Reproducibility of Measurement Results in Optical Biometry: Intraobserver and Interobserver Variability

Annette Vogel, H. Burkhard Dick,
Frank Krummenauer, Norbert Pfeiffer

Introduction

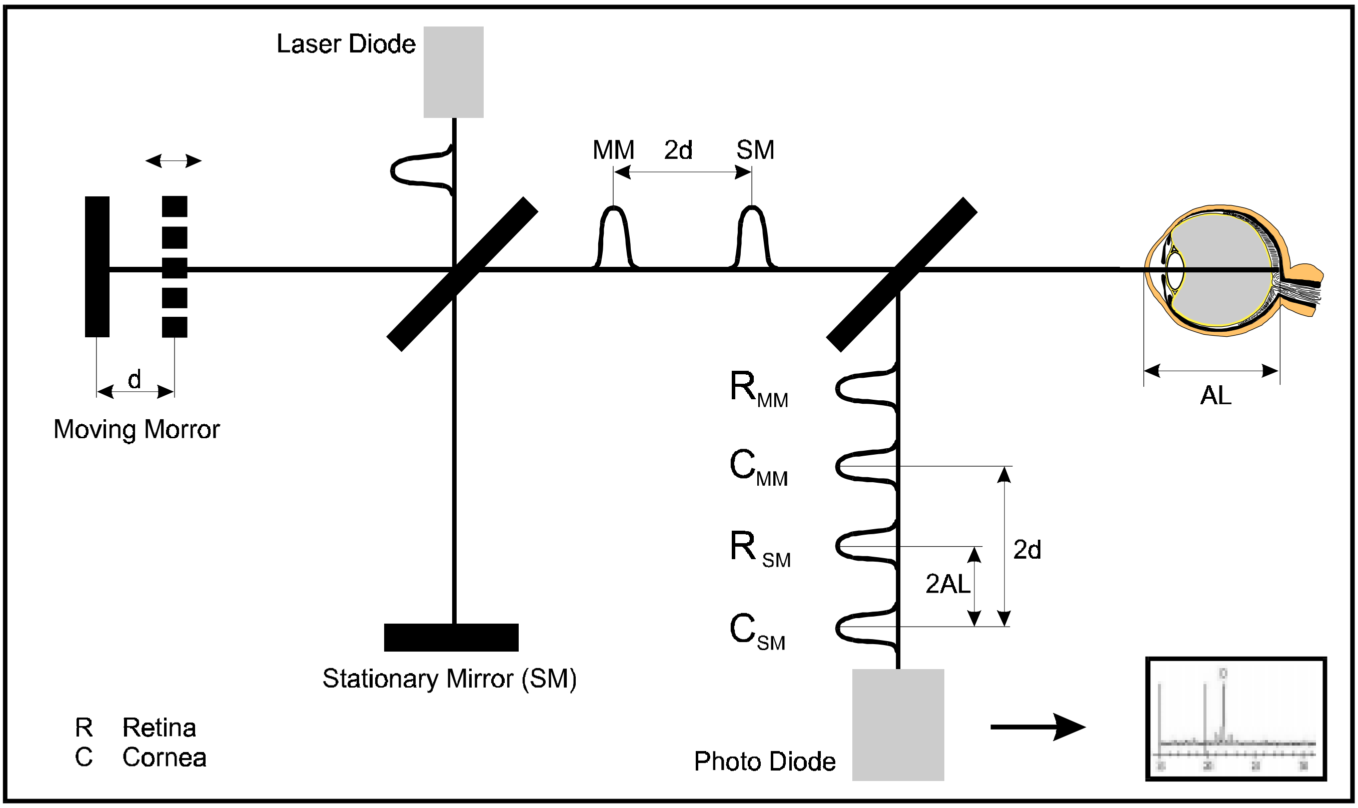
The knowledge of intraocular dimensions is of great significance for a diversity of applications in modern ophthalmology. Particularly the measurement of the axial length of the eye is indispensable for the determination of the power of intraocular lenses. Even today, 54% of false refractions after the implantation of intraocular lenses are a result of erroneous measurements of axial eye length (19).

The generally established method for the determination of intraocular distances is that of ultrasonic biometry, which has continuously been improved since the first measurements in 1956 (18). The major drawback of this method is the necessity of mechanical contact between ultrasonic head and eye requiring local anesthesia of the eye and representing a risk of infection to the patient. Using a 10 MHz transducer, the resolution is limited to 200 µm (20, 1), and the accuracy of this method is reported to be 100 – 120 µm (23). In axial eye length measurement, an error of 100 µm corresponds to a postoperative refraction error of 0.28 D (19, 21).

In recent years, non-invasive optical biometry methods were developed, which are based on the principle of partial coherence interferometry (12).

A laser diode emits an infrared light beam (=780 nm) of short coherence length (approx. 160 µm) that is split into two partial beams of different optical path lengths. The eye to be measured is located in one leg of the interferometer; the other leg contains a photodetector. Both partial beams are reflected at the cornea and at the retina. Interference occurs, if the path difference between the partial beams is smaller than the coherence length. The interference signal received by the photodetector is measured dependant on the position of the interferometer mirror that can very precisely be measured. The measured parameter is the optical path length between cornea and retina (10). The advantage of partial coherence interferometry is that it is a non-contact method that neither requires local anesthesia (4) nor represents a risk of infection (14). Besides, the method precludes an additional source of error of axial length measurement – the indentation of the cornea (16). Moreover, dilatation of the pupil is unnecessary.

In addition, partial coherence interferometry shows a very high longitudinal and transversal resolution (4). In various publications, the accuracy is reported to be between 5 µm and 30 µm (11, 9, 4, 14, 24). Retrospective calculations of the results of refraction based on optical axial length have yielded good results (11, 7, 4). Further applications of optical biometry include the highly precise measurement of corneal thickness (13) and of various distances in the anterior eye segment, e.g. the lens/posterior capsule distance (6). The main drawback of optical biometry is its limited usability in the case of fixation problems or advanced cataract (17, 12, 14).



Schematic diagramm

Objective of this study was to determine the reproducibility and examiner dependency of the measurement of axial length, anterior chamber depth and corneal radius using the first series-produced instrument employing optical biometry, the IOLMaster (Carl Zeiss, Jena, Germany).

Materials and Methods

Measurements were exclusively performed with the IOLMaster by examiners experienced in handling this instrument.

The IOLMaster is a combined biometry instrument for the measurement of data of the human eye needed for the calculation of an intraocular lens to be implanted. The instrument measures axial length, corneal radii and anterior chamber depth successively in one session. Axial length measurement is based on the principle of partial coherence interferometry. The measured and displayed axial length values are compatible with those obtained in acoustic immersion measurements by using an internal, statistically verified calculation algorithm. The corneal radii are determined by measuring the distance between point marks that are projected onto the cornea. The anterior chamber depth is calculated from the distance between the optical sections of lens and cornea produced by lateral slit illumination (Table 4).

If double or triple peaks appeared in axial length measurement, which may be produced by additional reflection at the inner limiting membrane and the choroid (whereas the principal maximum is produced by reflection at pigmented epithelium), proper position of the cursor was checked and manually corrected, if necessary.

The test group consisted of test persons having healthy eyes without noteworthy imperfect refraction and with a visual acuity of 1.0 and proper fixation behavior. Exclusion criteria among others were corneal irregularities, scars or irregular astigmatism.

For the determination of *intra*observer variability, one observer measured the axial length, the corneal radii and the anterior chamber depth 20 times each in 10 eyes. The *intra*observer variability resulted from the variation of measured values obtained by this observer.

To determine the *inter*observer variability and reliability, five different observers measured the axial length, the corneal radii and the anterior chamber depth four times each in 20 eyes. The *inter*observer variability resulted from the fluctuations of measured values between observers.

All measurements were taken on pupils that were unaffected by any drugs.

Statistics

All numerical analyses were performed with SAS (Version 6.12 for Windows). Purely descriptively, the *inter*- and *intra*observer coefficients of variation (ratio of standard deviation and mean value in percent) served as measure of the reproducibility of these three measurement parameters (axial length, anterior chamber depth, corneal radii). The reliability coefficients (ANOVA based calculation) were used as inference-statistical method (15).

The reliability is an inference-statistical measure of the reproducibility of a measurement method. A measured value obtained with a method always consists of the true clinical value and a measurement error (inter- and *intra*observer error). The reliability is calculated from the natural variance of the true value itself and the variance of the measuring error:

$$R = \frac{\text{Variance [true value]}}{\text{Variance [true value]} + \text{Variance [measuring error]}}$$

If the variance of the measuring error is small, the reliability will take up high values (maximally 100%); if it is very great, the reliability will take up small values (minimally 0%).

Results

The group of test persons for the determination of interobserver variability and reliability consisted of 7 females and 3 males of an average age of 36.7 years (26 – 72 years), in which both the right and the left eye was measured. The visual acuity in average was 1.0, with a minimum of 0.7 and a maximum of 1.2. The average refraction was –3.0 D (+3.0 D ··· – 8.75 D) at a mean eye length of 24.36 mm (22.4 ··· 26.87 mm). The determination of *intra*observer variability included three males and two females of an average age of 31.6 years (26···42 years), in which both the right and the left eye was measured, too. The visual acuity in average was 1.2, with a minimum of 0.8 and a maximum of 1.6.The average refraction was –2.5 D (0 D ··· – 7 D) at a mean eye length of 24.5 mm (22.9 mm ··· 25.5 mm) (Table 3).

Erroneous measurements occurred in 11 of 600 axial length measurements (1.8%), in four of 600 measurements of the corneal radii (0.7%) and in 0 of 600 measurements (0%) of the anterior chamber depth. In six of 600 axis length measurements, the measurement curve was edited after the measurement due to the occurrence of double peaks appearing at a distance of 200 – 250 µm.

Table 1 shows the *intra*observer variability for axial length, anterior chamber depth and corneal radii. The variation of measured values within one observer was very little for all three measurement parameters: ± 25.6 µm for axial length corresponding to a coefficient of variation of 0.1%, ± 12.9 µm for corneal radii corresponding to a coefficient of variation of 0.17%. The highest variation of measured values found was ± 33.4 µm for anterior chamber depth measurement corresponding to a coefficient of variation of 0.9%.

In Table 2, the *inter*observer variability is shown for the three measurement parameters. Here, too, the variation of measured values between the five observers was very little for all three parameters: ± 21.5 µm for axial length data corresponding to a coefficient of variation of 0.09%, ± 15.9 µm for corneal radii corresponding to a coefficient of variation of 0.21%. With ± 29.8 µm, the variation of measured values of anterior chamber depth measurement was highest corresponding to a coefficient of variation of 0.82%.

The reliability coefficients were 99.9% for axial length data, 97.8% for anterior chamber depth data, and 99.7% for corneal radii. The loss of reliability in anterior chamber depth measurement was caused by the slightly reduced *intra*observer reliability (87%) of one of the five observers.

Conclusion

Objective of this study was to determine the reproducibility and observer dependence of the measurement of axial length, anterior chamber depth and corneal radius using the first series-produced instrument employing optical biometry, the IOLMaster (Carl Zeiss, Jena, Germany).

For all three measurement parameters, the variation of measured values within one observer (*intra*observer variability) differed only insignificantly from the variation of measured values between various observers (*inter*observer variability), and altogether it was very low.

With ± 25.6 µm (1 observer) and ± 21.5 µm (5 observers), the accuracy of axial length measurements was comparable with the data reported in literature, that were obtained with the prototype version of the IOLMaster, which however was different from the series-produced IOLMaster in many respects. There, values between ± 10 µm and ± 30 µm were described (4, 14). In literature, however, no statements can be found on observer independence. So far, precision investigations were performed only by *one* observer.

The accuracy of measurements of anterior chamber depth and corneal radii in the study on hand was recently confirmed by Haigis et al. (8). They also ascertained the highest variability of measured values in anterior chamber depth measurement. In our study, the loss in reliability in anterior chamber depth measurement is attributed to the slightly reduced *intra*observer reliability (87%) of one of the five observers.

Possibly, the problems in anterior chamber depth measurement arise from the fact, that particularly with eyes having narrow pupils, no light is sent back from the crystalline lens into the viewing optics. In this case, the distance between the anterior cornea surface and the iris is erroneously measured as anterior chamber depth. With 99.9% for axial length and 99.7% for corneal radii, the reliability coefficients of the measurements meet very high requirements, as demanded, for instance, for reference laboratories. A reliability coefficient of 97.8% for anterior chamber depth measurement satisfies the requirements for informative measuring methods. In our study, the accuracy and observer dependence of the IOLMaster was examined on healthy test persons. Another parameter being of great interest, too, is the dependence of the accuracy from the degree of lens opacity. Hitzenberger et al measured 196 cataract eyes by means of laser Doppler interferometry and even with severe lens opacities did not find any effect on the accuracy of the measurement. Only 4% of the eyes could not be measured due to a marked lens opacity (14).

In summary, based on the current results of the study, it can be stated that optical biometry with the IOLMaster is a highly precise and reliable examination method delivering observer independent results. Future studies must show the accuracy and observer dependence of the IOLMaster on cataract eyes with lens opacities of various degrees, on highly myopic and highly hyperopic eyes.

	Axial Length	Anterior Chamber Depth	Corneal Radii
Mean Value	24.56 mm	3.68 mm	7.73 mm
Standard Deviation	25.6 µm	33.4 µm	12.9 µm
Coefficient of Variation	0.1%	0.9%	0.17%

Table 1: *Intra*observer variability

	Axial Length	Anterior Chamber Depth	Corneal Radii
Mean Value	24.23 mm	3.64 mm	7.61 mm
Standard Deviation	21.5 µm	29.8 µm	15.9 µm
Coefficient of Variation	0.09%	0.82%	0.21%

Table 2: *Inter*observer variability

	Interobserver / Reliability Study	Intraobserver Variability
Male	3 (both eyes each)	3 (both eyes each)
Female	7 (both eyes each)	2 (both eyes each)
Age	36.7 y (26 ... 72 y)	31.6 y (26 ... 42 y)
Refraction	-3.0 D (+3.0 D ... 8.75 D)	- 2.5 D (0 D ... 7.0 D)
Axial Length	24.36 mm (22.41 ... 26.87 mm)	24.56 mm (22.9 ... 25.5 mm)

Table 3: Groups of test persons

Source	Semiconductor diode laser (MMDL)
Wavelength	780 nm
Max. power for measurement	450 µW
Max. power for adjustment	80 µW
Measuring time for single measurement	0.5 s
Number of possible single measurements	20 per eye and day
Laser Class	1

Table 4: Technical data of axial length measurement with the IOLMaster

Literature

1) Bamber J.C., Trstam M., ,"Diagnostic ultrasound." In: Webb S., editor, „The physics of medical imaging." Philadelphia: Adam Hilger: 319, 1988
2) Boerrigter R.M.M., Thijssen J.M., Verbeek A.M., ,,Intraocular lens power calculations: The optimal approach." Ophthalmologica 191: 89, 1985
3) Drexler W., Baumgärtner A., Findl 0., Hitzenberger C.K., Sattmann H., Fercher A.F., „Submicrometer precision biometry of the anterior segment of the human eye." Invest Oplithalmol Vis Sci 38, No. 7:1304, June 1997
4) Drexler W., Findl 0., Menapace R., Rainer G., Vass C., Hitzenberger C.K., Fercher A.F., „Partial coherence interferometry: a novel approach to biometry in Cataract surgery." Am J Ophthalmol Vol. 126, No. 4: 524, October 1998
5) Findl O., Drexler W., Menapace R., Bobr B., Bittermann S., Vass C., Rainer G., Hitzenberger C.K., Fercher A.F., „Accurate determination of effective lens position and lens-capsule distance with 4 intraocular lenses." J Catarac Refract Surg 24: 1094, 1998
6) Findl O., Drexler W., Menapace R., Hitzenberger C.K., Fercher A.F., ,,High precision biometry of pseudophakic eyes using partial coherence interferometry." J Cataract Reftact Surg 24: 1087, 1998
7) Findl 0., Drexler W., Menapace R., Rainer G., Vass C., Hitzenberger C.K., Fercher A.F., „Teilkohärenz-Laserinterferometrie: eine neue hochpräzise Biometrie-Methode zur Verbesserung der Refraktion nach Kataraktchirurgie." Klin Monatsbl Augenheilkd 1998; 212
8) Haigis W., Lege B., „Akustische und optische Biometrie im klinischen Einsatz." DGII Luzern, Februar 2000
9) Haigis W., Lege B., „Optical and acoustical biometry." ASCRS 1999
10) Haigis W., Lege B., „Ultraschallbiometrie und optische Biometrie: Erweiterung der Möglichkeiten." Ophthalmologische Nachrichten, S. 18, April 1999
11) Haigis W., Lege B., Miller N., Schneider B., „Optische Biometrie und IOL-Berechnung." 97. Tagung der Deutschen Ophthalmologischen Gesellschaft 1999
12) Hitzenberger C.K., „Optical measurement of the axial eye length by laser doppler interferometry." Invest Ophthalmol Vis Sci, Vol. 32, No. 3: 616, March 1991
13) Hitzenberger C.K., Drexler W., Fercher A.F., ,,Measurement of corneal thickness by laser doppler interferometry." Invest Ophthalmol Vis Sci, Vol. 33, No. 1: 98, January 1992
14) Hitzenberger C.K., DrexlerW., Dolezal C., Skorpik F., Juchem M., Fercher A. F., Gnad H.D., „Measurement of the axial length of cataract eyes by laser doppler interferometry." Invest Ophthalmol Vis Sci, Vol. 34, No. 6:1886, May 1993
15) Krummenauer F., Förster G., „The evaluation of nuclear imaging data: an overview on classical ANOVA-based approaches." Informatik, Biometrie und Epidemiologie in der Medizin und Biologie 29, 1999
16) Kuck H., Makabe R., „Vergleichende axiale Biometrie des Auges." Fortschr Ophthalmol 82: 91, 1985
17) Lege B., Haigis W., „Optical biometry, first clinical experiences." ASCRS 1999
18) Mundt G.H., Hughes W.F., „Ultrasonics in ocular diagnosis." Am J Ophthalmol 41: 488, 1956
19) Olsen T., „Sources of error in intraocular lens power calculation." J Cataract Refract Surg, 18: 125, 1992
20) Olsen T., „The accuracy of ultrasonic determination of axial length in pseudophakic eyes." Acta Ophthalmol (Copenh), 67:141, 1990
21) Olsen T., „Theoretical approach to intraocular lens calculation using Gaussian optics." J Cataract Refract Surg 13: 141, 1987
22) Richard D., Binkhorst M.D., „The accuracy of ultrasonic measurement of the axial length of the eye." Ophthalmic Surg 12: 363, 1981
23) Schachar R.A., Levay N.S., Boney R.C., „Accuracy of intraocular lens powers calculated from a-scan biometry with the Echo-Oculometer." Ophthalmic Surg 11: 856, 1980
24) Schmid G.F., Papastergiou G.I., Nickla D.L., Riva C. E., Lin T., Stone R.A. Laties A.M., „Validation of laser doppler interferometry measurements in vivo of axial eye length and thickness of fundus layers in chicks." Curr Eye Res, 15 (6): 691, June 1996

Annette Vogel, H. Burkhard Dick,
Johannes Gutenberg University, Mainz, Department of Ophthalmology
Frank Krummenauer,
Johannes Gutenberg University, Mainz, Coordination Center for Clinical Studies
Norbert Pfeiffer
Johannes Gutenberg University, Mainz, Department of Ophthalmology

The authors do not have any financial interest in the instrument.

Carl Zeiss
Ophthalmic Instruments

D - 07740 Jena
Telephone: +49 03641 64-2030
Fax: +49 03641 64-2043
e-mail: ophthalmo@zeiss.de
Internet: http://www.zeiss.de/ophthalmology