Comparison of four formulas for the intraocular lens power prediction

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Abstract

Purpose To assess the accuracy of four formulas for intraocular lens (IOL) power prediction in cataractous eyes. **METHODS** In this prospective study, 51 eyes of 38 cataractous patients with an axial length (AL) between 24.0 and 26.0 mm were included. Preoperatively, Topolyzer, IOLMaster and A-scan were performed. At least 3 months after the surgery, subjective refraction was conducted. Haigis, SRK/T, Hoffer Q and Holladay 1 formulas based on ocular biometry from A-scan combining Topolyzer, IOLMaster combining Topolyzer and IOLMaster only were applied for IOL power prediction. **RESULTS** The four formulas based on biometry from IOLMaster combining Topolyzer and IOLMaster only performed better than those based on biometry from A-scan combining Topolyzer. Based on biometry from IOLMaster combining Topolyzer, Haigis formula had a mean NEs of -0.03 ± 0.71 D and a mean AEs of 0.53 ± 0.47 D, SRK/T formula had a mean NEs of 0.37 ± 0.72 D and a mean AEs of 0.63 ± 0.50 D, Hoffer Q formula had a mean NEs of 0.05 ± 0.62 D and a mean AEs of 0.43 ± 0.44 D, Holladay 1 formula had a mean NEs of 0.32 ± 0.63 D and a mean AEs of 0.54 ± 0.45 D. Based on biometry from IOLMaster only, Haigis formula had a mean NEs of 0.02 ± 0.54 D and a mean AEs of 0.41 ± 0.36 D, SRK/T formula had a mean NEs of 0.41 ± 0.54 D and a mean AEs of 0.52 ± 0.43 D, Hoffer Q formula had a mean NEs of 0.05 ± 0.58 D and a mean AEs of 0.36 ± 0.46 D, Holladay 1 formula had a mean NEs of 0.32 ± 0.45 D and a mean AEs of 0.43 ± 0.35 D. **CONCLUSIONS** Haigis and Hoffer Q formulas performed slightly better than SRK/T and Holladay 1 formulas. Therefore, for cataractous patients with moderate AL, all four formulas based the biometry from IOLMaster combining Topolyzer and IOLMaster only can be used for the prediction of IOL power, and the Haigis and Hoffer Q formulas are particularly recommended.

Background

Accurate prediction of intraocular lens (IOL) power is crucial to perform cataract surgery of high quality. There are two indispensable requirements that account for accurate prediction: precise ocular biometry¹⁻⁴ and proper IOL formulas⁵⁻⁷. For ocular biometry, axial length (AL) can be measured using devices based on ultrasonic principle (such as A-scan)⁸ and devices based on optical principles (such as IOLMaster and Lenstar)^{4,9}, and keratometry (K) values can be measured using keratometry and corneal topography¹⁰⁻¹⁴. For IOL formulas, there have been various formulas created and recommended since the 1960s. Currently, there are third generation theoretical formulas including Haigis¹⁵, SRK/T^{16,17}, Hoffer Q^{18,19}, and Holladay 1²⁰, which are highly recommended.

In a study by Hoffer et al.²¹, comparing the predicted results of Holladay 1, Holladay 2, Hoffer Q and SRK/T formulas based on AL measurements from A-scan and K values from keratometer, Hoffer Q and Holladay 2 formulas performed better in short eyes (AL < 22.0 mm), Hoffer Q and Holladay 1 formulas had a lower mean absolute error in the average length eyes (AL between 22.0 and 24.5 mm), and SRK/T showed a trend toward the lowest mean AE in all long eyes (AL > 24.5 mm). In a study by Narvaez et al.⁵ used AL measurements from A-scan and K values from manual keratometry, the accuracy of Hoffer Q, Holladay 1, Holladay 2, and SRK/T formulas were comparable for prediction of IOL in short (AL < 22.0

mm), average (AL between 22.0 and 24.5 mm), medium long (AL between 24.5 and 26.0 mm) and very long (AL > 26.0 mm) eyes.

Ever since IOLMaster devices, which are based on partial coherence interferometry (PCI) principles, could be obtained at the end of last century²², several studies have shown that ocular biometry obtained by IOLMaster were comparable to those obtained by A-scan and Keratometry^{23,24}. Due to the non-contact measurement and comparable predicted results with previous methods, IOLMaster has become more and more popular since the early 2000s. However, until now, it was impossible for IOLMaster to completely replace previous methods. This is because failure rates of AL measurements using IOLMaster rise as the opacity of cataracts increase. In this case, the traditional A-scan is still the first choice for AL measurement.

Several studies have compared the accuracy of prediction between A-scan and IOLMaster, and evaluated the K values obtained by Topography for IOL power prediction. However, few studies report comprehensive data from A-scan, corneal topography and IOLMaster obtained simultaneously for the IOL power prediction. In the present study, three different methods (A-scan combining Topolyzer, IOLMaster combining Topolyzer and IOLMaster only) and four formulas (Haigis, SRK/T, Hoffer Q, and Holladay 1) were applied, and twelve predicted results were generated for the IOL power prediction in medium long eyes (AL between 24 and 26 mm). In addition, accuracy of each result was evaluated.

Methods

In this prospective study, a series of consecutive cataractous patients that underwent uneventful surgery of phacoemulsification and IOL implantation were included in the Department of Ophthalmology, Shanghai Jiao Tong University Affiliated Sixth People's Hospital between March 2016 and August 2016. Inclusion criteria were 1) axial length measurements between 24.0 and 26.0 mm (measured by IOLMaster) and 2) postoperative best corrected distance visual acuity equal to or better than 20/40. The exclusion criteria were 1) history of ocular pathology and surgery, 2) history of corneal or intraocular trauma, or 3) severe postoperative complications. All the research process adhered to the tenets of the Declaration of Helsinki. The study was approved by the Office of Research Ethics Committee, Shanghai Jiao Tong University Affiliated Sixth People's Hospital. All subjects provided written informed consent after the purpose of the study was explained in detail.

Preoperatively, each subject underwent general ophthalmic examinations including slit-lamp examination, non-contact intraocular pressure, fundus examination, *objective and subjective refraction*. In addition, *Topolyzer* (WaveLight, America), *IOLMaster* (Carl Zeiss, Germany), and A-scan *ultrasound biometry* (Alcon, America) were performed for each included eye. For all patients, cataract surgeries were randomly conducted by three experienced surgeons within 20 minutes. Approximately three months after the surgery, *subjective refractions* were conducted.

The IOLMaster measures axial length from the anterior corneal surface to the retinal pigment epithelium based on of PCI principles. Anterior chamber depth is measured from the anterior corneal pole to the anterior crystalline lens surface using a slit beam of light. K value is calculated based on reflected curvature data obtained from six points at a hexagonal pattern of 2.3 mm zone central cornea²⁵. The Topolyzer is a Placido disk-based videokeratoscope with 22 rings, which generates data from the anterior corneal surface with 22,000 data points¹¹. In the present study, K values from 3 mm central corneal zone were obtained for analysis.

Statistical Analysis

MedCalc Statistical Software version 11.0 (MedCalc Software, Inc., Mariakerke, Belgium) was applied for statistical analysis. A *P* value of less than 0.05 was considered to have statistical significance. Kolmogorov-Smirnov tests were used for the normal distribution analysis of all data, and all the *P* values were more than 0.05. All the results are presented as the mean $\pm$ standard deviation (SD).

For IOL power prediction, the results were calculated based on three groups: A-scan combining Topolyzer (AL and ACD from A-scan and K values from Topolyzer), IOLMaster combining Topolyzer (AL and ACD from IOLMaster and K values from Topolyzer) and IOLMaster only (all the data from IOLMaster). In each group, Haigis, Hoffer Q, SRK/T, and Holladay 1 formulas were applied for the prediction. Consequently, 12 predicted results were obtained for each eye. According to the subjective refraction obtained after surgery, the mean numerical error (NE) and absolute error (AE) were calculated as follows:

NE = predicted SE $\times$ actual postoperative SE

AE = $\times$ actual postoperative SE $\times$ predicted SE

where actual postoperative SE is the spherical equivalent of subjective refraction three months after surgery, while the predicted SE is the predicted spherical equivalent of subjective refraction preoperatively.

One predicted result generated one NE and AE. Therefore, twelve NEs and AEs were obtained for each eye. The percentages of eyes that had an NE or AE within ± 0.5 D, ± 1.0 D, and ± 2.0 D were calculated.

Results

Fifty-one eyes of 38 patients (19 men) with an average age of 72.21 ± 7.43 years (ranging from 56 to 87 years old) were included in the present study. Table 1 shows the AL, ACD, and K values obtained by A-scan, IOLMaster and Topolyzer. The AL and ACD obtained by IOLMaster were 0.23 ± 0.12 mm and 0.18 ± 0.19 mm longer than the AL and ACD obtained by A-scan (both $P < 0.05$, Table 2). For the K values, IOLMaster obtained rather higher flat K and lower steep K than Topolyzer, and both of the discrepancies were near 0.5 D. However, the difference between mean K values obtained by IOLMaster and Topolyzer were very small (0.04 D, $P = 0.33$, Table 2).

Table 3 shows the mean NE and AE of Haigis, SRK/T, Hoffer Q, and Holladay 1 formulas in the three groups. In the group of A-scan combining Topolyzer, the mean NEs of Haigis and HofferQ were close to 0.5 D, while the mean AEs of the two formulas were close to 0.6 D; the mean NEs of SRK/T and Holladay 1 were between 0.8 D and 0.9 D, while the mean AEs were about 0.9 D (Fig. 1). In the group of IOLMaster combining Topolyzer, the mean NEs of Haigis and Hoffer Q were close to 0, while the mean AEs of them were close to 0.5 D; the mean NEs of SRK/T and Holladay 1 were between 0.3 D and 0.4 D, while the mean AEs of the two formulas were about 0.6 D (Fig 2). In the group of IOLMaster only, the mean NEs of Haigis and Hoffer Q were close to 0, while the mean AEs of the two formulas were close to 0.4 D; the mean NEs of SRK/T and Holladay1 were about 0.4 D, while the mean AEs of the two formulas were about 0.5 D (Fig. 3).

Table 4 shows percentages of eyes that have an NE or AE within ± 0.5 D, ± 1.0 D, and ± 2.0 D. In the group of A-scan combining Topolyzer, the percentages within 0.5 D were between 35% (Holladay 1) and 51% (Haigis), the percentages within 1.0 D were between 63% (SRK/T) and 82% (Hoffer Q), and all the percentages within 2.0 D were no less than 96%. In the group of IOLMaster combining Topolyzer, the percentages within 0.5 D were between 53% (SRK/T) and 71% (Hoffer Q), all the percentages within 1.0 D were close to 90%, and all the percentages within 2.0 D were above 95%. In the group of IOLMaster only, the percentages within 0.5 D were between 59% (SRK/T) and 76% (Hoffer Q), all the percentages within 1.0 D were no less than 90%, and all the percentages within 2.0 D were above 97%.

Discussion

There are three fundamental elements for IOL power calculation, including AL measurements, K values, and the evaluation of postoperative IOL position. Consequently, precise ocular biometry is particularly essential. It has been reported that an error of 0.1 mm in AL measurement may lead to a 0.25 D prediction error²⁶, while an error of a 0.1 D in K value may lead to about 0.1 D prediction error. In the present study, AL obtained by IOLMaster was 0.23 ± 0.12 mm statistically longer than that obtained by A-scan, and this result is similar to previous studies. This discrepancy may result in about a 0.5 D prediction error. However, the mean K values obtained by IOLMaster and Topolyzer were comparable ($P = 0.33$). This is different from the results of our previous study¹¹ in which we reported that the mean K values obtained by IOLMaster were a little higher than those obtained by *Topolyzer*, whereas the differences were quite small, only 0.18 ± 0.03 D. The differences may be caused by the different subjects included in the 2 studies. In our previous study, mainly young people with a mean age of 35.11 ± 12.88 years were recruited, where as older people with a mean age of 72.21 ± 7.43 years were included in the present study. Here, we observed that AL measurements were one of the most important factors for refractive errors, and it accord with previous studies.²⁷⁻²⁹

In the present study, we evaluated the accuracy of four IOL power calculation formulas (Haigis, SRK/T, Hoffer Q, and Holladay 1 formulas) using three different methods (A-scan combining Topolyzer, IOLMaster combining Topolyzer, and IOLMaster only) for cataractous eyes with AL between 24.0 and 26.0 mm. To our knowledge, the mean NEs and AEs of the four formulas using biometry obtained by the

three methods have never been evaluated simultaneously. We found that the four formulas based on biometry from IOLMaster combining Topolyzer and IOLMaster only performed better than those based on biometry from A-scan combining Topolyzer. The main factor responsible for this discrepancy was AL measurement. The AL measurements obtained by IOLMaster were statistically longer (0.23 ± 0.12 mm) than those obtained by A-scan. This could contribute to about a 0.5 D difference.

In the present study, Haigis based on biometry from IOLMaster combining Topolyzer performed accurately as that based on biometry from IOLMaster only (both mean NEs close to 0). Similar situations occurred using SRK/T (both mean NEs close to 0.4 D), Hoffer Q (both mean NEs close to 0) and Holladay 1 (both mean NEs close to 0.3 D). Moreover, it appeared that both Haigis and Hoffer Q performed more accurately than SRK/T and Hoffer Q. However, the discrepancies were not large (all the mean NEs < 0.5 D). This is similar to previous studies. Wang et al.³⁰ found that Haigis formula yielded superior refractive results in eyes with various ALs. Tsang et al.³¹ reported that the Hoffer Q formula provided better predicted results than SRK/T and Holladay 1 in Chinese eyes with AL of more than 25 mm. Wang et al.³², in which they analyzed 34 eyes with AL between 25.00 and 28.00 mm found that SRK/T and Haigis formula performed equally well than Holladay 1, SRK-II, and Hoffer Q formulas. Aristodemou et al.²⁰ reported that the Holladay 1 formula may perform better than other third-generation formulas for refractive outcomes in eyes with AL between 23.50 and 26.00 mm. Moreover, several studies found that the Haigis formula was the most accurate at predicting refractive error in long and short ALs³³⁻³⁷. In the present study, the Hoffer Q formula performed as well as the Haigis formula with both mean NE and AE close to 0.

This study has some limitations. First, the sample size was small, only 51 eyes were included. Second, only cataractous eyes with AL between 24.0 and 26.0 mm were included. The results could be different in short or long eyes.

In conclusion, the four formulas based on biometry from IOLMaster combining Topolyzer and IOLMaster only performed better than those based on biometry from A-scan combining Topolyzer. Based on biometry from IOLMaster combining Topolyzer and IOLMaster only, the four formulas performed comparably. However, Haigis and Hoffer Q performed slightly better than SRK/T and Holladay 1 formulas. Therefore, for cataractous patients with AL between 24.0 and 26.0 mm, all four formulas based on biometry from IOLMaster combining Topolyzer and IOLMaster only can be used for the prediction of IOL power, and Haigis and Hoffer Q formulas are particularly recommended.

Abbreviations

IOL: intraocular lens

AL: axial length

K: keratometry

PCI: partial coherence interferometry

ACD: anterior chamber depth

NE: numerical error

AE: absolute error

SD: standard deviation

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Tables

Table 1. Parameters obtained by A-scan, IOLMaster and Topolyzer.

	A-scan		IOLMaster		Topolyzer	
	Mean $\pm$ SD	95% CI	Mean $\pm$ SD	95% CI	Mean $\pm$ SD	95% CI
AL (mm)	24.85 $\pm$ 0.52	24.71 to 25.00	25.08 $\pm$ 0.53	24.93 to 25.23	-	-
ACD (mm)	3.03 $\pm$ 0.35	2.93 to 3.13	3.21 $\pm$ 0.32	3.12 to 3.30	-	-
flat K (D)	-	-	43.52 $\pm$ 1.40	43.13 to 43.92	44.09 $\pm$ 1.35	43.71 to 44.47
steep K (D)	-	-	44.52 $\pm$ 1.34	44.14 to 44.90	43.88 $\pm$ 1.40	43.48 to 44.27
mean K (D)	-	-	44.02 $\pm$ 1.35	43.64 to 44.40	43.99 $\pm$ 1.30	43.62 to 44.35

AL: axial length, ACD: anterior chamber depth, flat/steep/mean K: flat/steep/mean keratometry, SD: standard deviation, 95% CI: 95% confidence interval.

Table 2. Comparison of AL, ACD and K values obtained by A-scan, IOLMaster and Topolyzer.

	Mean Differences $\pm$ SD	95% CI	t	P values
AL _{A-scan v.s. IOLMaster} (mm)	0.23 $\pm$ 0.12	0.19 to 0.26	13.75	< 0.05
ACD _{A-scan v.s. IOLMaster} (mm)	0.18 $\pm$ 0.19	0.13 to 0.23	6.93	< 0.05
flat K _{Topolyzer v.s. IOLMaster} (D)	-0.57 $\pm$ 0.67	-0.756 to -0.38	-6.09	< 0.05
steep K _{Topolyzer v.s. IOLMaster} (D)	0.64 $\pm$ 0.65	0.46 to 0.83	7.11	< 0.05
mean K _{Topolyzer v.s. IOLMaster} (D)	0.04 $\pm$ 0.27	-0.04 to 0.12	0.98	0.33

AL: axial length, ACD: anterior chamber depth, flat/steep/mean K: flat/steep/mean keratometry, SD: standard deviation, 95% CI: 95% confidence interval.

Table 3. Mean refractive prediction error.

	NEs		AEs	
	Mean±SD (D)	95% CI	Mean±SD (D)	95% CI
A-scan combining Topolyzer				
Haigis	0.44±0.67	0.25 to 0.63	0.64±0.49	0.50 to 0.78
SRK/T	0.86±0.66	0.68 to 1.05	0.91±0.59	0.74 to 1.08
HofferQ	0.55±0.59	0.39 to 0.72	0.62±0.52	0.47 to 0.76
Holladay1	0.82±0.59	0.65 to 0.98	0.86±0.52	0.72 to 1.01
IOLMaster combining Topolyzer				
Haigis	-0.03±0.71	-0.23 to 0.15	0.53±0.47	0.40 to 0.66
SRK/T	0.37±0.72	0.17 to 0.57	0.63±0.50	0.49 to 0.77
HofferQ	0.05±0.62	-0.13 to 0.22	0.43±0.44	0.13 to 0.56
Holladay1	0.32±0.63	0.14 to 0.50	0.54±0.45	0.41 to 0.66
IOLMaster only				
Haigis	0.02±0.54	-0.13 to 0.17	0.41±0.36	0.31 to 0.51
SRK/T	0.41±0.54	0.25 to 0.56	0.52±0.43	0.40 to 0.64
HofferQ	0.05±0.58	-0.11 to 0.21	0.36±0.46	0.23 to 0.48
Holladay1	0.32±0.45	0.19 to 0.45	0.43±0.35	0.33 to 0.52

SD: standard deviation, 95% CI: 95% confidence interval, NE: numerical error, AE: absolute error.

Table 4. Percentage of eyes within 0.5 D, 1.0 D, and 2.0 D of refractive prediction error.

	%±0.5 D	%±1.0 D	%±2.0 D
A-scan combining Topolyzer			
Haigis	51	78	98
SRK/T	41	63	96
HofferQ	59	82	100
Holladay1	35	67	96
IOLMaster combining Topolyzer			
Haigis	65	88	100
SRK/T	53	88	96
HofferQ	71	90	100
Holladay1	63	90	96
IOLMaster only			
Haigis	71	92	100
SRK/T	59	94	100
HofferQ	76	90	98
Holladay1	69	96	100

SD: standard deviation, 95% CI: 95% confidence interval.

Figures

Figure 1

Multiple variables graph of the mean NEs using Haigis, SRK/T, Hoffer Q and Holladay 1 formulas in A-scan combining Topolyzer group.

Figure 2

Multiple variables graph of the mean NEs using Haigis, SRK/T, Hoffer Q and Holladay 1 formulas in IOLMaster combining Topolyzer group.

Figure 3

Multiple variables graph of the mean NEs using Haigis, SRK/T, Hoffer Q and Holladay 1 formulas in IOLMaster only group.