EFFECT OF RAISED OCULAR TENSION ON THE EPISCLERAL VESSELS*

DEVELOPMENT OF THE CAPUT MEDUSAE IN PRIMARY GLAUCOMA

BY

J. H. DOBREE

From the Glaucoma Clinic, Institute of Ophthalmology, London

Since Mackenzie (1854) published his classical descriptions of glaucoma, his "varicosity of the external vessels" has been recognized as an important physical sign of the later stages of the disease. There is still, however, no general consensus of opinion as to how, or why, the vascular changes develop.

The results of an investigation into the vascular changes occurring in the transient diurnal variations of pressure of chronic glaucoma have recently been presented. Observations on the episcleral vessels were made by serial photographs, and among the conclusions were two of importance to the present study. The first was that, if the tension of the eye observed was moderate or low in degree, a physiological vaso-dilatation, mainly affecting the venous side of the circulation, was associated with the periods of lowered tension. The second was that, if the tension rose to sufficient heights, a dilatation of the anterior ciliary arteries occurred (Dobree, 1953). The latter finding was thought to be secondary to the pressure itself and this view was further supported by the observation, subsequent to successful filtering operations, that these same vessels showed a marked decrease in calibre.

This suggested one method of studying the relationship between the ocular pressure and the associated vascular changes occurring at the higher tension levels. For, by photographing the vessels before and after operation in a large series of cases in which the general level of tension was known, information would be obtained regarding the degree of tension necessary to produce the vascular changes. Another method which presented itself was to study a series of cases in which the reduction of tension had been effected by miotics. Finally, in order to observe the extreme type of case in which the pressure had been very high and prolonged, a number of selected cases of absolute primary glaucoma were studied.

Technique

A 35-mm. camera was fitted to one side of a slit-lamp binocular in place of the eye-piece, and visual observations were made through the second eye-piece. The termination of a suitable anterior ciliary artery, preferably with a large vein lying alongside, was selected. Preliminary focussing was done with the narrow beam of the slit-lamp and when the required area was in focus the slit was opened to its full extent and the shutter released. After the photograph was taken, the tension was taken by a Schiötz tonometer.

*Received for publication March 5, 1954.

500
RAISED OCULAR TENSION AND EPISCLERAL VESSELS

Clinical Material

Altogether 51 glaucomatous eyes were examined; forty were of the chronic type in which the function was good, the vision being 6/18 or better, and these cases were photographed before and after reduction of tension; in the other eleven eyes the glaucoma was absolute and all had vision of hand movements or less. The changes in these cases were compared with a low tension fellow eye.

(A) Chronic Glaucoma Cases examined before and after Reduction of Tension.—The forty chronic glaucoma cases were classified according to the height of tension prevailing before treatment, and the initial photographs were taken as far as possible at the highest level of tension before any form of therapy had been started. They were grouped according to the initial tension as follows:

<table>
<thead>
<tr>
<th>Level of Tension</th>
<th>Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 60 mm. Hg</td>
<td>...</td>
</tr>
<tr>
<td>Between 30–60 mm. Hg</td>
<td>...</td>
</tr>
<tr>
<td>Below 30 mm. Hg</td>
<td>...</td>
</tr>
</tbody>
</table>

High tension (eleven cases)
Moderate tension (twenty-one cases)
Low tension (eight cases)

This grouping is approximate as the diurnal variations are sometimes considerable, and, although all cases were phased for at least 6 hours at a subsequent examination, it is possible that some of these classified as of moderate tension should have occasionally qualified for inclusion in the high-tension group. However, as the series is a large one, and as the object was to determine the general pattern of vascular change, it is probable that there is no great error in adopting this rather over-simplified method of classification.

(i) the eleven high-tension cases included six of congestive and five of chronic simple glaucoma.
(ii) The 21 moderate-tension cases included six congestive, thirteen chronic simple, and two juvenile glaucomas.
(iii) The eight low-tension cases comprised two congestive and six chronic simple glaucomas.

The forty eyes also fell into two series according to the treatment adopted:

Series 1, photographed before and some 2 months after reduction of tension by operation, included six high, eleven moderate, and two low-tension cases.

Series 2, photographed before and after control by miotics, consisted of five high, ten moderate, and six low-tension cases.

The object of studying this second series was two-fold: first the greater control available in the reduction of tension obtained by miotics proved a convenient means of finding out how long it took the changes in calibre to regress; secondly, it was important to ensure that the vascular changes following filtering operations were not due to the surgical procedures themselves, but were directly related to the reduction in tension. As an additional precaution, to ensure that the changes in calibre were not consequent on the use of miotics themselves, some observations were carried out on ten normal and low-tension eyes to ascertain the normal response of the episcleral vessels to eserine and pilocarpine. A more detailed account of these and other findings will be published subsequently, but the main effects of these drugs as shown by serial photographs, are as follows:

Eserine, in 0.5 or 1 per cent. solution, usually causes an immediate spasm of both the episcleral arteries and veins, but after 10–15 minutes these again dilate. This dilatation is much more in evidence on the venous side of the circulation than on the arterial, and lasts for several hours.
Pilocarpine, in 1 or 2 per cent. solution, has a pure dilatatory effect, again mainly on the veins and capillaries, but more transient.

These tests showed that the miotics themselves were not responsible for the decrease in the calibre of the arteries which occurred when the ocular pressure was reduced by their agency.

(B) Absolute Glaucoma Cases.—Although absolute glaucoma is still a relatively common condition and there are often gross changes in the calibre of the episcleral vessels in most of the examples seen, the changes could be related to the causal lesion rather than to the raised tension itself. Cases of absolute thrombotic glaucoma, for example, usually show prolific new vessel formation on the iris and in the filtration angle. Again, cases of absolute congestive glaucoma often have antecedent attacks in which ciliary congestion is a prominent feature. Considerable care was therefore taken to exclude any case of secondary glaucoma or of primary glaucoma with a history of acute attack. Furthermore, as a direct comparison was made between the two eyes, it was necessary that in this series the fellow eye showed, at the most, only a moderate degree of tension. Out of some 1,000 available glaucoma patients, only eleven had eyes which answered these somewhat exacting requirements, and they were of the following types:

<table>
<thead>
<tr>
<th>Condition</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute simple glaucoma</td>
<td>...</td>
</tr>
<tr>
<td>Absolute congestive glaucoma (without antecedent acute attack)</td>
<td>3</td>
</tr>
<tr>
<td>Absolute glaucoma capsulare</td>
<td>...</td>
</tr>
</tbody>
</table>

Findings

(A) Chronic Glaucoma Cases examined before and after Reduction of Tension

1) Changes in Calibre of Anterior Ciliary Arteries.—There were eleven high-tension cases, of which six had the pressure reduced by operation and five by miotics. All except one showed a marked reduction in the calibre of the arteries when the tension had been lowered (Figs 1a and 1b). In five cases this decrease in calibre amounted to about one-half of the original diameter, and in the others to between one-third and one-quarter.

Of the 21 moderate-tension cases, eleven had the tension reduced by operation and ten by miotics. Six of the cases operated upon and three of the others showed a definite reduction in arterial calibre, although the reduction was less marked in most instances than in the high-tension group. Only one with initial tension lower than 40 mm. Hg showed this decrease, and that was a juvenile glaucoma case with an initial tension of 35 mm. Hg.

No changes were noted in any of the eight low-tension cases; These comprised two in which the pressure was lowered by operation and six in which this was effected by miotics.

The actual branches of the arteries affected by the changes in calibre showed some interesting points. They did not show an equal degree of dilatation; the main perforating stems, for example, usually showed more alteration than their smaller superficial branches which, indeed, were often unchanged after the operation.

It was shown by Leber (1873), and recently by Ashton and Smith (1953),...
(a) Untreated case at initial examination, tension 80 mm. Hg Schiötz.

(b) The same 2 months after operation, tension 25 mm. Hg Schiötz.

Figs 1 (a) and 1 (b).—Calibre change of anterior ciliary artery in chronic simple glaucoma after reduction of tension by operation.

A = anterior ciliary artery,
B = vein arising from vicinity of deep scleral plexus,
C = vein arising from superficial episcleral venules.
Untreated chronic simple glaucoma, tension 63 mm. Hg Schiötz.

2½ hours after initial instillation of pilocarpine, tension 22 mm. Hg Schiötz.

2 weeks after continuous pilocarpine therapy, tension 22 mm. Hg Schiötz.

Figs 2 (a) to 2 (c).—Fall in tension not immediately followed by reduction in arterial calibre.
that these main arterial trunks are destined for the interior of the globe, and that the smaller branches are superficial and destined mainly for the deep scleral plexus in the region of the canal of Schlemm.

(2) Time Relationships of Calibre Changes.—A striking fact which emerged from a review of the cases in which the pressure was reduced by miotics was that a reduction in arterial calibre did not immediately follow the reduction in tension, so that arteries did not attain their fully-constricted state for several days (Figs 2a to 2c). This may explain the constancy in arterial calibre in the diurnal tension variations of the cases of moderate tension to which attention was previously drawn (Dobree, 1953).

(3) Changes in Episcleral Veins.—The trunks of the main episcleral veins were, if possible, included in the photographs. In contrast to the changes on the arterial side of the circulation, there was very little alteration in the calibre of the venules and veins before and after operation. This was true whether the vein derived from superficial tributaries or emerged as a sizeable trunk, presumably from the deep scleral plexus. In Figs 1a and 1b, for example, although the calibre of the artery diminished to less than one-third its original size, both the deep and superficial episcleral veins showed very little change in calibre. It has been previously shown that after filtering operations the diurnal fluctuations in the calibre of the veins continue as before, and it was therefore important to photograph the vessels at comparable times of the day. Further, as might be expected from the observations on the effect of miotics on the episcleral vessels described above, in those cases wherein the tension was reduced by this means, there was some dilatation of the veins, but the alterations in calibre were not as striking as those occurring in the arteries.

It must be noted here that this discrepancy between the calibres of the arteries and of the veins is a most unusual finding. In ciliary congestion, for example, however caused and however mild, an arterial dilatation comparable to that just described is associated with an enormous dilatation of the venules and veins and a great increase in the capillary network. It must be emphasized that in these cases of chronic glaucoma the eyes were quite white at the height of tension, and were not the subject of anything in the nature of a sub-acute attack.

(B) Changes in Cases of Absolute Glaucoma

In these cases a direct slit-lamp comparison was made between the two eyes and, as has been stated, the cases were so selected that it was possible to compare the vessels of the high-tension eye with those of a low-tension fellow eye.

All of the eleven eyes had a tension of 60 mm. Hg or over. In one case, with a tension of 63 mm. Hg, there was little difference between the vessels of the two eyes, but in the remainder the differences were striking. In the first place the average diameter of the anterior ciliary arteries was double
that in the fellow (low-tension) eye. Furthermore, another important difference became apparent; a dilatation of the veins was also present in some of the more long-standing cases. Thus, three eyes showed an arterial dilatation alone, two showed a definite dilatation of some of the veins in addition, and in the other five there was a gross increase in the diameter of some of the veins as compared with the main trunks in the fellow eye.

The veins in question are large trunks which originate near the limbus. They form in pre-existing channels which are often quite insignificant before the rise in tension. They have important tributaries from the venous ends of the limbal loops or from corneal pannus vessels which are often present in these cases. Other tributaries emerge from the superficial episcleral venous plexus lying adjacent to the limbus and also from branches which presumably derive from the deep corneal plexus as well. The limbal loops, the pannus vessels, and the superficial episcleral veins normally obtain part of their arterial supply from minute twigs which spring from the anterior ciliary arteries before the latter perforate the sclera (Graves, 1934; Dobree, 1950). Now in those cases where the veins were engorged, these superficial twigs were found to be greatly enlarged and were clearly sending more blood to the region of the limbus than in normal eyes. There is therefore an anatomical basis for supposing that where the dilated veins are a prominent feature a quantity of arterial blood is diverted into them through superficial channels. In point of fact, it is probable that much of the arterial supply of the superficial episcleral circulation comes from arterial twigs lying more deeply in the sclera in the region of Schlemm's canal, but these too are purely superficial vessels which derive from the smaller perforating branches of the anterior ciliaries which form a plexus in the vicinity of the canal (Ashton and Smith, 1953).

A further interesting difference between those eyes which showed a purely arterial dilatation and those in which there were also engorged venous trunks concerned the state of the crystalline lens; in the former the lenses were clear, but where the veins were dilated there was a cataract. This may add weight to the suggestion which will be made below, namely, that an arterial dilatation is the initial stage in the formation of a caput medusae, and that where a venous engorgement is also present a much more serious circulatory embarrassment is indicated.

**Interpretation of Vascular Changes**

It will be recalled that no vascular changes were found in the low-tension cases and that it is unusual to find any unless the tension rises above 40 mm. Hg. Above this level the proportion of cases showing changes in the arteries increases, until at tensions above 60 mm. Hg an arterial dilatation is nearly always present. It is likely, therefore, that the increase in diameter of the anterior ciliary arteries is a direct result of the raised intra-ocular pressure. The anterior ciliary arteries constitute only one group of arteries entering the globe, but the behaviour of the others may well follow the same pattern.
RAISED OCULAR TENSION AND EPISCLERAL VESSELS

It is suggested that the cycle of events may be as follows: if, for any reason, the ocular pressure rises, this pressure is transmitted in the first place to the intra-ocular veins, and hence the resistance to the flow of blood through the eye is increased. This will tend to cause a reduction in the quantity of blood flowing through the globe in a given time. The resistance to flow will cause the pressure in the arteries to rise, and if there is, at the same time, a widening of their lumina, the rise will be further augmented. In other words, the arterial pressure-head will increase so that the quantity of blood flowing through the eye will, to a greater or lesser extent, be restored.

The dilatation of the arteries may be purely mechanical in origin, analogous to the distension of the pulmonary artery which occurs when the pressure in the pulmonary veins is increased in conditions such as mitral stenosis, emphysema, or, more acutely, in pulmonary embolus. The vessels now under consideration are, however, of a quite different order of magnitude, and are sufficiently small to be under nervous or chemical control; it is thus theoretically possible that their calibre could be altered by changes of this nature occurring within the globe, but the fact that the distension of the arteries takes some time to regress, strengthens the belief that it is mainly mechanical in origin.

The changes noted in the cases of absolute primary glaucoma may be explained as follows:

In cases which show only arterial distension, the circulation may be compensated for the rise in ocular tension by the mechanism already suggested; indeed the absence of cataract in such eyes suggests that the intra-ocular circulation is adequate. Cases in which large venous trunks appear among the episcleral vessels always have an associated cataract, which may indicate a considerable defect in the intra-ocular blood supply. The explanation of the presence of these large veins, which, it will be remembered, arise near the limbus, may be simply that the arterial pressure cannot surmount the ocular pressure in degree sufficient to do more than maintain a greatly reduced circulation inside the eye and that the arterial blood is short-circuited on the surface of the globe via the superficial vessels into the limbal loops and superficial and deep scleral plexi.

No positive information regarding the state of the intra-ocular circulation can be deduced from this study, but it is possible that in extreme cases of tension very little blood passes into the interior of the globe and that most of it is shunted through these superficial anastomoses. Further, if this already inadequate intraocular circulation were further reduced, a point might be reached, when the ocular tension would actually fall, a possible explanation of the phthisis bulbi which marks the final stage of glaucomatous degeneration.

Summary

The changes in the episcleral vessels after prolonged periods of raised ocular tension have been investigated.

In chronic glaucoma, of both the chronic simple and congestive types,
the most striking change was a dilatation of the anterior ciliary arteries. This finding was uncommon when the tension was below 40 mm Hg, but above 60 mm Hg it was nearly always present. The perforating branches of the arteries were particularly involved, and, after the reduction of the intraocular pressure, the arterial distension took at least some days to regress. The episcleral veins, by contrast, showed little change.

Some advanced cases of absolute primary glaucoma, in which the tension was particularly high and prolonged, showed a number of greatly distended episcleral veins in addition to the arterial dilatation.

The significance of these findings is discussed. The arterial dilatation seems to be a compensatory change consequent on the raised tension, and the occurrence of dilated veins probably implies that much of the blood destined for the interior of the globe has been short-circuited into the superficial veins through anastomotic channels in the vicinity of the limbus.

I should like to express my thanks to Sir Stewart Duke-Elder for his interest and helpful criticism, to Dr. M. Langham, Dr. J. F. Heggie, and Mr. M. Bates for guidance on the physiology and pathology of blood vessels, and to the Medical Illustration Dept. of the Institute of Ophthalmology, for help in the preparation of the photographs.

REFERENCES

——— (1953). Ibid., 37, 293.
Graves, B. (1934). Ibid., 18, 305.