Comparison of 2 laser instruments for measuring axial length

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PURPOSE: To compare axial length (AL), anterior chamber depth (ACD), and keratometric (K) measurements of 2 laser biometers.

SETTING: Private practices, Lynwood and Santa Monica, California, USA.

METHODS: In this prospective comparative observational study of eyes with cataract and eyes with a clear lens, AL, ACD, and K measurements were performed using an IOLMaster biometer, which uses partial coherence interferometry (PCI), and a Lenstar LS 900 biometer, which uses optical low-coherence reflectometry (OLCR). Intraocular lens (IOL) power calculation was performed using the Haigis formula. The IOL prediction error was calculated for each eye.

RESULTS: The study evaluated 50 eyes with cataract and 50 eyes with a clear lens. There was a good correlation between AL, ACD, and K measurements in the cataractous eyes ($r = 0.9993$, 0.9667, and 0.9959, respectively) and in eyes with a clear lens ($r = 0.9995$, 0.8211, and 0.9959, respectively). The OLCR unit measured a slightly longer AL in the cataract group and clear lens group (mean difference 0.026 mm and 0.023 mm, respectively), a deeper ACD (0.128 mm and 0.146 mm, respectively), and a flatter K (−0.107 diopter [D] and −0.121 D, respectively). The differences were statistically significant ($P<.0001$). The mean absolute error in IOL power prediction was 0.455 D ± 0.32 (SD) with the OLCR unit and 0.461 ± 0.31 D with the PCI unit ($P>.1$).

CONCLUSIONS: Measurements were comparable between the OLCR device and the PCI device. A slight decrease (0.050) in the a_0 constant is recommended if the Haigis formula is used.

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Since 1999, optical biometry has become the standard technique for axial length (AL) measurement.[1–3] The IOLMaster optical biometer (Carl Zeiss Meditec) uses partial coherence interferometry (PCI) with a 780 μm laser diode infrared light to measure AL. The anterior chamber depth (ACD) is measured through a lateral slit-illumination and is defined as the measurement between the corneal epithelium and the anterior lens surface. The keratometry (K) readings are calculated by analyzing oriented the anterior corneal curvature at 6 reference points in a hexagonal pattern at approximately the 2.3 mm optical zone.

Recently, the Lenstar LS 900 optical biometer (Haag-Streit AG) became available for clinical use.[4,5] It measures the axial dimensions of the eye in a single step. The technology is based on optical low-coherence reflectometry (OLCR), with an 820 μm superluminescent diode. In addition to AL, the unit measures central corneal thickness (CCT) and aqueous depth, defined as the measurement from the corneal endothelium to the anterior lens surface. It also measures crystalline lens thickness and retinal thickness. The

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Teresa Boenzi provided technical assistance. Michael Swearingen, OD, obtained the measurements with the 2 units.

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K readings are calculated by analyzing the anterior corneal curvature at 32 reference points orientated in 2 circles at approximately the 2.30 mm and 1.65 mm optical zones. It also measures the size and centricity of the pupil.

In this prospective study, we compared the biometric measurements obtained with the PCI biometer (version 5.2) and the OLCR biometer in eyes with cataract and eyes with a clear lens. We then analyzed accuracy of intraocular lens (IOL) power calculation using values obtained by both units after cataract surgery in the cataractous eyes.

PATIENTS AND METHODS

This prospective observational study enrolled adult patients scheduled for cataract surgery and adult patients with clear lenses between February 15 and April 15, 2009. One eye of each patient was included in the study. In patients with cataract, the first operated eye was evaluated. In patients with clear lenses, the eye was randomly selected using a randomization list. All patients provided informed consent.

Using the PS program for power and sample size calculations (version 3.0.12) (http://biostat.mc.vanderbilt.edu/twiki/bin/view/Main/PowerSampleSize. Accessed December 30, 2009), a sample size of 14 eyes per group was estimated to detect a difference in AL of 0.02 mm with a standard deviation of ±0.04 mm and a power of 95% at a significance level of 5%; for a power of 90%, a sample of 9 eyes was needed.

Each eye was evaluated on the same day using the OLCR unit and PCI unit. Half the eyes in each category were measured first using the OLCR unit and then using the PCI unit, and the other half, vice versa. Two unmasked examiners performed all measurements. Five measurements were taken in each eye with both units. For the PCI measurements, the composite AL value, mean ACD value, and mean flattest and steepest K values were recorded. For the OLCR measurements, the mean AL, CCT, aqueous depth, crystalline lens thickness, and flattest and steepest K values were recorded. All K values reported here are average Ks, derived from the anterior corneal curvature and using a 1.3375 keratometric index of refraction. The mean difference between each of the AL, ACD, and K values and the 95% confidence intervals (CIs) around the means were recorded. Intraocular lens power calculations were performed using the Haigis formula[6] in eyes with cataract. The Haigis a_0 constant was personalized for each set of biometric measurements from each unit.

The same surgeon (H.J.S.) performed all cataract surgeries using a 2.75 mm limbal incision. An acrylic IOL (AcrySof SN60WF, Alcon, Inc.) was implanted in the capsular bag in all cases. The final refractive error was obtained 10 to 12 weeks after cataract surgery.

For each operated eye, the predicted IOL power that would give the actual postoperative refraction was calculated. The IOL prediction error was obtained by subtracting the predicted IOL power from the implanted IOL power. A positive error indicates that the formula predicted a lower power IOL than was implanted and would have left the eye more hyperopic than desired. A negative error indicates that the formula predicted a higher power IOL than was implanted and would have left the eye more myopic than desired. In addition, the following were evaluated: the IOL prediction mean error and its standard deviation, the mean absolute error (MAE) and its SD, the range of the prediction errors, and the number of eyes in which the error was within ±0.50 D, ±1.00 D, and ±1.50 D.

Statistical analysis was performed using GraphPad InStat software for Macintosh (version 3a, GraphPad Software). Linear regression was used to quantify how well the measurements by the 2 instruments varied. The Pearson product moment correlation coefficient (r) was used to statistically evaluate each correlation. Agreement was evaluated using the method of Bland and Altman,[7] who suggest plotting the differences between the measurements (y-axis) against their mean (x-axis). The 95% limits of agreements (LoA) were defined as the mean ± 2 SD of the differences between the 2 measurement techniques. The mean ACD and K values were compared using a paired t test because the data followed a Gaussian distribution according to the method of Kolmogorov-Smirnov. The mean AL values were compared by the nonparametric Wilcoxon matched-pairs test because the data did not follow a Gaussian distribution. A P value less than 0.05 was considered statistically significant.

RESULTS

Eyes with Cataract

Fifty eyes of 50 patients (21 men) with a cataractous lens were evaluated. The mean age of the patients was 74.13 years ± 7.12 (SD) (range 64 to 85 years). Table 1 shows the AL, ACD, and K measurements taken by the OLCR unit and the PCI unit.

The mean difference in AL measurements was +0.026 mm ($P<.0001$; 95% CI, 0.015 to 0.037). Linear regression showed an excellent correlation ($r = 0.9993$, $r^2 = 0.9986$; $P<.0001$). Figure 1 shows a Bland-Altman plot of the agreement; the agreement was excellent (95% LoA, −0.05 to 0.10 mm) (Figure 1).

The mean difference in ACD measurements was +0.128 mm ($P<.0001$; 95% CI, 0.094 to 0.162). Linear regression showed an excellent correlation ($r = 0.9667$, $r^2 = 0.9345$; $P<.0001$). Figure 2 shows a Bland-Altman plot of the agreement (95% LoA, −0.12 to +0.38 mm).

The mean difference in K readings was −0.107 D ($P<.0001$; 95% CI, −0.156 to −0.058). Linear regression showed an excellent correlation ($r = 0.9959$,

Table 1. Measurements in eyes with cataract.

Parameter	Mean Measurement ± SD: OLCR Unit	PCI Unit	Range
AL (mm)	23.71 ± 1.04	23.68 ± 1.04	−0.05 to +0.14
ACD (mm)	3.11 ± 0.47	2.98 ± 0.49	−0.22 to +0.55
K (D)	43.58 ± 1.87	43.69 ± 1.92	−0.61 to +0.34

ACD = anterior chamber depth; AL = axial length; K = keratometry; OLCR = optical low-coherence reflectometry; PCI = partial coherence interferometry

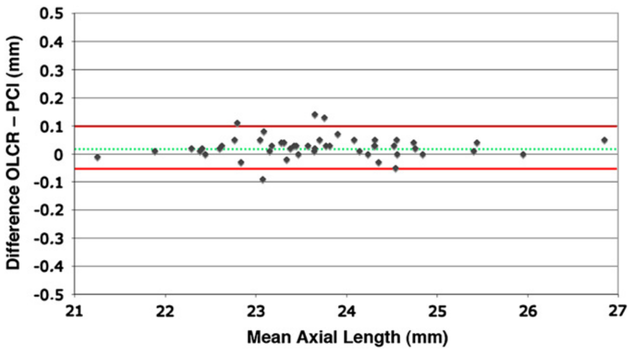

Figure 1. Bland-Altman plot of AL measurements in eyes with cataract (OLCR = optical low-coherence reflectometry; PCI = partial coherence interferometry).

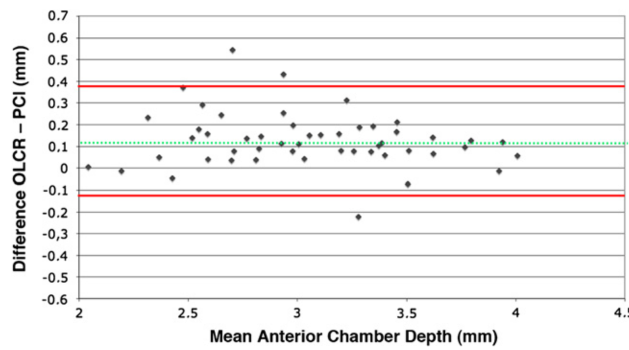

Figure 3. Bland-Altman plot of ACD in eyes with cataract (OLCR = optical low-coherence reflectometry; PCI = partial coherence interferometry).

$r^2 = 0.9919$; $P<.0001$). Figure 3 shows a Bland-Altman plot of the agreement (95% LoA, −0.46 to +0.25 D.

Eyes with a Clear Lens

Fifty normal eyes (24 right) with clear lenses of 50 patients (24 men) were evaluated. The mean age of the patients was 66.22 ± 6.43 years (range 52 to 73 years). Table 2 shows the AL, ACD, and K measurements taken by the OLCR unit and the PCI unit.

The mean difference in AL measurements was +0.023 mm ($P<.0001$; 95% CI, 0.013 to 0.033). Linear regression showed an excellent correlation ($r = 0.9995$, $r^2 = 0.999$; $P<.0001$). The Bland-Altman plot was very similar to that in Figure 1 (95% LoA, −0.05 to +0.099).

The mean difference in ACD measurements was +0.146 mm ($P<.0001$; 95% CI, 0.080 to 0.212). Linear regression showed a good correlation ($r = 0.8211$, $r^2 = 0.6742$; $P<.0001$). The Bland-Altman plot was very similar to that in Figure 2 (95% LoA, −0.33 to +0.63 mm).

The mean difference in K readings was −0.121 D ($P = .002$; 95% CI, −0.179 to −0.063). Linear regression showed an excellent correlation ($r = 0.9959$, $r^2 = 0.9919$, $P<.0001$). The Bland-Altman plot was very similar to that in Figure 3 (95% LoA, −0.54 to +0.30 D).

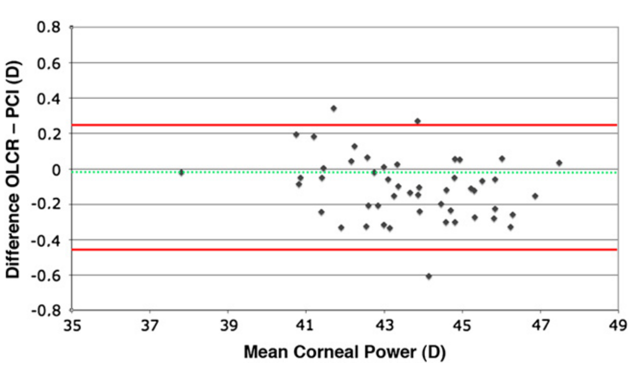

Figure 2. Bland-Altman plot of corneal power in eyes with cataract (OLCR = optical low-coherence reflectometry; PCI = partial coherence interferometry).

Intraocular Lens Power Calculation

The optimized Haigis a_0 constant was −1.050 for the OLCR measurements and −0.997 for the PCI measurements. The Haigis a_1 and a_2 constants were 0.292 for each unit.

Table 3 shows the IOL power prediction errors with each unit. No error exceeded ±1.50 D. The difference in the MAE between the OLCR unit and the PCI unit was not statistically significant ($P>.1$).

DISCUSSION

In this study, there was excellent agreement between the AL measurements taken by the OLCR unit and those taken by the PCI unit; the correlation coefficient was 0.9993 in eyes with cataract and 0.9995 in eyes with a clear lens. The 95% LoA confirmed the very high level of agreement between the 2 devices. However, the OLCR measurements were slightly higher than the PCI measurements in 38 (76%) of the 50 cataractous eyes (mean difference +0.026 mm) and in 39 (78%) of the 50 eyes with a clear lens (mean difference

Table 2. Measurements in eyes with a clear lens.

Parameter	Mean Measurement ± SD: OLCR Unit	Mean Measurement ± SD: PCI Unit	Range
AL (mm)	23.72 ± 1.21	23.70 ± 1.20	−0.05 to +0.11
ACD (mm)	3.10 ± 0.41	2.95 ± 0.39	−0.24 to +0.40
K (D)	43.41 ± 2.13	43.53 ± 2.13	−0.80 to +0.33

ACD = anterior chamber depth; AL = axial length; K = keratometry; OLCR = optical low-coherence reflectometry; PCI = partial coherence interferometry

Table 3. Intraocular lens prediction error.

Parameter	OLCR Unit	PCI Unit
Mean arithmetic error (D) ± SD	−0.002 ±0.56	0.003 ±0.55
Mean absolute error (D) ± SD	0.455 ± 0.32	0.461 ±0.31
Range (D)	−1.06 to +1.38	−1.17 to +1.13
Prediction error		
Within ±0.50 D, n (%)	29 (58)	28 (56)
Within ±1.00 D, n (%)	47 (94)	47 (94)
Within ±1.50 D, n (%)	50 (100)	50 (100)

OLCR = optical low-coherence reflectometry; PCI = partial coherence interferometry

0.023 mm). Holzer et al.[4] and Buckhurst et al.[5] found the same change in AL measurements, reporting a 0.01 mm longer AL with the OLCR unit. This kind of systematic difference explains the high statistical difference ($P<.0001$) between the measurements given by the 2 units notwithstanding the extremely low mean difference. The reason for such a discrepancy is unclear. It is likely related to the fact that measurements from the PCI unit are recalibrated to improve agreement with immersion ultrasound (US) biometry. The PCI unit measures the distance from the anterior corneal vertex to the retinal pigment epithelium, whereas US biometry measures the distance up to the internal limiting membrane.[8] Without recalibration, PCI biometry would result in higher measurements than US biometry. Although the medical literature does not provide scientific data on recalibration of the OLCR measurements, we can speculate that the longer mean AL measured by this instrument depends on a different algorithm used to closely reflect US values.

There was only moderate agreement between the 2 units in ACD measurements. The OLCR unit measured a deeper ACD in 45 eyes (90%) with cataract (mean difference 0.13 mm) and in 42 eyes (84%) with a clear lens (mean difference 0.15 mm). Using the OLCR unit, the ACD measured a mean of 0.16 mm deeper in the study by Holzer et al.[4] and a mean of 0.10 mm deeper in the study by Buckhurst et al.[5] Such a difference might be attributed to the ACD measurement technique used by each instrument. The PCI unit measures ACD through a lateral slit illumination, while the OLCR unit measures ACD with optical biometry. The PCI unit[1] evaluates a slit image of the anterior segment of the eye using sophisticated image analysis software. In a comparative study, Nemeth et al.[9] found a mean ACD measurement of 2.95 ± 0.34 mm using immersion ultrasonography and slightly higher values (3.12 ± 0.33 mm) when the ACD was measured using anterior segment optical coherence tomography (AS-OCT) (Visante, Carl Zeiss Meditec). The OLCR unit uses a method similar to that of the AS-OCT unit, measuring ACD with optical biometry.

There was good agreement between the 2 instruments in the K readings. The OLCR unit evaluates 32 light points from the anterior corneal surface and measured, on average, a 0.11 D flatter cornea than the 6 light point measurements taken from the PCI unit. Holzer et al.[4] and Buckhurst et al.[5] recorded 0.04 D and 0.05 D flatter average K values, respectively. It is impossible to conjecture which is more correct.

The clinical relevance of these differences in AL, ACD, and K measurements is insignificant when performing IOL power calculations. All commonly used third-generation formulas, including the Hoffer Q,[10] Holladay I,[11] and SRK/T,[12] base their calculations on AL and K measurements. A 0.023 mm longer AL decreases the calculated IOL power by less than 0.06 D depending on the AL in the eye. A 0.11 D flatter K reading increases that IOL power by approximately 0.10 D, leaving a difference of less than 0.05 D. We always recommend personalizing formula constants when any measurement or surgical technique is modified; however, initial calculations with the new OLCR unit can be accurately performed using the same ACD constant for the Hoffer Q, surgeon factor for the Holladay 1, and A constant for the SRK/T formula used with the PCI unit. The Haigis formula uses preoperative ACD measurements in addition to AL values but does not use K readings. In our study, using the OLCR unit with the Haigis formula in an average eye, the 0.023 mm longer AL decreased the IOL power by approximately 0.07 D, the 0.11 D flatter Ks increased the IOL power by approximately 0.15 D, and the 0.13 mm deeper ACD increased the IOL power by approximately 0.06 D. The resulting difference in IOL power was approximately 0.14 D (depending on the IOL power.) The optimized a_0 constant had to be decreased from −0.997 to −1.050. We recommend a similar decrease of (approximately 0.050) in the a_0 constant when the Haigis formula is first used with the OLCR unit until the constant is properly personalized.

We believe this is the first study to report the accuracy of the OLCR unit in patients having cataract extraction with IOL implantation. The mean absolute error in the 50 operated eyes was slightly lower with the OLCR measurements than with the PCI measurements (0.455 ± 0.32 versus 0.461 ± 0.31). However, the difference was not statistically significant ($P>.1$).

The OLCR unit also evaluates crystalline lens thickness. This measurement is used in some other IOL power calculation formulas, such as the Holladay II[13] and Olsen.[14] At present, surgeons using these 2 formulas have to measure lens thickness by ultrasonography, an added step. Thus, additional CCT and ACD measurements by the OLCR unit will be valuable in refractive IOL surgery.

The present study has 2 limitations that warrant further investigation. First, our sample did not include short eyes (<21.0 mm) or long eyes (>27.0 mm), for which different results might be observed. Second, the examiner who performed the OLCR measurements was not masked to the PCI measurements.

In conclusion, the OLCR unit was user friendly, although slightly more time consuming, than the PCI unit in obtaining AL measurements. In addition, the OLCR unit provided measurements that can be considered clinically interchangeable with those provided by the PCI unit and lead to high accuracy in IOL power calculation.

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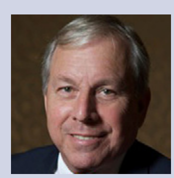

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