The effect of external compression of the eye on intraocular pressure

I. Its variations with magnitude of compression and with age

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The effect of different magnitudes of force applied externally to the globe, or to the other eye, on intraocular pressure was investigated in two age groups. The results indicated that the dynamics of the precompression steady state must have been altered during compression. The recovery of the precompression steady state was related to the magnitude of the applied force and was absent in the older age group.

The prevailing techniques of investigating aqueous dynamics accept, as a first approximation, a model which treats the eye as an elastic hydrodynamic system with fixed dynamics. Such a model is necessary for these techniques to provide a quantitative estimate of the outflow facility and inflow rate that prevail at a certain steady state intraocular pressure level.

The present study examined this model by investigating, in two age groups, the effects of graded external compression on intraocular pressure and the recovery of the reduced postcompression intraocular pressure level. The results deviated significantly from those of an elastic model with fixed dynamics, and were found to vary profoundly with the compressing force and with age.

General considerations

If the eye were considered as a distensible sphere into which fluid was poured at a certain inflow rate and from which fluid escaped with a certain limited outflow facility, then, at steady state, the magnitude of the pressure gradient existing between the two sides of the outflow passages would be that which would render the outflow rate equal to the rate of inflow. If this system were then compressed from the outside, the events during and following compression might be accurately predicted, provided that the dynamics of the system were not altered by the compression.

Thus, during compression, the rise in intraocular pressure level above the steady state would increase, proportionately, the rate of outflow, which, in the absence of...
a change in inflow rate, would lead to a progressive reduction in the raised intraocular pressure level. On removal of compression, the preceding increase in outflow rate would be reflected as a net loss of intraocular volume and as a reduced intraocular pressure level. The reduced postcompression pressure and, proportionately, the outflow rate would progressively increase to attain the precompression steady state pressure level.

If different magnitudes of compression were applied for the same duration, then the reduction of the precompression pressure would be proportional to the compressing force; also, the recovery time required to attain precompression pressure level would vary directly with the magnitude of pressure reduction. A deviation from these predictions will then mean the hypothesis that the eye is an elastic hydrodynamic system with fixed dynamics is not tenable.

Sample and techniques
The sample consisted of 26 subjects with normal eyes. The younger age group consisted of 12 individuals whose ages varied between 18 and 25 years; the older age group consisted of 14 individuals whose ages varied between 58 and 70 years. The right eye was always used for the study of the effect of ipsilateral and contralateral compression. Experiments were performed on different days, but at the same time of day for each individual.

Adequate anesthesia was attained by the topical application of 0.5 per cent proparacaine ophthalmic drops to the cornea and conjunctival sac.

The Mueller electronic Schiotz tonometer, with its 5.5, 7.5, and 10 gram plunger loads, was used to apply different magnitudes of compression. Ipsilateral compression consisted of applying the tonometer vertically over the temporal sector of the right globe, just outside the limbus, in order to avoid any interference with the corneal surface. This area of the globe was exposed by having the subject fixate on an object appropriately placed to his left. The duration of ipsilateral compression for all weights was 30 seconds. Contralateral compression consisted of performing a 4 minute tonography on the left eye.
The intraocular pressure before and after compression was monitored by applanation tonometry.

**Procedure**

Three applanation readings were first obtained on the right eye at 30 second intervals in order to insure the stability of the precompression pressure reading. The subject was then placed in a supine position and subjected to ipsilateral or contralateral compression. Following compression, applanation tonometry was resumed and repeated every 2 minutes until the precompression pressure level was attained. Control experiments were performed on each subject by holding the Schiotz tonometer above, but without touching, the globe.

All applanation readings were obtained by one examiner (A. H.) without any knowledge of the nature or the magnitude of compression. Four experiments with each plunger load were carried out on each subject.

**Results**

**Pressure response to ipsilateral compression in the younger age group.** The characteristic pressure response following 30 seconds of compression with the 5.5 gram plunger load is shown in Fig. 1, A. Immediately after compression, the pressure level was lower than the precompression level. It continued, however, to become progressively lower, until a minimum level was attained in 8 to 12 minutes. The pressure level then increased progressively until it attained, but did not surpass, the precompression pressure level. This behavior occurred in 85 per cent of the experiments. In the remaining 15 per cent, the postcompression pressure was either equal to the precompression level or, if lower, it immediately increased progressively to attain the precompression level (Fig. 1, B).

In the control experiments in which compression was simulated but not actually applied, the “postcompression” pressure did not show any change from the precompression level in any of the subjects included in this study (Figs. 1, C and 2, C).

When the 7.5 gram plunger load was used, the postcompression pressure in all experiments was lower than the precompression level. From there on, the most frequent behavior was for the pressure to increase progressively until it attained the precompression level (Fig. 2, A). However, in 30 per cent of the experiments, the reduced pressure following compression con-
continued to become progressively lower, reaching a minimum value in 4 to 6 minutes before it started the progressive rise of recovery (Fig. 2, B).

With the 10 gram plunger load, the postcompression pressure level was always lower than the precompression level. Following compression, the reduced pressure level increased progressively until it attained the precompression level (Fig. 3).

Pressure response to contralateral compression. When tonography was performed on the left eye with the 5.5 gram plunger load for 4 minutes, the posttonography pressure level in the right eye was reduced in 50 per cent of the experiments, increased in 20 per cent, and unchanged in 30 per cent. After contralateral tonography, the changed pressure level in the right eye proceeded immediately in the direction of recovery of the pretonography level (Fig. 4).

Analysis of results

Because of the dependence of the pressure-volume relationship upon the initial pressure level, it was felt that, from the standpoint of dynamics, the intraocular pressure level following compression should be expressed as a per cent ratio of the precompression level, rather than in millimeters of mercury. Having done this in all experiments, the following statistics were calculated:

1. The mean pressure level immediately after compression.
2. The mean of the lowest postcompression pressure level attained.
3. The mean pressure level calculated at 4 minute intervals during recovery. Recovery was considered to start from the time the lowest postcompression pressure was attained.
4. The mean recovery time. This was calculated from the distribution of time lapse in minutes between the lowest postcompression pressure and the complete recovery of the precompression pressure level.
5. The mean 50 per cent recovery time. This was calculated from the distribution of time lapse in minutes between the beginning of recovery and the attainment of a pressure level at which 50 per cent of the reduction was recovered.

In constructing the distributions of these measures in the group, the average value obtained from the four experiments performed on each individual for each experimental condition was used as the score distribution. The statistics of these measures representing that individual in the group appear in Tables I and II, and in Fig. 5.

Compression with 5.5 gram plunger load in the older age group. The postcompression pressure level in 9 subjects was identical with the precompression level, and remained unchanged for as long as 1 hour of observation. In 5 the postcompression pressure was lower than the precompression level, the reduction varying between 10 per cent and 18 per cent of the precompression pressure level. This reduced pressure did not show a tendency for further reduction or for recovery of the precompression level. It remained unaltered for as long as 1 hour of observation.
Fig. 5. The change in the mean ratio \( \frac{\text{postcompression pressure}}{\text{precompression pressure}} \) in the younger age group. The time when the lowest postcompression pressure level was attained was considered zero time. The mean ratio for the group was calculated at 4 minute intervals thereafter, until there was complete recovery in all subjects. Open circles refer to the recovery from contralateral tonography; solid triangles, from ipsilateral compression with the 10 gram weight; open triangles, from ipsilateral compression with the 7.5 gram weight; solid circles, from ipsilateral compression with the 5.5 gram weight.

Fig. 6. Individual records of intraocular pressure in the right eye before and after a 4 minute tonography was performed on the left eye in the older age group. Note the difference in behavior between this and the younger age group; in this, when the postcompression pressure was altered, it did not show any attempt at recovering the precompression pressure level. Stippled vertical bar denotes 4 minute tonography on the left eye.
Table I. The immediate and maximum effect of compression in the younger age group

<table>
<thead>
<tr>
<th>Magnitude of compression</th>
<th>Mean ± S.D.M.* of the per cent ratio of postcompression to precompression pressure level</th>
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<tbody>
<tr>
<td></td>
<td>Immediate postcompression pressure level</td>
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<tr>
<td>Schiotz 5.5 gram weight</td>
<td>85% ± 1.9</td>
</tr>
<tr>
<td>Schiotz 7.5 gram weight</td>
<td>79% ± 2.0</td>
</tr>
<tr>
<td>Schiotz 10 gram weight</td>
<td>78% ± 3.0</td>
</tr>
<tr>
<td>Contralateral tonography</td>
<td>85% ± 2.0</td>
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</tbody>
</table>

*Standard deviation of the mean.

Table II. Recovery time in the younger age group

<table>
<thead>
<tr>
<th>Magnitude of compression</th>
<th>Mean time in minutes ± S.D.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100% recovery</td>
</tr>
<tr>
<td>Schiotz 5.5 gram weight</td>
<td>41 ± 1.7</td>
</tr>
<tr>
<td>Schiotz 7.5 gram weight</td>
<td>28 ± 2.1</td>
</tr>
<tr>
<td>Schiotz 10 gram weight</td>
<td>26 ± 2.1</td>
</tr>
<tr>
<td>Contralateral tonography</td>
<td>18 ± 2.0</td>
</tr>
</tbody>
</table>

Compression with 10 gram plunger load in the older age group. In 6 subjects compression produced no change in intraocular pressure. In 5 the postcompression pressure was reduced by 10 to 15 per cent; this reduced level was maintained, without an attempt at further reduction or recovery, for as long as 1 hour of observation. In 3 subjects the postcompression pressure was 15 to 20 per cent higher than the precompression level. This increased pressure level was maintained for 1 hour of observation without any attempt at recovery.

Effect of contralateral tonography in the older age group. In 7 subjects there was no change in pressure following contralateral tonography (Fig. 6, A). In 4 the postcompression pressure was 15 to 21 per cent lower than the precompression level; this reduced level was maintained unchanged for 1 hour of observation (Fig. 6, B). In 3 subjects the postcompression pressure was 20 to 25 per cent higher than the precompression level and, again, the raised pressure level showed no attempt at recovery, but was maintained unchanged throughout the 1 hour period of observation (Fig. 6, C).

Comments

In evaluating the significance of these findings, it is to be remembered that all experiments were performed on the same eye of the same individual at the same time of the day. This renders unlikely that differences in results, obtained by different compressing forces, might be due to differences in the intraocular pressure level or its dynamics prior to compression. This is more so because experiments with each compression force were repeated four times on different days, thus permitting "eye" variables to be included unselectively in each experimental condition.

If we examine Table I, we find that the reduction in pressure due to compression did not vary proportionately with the compressing force. This reduction in a system with fixed dynamics reflects the increased outflow rate during compression, which, in turn, is dependent upon the magnitude of the rise in intraocular pressure above the steady state or upon the magnitude of the compressing force. It is assumed in this study that external compression with larger tonometer weights produces higher intraocular pressure levels. While the mean intraocular pressure immediately after com-
pression with a 5.5 gram weight was higher than that following compression with the 7.5 or 10 gram weight, the differences are not statistically significant at the 1 per cent level of confidence. Furthermore, the mean intraocular pressure following compression with the 7.5 gram weight was identical to that of the 10 gram weight. This indicates that during compression the net fluid loss was not increased proportionately with the compressing force, as predicted.

Following compression, the reduced pressure should have proceeded in the direction of recovery of the precompression level. This was not the case with the 5.5 gram weight; a progressive reduction in pressure level followed cessation of compression. The duration of this process was too long to be explained by transient extra or intraocular causes. This phenomenon was less frequent and of a shorter duration with the 7.5 gram weight. It was absent with the 10 gram weight and with contralateral compression. As a result, the mean minimum intraocular pressure level attained following compression was virtually the same for all three weights (Table I). That, again, was another deviation from a model with fixed dynamics.

Having reached identical levels of reduction, the recovery process for the three weights was not the same. The mean recovery time was significantly greater for the 5.5 gram weight (Table II). The same was true for the time required to attain 50 per cent recovery (Table II). Examination of the pressure-time course (Fig. 5) shows that equal magnitudes of reduction recovered with different rates that varied with the magnitudes of the compressing force. With ipsilateral compression, the recovery time was inversely related to the magnitude of the compressing force; the difference between the 5.5 and the 7.5 or the 10 gram weight is statistically highly significant at the 1 per cent level of confidence.

Recovery from contralateral compression was not significantly different from that of ipsilateral compression with high weights when similar magnitudes of reduction were considered.

While the above findings show a deviation from the model, they do not define the nature of this deviation. One can only speculate as to which one or more of the various parameters, that can influence outflow rate and intraocular pressure recovery, were influenced by the magnitude of the compressing force. A change in aqueous outflow facility, inflow rate, and/or episcleral venous pressure with the compressing force, such that greater compressing forces would not produce a proportionately greater outflow rate, has to be assumed to explain the findings immediately following compression.

The persistence of reduction in intraocular pressure after cessation of compression with smaller weights seems to imply the persistence of a pressure-reducing mechanism evoked during compression. Its absence with higher weights and with contralateral compression may be due to the masking effect of fast recovery. The rate of recovery was shown to depend upon the compressing force, rather than the magnitude of pressure reduction it produced. The faster rate was evoked by a greater force of compression and by contralateral compression.

An even more striking deviation from the model was depicted in the reaction of the older age group. One might evoke the reduced outflow facility with age to explain the reduced outflow during compression with the resulting absence or negligible reduction of postcompression pressure; however, the tonographic C values of this sample varied between 0.18 and 0.32, a range well within that of the younger age group.

Absence of recovery was another significant feature in the older age group. When the postcompression pressure was reduced, it showed no attempt at recovery for a whole hour of observation. This absence of recovery prevailed also when the reduction was produced by contralateral compression. Equally significant was its ab-
sence when the pressure level was actually increased following contralateral compression. This indicates that the change in the dynamics of the precompression steady state was virtually permanent, and that whatever mechanism is responsible for recovery from such a change was ineffective in the older age group.

A possible effect of repeated applanation tonometry on intraocular pressure was ruled out by the control experiments on all subjects included in this study. Furthermore, such an effect cannot explain the various deviations encountered in this study, or the differences between the two age groups. The same holds true for factors such as anelasticity of the eye and changes in intraocular blood volume; while changes induced by these factors can complicate the results obtained, they do not exclusively account for them.

In order to gain some insight into the possible mechanism of the compression effect and the recovery process, a tonographic investigation was conducted. Its results, as well as those describing the effects of various pharmacologic agents on the compression effect, will be reported in a separate communication.

In conclusion, the results of this study indicate that the eye does not react to external compression in a manner compatible with a hydrodynamic model with fixed dynamics. The magnitude and manner of the compressing force determine the behavior of the intraocular pressure after compression, as well as the recovery process. There are marked differences in behavior in different age groups, the most pronounced being the relative inability of the eye with age to compensate for, or recover from, changes in intraocular pressure evoked by ipsilateral or contralateral compression as employed in this study.