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ORIGINAL PAPER

Comparison of preoperative and postoperative measurements of optical low-coherence reflectometry biometry and assessment of its refractive predictability

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Abstract
Purpose To compare the preoperative and postoperative measurements of optical low-coherence reflectometry (OLCR) biometry and assessment of its refractive predictability.
Methods A total of 114 eyes of 102 patients who underwent cataract treatment were prospectively examined. The axial length (AL), central corneal thickness (CCT), anterior chamber depth (ACD), lens thickness (LT), K (keratometry) 1, K2, K average (KAVE) and K astigmatic (KAST) values were recorded using Lenstar LS 900 (Haag-Streit, Koeniz, Switzerland) OLCR device. The IOL (intraocular lens) power was measured based on the SRK/T formula. The cases were divided into three subgroups according to AL (Group 1: AL $<$ 22 mm, Group 2: 22 mm $\leq$ AL $<$ 24 mm, Group 3: 24 mm $\leq$ AL). The mean absolute error (MAE) calculated for each eye.
Results The right eyes of 45 patients (44.1%), left eyes of 45 patients (44.1%), and both eyes of 12 patients (11.7%) were examined. The average AL in the preoperative period was 23.19 $\pm$ 1.01; it was 23.20 $\pm$ 0.99 in the postoperative period ($p > 0.05$). A significant deepening was detected in the postoperative ACD (preop 2.76 $\pm$ 0.38 mm, postop 3.81 $\pm$ 0.46 mm, $p < 0.001$). CCT was measured as 521.4 $\pm$ 36.3 μm in the preoperative period and as 530.8 $\pm$ 42.8 ($p > 0.05$) μm in the postoperative period. The average mean absolute error (MAE) was measured as 0.48 $\pm$ 0.41 D, whereas refractive error was $-$ 0.081 $\pm$ 0.67 D. The MAE distribution of cases was found to be $\leq$ 1.5 D 109 (95.6%) eyes, and $\leq$ 2.0 D in 114 (100%) eyes. MAE values according to AL of the cases were calculated as 0.71 $\pm$ 0.83 D in group 1, 0.49 $\pm$ 0.43 D in group 2 and 0.41 $\pm$ 0.36 D in group 3 ($p > 0.05$).
Conclusion When the measurement and refractive results of the OLCR biometry were evaluated, it was observed that there was a very satisfactory result and a predictable device compatible with the current literature. The SRK/T formula, one of the new generation formulas, has shown high MAE and RE results in eyes with AL $\leq$ 22 mm, although not statistically significant. Other new generation formulas should be tried in these eyes.

Keywords Biometry · Lenstar · Keratometry · Mean absolute error · Axial length

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Introduction

Cataract is currently one of the most prevalent public health problems that lead to decreased vision and blindness [1]. Cataract surgeries are among the most frequently performed surgical operations worldwide, and its frequency is gradually increasing [2]. The most critical phase in the postoperative period for successful treatment is to accurately calculate the intraocular lens (IOL) power [3]. Parameters used to calculate the IOL power are based on corneal refractive power, the distance between the anterior surface of the cornea and the anterior surface of the IOL in the postoperative period, and the axial length (AL) of the eye. Among these parameters, the AL is of utmost importance, as an error of 100 μm in its measurement leads to a refractive deviation of 0.28 diopter (D). Nevertheless, the anterior chamber depth (ACD) and keratometry (K) are also fundamental parameters, as an error of 1 mm in the ACD leads to a deviation of 1 D in the myopic eye, 1.5 D in the emmetropic eye, and 2.5 D in the hypermetropic eye, whereas an error of 1 D in K values leads to a deviation of the same rate as that in the IOL measurement or to a deviation of 1.3–1.6 D [4, 5]. Since the 2000s, various optical biometric devices capable of measuring all or most of these parameters in a single procedure have been used [6].

Lenstar LS 900 (Haag-Streit, Koeniz, Switzerland) is one of the optical biometric devices that recently came into use [7]. Its operating principle is based on optical low-coherence reflectometry wherein a super-luminescent diode serves as the laser source at a wavelength of 820 μm. With this method, the AL, central corneal thickness (CCT), the ACD, aqueous depth (the distance between corneal endothelium and the anterior surface of the lens), thickness of the crystalline lens, corneal diameter calculated as limbus-to-limbus distance, pupil diameter, and retinal thickness can be measured [8]. A dual-zone automated keratometer calculates the anterior corneal curvature by analyzing it at 32 reference points oriented in two circles at optical zones of approximately 2.3 and 1.65 mm. The keratometric reading is calculated using a 1.3375 index of refraction and includes the flattest meridian, steepest meridian, and astigmatic cylinder axis.

The present study aimed to compare the preoperative and postoperative parameters measured using Lenstar LS 900 and assess the postoperative refraction findings.

Materials and methods

Our study is a prospectively randomized original research article. We prospectively examined 114 eyes (45 eyes right, 45 eyes left, both eyes 12) from 102 patients (58 males, 44 females, the average age 65.4 ± 13.1 years) who underwent surgery between March 2012 and February 2013 at The Eye Clinic of Ankara Ulucanlar Eye Training and Research Hospital. The study conformed to the principles of the Declaration of Helsinki and was approved by the local ethics committee. We obtained informed consent from all patients. In our study, we included patients who underwent phacoemulsification cataract surgery without any complications. Those with active intraocular infection or uveitis; history of ocular surgery; corneal pathology such as diffuse corneal opacity, keratoconus, or Fuchs' endothelial dystrophy; lens subluxation or phacodonesis; vitreous loss; posterior capsule rupture after surgery; Descemet's membrane detachment; postoperative lens dislocation; anterior chamber reaction; or bullous keratopathy were not included in the study.

In all cases, a complete ophthalmic examination was performed before surgery. The AL, CCT, ACD, lens thickness (LT), and K1 and K2 values were measured by the same physician using the Lenstar. After patients fixed their gaze on the red light of the device, and their eyes were focused on the monitor, three subsequent measurements were made. We used the average value of these measurements. Unsuitable measurements or those who failed to fixate on the red light were excluded from the study. The ACD was measured as the distance between the corneal endothelium and the epithelium of the crystalline lens (the functional anterior chamber). K values were measured as K FLAT = K1, K STEEP = K2, average K (KAVE) = [(K1 + K2)/2], and average keratometric astigmatism (KAST) values = (K2 − K1). Emmetropia was planned in all eyes, and the IOL power was calculated with the Lenstar using the SRK/T formula. The same physician performed phacoemulsification on all patients via a 2.8-mm clear corneal incision in two stages. In all cases, an acrylic (Acrysoft SA60AT, Alcon, Inc.) IOL was implanted in the capsular bag.

After surgery, all patients were called for clinical examination on day 1, week 1, month 1, and month 6 and underwent full ophthalmologic examination. In month 6, in addition to refraction measurements, the AL, CCT, ACD, and K values of all patients were measured and recorded using the Lenstar. Refractive findings were calculated as refractive error (RE), expected error (EE), and mean absolute error (MAE). RE is the error that is calculated as the spherical equivalent by adding half of the cylindrical value to the postoperative spherical value. EE is the difference between the expected and postoperative refraction in IOL power calculation. In all cases, the expected error was calculated according to SRK/T formula by targeting emmetropia. MAE is the absolute difference obtained by subtracting EE from RE. Refractive success was classified in terms of MAE and within the range of ≤ 0.50, ≤ 1, ≤ 1.50, and ≤ 2 D.

To analyze in detail other factors that affect refractive findings, we divided the cases into three groups subsequent to their standard AL measurements:

Group 1: Short eyes with an AL of < 22 mm.
Group 2: Normal eyes with an AL of 22–24 mm.
Group 3: Long eyes with an AL of > 24 mm.

Table 1 Average measurements in all cases

	Preoperative	Postoperative	*p value
K1 (D)			
Ave ± SD	43.63 ± 1.69	43.34 ± 1.67	> 0.05
R	40.20–47.95	39.03–47.85	
K2 (D)			
Ave ± SD	44.67 ± 1.87	44.58 ± 1.79	> 0.05
R	40.79–48.98	40.78–50.19	
KAVE (D)			
Ave ± SD	44.15 ± 1.73	43.96 ± 1.73	0.008
R	40.65–48.72	40.06–49.06	
KAST (D)			
Ave ± SD	1.04 ± 0.86	1.06 ± 0.81	> 0.05
R	0–4.38	0–3.84	
AL (mm)			
Ave ± SD	23.19 ± 1.01	23.20 ± 0.99	0.403
R	19.7–26.9	19.7–26.7	
CCT (μm)			
Ave ± SD	521.4 ± 36.3	521.08 ± 36.02	> 0.05
R	391–626	452–624	
ACD (mm)			
Ave ± SD	2.76 ± 0.38	3.81 ± 0.46	< 0.001
R	1.6–3.7	2.4–4.82	
LT (mm)			
Ave ± SD	4.26 ± 0.47	–	–
R	2.86–5.26		

*Paired samples t test was used for the statistical analysis of preoperative and postoperative values

K keratometry, *D* diopter, *Ave* average, *SD* standard deviation, *R* range, *KAST* k astigmatism, *AL* axial length, *CCT* central corneal thickness, *ACD* anterior chamber depth, *LT* lens thickness

Statistical analysis

Data entries of the cases and their statistical evaluations were conducted using SPSS 16.0 (Statistical Package for Social Science for Windows, software version 16.0, Chicago). We determined whether the data set follows normal distribution using one-sample Kolmogorov–Smirnov test. As for the comparison of qualitative data, Chi-square test was used. Difference between repeated measures was analyzed using the paired sample t test. Results were evaluated using 95% confidence interval, and a p value of < 0.05 was considered statistically significant.

Results

The measurements of the anterior segment parameters K1, K2, KORT, KAST, AU, CCT, LD and LK are shown in Table 1.

If we consider keratometric findings, KAST values were calculated as 1.04 ± 0.86 D preoperatively and 1.06 ± 0.81 D postoperatively. Despite the increase in KAST values, the difference was not statistically significant ($p > 0.05$).

There was no significant difference in the AL and CCT values ($p > 0.05$). Postoperative ACD values were measured in 48 patients, and there was a significant increase in ACD values in measured eyes. The preoperative average LT value was 4.26 ± 0.47 (2.86–5.26) mm.

In terms of refractive findings, MAE distribution was observed as ≤ 0.5 D in 69 (60.5%) eyes, ≤ 1.0 D in 94 (82.4%) eyes, 1.5 D in 109 (95.6%) eyes, and ≤ 2.0 D in 114 (100%) eyes (Table 2). Furthermore,

Table 2 Postoperative refractive findings in all cases

	Postop, 6 Months
Refractive error (D)	
Ave ± SD	− 0.081 ± 0.67
R	− 1.51 to 2.01
Expected error (D)	
Ave ± SD	− 0.067 ± 0.22
R	− 0.60 to 0.37
Mean absolute error (D)	
Ave ± SD	0.48 ± 0.41
R	0–1.85
Intervals of mean absolute error (D)	n = 114
≤ 0.5	69 (60.5%)
≤ 1.0	94 (82.4%)
≤ 1.5	109 (95.6%)
≤ 2.0	114 (100%)

when the direction of the refractive errors was analyzed, myopic shift was observed in 63 (55.2%) eyes, and hypermetropic shift was observed in 51 (44.8%) eyes.

When cases that were divided into three groups based on their axial lengths were examined, there were eight cases (7%) in Group 1, 89 (78.1%) in Group 2, and 17 (14.9%) in Group 3. Although preoperative ACD values were high in Group 3 and low in Group 2 as predicted, there was no statistically significant difference ($p > 0.05$) (Table 3). When refractive findings were analyzed (Table 4), we found no statistically significant difference between the three groups ($p > 0.05$).

Discussion

The findings in the literature demonstrate that the replicability and reproducibility of the Lenstar are high, and there is a strong correlation between the device and other gold standard biometric devices [5, 9–12]. In a study conducted by Mylonas et al. on 51 sets of eyes from 51 patients with age-related cataract, when preoperative values were compared using IOL Master V.5, Visante OCT, and Lenstar LS 900 biometric devices, a strong correlation was found between the Lenstar and IOL Master in terms of the AL, ACD, and K values. ACD values of Visante OCT were found to be significantly high compared with those of the other devices ($p < 0.001$), whereas CCT values were low compared with those of the Lenstar, although they were not statistically significant [13].

Salouti et al. [5] studies 232 patients who were scheduled for cataract surgery and found an analogy between the Lenstar and IOL Master in terms of ocular biometry and accuracy, sensitivity, clinical benefit, and calculation of the IOL power. In the Buckhurst et al. study on 112 cataract cases, average Lenstar measurements were as follows: AL, 23.25 mm; CCT, 550 µm; ACD, 2.64 mm; LT, 4.41 mm; K1, 42.78 D; K2, and 43.88 D. Although the Lenstar showed greater ACD than the IOL Master, it was not clinically significant, and a high correlation with the IOL Master was detected [14]. In the present study, the average values were measured as AL, 23.18 mm; CCT, 521.4 µm; ACD, 2.76 mm; LT 4.26 mm; K1, 43.63 D; and K2, 44.67 D. *Preoperative Lenstar biometric measurements in this study were consistent with those in the literature* [5, 7, 14–16].

The present study measured the distance between the corneal endothelium that reflects the anatomic anterior chamber and the anterior surface of the crystalline lens as the ACD; although the ACD was measured with precision using the Lenstar in all eyes in the preoperative period, only 48 (42.1%) patients with pseudophakic eyes were assessed. As expected, we detected a significant increase ($p < 0.001$) in postoperative ACD values (3.81 ± 0.46); we also detected a deepening on an average of 1.05 mm.

Table 3 Changes in preoperative values based on axial lengths

	Group 1 (AL ≤ 22 mm)	Group 2 (22 mm < AL ≤ 24 mm)	Group 3 (24 mm < AL)	*p value
Frequency (n: 114)	8 (7%)	89 (78.1%)	17 (14.9%)	0.164
ACD (mm)				
Ave ± SD	2.64 ± 0.32	2.74 ± 0.40	2.92 ± 0.33	
R	2.15–2.92	1.68–3.64	2.32–3.7	

*Kruskal–Wallis test

Table 4 Changes in postoperative values based on axial lengths

	Group 1 (AL < 22 mm)	Group 2 (22 mm ≤ AL < 24 mm)	Group 3 (24 mm ≤ AL)	*p value
Mean absolute error (D)				
Ave ± SD	0.71 ± 0.83	0.49 ± 0.43	0.41 ± 0.36	0.307
R	0.03–1.85	0–1.68	0.04–1.08	
Refractive error (D)				
Ave ± SD	0.24 ± 1.19	− 0.08 ± 0.64	− 0.21 ± 0.71	0.406
R	− 1 to 2.01	− 1.51 to 1.75	− 1 to 1.41	

*Kruskal–Wallis test

Kakoulidis et al. [17] in a study on 60 cases reported a 1.44-mm deepening in postoperative ACD values. In Olsen's retrospective study on 1235 cases, postoperative ACD was measured in 232 cases using the Lenstar and postoperative average ACD value was calculated as 4.54 ± 0.36 mm [18]. Hildebrandt et al. [19] were able to obtain ACD values from 42 (30%) cases out of 140 pseudophakic cases using the Lenstar, and calculated the other cases manually, and reported the ACD value as 4.73 ± 0.53 mm. Hildebrandt et al. argued that the IOL surface did not create sufficient interference signal; therefore, ACD values were insufficient. Furthermore, they also stated that the software used to measure the IOL surface could be improved. In our study, although we used the device's special mode for measuring the pseudophakic cases, signals received in all cases were not sufficient. *Therefore, we agree with Hildebrandt* et al. *Additionally, we examined the change in preoperative ACD values based on the AL and detected an increase in ACD; however, there was no statistically significant difference in relation to the increase in AL ($p = 0.164$).*

The most important part of our clinical study was the assessment of refractive findings that suggested that measurements using the biometric device were reliable and predictable. In line with the literature, the present study also measured MAE and RE as indicators of refractive findings. *In our study, MAE was found as 0.48 ± 0.41* D *and RE as − 0.081 ± 0.67* D. *Additionally, the MAE distribution of cases was determined as 109 (95.6%) cases with ≤ 1.5* D *and 114 (100%) cases with ≤ 2.0* D (Table 3). In the Hoffe r et al.'s study on 50 cataract cases, which was the first study in the literature that investigated surgical results using the Lenstar [20], the Lenstar and IOL Master were used for measurements, and the findings were compared. With the Lenstar, MAE was 0.455 ± 0.32 D and RE was −0.002 ± 0.56 D, and with the IOL Master, MAE was 0.461 ± 0.31 D and RE was 0.003 ± 0.55 D. Although the results were not statistically significant, the Lenstar results were found to be slightly more accurate. Hoffer et al. achieved more accurate results than our study, and this can be explained by the fact that they excluded cases with AL of < 21 and > 27 mm, they had smaller number of cases, and they used the Haigis IOL formula. Olsen's retrospective study calculated the MAE as 0.41 D using the IOL Master and the SRK/T formula [18]. Olsen also performed clear corneal incision on some patients, whereas in other cases, scleral tunnel method was used. Kim et al. [21] studied 209 cataract cases and used the IOL Master; they compared SRK II and SRK/T formulas, and MAE was calculated as 0.496 ± 0.368 and 0.414 ± 0.316 D, and RE as 0.200 ± 0.585 and 0.161 ± 0.496 D, respectively. In this study, the SRK/T formula was found to be significantly more accurate that of the SRK II ($p < 0.001$). Eleftheriadis measured MAE in 100 cases using the IOL Master and the SRK/T formula, and it was found to be 0.35 ± 0.31, and its distribution was calculated as ≤ 0.50 D (81%), ≤ 1 D (95%), ≤ 1.50 D (99%), ≤ 2 D (100%), in line with the findings of our study [22]. Furthermore, we also compared the Holladay, SRK/T, and Hoffer Q formulas, and the highest MAE was found with SRK II formula. Several studies demonstrated that SRK/T, Haigis, Hoffer Q, and Olsen formulas were more accurate than the SRK II formula [20, 21, 23].

In our study, when we assessed the MAE variance findings based on the ALs, the most accurate findings were obtained in Group 3 with an AL of ≥ 24 mm (MAE values; Group 1: 0.71 ± 0.83, Group 2: 0.49 ± 0.43, Group 3: 0.41 ± 0.36). *When RE values were assessed, there was a high hypermetropic shift in* *eyes with AL of < 22 mm, although the results were not statistically significant*.

Kim et al. [21] studied 209 cases, which were categorized into four groups based on AL values, and MAE findings that were calculated using the SRK/T formula were ≤ 23 mm = 0.44 ± 0.34, 23 < ≤ 24 mm = 0.41 ± 0.33, 24 < ≤ 25 mm = 0.38 ± 0.26, 25 mm < 0.33 ± 0.23. In the present study, although not statistically significant, a higher hypermetropic shift was observed in eyes that were ≤ 23 mm, and we obtained more accurate results in eyes that were > 25 mm. Häsemeyer et al. [24] reported that the predicted error value was higher in eyes with AL of < 23.2 mm. Conversely, Song et al. reported an increase in MAE values with increase in AL [25]. *Similar to the Mo Kim and Häsemeyer studies, the present study also detected higher MAE and RE values and hypermetropic shift in eyes with AL of < 22 mm, although it was not statistically significant. The most accurate results were obtained in eyes with AL of ≥ 24 mm. In light of these findings, it is essential to consider the fact that eyes with short AL may lead to significant hypermetropic shift in refraction.*

There are few studies in the literature prospectively evaluating the long-term postoperative (postop. 6 months) anterior segment measurements and the accuracy of IOL power calculations, and also comparing the results according to axial lengths. In our study, the measuring physician, the operating surgeon, and the inserted IOL were standardized to evaluate the refractive performance of IOL calculated by Lenstar and SRK/T formula, and the results were presented according to axial lengths and some suggestions were made to the surgeons. In addition, some information about the long-term results of changing anterior segment values after cataract surgery has been given. We think that by filling these features, we fill the void in this area by contributing to the literature.

The weakness of our study is that we only use the SRK/T formula in the calculation of IOL power and not compare it with other formulas. The number of cases, the measurements done in one center, by the same service doctor, and the follow-up period are the strengths of our study.

In conclusion, when the measurement and refractive results of the OLCR biometry were evaluated, it was observed that there was a satisfactory result and a predictable device compatible with the current literature. The SRK/T formula, one of the new generation formulas, has shown high MAE and RE results in eyes with AL ≤ 22 mm, although not statistically significant. Other new generation formulas should be tried in these eyes.

Compliance with ethical standards

Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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