and records of lowering the intra-ocular pressure on the descending scale.

Another criticism is that the pressure measurements in the canal might be expected to bear a constant relationship to the pressure in the anterior chamber, but such a relationship is not apparent in the results from the left eye of Experiment 1. In the three readings from the right eye of Experiment 1, there is approximately the same ratio for the readings at 25 cm. saline and at 50 cm. saline. In Experiment 8 (Figure) there is a fairly constant ratio between the two pressures.

Further Experiments.—Grant (personal communication) has measured the rate of entry of fluid into enucleated human eyes and has attempted to open the canal of Schlemm by shaving away the sclera over the canal. He found no change in the rate of flow, and subsequent histological examination of the eyes showed that the canal had not been opened.

This experiment has been repeated, except that the canal was definitely opened,

on one human eye and one monkey eye, using a reservoir of saline connected to the excised eye *via* a calibrated capillary tube. From the rate of movement of an air bubble in the capillary the rate of flow of fluid through the eye could be measured.

In the human eye the rate of flow at a pressure of 57.5 cm. saline was 4.59 mm.³/min. saline before opening the canal, and 15.5 mm.³/min. at the same pressure after opening the canal. The trabeculae were found to be intact on examining the eye microscopically.

In the monkey eye, the initial flow was 16 mm.³/min. at 25 cm. saline, and 37.7 mm.³/min. after opening the canal. Again the trabeculae were found to be intact after the experiment.

A similar experiment was then performed on the living monkey. The initial flow at 25 cm. saline was found to be 13.5 mm.³/min. and after opening the canal at the same pressure the flow was 51.66 mm.³/min. Sections of this eye showed the trabeculae to be intact.

The results of these three experiments are shown in Table III.

TABLE III
RESULTS OF THREE EXPERIMENTS BASED ON THOSE OF GRANT (1954)

Eye	Pressure (cm. saline)	Rate of Flow (mm. ³ /min.)	
		Initially	After Opening Schlemm's Canal
Enucleated human ...	57.5	4.59	15.5
Enucleated monkey ...	25	16.0	37.7
Living monkey ...	25	13.5	51.66

Discussion

The discovery of aqueous veins (Ascher, 1942) opened new fields of investigation; in particular the "glass-rod" test has been used to assess pressure relationships between the canal of Schlemm and the episcleral veins. Goldmann (1949) states that as the glass-rod phenomenon is slightly more often negative than positive in normal eyes, the pressure in the canal of Schlemm is a little, but not much, higher than that in the episcleral veins. A positive glass-rod test, *i.e.* blood-influx into the aqueous vein, is said to mean that the pressure in the canal of Schlemm is a little lower than in the episcleral veins. Goldmann (1949) gives a figure of 8 mm. Hg for the average pressure in aqueous veins in normal eyes and therefore implies that the pressure in the canal of Schlemm is also of that order. The average intra-ocular pressure of his normal eyes is stated to be 16 mm. Hg.

The results of direct measurement of the pressure in Schlemm's canal by the experimental methods described give a figure much nearer to the intra-ocular pressure. In the last experiment of the series (Figure) the ratio of the pressure in the canal to that in the anterior chamber is approximately 9/10.

Moreover the experiments on the rate of flow of saline into eyes before

and after opening the canal of Schlemm show that the rate increases two to three times in enucleated human and monkey eyes and rather more in the living monkey eye. In these experiments only a small opening has been made into the canal so that it is not justifiable to make mathematical deductions from the figures obtained, but the results do indicate that there is a considerable resistance to flow between the canal of Schlemm and the venous system, suggesting that *in the normal eye* the main resistance to outflow may be here rather than between the anterior chamber and the canal.

It must be emphasized of course that these experiments relate only to normal eyes (and mainly monkey eyes), and that no conclusions regarding the pressure relationships in glaucomatous eyes can be drawn from the results. So far as the present experiments are concerned, the resistance in glaucomatous eyes may be in the trabeculae or in the efferent channels distal to the canal.

Summary

- (1) The canal of Schlemm of monkeys' eyes has been cannulated and the pressure in it recorded during artificial variation of the intra-ocular pressure.
- (2) The pressure in the canal was found to be approximately 10 per cent. lower than that in the anterior chamber.
- (3) The rate of flow of saline into enucleated monkey and human eyes and into the living monkey eye has been measured before and after opening the canal of Schlemm. A marked increase in the rate of flow followed the opening of the canal.

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