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Accuracy of Haigis Formula Using Total Keratometry for IOL Power Calculation in Eyes with Previous Myopic and Hyperopic LASIK and PRK

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Abstract: Background: this retrospective study aimed to analyze the results of the combination of the Haigis formula and total keratometry (TK) in calculating the IOL power in eyes with previous corneal refractive surgery. Methods: the TK value provided by the IOL Master 700 (Carl Zeiss Meditec) was introduced into the Haigis formula; the mean prediction error (PE), mean absolute error (MAE), median absolute error (MedAE) and percentage of eyes with a PE within ±0.25 D, ±0.5 D, ±0.75 D and ±1.00 D were calculated. Results: ninety-three eyes of 93 patients with previous laser refractive surgery were evaluated. Two groups were defined: the Myopic Group included 51 previously myopic eyes and the Hyperopic Group included 42 previously hyperopic eyes. The mean PE in the Myopic Group was +0.09 ± 0.44 D and 76.47% of eyes had a PE within ±0.50 D. In the Hyperopic Group, the mean PE was −0.15 ± 0.46 D and 66.67% of eyes had a PE within ±0.50 D. Discussion: when compared to the results previously published with other formulas or methods, the Haigis formula combined with TK provided very accurate refractive outcomes for IOL power calculation in eyes with prior myopic and hyperopic corneal refractive surgery. In such eyes the results are similar to or better than those reported in previous studies.

Keywords: Haigis formula; total keratometry; corneal refractive surgery; IOL power calculation; cataract surgery

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1. Introduction

Many methods have been described over the last two decades to calculate the intraocular lens (IOL) power in eyes with previous corneal refractive surgery [1]. One of the most interesting solutions has been devised by Wang et al. [2], who entered the total keratometry (TK) provided by the IOLMaster 700 (Carl Zeiss Meditec, Jena, Germany) (which is not affected by the keratometric index error) into the standard Haigis formula (which is not affected by the formula error, as it does not use keratometry to predict the IOL position). Various studies have evaluated this approach and found good results in previously myopic eyes, with 58.5 to 64.06% of eyes showing a prediction error (PE) within ±0.50 diopters (D) [2–5]; similar results have been reported in previously hyperopic eyes (56.3% of eyes with a PE within ±0.50 D) [2]. However, these results—although reasonably good—are not as accurate as those reported with other methods or formulas in eyes with prior corneal

refractive surgery. Percentages higher than 70% were found in several studies that applied the same methodology to calculate the PE [3,5–7].

Hence, the primary purpose of this study was to again analyze the results of the Haigis–TK formula in both previously myopic and hyperopic LASIK/PRK eyes and compare our findings to those of published studies.

2. Materials and Methods

This retrospective study included patients that underwent cataract surgery after previous corneal laser refractive surgery from two independent samples, one from Italy (I.R.C.C.S. Bietti Foundation, Rome, Italy) and one from Colombia (Centro Oftalmologico Virgilio Galvis, Floridablanca, Colombia). The Italian sample was composed of myopic LASIK/PRK patients, while the Colombian sample included cases of both myopic and hyperopic LASIK/PRK. All patients gave their written informed consent for the study, which was defined according to the Declaration of Helsinki. The study was approved by the Bietti Foundation Ethics Committee.

Exclusion criteria were any pathologies including pseudoexfoliation, previous ocular surgery, and any complication during or after cataract surgery. Patients were included only if their distance-corrected visual acuity (DCVA) was 20/25 or better, and if refraction could be measured at a minimum of 1 month after surgery.

A complete preoperative examination was performed, including an assessment of DCVA and slit lamp biomicroscopy. Biometric measurements were obtained with the IOLMaster 700 (Carl Zeiss Meditec, Jena, Germany, software version 1.90.12.05), which also provides the so-called TK by combining telecentric keratometry and SS-OCT technology to provide measurements of the anterior and posterior corneal surfaces. The method used to calculate TK is proprietary and has not been disclosed by the manufacturer, although it is known that it is paraxial and is not based on ray-tracing, in contrast to the total corneal power measurements provided by Scheimpflug cameras. TK has been shown to have high repeatability and to accurately reflect laser-induced refractive changes, in comparison to standard keratometry, which underestimates them [8,9], since it is not affected by the keratometry index error. Only measurements of good quality, as revealed by the lack of alerts (!) on the software of the optical biometer, were included in the analysis. Subjective manifest refraction was determined for each patient at a minimum of 1 month postoperatively with a chart distance of 4 m.

Regarding the IOL power calculation, the Haigis formula was chosen, since it does not use keratometry to predict the IOL position [10]. Therefore, it does not suffer from the so-called formula error (i.e., a wrong prediction of the IOL position based on the post-refractive surgery keratometry), which would require the double-K solution proposed by Aramberri [11]. As a consequence, the TK provided by the IOL Master 700 can be easily introduced into it. Optimized constants from the ULIB website (ocusoft.de/ulib/c1.htm, accessed on 18 March 2023) or the IOLCON website (https://iolcon.org, accessed on 18 March 2023) were used for the different IOL models.

The prediction error (PE) was calculated as the difference between the measured and predicted postoperative refractive spherical equivalent for the power of the implanted IOL. Negative PE values indicate a more myopic result than the predicted refraction and positive PE values represent a more hyperopic result. The mean prediction error (Mean PE) $\pm$ its standard deviation, mean absolute error (MAE), median absolute error (MedAE) and percentage of eyes with a PE within $\pm$0.25 D, $\pm$0.5 D, $\pm$0.75 D, $\pm$1.00 D were calculated for both groups.

A minimum sample size of 32 eyes, as previously recommended by Wang et al., was selected [2].

3. Results

A total of 93 eyes of 93 patients were enrolled, 62 from Colombia and 31 from Italy (all data are available as Supplementary Materials). In cases of bilateral surgery, the first

operated eye was selected for each patient. Two groups were defined; the Myopic Group included 51 eyes of 51 myopic patients (mean age 60.4 ± 7.9 years, 29 females) from both the Italian and Colombian samples, and the Hyperopic Group included 42 eyes of 42 hyperopic patients (mean age 66.9 ± 6.3 years, 29 females) from the Colombian sample. The results of the preoperative measurements, and the power of the implanted IOLs, are shown in Table 1.

Table 1. Mean preoperative biometry measurements and implanted IOL power.

	Mean ± SD		**Range**	
	Myopic Group	**Hyperopic Group**	**Myopic Group**	**Hyperopic Group**
Axial length (mm)	26.49 ± 2.28	22.97 ± 0.77	21.98–33.54	21.66–24.52
Mean keratometry (D)	40.17 ± 2.82	45.17 ± 1.36	35.96–49.55	42.20–47.25
Mean TK (D)	39.85 ± 3.09	45.39 ± 1.51	35.42–50.21	42.08–47.72
Implanted IOL power (D)	19.06 ± 3.19	22.32 ± 1.91	11.00–25.00	19.00–26.50

Eleven IOL models were implanted (Table 2).

Table 2. Models and numbers of IOLs used in the study.

Manufacturer	**Model**	**ULIB Constant**	**N° of Implanted IOLs**	
			Myopic Group	**Hyperopic Group**
Alcon Laboratories, Inc.	AcrySof SN60WF	119.0	20	15
Alcon Laboratories, Inc.	AcrySof Toric SN6Atx	119.2	17	13
Alcon Laboratories, Inc.	Vivity DFT015	119.1	1	1
Alcon Laboratories, Inc.	Vivity Toric DF315	119.1	2	0
Alcon Laboratories, Inc.	Panoptix TFNT00	119.1	1	1
Alcon Laboratories, Inc.	Panoptix toric TFNT20	119.1	1	0
Alcon Laboratories, Inc.	Clareon CNA0T0	119.1	4	11
Alcon Laboratories, Inc.	AcrySof SN60AT	118.8	0	1
J&J Vision	ZCB00/DCB00	119.3	2	0
J&J Vision	AAB00	119.3	1	0
Rayner Intraocular Vision	Rayone	118.6	1	0
Soleko SPA	FIL611	119.1	1	0

The mean PE obtained with the Haigis TK in the Myopic Group was 0.093 ± 0.440 D (range: −0.83 to +1.14 D) and 76.47% of eyes had a PE within ±0.50 D. In the Hyperopic Group, a slightly myopic outcome was obtained, as the mean PE was −0.148 ± 0.462 D (range: −0.96 to +1.03 D) and 66.67% of eyes had a PE within ±0.50 D. The complete refractive outcomes of IOL power calculations are reported in Table 3. Linear regression did not reveal any significant correlation between the PE and the preoperative biometric variables (i.e., K, TK, ACD and AL) in either group.

Table 3. Refractive outcomes of IOL power calculation, using the combination of the Haigis formula and total keratometry, in eyes with previous myopic and hyperopic laser corneal refractive surgery.

	Myopic Group	**Hyperopic Group**
Mean PE	0.093 ± 0.440	−0.148 ± 0.462
MAE	0.364	0.381
MedAE	0.260	0.342
Eyes with PE ≦ ±0.25 D	50.98%	42.86%
Eyes with PE ≦ ±0.50 D	76.47%	66.67%
Eyes with PE ≦ ±0.75 D	90.20%	88.10%
Eyes with PE ≦ ±1.00 D	96.08%	97.62%

MAE = mean absolute error; MedAE = median absolute error.

4. Discussion

Our data confirm that the combination of the standard Haigis formula and IOLMaster 700 total keratometry leads to very accurate outcomes when the IOL power is calculated in eyes with previous myopic and hyperopic laser refractive surgery. The results are superior to those previously reported for the Haigis-L, which was specifically developed for post-LASIK eyes [12]. Several authors, in fact, found that this formula produces moderate outcomes, with 34.38% to 66% of eyes with a PE within ±0.50 D in previously myopic eyes, and 46.9% to 68.8% of eyes with a PE within ±0.50 D in previously hyperopic eyes [2–5,13,14].

When compared to the data previously reported by other authors who investigated the Haigis–TK combination, our refractive outcomes were more accurate, especially in eyes that had undergone myopic correction. In 53 eyes of 37 previously myopic patients, Wang et al. reported 58.5% of eyes with a PE within ±0.50 D, while Lawless and Choi reported values of 60% in two series of 50 and 40 eyes, respectively. Better outcomes were found by Yeo, with a percentage of 64.06% of eyes with a PE within ±0.50 D (64 eyes of 49 patients). We do not have a clear explanation as to why we had more than 76% of eyes with a PE within ±0.50 D. Considering that the axial length was similar in all studies and cannot be considered as an influencing factor, we may hypothesize that racial differences, or different methods to measure the refraction, may have played a role. However, these are only theoretical assumptions: while racial differences have been previously described [15], there is no evidence that different ethnic groups show different refractive outcomes after cataract surgery. Similarly, our results in previous hyperopic LASIK/PRK eyes are slightly more accurate than those previously reported [2].

A comparison of our results with those of studies that investigated other methods for IOL power calculation in eyes with previous myopic excimer laser surgery shows that the Haigis–TK combination can provide one of the most accurate solutions, with 76.47% of eyes showing a PE within ±0.50 D. Our group previously reported that percentages close to 75% could be obtained by means of ray tracing [7] and with Masket's formula based on measurements by different Scheimpflug cameras [6,16]. Similarly, the Barrett True-K formula, with clinical data and posterior curvature measurements, was able to reach 70% of eyes with a PE within ±0.50 D [17]. In contrast, with no-history formulas (Barrett True-K, Haigis-L, Shammas-PL and Triple-S) the same percentages ranged between 40.2 and 53.3% [18]. Many other formulas and methods obtained percentages between 50 and 60% [6,19,20].

The results of the present study are also good when compared to those obtained in long eyes that did not undergo corneal refractive surgery. For example, Liu et al. observed that the most accurate formula in eyes longer than 26.0 mm was the Barrett Universal II (78% of eyes with a PE within ±0.50 D); in their sample, the mean AL was 28.85 mm, a value slightly higher than ours [21]. A lower percentage (70%) with the same formula was reported by Rong et al. in a sample of eyes whose mean AL was 29.3 mm [22].

Regarding previously hyperopic eyes, our results stand, again, amongst the most accurate ones, since rarely had more than 65% of eyes with a PE within ±0.50 D been reported [2,23,24].

This paper has some limitations. Firstly, different IOL types were included in the study—this precluded constant optimization. However, recent guidelines have suggested that constant optimization is not mandatory in subgroups of eyes such as the present ones, where optimized constants from larger datasets (such as those we used) may be preferred [25]. Secondly, we did not compare the results of the Haigis–TK combination to those of other formulas. However, this was a deliberate decision that was based on the fact that the literature already has a very large number of articles with such comparisons, and the results of the competing formulas (such as, for example, the Haigis-L, Shammas-PL and Barrett True-K) have been known for 10 years, whereas the Haigis–TK combination is relatively new.

In conclusion, our data suggest that the IOL power calculation with the Haigis formula combined with TK represents one of the most accurate available methods in both myopic

and hyperopic eyes with previous corneal refractive surgery. Given that it does not rely on historical data/information, it is particularly useful for all surgeons that can have access to TK.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/photonics10060624/s1, preoperative biometry of all patients and individual refractive outcomes.

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Data Availability Statement: Data on all patients are available as Supplementary Materials.

Conflicts of Interest: Kenneth J. Hoffer licenses the registered trademark name Hoffer® to ensure the accurate programming of his formulas to Carl Zeiss-Meditec (IOLMasters), Haag-Streit (LenStar/EyeStar), Heidelberg Engineering (Anterion), Oculus (Pentacam AXL), Movu (Argos), Nidek (AL-Scan), Tomey (OA-2000), Topcon EU/VisiaImaging (Aladdin), Ziemer (Galilei G6) and all A-scan biometer manufacturers. Dr. Savini is a consultant to CSO and has received personal fees from Alcon, Johnson & Johnson, Oculus, Staar and Zeiss. The remaining authors have nothing to declare. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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