CLINICAL INVESTIGATION

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Reliability of intraocular pressure measurement with the Goldmann applanation tonometer in epidemiological studies

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Abstract The reproducibility of intraocular pressure (IOP) measurement with the Goldmann applanation tonometer was investigated as part of a population-based epidemiological study. Sixty-two subjects were examined in a first measurement session. The IOP was measured three times consecutively in both eyes according to a fixed protocol. The mean standard deviation (SD) of these measurements was 0.8 mmHg. The mean intra-observer variation for the first measurement was 1.64 (SD 2.07) mmHg. For the median of the three measurements the intra-observer variation was 1.50 (SD 1.96) mmHg. The mean inter-observer values were 1.79 (SD 2.41) mmHg for the first measurement and 1.60 (SD 2.15) mmHg for the median measurement. The correlation coefficient between the median values of the three measurements of both observers was 0.81. No systematic differences were found between the two observers. Using the median value of three consecutive measurements reduced the inter-observer variation by 11% and the intra-observer variation by 9% compared with a single measurement.

Introduction

The Goldmann tonometer for measurement of intraocular pressure (IOP) has been in use since 1957 [5]. It is the accepted standard in ophthalmology [5, 14, 21]. In comparison with other measurement techniques, the Goldmann device is thought to give more accurate results over a wider range of IOP values [4, 10, 19, 21]. In practice, however, there is intra- and inter-observer variation [3, 12, 15, 16, 18, 24]. IOP in epidemiological studies has been defined in many different ways (Table 1). In most studies no validation for these techniques has been given. In order to check the reliability of IOP measurements in an epidemiological study we compared reproducibility of the median of three consecutive measurements with a single measurement of IOP with the Goldmann applanation tonometer.

Subjects and methods

Subjects

Sixty-two persons out of the first 1000 randomly selected participants of the Rotterdam Study participated in this study [7]. The Rotterdam Study is a population-based follow-up study of 11 854 people aged 55 years or over, concentrating on chronic disabling diseases in the elderly, including glaucoma and age-related macular degeneration. The study protocol had been approved by the medical ethical committee of the Erasmus University. The validation study of IOP measurement consisted of two parts.

In the *inter-observer variation study*, 17 men and 23 women, consecutive participants of the Rotterdam Study, were included. Their mean age was 69.6 years (SD 7.7 years) and they had no corneal abnormalities. The IOP of first the right and then the left eye of each subject was taken three times by one observer. After 10 min a second observer took a similar series of three measurements of each eye. Ten minutes was arbitrarily chosen as the interval between the two measurement series in order not to keep the subjects waiting too long. Both observers were well trained and had taken applanation IOPs in over 4000 subjects. The sequence of the observers was random.

In the *intra-observer study*, an additional 22 consecutive participants of the Rotterdam Study, in the same age group as in the first part of the study (mean age 69.6 years, SD 6.6 years) and also without corneal abnormalities were examined, using the same protocol. The only difference was that IOP measurements were repeated after 10 min by the same observer.

Study protocol

All readings were obtained with the same Goldmann tonometer (Haag-Streit, Bern, Switzerland), mounted on a Haag-Streit 900 BM slit lamp with a standard blue filter. The calibration of the tonometer had been checked just before the study.

The protocol for IOP measurement was as follows. One drop of oxybuprocaine 0.4% was instilled into each eye of the subject. Both inferior conjunctival sacs were touched with a dry fluorescein strip (Haag-Streit). Before each measurement the scale of the tonometer was set at 10 mmHg. If necessary, the upper eyelid was lifted by rotating a cotton-tipped stick against the orbital rim, taking great care to avoid compression of the globe. The tip of the tonometer was illuminated with a wide-open slit at an angle of 45 deg. The applanating prism, with its axis on 0 deg, was lightly pressed against the center of the cornea. In the case of a marked corneal astigmatism resulting in an elliptical rather than a circular contact area, the prism must be rotated so that the dividing line lies at about 45 deg to the major axis of the ellipse [5]. The tonometer was raised or lowered in such a position that both semicircles were of equal size. Care was taken that the menisci were of equal circumference and of appropriate width, namely, approximately 0.05th part of the outer diameter of the semicircle. Strictly without looking at the dial, the rotating knob of the tonometer was set at a level in such a way that the inner aspect of the two mires just touched. If the IOP fluctuated during the cardiac pulse cycle, the measurement was taken at mid-cycle. If the bar on the rotating dial touched a fixed bar of the tonometer, that pressure was noted. If the movable bar was free of the fixed bars, the intermediate pressure was taken. Subsequently, the dial of the tonometer was set again at 10 mmHg. In this way, three consecutive measurements were performed on each eye and each value was recorded immediately after the measurement. The right eye was always measured first.

Data analysis

The data were analyzed by means of determination of standard deviations and coefficients of variation of three consecutive IOP measurements and of differences between the median values of the two observers. The coefficient of variation was defined as the standard deviation divided by the mean value of the three consecutive IOP measurements. Correlation coefficients of the median values of the two observers were determined. The paired standard deviations of the three measurements of individual cases were compared between the observers using Wilcoxon's test. Median values of the three consecutive measurements were compared between and within the observers using paired t-tests [6]. All P values given are two-sided, with 0.05 taken as the level of significance.

Results

In the *inter-observer study*, 40 right and 39 left eyes (one subject wore a prosthesis) were examined. The differences between three consecutive IOP measurements taken by one observer varied between 0 and 5 mmHg.

Table 1 Methods of defining intraocular pressure in validation studies and epidemiological studies using applanation tonometry with the Goldmann tonometer

Method	Reference(s)
First single measurement value	1, 3, 11, 12, 15, 19
Taking measurements until three successive readings were within 1 mmHg of each other	16, 18
Mean of three consecutive readings	9
Mean of two consecutive readings	24
Median of three consecutive readings	23, this paper
No description	2, 8, 13, 22

Table 2 Difference between first and median IOP measurements (mmHg) between and within observers
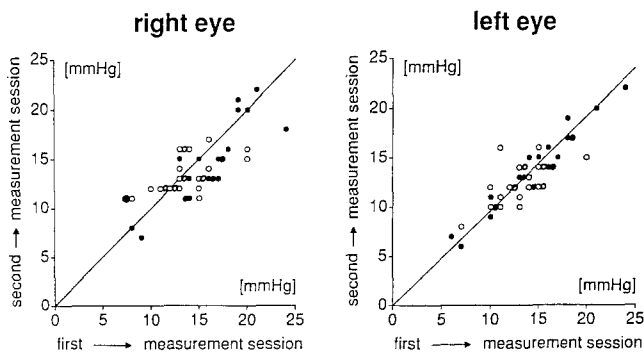
	First measurement (A)	Median of three measurements (B)	Difference (A–B)
Difference between observers ($n=79$ eyes of 40 subjects)			
Mean	1.79	1.60	0.19 (11%)
SD	2.41	2.15	0.26 (11%)
Difference within observers ($n=44$ eyes of 22 subjects)			
Mean	1.64	1.50	0.14 (9%)
SD	2.07	1.96	0.11 (5%)

The SDs of these three measurements for the right eye were 0.7 mmHg for both observers (coefficient of variation, CV, 5%). For the left eye the SD was 0.8 mmHg (CV 6%) for observer A and 0.9 mmHg (CV 7%) for observer B. The mean of these four SDs was 0.8 mmHg. The level and variability of the IOP readings were independent of the age and gender of the subjects.

The correlation coefficient of the median values for the two observers was 0.75 for the right eye and 0.87 for the left eye. Taking the mean of the values of both eyes, the correlation coefficient was 0.81. The difference between the median values of the two observers had a mean of 1.60 mmHg (SD 2.15 mmHg). The difference between the first measurements of the two observers had a mean of 1.79 mmHg (SD 2.41 mmHg)(Table 2).

Comparing median values of the three consecutive IOP readings between the two observers, the second observer, 10 min after the first, measured lower values. The average decrease was 0.7 mmHg (standard error 0.4 mmHg, $P=0.07$) for the right and 0.5 mmHg (standard error 0.2 mmHg, $P=0.04$) for the left eye. Figure 1 shows the measured IOP at both occasions for both eyes.

In the *intra-observer study*, both eyes of an additional 22 subjects were examined. The mean difference between the median values was 1.50 mmHg (SD 1.96 mmHg). The mean difference between the first measure-

right eye　　　　**left eye**

Fig. 1 Intraocular pressure (IOP) in first and second measurement sessions. The line denotes identity. Each IOP represents the median value of three measurements $(n=40)$. *Closed* and *open circles* indicate subjects in whom the first measurement was done by the first and second observer, respectively

ments of the series of three was 1.64 mmHg (SD 2.07 mmHg) (Table 2). The average decrease of the median values at the second measurement session was 0.9 mmHg for both eyes (P < 0.01).

Discussion

The findings indicate that a protocol using the median of three readings of IOP measurement with the Goldmann tonometer gives better reproducibility of the IOP than single measurements. In comparison with the first single IOP measurement the inter-observer variation decreased by 11% and the intra-observer variation by 9%. For IOP measurements in a glaucoma clinic this may seem to be a small improvement, given the fact that nowadays more emphasis is put on visual field and optic nerve head evaluation than on absolute values of IOP. However, in epidemiological studies, where differences in IOP of 1–3 mmHg may point to an increased risk of glaucoma, there is a need for reproducible and precise measurement techniques.

Because one IOP measurement is subject to variation [16], it was decided to perform three consecutive measurements to obtain a better estimate of the actual IOP. The SD of the three consecutive IOP measurements at one occasion by one observer on one eye was 0.8 mmHg in this study. This figure is similar to that from a study by Thorburn (0.9 mmHg) in which two consecutive measurements were made by the same observer [24].

However, in other studies this SD amounted to 3 mmHg [16] and 4.07 mmHg [20].

A fixed number of consecutive measurements was chosen because each subsequent measurement lowers the IOP by 0.1–0.4 mmHg [16, 17]. These values fit within the 0.5–0.7 mmHg difference that were found in this study after 10 min. Medians were used instead of mean values in order to reduce the influence of outlying values. The correlation coefficient of the two observers' median values was quite high (0.81) in this study. In a study with a variable number of measurements [18], the correlation coefficient was 0.71.

The standard deviation of the inter-observer differences in the present study was 2.15 mmHg, similar to the value of 2.5 mmHg given in the study of Phelps and Phelps [18]. The SD of the intra-observer differences was 1.96 mmHg in this study, which is similar to the value of 1.4 mmHg found by Moses and Liu [16].

In this study a fixed protocol of IOP measurement was used to standardize effects of factors known to influence the result, such as the use of fluorescein. Applanation tonometry without the use of fluorescein resulted in a mean IOP value 5.62 mmHg lower than applanation tonometry with fluorescein use [20]. A dry fluorescein strip was used, not a mixture of fluorescein with a local anesthetic drop, as the former was used in the original calibration technique of the Goldmann tonometer [5] and resulted in a mean IOP value 3.94 mmHg lower than the latter [20]. The menisci were of equal circumference and of appropriate width when the measurement was made, and the measurement was taken in mid-cycle [5, 14, 18, 20].

In conclusion Goldmann applanation tonometry readings varied by 6% among three measurements. The present study suggests that the reliability of IOP measurement with the Goldmann tonometer may be moderately improved by using the median of three consecutive IOP measurements rather than relying on one measurement.

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