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Correlations between intraocular pressure, visual field and visual acuity, based on 11 years of observations of treated chronic glaucomas

P. NIESEL & J. FLAMMER
Bern, Switzerland

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Abstract

In a retrospective study of 114 patients under treatment for chronic glaucoma (81 without and 33 with visual field defect) over an 11-year period of observation, a highly significant correlation between intraocular pressure and progression of visual field defects could be demonstrated. This correlation could be shown for the visual field outer boundary in 81 eyes with ocular hypertension and for typical visual field defects in 33 eyes with chronic glaucoma. The relationship was, however, only significant when both the standard deviation of the annual intraocular pressure and the influence of cataract development upon visual acuity were considered. Quantitative analysis of the results of Goldmann perimetry was by planimetry and took into account only changes during the 11-year observation period.

Introduction

In chronic glaucoma, the question of the relationship between intraocular pressure and visual field loss has been primarily addressed from the standpoint of the prognostic value of eye pressures measured at the beginning of the observational period (2, 3, 7). All of these studies are characterized by a semi-quantitative statistical treatment only of intraocular pressures and a purely qualitative treatment of visual field results. The eye pressure during the observational period was taken as the mean of three measurements (6), or as the mean of a not further defined number of measurements (2). It is clear from these observations that the probability of visual field defects increases with increasing intraocular pressure. On the other hand, while eye pressure is a highly sensitive prognostic criterion, its specificity must be regarded as low.

We have statistically analysed the data from 11 years of eye pressure measurements, Goldmann perimeter visual field determinations on 114 patients under medication for chronic glaucoma. The inclusion of visual acuity analyses in this statistical analysis was based on another statistical analysis of the behaviour of visual field outer boundaries in the case of cataract development (5). In this work, visual acuity was used in a first approximation as a parameter for the development of a cataract.

Materials and methods

During the years 1964 to 1974 inclusive, 174 patients undergoing regular medical or surgical treatment were observed. Average age at commencement of treatment was 61.2 ± 10 years. Of the total of 274 chronic glaucomatous eyes, 90% could be classified as ocular hypertension and 10% as glaucoma with typical glaucomatous visual field defects. Seventy-seven per cent had open angle glaucoma (including 5% capsular glaucoma), 11% a chronic angle closure glaucoma and 12% a secondary glaucoma. Statistically significant differences (5% level) between these forms of glaucoma could not be found for the measured parameters.

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Eighty-one of the 274 eyes, not showing typical glaucomatous visual field losses – ocular hypertension – were subject to regular medical treatment, and no surgical correction was undertaken either during or after the observation period. They still show no disease state (apart from cataract formation), which might have influenced visual field or visual acuity measurements. For these eyes, a statistical analysis of the relationships between intraocular pressure, visual acuity and the outer boundaries of the visual field was performed.

In 33 eyes, a typical glaucomatous visual field defect was observed at the end of the observation period. This developed in 6 of the 33 eyes. For these eyes, the statistical relationships between eye pressure, visual acuity and the progression of the visual field defect as measured with a Goldmann perimeter, were investigated. The other 160 eyes were not suitable for this study, either because they were operated on, or because they had other ocular diseases such as macular degeneration or degenerated myopia.

Both groups, the 81 eyes with ocular hypertension and the 33 glaucomatous eyes, could not be distinguished statistically at the 5% level of significance, from the total of 274 eyes, with regard to type of glaucoma, patient age, visual acuity at commencement of observation period, or intraocular pressure measured in 1964.

Intraocular pressure was measured with a Goldmann applanation tonometer. On the average, 8-9 pressure measurements per year at various times of day, were performed. In the case of eye pressure exceeding 18 mmHg on the average, the frequency with which measurements were performed increased by 1 per year for each 2 mmHg eye pressure above 18 mmHg. The frequency of measurement also increased by 1 per year for each 0.89 mmHg standard deviation of the mean annual intraocular pressure. Statistical treatment of the intraocular pressure data was via arithmetic mean and standard deviation of all values found per calendar year, independent of the frequency of measurement.

Visual field measurements were carried out using the kinetic method, with the Goldmann perimeter. On the average, one visual field measurement per year was performed. In 80% of the eyes examined, visual field examinations were carried out at least once or twice per year. For statistical calculations, the area enclosed by the I/4 isopter (1/4 mm^2, 1.0 relative intensity) was determined by planimetry on the Goldmann perimeter registration paper and the square root of the resulting value taken. When more than one visual field determination per year was performed, the arithmetic mean of the square root of the enclosed area per year was used in the statistical calculations.

In the case of the 33 eyes with typical glaucomatous visual field defects, the defective area was measured by planimetry (cm^2) on the registration paper of the Goldmann perimeter. When the defect extended beyond the boudary of measurement, the difference between the actual result and the extrapolated isopter course extrapolated to the norm was used. When more than one examination per year was performed, the arithmetic mean of the defects measured per year were used in the statistical treatment. During the visual field measurements, the pupil size was measured by means of an ocular micrometer, and the arithmetic mean of these values included in the statistical data, when more than one examination per year was performed.

Visual acuity was tested by means of a sight test table at a distance of 5 m, with optimal optical correction. Tests of visual acuity were performed on the average twice as frequently as visual field examinations. The arithmetic mean per calendar year of all visual acuity tests was used in the statistical treatment.

Results

Table 1 shows the behaviour of the three parameters examined, namely, intraocular pressure, visual field and visual acuity in the case of 81 eyes with ocular hypertension and 33 eyes with chronic glaucoma. The intraocular pressure increased significantly by 8% during the 11 years of observation, despite changes in medication in some of the cases. In 21% of the 114 eyes, a significant regression in visual acuity was found. In 61% of the cases, a significant concentric narrowing of the Goldmann perimeter I/4 could be determined, while in 15% a significant increase in area of visual field defects was found. Statistical analysis of the data, with a view to detecting possible relationships between the observed changes in the

Table 1. Frequency of changes in intraocular pressure, visual field outer boundary, glaucomatous scotoma and visual acuity for 114 chronic glaucomas under medication during the years 1964-1974 inclusive.

Parameter	Change per 11 years	Frequency	Frequency of significant changes (5% level)
Intraocular pressure mmHg	± 0	80%	–
	+ 5	17%	5%
	+ 10	3%	3%
Visual field			
a. outer boundaries	+ 2,5	2%	1%
	± 0	14%	–
	– 1,0	84%	61%
b. scotoma cm^2	± 0	80%	–
	+ 2,0	20%	15%
Visual acuity	± 0	71%	–
	– 0,3	8%	–
	– 0,6	10%	10%
	– 0,9	11%	11%

Table 2. Partial correlation coefficients of the multiple correlation between the parameters – intraocular pressure; visual field outer boundary; visual acuity; pupil diameter and patient age – in 81 eyes with ocular hypertension during the observation period 1964 to 1974. Dependant variable: visual field outer boundary. Visual field changes of 81 eyes: 1964-1974. Goldmann perimeter I/4

Depended on	Regression coefficient	F-value	Significance
1. Mean intraocular pressure/year	0.0122	1.0342	N.S.
2. Standard deviation of the intraocular pressure/year	-1.9117	12.8556	1%
3. Change of visual acuity/year	0.9245	7.9011	1%
4. Visual acuity 1964	0.3268	6.3058	1%
5. Age 1964	-0.0066	3.3310	N.S.
6. Visual field 1964	-0.0295	0.9407	N.S.
7. Change of pupil diameter/year	-0.0132	0.9687	N.S.

three parameters and the situation at commencement of the observations, revealed no apparent interdependencies.

Table 2 shows the results of a multiple correlation analysis of the I/4 isopter visual field boundary data for the 81 eyes with ocular hypertension. The visual field is the dependent variable. As index for a change in these variables, the average increase per year of the annual mean and standard deviation of the intraocular pressure, as well as the annual means of visual acuity, visual field outer boundary and pupil diameter, were weighted by half the sum of the values for the first and last year (A). In order to approximate a normal distribution, this variable A was transformed as follows: $D = (e^A)^{I/4}$. With a multiple correlation coefficicient of 0.5792, n = 81, a significant partial regression at the 1% level can be demonstrated between changes in the outer boundary of the visual field, the standard deviation, of the intraocular pressure, changes in the visual acuity and visual acuity at the beginning of the observation period. It is interesting to note that there is no apparent relationship to the mean annual eye pressure, patient age, or the visual field findings in 1964. This is also the case for the pupil diameter. The signs of the regression coefficients show that, with an increase in the standard deviation of the intraocular pressure measured over a period of 1 year, or a decrease in visual acuity, the visual field exhibits a definite concentric narrowing. This is even more significant for those cases in which the visual acuity was considerably lowered at the beginning of the observation period.

In Fig. 1, the multiple regression between intraocular pressure, change in visual acuity and change in glaucomatous visual field defect for the 33 eyes with chronic glaucoma is shown in graph form. The equation to the regression line with a correlation coefficient of 0.71 (significant at the 0.001 % level) is as follows:

$$y = 0.47 + 1.78\,x + (1 \times 10^{-4})\,z^2$$

Y is the increase in visual field defect in cm^2 as measured with the Goldmann perimeter, x the decrease in visual acuity in tenths and z the mean annual pressure plus twice its standard deviation. The intraocular pressure parameter is the square of the highest value measured. The choice of this parameter follows from observations upon the 81 eyes with ocular hypertension with the following interpretation: the highest pressures measured or attained during the observation period have the greatest effect upon the visual field, while changes in pressure over a period of 1 day or 1 year have little effect.

It is interesting to observe from Fig. 1, that when a

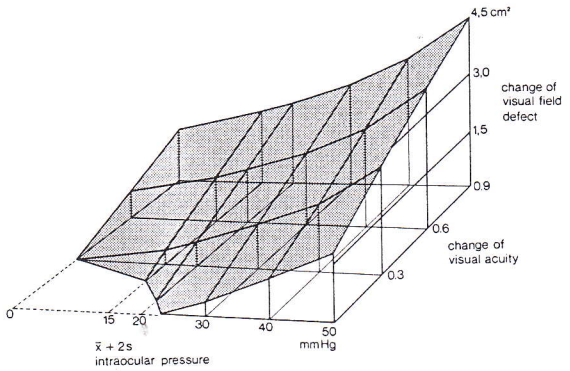

Fig. 1. Multiple regression between change in visual acuity, mean annual pressure plus twice its standard deviation, and change in glaucomatous visual field defect in 33 eyes with chronic glaucoma during the years 1964 to 1974.

linear regression is assumed between the chosen pressure criterion, the visual field defect and the visual acuity, the correlation coefficient sinks to 0.5, with a level of significance of 0.1%. Even though this difference is only significant at the 5% level, this is evidence that the importance of the highest value of eye pressure measured increases in a non-linear fashion for the visual field defect.

Another interesting observation from Fig. 1 is that the influence of intraocular pressure upon visual field defect appears to begin at approximately 23 mmHg, while cataract development makes itself felt upon the development of the defect at a visual acuity of approximately 0.7. The values are in accord with those one would expect from observations in daily clinical practice.

Discussion of results

A limiting factor for the practical importance of the results here described is the relatively small number of cases in which changes in the paramaters occurred over the 11-year period. It is therefore probably somewhat early to reach definite conclusions concerning the quantitative relationships between the parameters examined. It must therefore also remain an open question as to whether the results of observations made upon chronic glaucomas under medication can also be applied to untreated glaucomas. The fact that different types of chronic glaucomas were included in the statistical analysis is relatively unimportant, since no significant differences were found in the measured parameters.

1) A definite correlation exists between the intraocular pressure and the development of a visual field defect. The statistical relationship is evident from the analysis of quantitative data if the influence of cataracts upon the visual acuity parameter is taken into account. The quantification of visual field examination results thereby strongly contributes to the definition of the relationship.
2) The correlation between intraocular pressure and visual field, after statistically taking into account the influence of cataracts, is valid for the outer boundary of the visual field as well as for typical glaucomatous visual field defects such as paracentral or Bjerrum scotomata. From the pathophysiological standpoint, a differentation between ocular hypertention and glaucoma is not justifiable. This is only justifiable in terms of the clinical difficulties in distinguishing between a functional defect caused by intraocular pressure and the effect of a cataract.
3) The occurrence of functional defects is probably best described in terms of the peak intraocular pressures attained and their frequency. This can be seen from the fact that the correlation between eye pressure and changes in visual field is only apparent when the standard deviation of the annual intraocular pressure is included in the analysis. The mean eye pressure does not change significantly enough that the theoretically-awaited correlation can be demonstrated. The definite evidence for the non-linear effect of intraocular pressure also explains why all studies to date which have only taken into account the eye pressures as parameter, without regard to its variance, have shown too little or misleading specificity.
4) The clinical progress of the examined parameters in the case of chronic glaucomas under at least partially changing medication cannot be foreseen from singly-determined data. Every attempt should then be made even more so in clinical care to determine the highest-occurring intraocular pressure, and thereafter to adjust therapeutic measures accordingly. It is possible that the increased effort necessary may at least partially be circumvented,

if the more sensitive and more easily quantifiable methods of automatic perimetry can detect visual field defects in an earlier stage (4), or observation of the papilla with the chronostereoscope (1) can detect the organic defect before the functional defect becomes apparent.

To sum up, from this retrospective study a highly significant relationship between intraocular pressure and functional damage to the visual field in the case of chronic glaucoma has been demonstrated. In order to reveal this relationship, however, a quantitative analysis of both parameters is necessary: for the intraocular pressure, a non-linear weighting of all determined values with regard to at least the standard deviation, is probably of decisive importance. The visual field functional defect itself must be quantitatively measured with as sensitive methods as possible, if necessary taking into account cataract development or changes in pupil diameter in a quantitative manner.

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Authors' address:
University Eye Clinic Bern
3000 Bern
Switzerland