

Optical Biometry as Alternative to Acoustical Biometry

W. Haigis
B. A. M. Lege

Summary

Optical biometry represents a fascinating add-on to our biometric possibilities. It is user and patient-friendly (no local anaesthesia necessary, no infection transfer, no corneal lesions, minimal light load); however, a minimum of patient cooperation is necessary (fixation ability, no corneal scars, no dense cataracts, no obstructions in light path). The tested IOLMaster™ prototype of Carl Zeiss Jena proved to be comparable in its measurement quality to the most precise ultrasound immersion technique. A further increase in accuracy may be expected from a modification of the signal analysis software. As long as there is no possibility to carry out segmental measurements with this technique, the results of optical axial length measurements, e.g. for the purpose of IOL calculations should be corrected by a relation 'acoustical axial length = f (optical axial length)' as reported. Furthermore, it is recommended for the mean group refractive index that a value of 1.3574 based on biometric averages be used rather than the commonly applied value of 1.3549, which stems from the Gullstrand eye. For a number of other biometric applications (e.g. off-axis), acoustical biometry will continue to be indispensable.

Two hundred years ago, the Italian scholar Lazzaro Spallanzani discovered, that bats utilise ultrasound for locating purposes. Today, acoustical biometry has become established as precise and reliable method for the measurement of ocular segments. It is applied specially to the measurement of axial length and its segments for the calculation of intraocular lenses. With laser interference biometry (LIB), an optical measuring method has recently become available as a possible alternative. The use of this method for eye length measurement goes back to A. F. Fercher et al. (1986). Since the mid-eighties this technique in its tomographic variant as optical coherence tomography (OCT) has become well accepted in ophthalmology, whereas optical axial length measurement has only now reached application maturity with the innovation from Carl Zeiss Jena, the IOLMaster. Optical biometry represents a fascinating add-on to the biometric possibilities, as it provides measurements strictly along the visual axis. As measurements are taken in non-contact technique, the system permits also freshly operated eyes to be (re-)measured.

Measuring principle of optical biometry

Comparing optical coherence tomography with ultrasound B-scan systems, laser interference biometry corresponds to the recording of an A-scan echogram. The technique is based on the principle of partial coherence interferometry (PCI). The term coherence describes the physical property of two wavefronts having a temporally constant or a regularly varying phase difference at every point in space. With this technique, a laser diode in a Michelson interferometer configuration emits infrared light ($\lambda = 780 \text{ nm}$) of short coherence length (approx. $160 \mu\text{m}$) that is split into two partial beams of different optical path length. 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. In one leg of the interferometer, the eye to be measured is arranged while the other leg contains the photodetector. The interference signal received by the photodetector is measured in relation to the position of the interferometer mirror that can very precisely be measured. The measured parameter is the optical path length between cornea and retina (Figure 1).

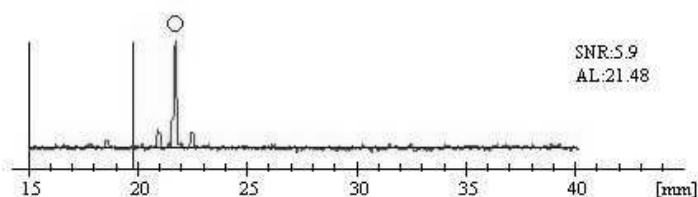


Figure 1: Optical biometry through partial coherence interferometry with a prototype (IOLMaster™) of Carl Zeiss Jena: The axial length is measured as optical path length between the anterior cornea and the retinal pigment epithelium. The optical measurement curve shows the position-dependent envelope curve of the interference signal of the photodetector. The strong peak can be assigned to the retinal pigment epithelium; the symmetrically located side maxima are artefacts of the laser diode used.

About 9% of measurements were not analysable

We (W. Haigis and B. A. M. Lege) had the opportunity to test the prototype of the IOLMaster optical biometry device at the University Eye Clinic of Würzburg. On volunteers and patients, who were to be examined by acoustical biometry for preparing surgery, additional laser-optical comparison measurements were performed. Acoustical biometric measurements were taken with the GBS (Grieshaber Biometric System) in immersion mode.

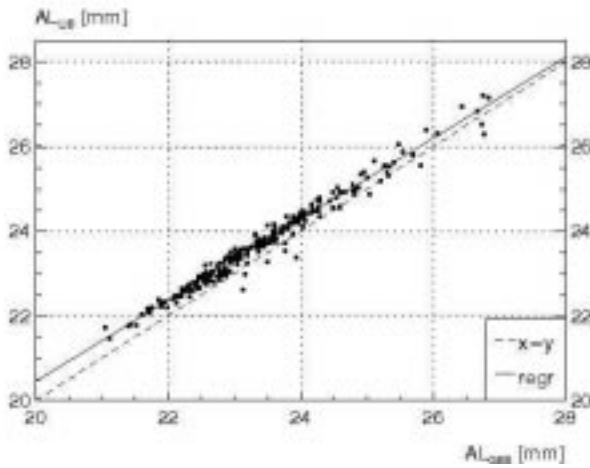


Figure 2 Relation between optically and acoustically measured axial lengths for the best $n = 265$ measurements with a standard deviation of the mean value of 5 individual measurements $< 100 \mu\text{m}$. On average, the optical values are higher than the acoustical values; the slope of the regression line is significantly < 1 .

The examinations aimed at obtaining precise values for the comparison between acoustically and optically measured axial lengths and experimentally verifying the dependence to be expected between acoustical and optical biometry. Regarding the question of up to which visual acuity patients can still be measured optically, no studies have been made yet.

Totally, 678 eyes were examined. On 620/678 $\gg 91\%$, results could be obtained by optical measurements. The 620 optically obtained results fell to 563 phakic, 48 pseudophakic, and 9 aphakic eyes. Figure 3 shows the typical signal trace of an optical measurement.

58 measurements did not yield any analysable optical data. These measurements included 12 myopic ($AL > 25 \text{ mm}$), 22 hyperopic ($AL < 22 \text{ mm}$) and 24 "normal" ($22 \text{ mm} \leq AL \leq 25 \text{ mm}$) eyes. Thus, dependence between analysability and marginal ranges of axial length did not seem to play an obvious part. Measurements in problematic cases were not provoked in extenso.

In 62% of the cases, the visual acuity documented in 37 data records amounted to meter VA or worse. Further 27% had a visual acuity of up to 0.2. Thus, for 89% the visual acuity was 0.2 or worse. Pathologies in the anterior eye segment that caused the poor visual acuity on the one hand, and/or impeded fixation on the other hand included the following: marked lacrimal film pathology, keratopathy, central corneal scars, mature cataract or nystagmus. The shift of the pupillary plane by dermatochalasis or ptosis, too, involved problems, which could be solved, however, by passive lid retraction. In the posterior eye segment, vitreous hemorrhage, membrane formation, maculopathy or retinal detachment presented unfavourable conditions. In the case of good visual acuity, tremor, respiratory insufficiency or insufficient patient compliance was responsible for erroneous measurements.

Thus, unfavourable measuring conditions can generally be summarised as follows:

- The incident and the emerging laser beam on its way from and to the fovea must not be deflected indefinitely strongly;
 - the patient must be able to fixate for a short time (0.3 – 0.4 seconds).
- Only then, useful and very precise data acquisition is possible.

The quality of the measurement is indicated to the examiner by display of the signal-to-noise ratio (SNR). It results from the ratio between the measured maximum and disturbing background signals. The higher this value, the better is the quality of results.

Optical and acoustical biometry provide almost the same accuracy

For the best ($n = 256$) data records with standard deviations of the optically measured average over 5 individual measurements of $< 0.1 \text{ mm}$ (= quality criterion of a "good" ultrasound measurement), the results are shown in Table 1 and Figure 4. The measurement quality of the tested prototype of the IOLMaster came up to the most accurate acoustical immersion technique. The accuracy may additionally be increased by a modification of measurement software, which is already integrated in the current version of the IOLMaster. As expected, the optically measured values were higher than those obtained by ultrasound: Due to the use of a refractive index of $n = 1.3549$, as is factory-adjusted on the IOLMaster, the optically measured axial length of the eye was longer by $0.30 \pm 0.17 \text{ mm}$ than the acoustically measured AL. This was to be expected as ultrasound systems measure the distance between the anterior cornea and the inner limiting membrane, while laser interference biometry systems measure the distance up to the retinal pigment epithelium. For a refractive index of $n = 1.3574$ preferred here, the resulting difference was $0.25 \pm 0.17 \text{ mm}$ (Table 1).

	$n = 1.3549$		$n = 1.3574$	
	$N=265$			
[mm]	$AL_{acoustical}$	$AL_{optical}$	$AL_{opt. - acoust.}$	$AL_{opt. - acoust.}$
Mean value	23.45	23.74	0.30	0.25
\pm SD	1.09	1.05	0.17	0.17
Minimum	21.05	21.4	-0.56	-0.60
Maximum	26.84	27.20	0.66	0.62

Table 1 Statistical data of acoustically and optically measured axial lengths of phakic eyes ($n = 256$), where the standard deviation of the mean value of 5 individual measurements was $< 100 \mu\text{m}$, for group refractive indices of 1.3549 and 1.3574.

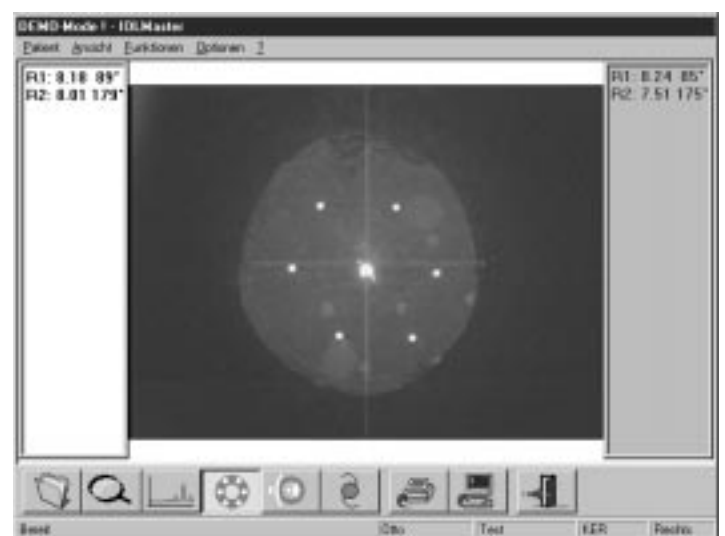


Figure 4 Screen display of the IOLMaster in corneal radius measurement

New: Optical Axial Length Measurement with the IOLMaster

The IOLMaster of Carl Zeiss, Jena, is a new device for the measurement of axial length and for preoperative calculation of intraocular lenses. This novel biometry device permits corneal radii, anterior chamber depth and axial length of the eye to be measured very accurately at low light load thus delivering the starting data for cataract surgery. Measurements are performed along the visual axis and require a minimum of patient compliance. The fixation ability must be maintained for 0.3 – 0.4 seconds. High ametropia, pupillary size and accommodation state of the eye does not affect the result of axial length measurement. Disturbing effects, however, come from corneal scars, very dense cataracts and epiretinal membranes. As optical biometry is a non-contact technique, the method is distinctly more patient-friendly compared to acoustical measurement. There is no risk of infection from patient to patient and no application of local anaesthetics, no use of a transducer in acoustical contact measurements or of the scleral shell in immersion coupling techniques, which are often found unpleasant. Latest software with self-explanatory graphical user interface makes operation of the device easy. Measurements are taken with the patient seated. Operating processes are analogous to those of conventional biometric techniques. The IOLMaster automatically detects right and left eye thus excluding any risk of a mistake. As corneal radii and axial length can be measured on the same device, the patient need not change seats or lay down. The data needed for the calculation of intraocular lenses is stored and instantly recallable. The measuring range is 5 – 10 mm for corneal radii, 1.5 – 6.5 mm for anterior chamber depth and 14 – 40 mm for axial length. Due to the fixed scaling of the display, result display is accurate to 0.01 mm.

The software also provides calculation of IOL data using the following biometric formulas: SRK II, SRK/T, Holladay, Hoffer Q and Haigis. Furthermore, it permits the lens type to be chosen from a database and data to be transferred to the local area PC network.



Figure 3 Total view of IOLMaster and examination situation

On average, the reproducibility (determined as mean value of the standard deviations of the average of 5 individual measurements) of the highly precise immersion technique was around $\pm 22 \mu\text{m}$ ($22 \pm 24 \mu\text{m}$); the optical technique yielded $\pm 37 \mu\text{m}$ ($37 \pm 25 \mu\text{m}$). This value may clearly be reduced by a new version of the analytical software.

The relation between optical and acoustical axial length could be described as linear function with a correlation coefficient of 98.8% (Figure 4). The cause of this dependence, on the one hand, is the fact that the results of optical measurements additionally include the retinal thickness, and on the other hand, that the concept of using an average refractive index for the conversion of optical path lengths leads to disproportionate differences in the case of short eyes because of the thicker lenses. For the first time, we found that the slope of this straight line is significantly smaller than 1. This had been expected and is due to the use of an average refractive index for the conversion of optical into geometrical path lengths. That way, the effect of the lens segment with short eyes is underrated.

Presently, there is no possibility of simultaneous segmental measurement, as the anterior chamber and the lens thickness are measured along the optical axis, while the axial length is measured along the visual axis. Therefore, for the purpose of IOL calculation, for instance, the optical axial length measurement should be corrected by means of the specified relation of optical axial length = f (acoustical axial length). On the IOLMaster, this is automatically done by the integrated regression line.

Optical biometry does not allow diagnosis

The optical biometry performed on the IOLMaster measures the axial length along the visual axis as required for IOL calculation at a higher accuracy than the customary ultrasound contact measurements. Clinical biometry, however, is more than 'only' axial length measurement for the purpose of IOL implantation. For all applications beyond that, the use of ultrasound biometry will continue to be necessary. The signal trace recorded by optical biometry corresponds to an ultrasound A-scan. While, however, for acoustical echograms a series of echoes is recorded, which can then be assigned to corresponding diseased and/or healthy structures of the eye, the optical measurement virtually covers only that narrow local region of the signal, for which the interference condition has been met. As one knows that the examined patient has fixated, and also knows about the reflection pattern from the retina, one knows to have measured the axial length, if one succeeded in measuring something at all. Measurements become problematic, if, for instance, membranes are in the light path, as happens, for example, with epiretinal gliosis, which causes signal structures similar to 'real' axial lengths. The identification of tissues on the basis of relatively isolated reflections is difficult, as there is no possibility of revealing neighbourhood relations and there are no 'landmarks' (for instance, typical lens signals), as appear with ultrasound. The accompanying B-technique, the optical coherence tomography, makes this possible.



Figure 5 Screen display of the IOLMaster in anterior chamber depth measurement

Interesting future outlooks

The laser interference measuring technique as implemented on the IOLMaster presents a new precise measuring method, that is surely superior to the widely accepted ultrasound contact biometry and comes up to the high-precision immersion technique in terms of accuracy and reproducibility. Unlike most of the acoustical biometry devices, the IOLMaster does not provide segmental measurements, but averages over all ocular segments similarly to an ultrasound biometry device that measures with a mean sound velocity. As a consequence of the use of a mean refractive index or a mean value of sound velocity, measuring errors occur both optically and acoustically when measuring short eyes. On the IOLMaster, these measuring errors are automatically taken into account by a built in correction function. Thus, the results will normally be comparable to precise immersion measurements even in the case of short eyes. The research on this subject and the measurement of the effective refractive indices of the eye tissue involved, however, is just in its infancy. It would be desirable to be also able to measure all ocular segments simultaneously by laser interferometry – perhaps this will be possible already on the successor model of the IOLMaster.

Apart from the innovative laser interference measuring technology, the IOLMaster as a combination device offers the possibility of optical corneal radii and anterior chamber depth measurement. Thus, all measurements necessary for IOL calculation can be taken on a single device. That way, the optimization of lens constants being necessary within the scope of quality management procedures is considerably simplified and becomes more efficient. Thus, in addition to simplifying the operating process, better postoperative refraction results are possible. All measurements that can be performed on the IOLMaster are non-contact measurements. Thus, both patient and examiner can profit from all the benefits involved. Conversely, however, this is also true for the drawbacks of optical methods: Measurements are impossible if no light is reflected back from the eye, whether by obstacles in the light path (scars, opacities, pathologies, etc.) or because the patient is unable to fixate during the short measuring period of 0.3 – 0.4 seconds. This is true for about 9 – 10% of cataract patients of a university eye hospital. For the remaining 90 – 91% the IOLMaster presents a convenient and precise examination tool for the acquisition of the biometric data required for preparing IOL implantation – no more and no less.

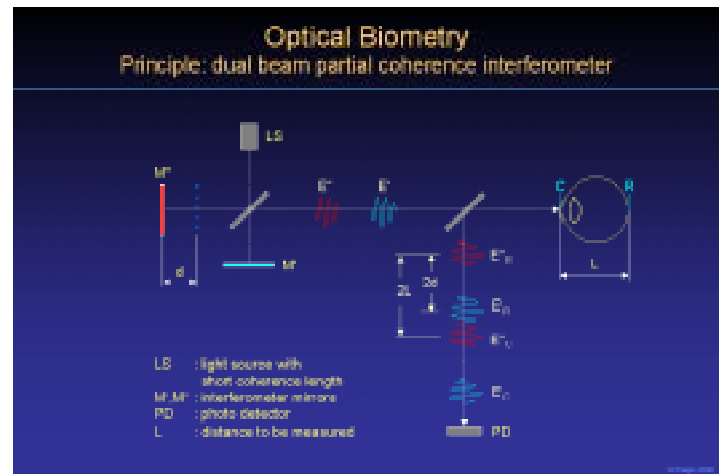


Figure 6 Principle of optical biometry, after FERCHER AF: Optical coherence tomography. Journal of Biomedical Optics 1(2): 157-173, 1996

Address of the author:

Dr. rer. nat. Wolfgang Haigis
 B.Sc. (Physics)
 Universitäts-Augenklinik
 Josef-Schneider-Str. 11
 D-97080 Würzburg

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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>