The influence of position on intraocular pressure

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To better understand the relationship of Schiött pressure determination (in the recumbent position) to Goldmann applanation pressure determinations (in the sitting position), we studied the change in intraocular pressure that occurs when a person changes from a sitting position to lying on his back, utilizing applanation tonometry for both positions. The average pressure rise was 0.3 mm. Hg in one series of measurements and 1.6 mm. in a second series. In both series, the standard deviation of the pressure change from the mean was 1.8 mm. Hg, with some individuals exhibiting a marked change in intraocular pressure when they changed position. When subjects turned to lie on their left sides rather than on their backs, there was an additional average pressure rise, but again there was considerable individual variation in the amount of change. The pressure change in patients receiving glaucoma therapy was greater than in patients not on treatment. The amount of pressure change with change of position is sufficiently variable from individual to individual that in critical studies, such as studies of ocular rigidity or in attempts to improve calibration in Schiött tonometry or tonography, one should determine what happens in each individual rather than to assume a standard change in relating measurements in one position with those in another.

Recently we tested the accuracy of the officially accepted 1955 calibration scale for Schiött tonometry by comparing Schiött readings with Goldmann applanation pressure determinations.1 In that study the Goldmann applanation measurements were made with the subject lying on his back, just as for Schiött tonometry. The results were not in complete agreement with previous studies in which Schiött tonometer readings were compared with applanation measurements that were performed with the patient sitting up or with the patient lying on his side.

Some of the discrepancies can be resolved if it is assumed that the intraocular pressure is higher in the supine position than it is in the sitting position. Such a rise is often assumed to be a plausible result of vascular hydrodynamic alterations when the eye comes close to being level with the heart. Some actual measurements have been done with tonometers that can be used in both positions,2-15 and these studies tend to confirm the idea that in

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normal eyes there is an average rise in pressure of about 1 to 2 mm. Hg upon lying down.

We became interested in restudying this matter to establish, not only the average change, but also the degree of variability in pressure changes upon postural change. Therefore, two series of measurements were made with applanation tonometers to determine the influence of position on intraocular pressure. We did not study the effect of placing the head below body level, which others have investigated.\(^{14}\)

**Series I**

**Materials and methods.** These subjects were, for the most part, patients who had been referred for consultation concerning the diagnosis or treatment of glaucoma. In the course of the complete eye examination, the intraocular pressure of each eye was measured with a Goldmann applanation tonometer attached to a slit-lamp. In accordance with Goldmann's recommendations,\(^{10}\) a series of at least three readings were made on each eye alternately until consistent readings were obtained.

Following this, the patient moved to an examination table about six feet away where in the supine recumbent position, with the head on a pillow approximately 5 cm. thick, the intraocular pressure was again measured with a Goldmann applanation tonometer which was modified for use in the supine position and attached to an operating microscope.\(^{1,17}\) Again 3 or more readings were obtained on each eye alternately until the readings were consistent. Both applanation tonometers were standardized at 20 and 60 mm. Hg with a gravimetric standard bar.

For information on the influence of repeating the set of applanation tonometries without change of position, a comparable group of 26 patients (51 eyes) had a second set of measurements with a Goldmann applanation tonometer at the slit-lamp operating microscope.\(^{1,17}\) Again 3 or more readings were obtained on each eye alternately until consistent readings were obtained. Both applanation tonometers were standardized at 20 and 60 mm. Hg with a gravimetric standard bar.

**Results.** The principal parameter determined in Series I was the change of intraocular pressure when changing from the sitting to the recumbent position. This change was calculated for each eye by subtracting the sitting applanation pressure from the recumbent applanation pressure and is hereafter represented by the expression R-S (recumbent minus sitting). Initially, no attempt was made to correct for effects of repeated applanation tonometry or evaporation.

The frequency distribution of R-S for the 1,234 eyes examined with change of position in this study is shown in Table I and distribution expressed as per cent of the study population is shown in the histogram (Fig. 1). The mean change was a rise of 0.2877 mm. Hg (i.e., R-S = 0.2877). The standard error of the mean\(^*\) was 0.0512, and the standard deviation from the mean was 1.7982. The most frequent occurrence was that the intraocular pressure did not change upon lying down, and in half the eyes the intraocular pressure stayed the same or rose only 1 mm. Hg. In 87 per cent of the eyes, the intraocular pressures rose or fell less than 2 mm. Hg, while in 13 per cent there was a rise or fall greater than 2 mm. Hg.

The data were further analyzed to determine whether the change in intraocular pressure (R-S) was influenced by other factors. To determine whether R-S in eyes with high pressures were different from R-S in eyes with low pressures, a linear regression and correlation coefficient was determined with the sitting applanation pressure as the independent variable and R-S as the dependent variable. For this analysis only data of

<table>
<thead>
<tr>
<th>R-S</th>
<th>Frequency</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>+11</td>
<td>2</td>
<td>0.16</td>
</tr>
<tr>
<td>+10</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>+ 9</td>
<td>1</td>
<td>0.08</td>
</tr>
<tr>
<td>+ 8</td>
<td>1</td>
<td>0.08</td>
</tr>
<tr>
<td>+ 7</td>
<td>2</td>
<td>0.16</td>
</tr>
<tr>
<td>+ 6</td>
<td>2</td>
<td>0.16</td>
</tr>
<tr>
<td>+ 5</td>
<td>9</td>
<td>0.73</td>
</tr>
<tr>
<td>+ 4</td>
<td>28</td>
<td>2.27</td>
</tr>
<tr>
<td>+ 3</td>
<td>54</td>
<td>4.38</td>
</tr>
<tr>
<td>+ 2</td>
<td>144</td>
<td>11.73</td>
</tr>
<tr>
<td>+ 1</td>
<td>279</td>
<td>22.61</td>
</tr>
<tr>
<td>0</td>
<td>369</td>
<td>29.90</td>
</tr>
<tr>
<td>-1</td>
<td>202</td>
<td>16.37</td>
</tr>
<tr>
<td>-2</td>
<td>82</td>
<td>6.65</td>
</tr>
<tr>
<td>-3</td>
<td>30</td>
<td>2.43</td>
</tr>
<tr>
<td>-4</td>
<td>16</td>
<td>1.30</td>
</tr>
<tr>
<td>-5</td>
<td>8</td>
<td>0.65</td>
</tr>
<tr>
<td>-6</td>
<td>1</td>
<td>0.08</td>
</tr>
<tr>
<td>-7</td>
<td>2</td>
<td>0.16</td>
</tr>
<tr>
<td>-8</td>
<td>2</td>
<td>0.16</td>
</tr>
<tr>
<td>Total</td>
<td>1,234</td>
<td>99.99</td>
</tr>
</tbody>
</table>

*Since the standard error of the mean is an estimate of the accuracy of the calculated mean, taking into account the number of individuals examined, it can be taken to indicate with 95 per cent confidence that the true mean of the population sampled by the study lies within the two standard errors of the mean obtained in the study. Thus, for this study, the chances are 95 per cent that the true mean lies between 0.19 and 0.39 (0.29 ± [2] [0.05]).
right eyes were used in order to avoid invalidation of the statistical methods due to a high degree of correlation between changes in the right and left eyes.º

For the 628 right eyes, the slope of the regression lines was -0.01056, and the correlation coefficient was -0.3299. These results indicate that the amount of change in intraocular pressure upon lying down is not influenced by whether the pressure while sitting was high or low.

It was next determined (Table II) that the R-S in eyes receiving antiglaucoma treatment was significantly higher than the R-S in eyes not receiving treatment (t = 3.5, p < 0.01); again, only data from right eyes were used. A more specific analysis of data from both eyes (Table III) confirmed that R-S was significantly higher in eyes treated with miotics. However, the number of patients on epinephrine alone or acetazolamide alone was too small to establish a significant difference from either the normal or the miotic-treated groups. In the surgery group the standard deviation of R-S was large compared with the untreated group, and an F-test for homogeneity of variance showed that the difference of the standard deviation in the two groups was significantly different (P < 0.001). This large variability in the surgery group is further reflected in the low correlation coefficient between sitting and recumbent positions. Note that because of the large difference in standard deviations, the usual t-test is invalidated and cannot be taken to prove statistical significance despite the P value yielded. In fact, a modified t-test that takes into account the difference in standard deviations fails to demonstrate a significant difference between the means of the surgery group and the untreated group. Thus it is not established whether the higher R-S in the treated group is due to the presence of the glaucomatous state (as has been claimedº 5 7 8 and disclaimedº) or due to the use of miotic drugs.

Series II

Materials and methods. The patients in this group were attending the glaucoma clinic of the Massachusetts Eye and Ear Infirmary, and most were receiving therapy for glaucoma. Intraocular pressure was measured with a Perkins applation tonometer,18 the same tonometer being used for all positions. The first pressure determination was always with the patient sitting on the edge
Table II. Comparison of treated and untreated right eyes, Series I

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Applied IOP sitting</th>
<th>R-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated right eyes</td>
<td>95</td>
<td>22.547</td>
<td>6.253</td>
</tr>
<tr>
<td>Untreated right eyes</td>
<td>496</td>
<td>21.8125</td>
<td>5.3627</td>
</tr>
<tr>
<td>All right eyes</td>
<td>628</td>
<td>21.865</td>
<td>5.534</td>
</tr>
</tbody>
</table>

*There were 37 right eyes for which treatment status was unknown. This accounts for the discrepancy between the total of 628 right eyes and the sum of the treated and untreated eyes.

of the examination table. The patient was then placed in a comfortable position lying on his back, and the intraocular pressure was determined again. The patient was then asked to roll over onto his left side with his head brought forward to the edge of the examination table. After the intraocular pressure had been determined in this position, the patient again sat up. Usually a final pressure determination was obtained in the sitting position.

In each position, the intraocular pressure was determined by repeated measurements until consistent readings were obtained. If consistent readings could not be obtained—such as might occur with tight eyelids or an unrelaxed patient—the data were discarded.

Whenever possible, pressure determinations were made in all positions. However, since many of the patients were elderly, this was not always possible. The procedure most often omitted, was rolling onto the side.

Often it was awkward to determine the pressure of both eyes when the patient was lying on his left side. In such cases, pressure readings were obtained on only one eye, since it seemed likely that the pressure readings would not be accurate unless both the patient and the examiner were comfortable.

Results.

Effect of changing from sitting position to lying on back. The results of the measurements or 89 eyes are shown in Table IV and Fig. 2. In 70 per cent of the eyes there was a pressure rise upon lying down; 20 per cent maintained the same pressure, and in 10 per cent there was a fall in pressure. The mean change was a rise of 1.60 mm. Hg. The standard error of the mean was 0.198 mm. Hg and the standard deviation from the mean was 1.872 mm. Hg.

Effect of changing position from lying on back to lying on left side. Fig. 3 shows the results for 52 eyes. Only 2 eyes had a fall in pressure. The most frequent occurrence was that the pressure did not change, but more than half of the eyes had a rise in pressure. The mean change was a rise of 1.38 mm. Hg. The standard error of the mean was 0.247 and the standard deviation was 1.78. However, because the frequency distribution is skewed (Fig. 2), these latter statistics (which apply to normal distribution) do not have their usual significance.

Net effect of changing from sitting position to lying on left side. There were 47 eyes for which reliable measurements were obtained in all three positions. For these there was a mean total rise in pressure of 2.02 mm. Hg when the patient changed from the sitting position to lying on his back. This is somewhat higher than the value obtained for the 89 eyes represented in Fig. 2 and Table IV, but can be explained as a sampling variation.

The total change from sitting to lying on the left side for these 47 eyes is represented in Fig. 4. There was a mean rise of 3.51 mm. Hg, about 2 mm. Hg of which can be attributed to the average change from sitting to lying, and 1.5 mm. of which can be attributed to the average change upon turning onto the left side. The 3.5 mm. mean pressure rise agrees with other studies that have compared intraocular pressure while sitting with intraocular pressure while lying on the side.10-21 These studies have shown a tendency to a greater pressure rise than studies which have compared intraocular pressures while sitting and while lying on the back.

Data were examined carefully to detect whether eyes which rose more than average upon lying down were the same eyes that rose markedly when the patient turned on his side. It was clear that no such correlation existed. For instance, the eye which had a rise of 8 mm. upon lying down had an additional rise of 5 mm. upon rolling over; however, the eye which rose 6 mm. upon lying down had no additional change upon rolling over. Similarly, the group of eyes which had no pressure change upon lying down contained some eyes with no additional change upon rolling over, as well as others that had a rise of 1, 2, 3, 4, or 6 mm. Hg upon rolling over.

Change upon sitting up again. Often the intraocular pressures were measured in both sitting positions after the pressures had been measured in the lying down positions. This final measurement was taken mainly as a check on the consistency of the first readings in the sitting
LYING ON BACK MINUS SITTING

Fig. 2. Frequency distribution from Series II of the change in intraocular pressure upon lying down from a sitting position.

LYING ON LEFT SIDE MINUS LYING ON BACK

Fig. 3. Frequency distribution from Series II of the change in intraocular pressure upon turning on to the left side from the supine.

It became apparent that the pressure tended to be lower upon sitting up again than it had been initially (Fig. 5). Draeger's data seem to show a similar phenomenon, but Whitty's do not. It is not clear whether this pressure drop, when it occurs, represents a kind of orthostatic hypotension, which can cause an acute reduction in intraocular pressure upon rising from a supine to a standing position, or whether there is some evaporation from the cornea during the course of repeated measurements, producing a pressure fall similar to the usual pressure fall that occurs when an anesthetized eye remains open during tonography.

Discussion

In Series I, the average change in pressure (R-S) was quite small, although large changes occurred in a few patients. In contrast, in Series II, the average change in intraocular pressure upon lying down from a sitting position was larger, there was a tendency toward at least a moderate elevation in pressure, and the occurrence of substantial rises in pressure occurred more frequently. There are several differences between the two studies that individually or together might account for the slightly discrepant results.

For instance, in Series I the patients were referred for consultation from the private practice of other ophthalmologists, and many were not receiving glaucoma therapy; but in Series II the patients were those attending the glaucoma clinic of the Massachusetts Eye and Ear Infirmary, most of whom were receiving treatment for glaucoma at the time they participated in the study. As shown in Series I, patients with glaucoma who are receiving therapy behave differently from patients not receiving therapy, although the average pressure rise in the treated group of Series I was still not quite as high as the average pressure rise in Series II.

Another difference was that in Series I, the sitting pressure was measured at a slit-lamp, following which the patient stood up, took several steps to an adjacent
LYING ON LEFT SIDE MINUS SITTING

Fig. 4. Frequency distribution from Series II of the total change in intraocular pressure between the sitting position and lying on the left side.

examining table, and then lay down; however, in Series II, the patient was seated on the edge of the examining table for measurement of sitting pressure, and he merely lay down for the second pressure determination. Possibly the different degree of exertion between the two measurements had an effect. Moses and Liu\textsuperscript{21} has reported a mean decrease of 0.40 mm. Hg when patients walked 30 feet between measurements with the same applanation tonometer in the same sitting position. If not exertion, then evaporation from the anesthetized cornea might serve to lower intraocular pressure in the second measurement, as has been shown to occur during tonography. Since, in our study, the time between the measurements was slightly greater in Series I, the additional evaporation may have counteracted the rise in pressure that occurred upon lying down. In fact, we found in a control group of 26 patients (51 eyes) that going through the same two sets of Goldmann applanation tonometer measurements as in Series I, but having the patient remain sitting at the same slit-lamp, rather than moving or lying down, resulted in a mean decrease of 0.745 mm. Hg in the second set of measurements (0 change in 24 eyes, 1 mm. Hg decrease in 9 eyes, 2 mm. Hg decrease in 13 eyes, 3 mm. Hg in 1 eye, and 4 mm. Hg decrease in another eye, and a higher pressure in only 3 eyes: 1 mm. Hg in 2 eyes, and 2 mm. Hg in one eye). If this effect of repeated measurements were taken into account in Series I, the mean rise of intraocular pressure upon lying down might be calculated to 1.05 instead of 0.3 mm. Hg.

The difference between the pressure change in Series I and II is significant statistically (since the standard errors of the mean are quite small), but the magnitude of the discrepancy is small compared to the individual variation. Based on our series and others,\textsuperscript{21} it might be fair to conclude that on the average there is a rise in intraocular pressure upon lying down, but that it is small (0 to 2 mm. Hg). If the
Table III. Intraocular pressures, sitting and recumbent, with different treatments, Series I

<table>
<thead>
<tr>
<th>Group (therapy)</th>
<th>N</th>
<th>Mean IOP (sitting)</th>
<th>S.D. IOP (sitting)</th>
<th>Mean IOP (recumbent)</th>
<th>S.D. IOP (recumbent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>878</td>
<td>22.095</td>
<td>5.382</td>
<td>22.227</td>
<td>5.702</td>
</tr>
<tr>
<td>Surgery</td>
<td>6</td>
<td>20.657</td>
<td>2.238</td>
<td>23.500</td>
<td>10.134</td>
</tr>
<tr>
<td>Pilocarpine</td>
<td>104</td>
<td>22.673</td>
<td>6.548</td>
<td>23.423</td>
<td>6.756</td>
</tr>
<tr>
<td>Carbachol</td>
<td>2</td>
<td>23.5</td>
<td>14.849</td>
<td>23.5</td>
<td>16.263</td>
</tr>
<tr>
<td>Echotriophate</td>
<td>23</td>
<td>23.9134</td>
<td>6.815</td>
<td>25.087</td>
<td>6.915</td>
</tr>
<tr>
<td>Miotic (type unknown)</td>
<td>13</td>
<td>21.769</td>
<td>3.632</td>
<td>23.462</td>
<td>4.075</td>
</tr>
<tr>
<td>Epinephrine without miotics</td>
<td>14</td>
<td>23.143</td>
<td>4.036</td>
<td>23.286</td>
<td>4.065</td>
</tr>
<tr>
<td>Acetazolamide alone</td>
<td>3</td>
<td>23.00</td>
<td>12.288</td>
<td>24.00</td>
<td>11.289</td>
</tr>
</tbody>
</table>

average intraocular pressure change needs to be known more accurately than this in a particular physiologic study, there is no figure that could be safely applied, but would have to be redetermined for the population in that particular study with the exact techniques.

When considering individuals rather than population, it is even more important not to assume an average change, since certain individuals do have a marked change in intraocular pressure when they change positions. In both the studies reported here, the standard deviation of the pressure change (R-S) was near 1.8, which implies that 95 per cent of the individuals will have a pressure change within the range of 3.5 mm. Hg above or below the average, but that 5 per cent will have an even greater change. A recently reported study suggests that the amount of pressure change upon lying down may be subject to diurnal variation.25

The positional change in intraocular pressure accounts for some of the disparity between Schiötz and applanation determinations, and is a factor—in addition to ocular rigidity—that results in varying amounts of discrepancies in different individuals. For this reason, comparison of applanation and Schiötz readings may not give a good estimate of all ocular rigidity in an individual patient unless the applanation and Schiötz determinations are both done in the recumbent position.

Of course, it is not possible to know what effect a great positional change has on intraocular pressure in the clinical course of glaucoma. Does a patient with a large rise of pressure on lying down have a greater risk of glaucomatous change in the optic nerve while he is lying down, or are there changes in intravascular pressures and blood flow at the optic disc that parallel the changes in intraocular pressure and compensate for it? At present, since one does not ordinarily measure intraocular pressure in both positions,
whether such a patient is considered to have an unsafe intraocular pressure may depend upon what method his ophthalmologist uses.

Also unanswered is whether the pressure change on lying down persists (and is thus a true equilibrium pressure) or whether the pressure reverts to the former level measured in the sitting position if the patient remains supine. In Series II, a few patients with marked pressure rises were asked to remain recumbent for 30 to 60 minutes in an effort to evaluate this in a cursory manner. In these few patients, the pressure remained at the pressure originally measured for the recumbent position. However, upon sitting up again the pressure instantly returned to the pressure originally obtained in the sitting position. These observations are quite preliminary however and dare not be relied upon or applied to other physiologic considerations until the findings are confirmed.

These latter observations are a little surprising, since it is difficult to hypothesize a single mechanism for a rise in intraocular pressure upon lying down that would occur instantaneously and yet be maintained.

A rise in episcleral venous pressure, for instance, would be expected to have approximately a millimeter for millimeter rise in the intraocular pressure at equilibrium. However, the equilibrium pressure would not be achieved immediately, but rather there would be a gradual rise to the equilibrium pressure over a period of several minutes. On the other hand, if there is uveal vascular engorgement upon

<table>
<thead>
<tr>
<th>Lying down minus sitting</th>
<th>Frequency</th>
<th>Per cent</th>
</tr>
</thead>
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<tr>
<td>-2</td>
<td>2</td>
<td>2.25</td>
</tr>
<tr>
<td>-1</td>
<td>7</td>
<td>7.87</td>
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<td>+8</td>
<td>1</td>
<td>1.12</td>
</tr>
<tr>
<td>89</td>
<td>100.00</td>
<td></td>
</tr>
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</table>
uate the individual variation in episcleral venous pressure change and to see if there is a greater rise of episcleral venous pressure in individuals who show an extraordinary large increase in intraocular pressure upon change in position, particularly in glaucomatous patients. It should also be instructive to further study the time course of changes in intraocular and episcleral venous pressures that occur upon lying down.

Dr. John P. Gilbert of the Research Computing Group, Harvard Computing Center, rendered statistical advice. Computer programming was done by Mrs. Judy Hushon and Miss Jacqueline Siegel of the Research Computing Group.

REFERENCES