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Original Article

Which IOL formula should be used to determine the lens power estimation? A data analysis based on 3258 eyes

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Abstract: This study is a data-based retrospective analysis using 5 formulas: Holladay I, Hoffer Q, SRK/T, Holladay II and Haigis to compare the accuracy of IOL power estimation, the mean absolute errors between postoperative and predictive refractions were compared among five most commonly used IOL power formulas. For the eyes with AL equal to 29 mm or shorter than 21 mm, the effect of Haigis formula performed better than other formulas. For other eyes, Haigis formula seemed to have similar accuracy with other formulae. In China, we suggest that it is better to use Haigis formula to predict the IOL power before cataract surgery.

Keywords: Intraocular lens power, IOL formula, AL, ELP

Introduction

Being an age-related ophthalmological disease, cataract is the cause for more than 30% of world blindness [1]. One of the most successful treatments today is the cataract surgery, in which the natural lens will be replaced by a clear intraocular lens (IOL). To achieve optimum outcomes of treatment, the IOL power should be accurately calculated before cataract surgery.

In the last two decades, IOL formulas have been optimized from the 1st generation to 4th. Generations, in which the third and fourth generation are theoretical formula based on geometrical optics and use the estimated lens position (ELP) to calculate the power of the IOL. The values of ELP are associated with axial length and corneal power.

The third-generation formulae estimate ELP in different way and had been reported to have “good balance” results of IOL power, in addition to those with high and extreme myopia [2, 3]. Until the fourth-generation formula came into being, it was the most commonly used formula, which included three lens constants and said to be more humanized. However, there was no single formula could be proved to be suitable for all eyes [4].

The objective of this study was designed to evaluate the accuracy of third and fourth generation IOL power formula and to explore which formula is suitable for cataract patients, especially for Chinese eyes, based on 3258 eyes of our outpatients in the past three years.

Patients and methods

The Beijing Tongren Eye Center is one of the biggest ophthalmological clinics in China with more than 800 outpatients and about 40 cataract surgeries daily. The data from the study would be collected from the patients operated from Aug. 1, 2013 to Aug. 31, 2016. Patients who had any ophthalmological surgery affecting the IOL power, perioperative complications associated with the index procedure or any eye pathology reducing the visual acuity before the cataract surgery were excluded from the data collection. To avoid two same genetically identical eyes in the data pool when both eyes need to be operated in one patient, the operated

Table 1. Ocular biometry of 3258 patients

	Mean ± SD	Median	Range
Age (years)	60.30±12.70	62.40	33.90-88.40
K1 (D)	7.72±0.28	7.71	5.87-9.27
K2 (D)	7.53±0.27	7.53	6.04-9.26
ACD (mm)	2.97±0.62	2.97	1.25-4.89
Axial length (mm)	25.03±3.41	27.42	18.00-32.42
IOL (D)	21.00±5.87	23.11	5.22-38.10

right eye on the patient would be the only one included within the study.

All of recruited patients were operated on by one surgeon (Dr. SQ Zhu) using one technique (Phacoemulsification) and one intraocular lens style (AA4203). It is known that the different lens style has a different predictive error by the same IOL power [5]. The axial lengths (AL) of the lens would be measured by one ophthalmologist with Zeiss IOL Master (version 4.02). Manual keratometry was obtained from all patients. All the other ocular biometry needed by IOL formulae (including horizontal white-to-white (WTW) corneal diameter, mean keratometric (K1 and K2) readings, anterior chamber depth (ACD) and axial length) were also measured using Zeiss IOL Master. The predictive IOL powers were estimated by each IOL formulae (SRK/T, Hoffer Q, Holladay I, Holladay II and Haigis) with ULIB optimized constants. Based on measured AL by IOL Master, an optimized AL was recalculated in the present study according to $AL_{opt} = (AL_{IOL} \times 0.9571 + 1.3033) \times 1.3549/1.3616$ referred by Olsen [6].

The visual acuities were examined at the first and the third month by the same optometrist after surgery separately. The best corrected distance visual acuity was used to calculate the spherical equivalent refraction (IOL power). The absolute differences between predicted IOL power and postoperative IOL power are defined as the absolute error. The normality and homogeneity was examined before statistical analysis and mean absolute error (MAE) or median absolute error (MedAE) would be used to evaluate the difference between Haigis' formula and Holladay 2 using signed ranks test. The absolute errors were also analyzed between Haigis and the other formulas using analysis of variance (ANOVA). When the density distribution of data is abnormal, Friedmann test would be used to check if there was significant difference between them. Since the present study was a retrospective analysis based on available data, IRB's approval was not required [7].

In the present study, eyes were classified into seven groups (<21 mm, 21 to <23 mm, 23 to <25 mm, 25 to <27 mm, 27 to <29 mm, 29 to <31 mm, ≥31 mm) according to their axial length[5] and would be analyzed respectively. The study was designed as paired comparison with power of 80%. The significant level was set at 0.05. All the statistical analysis was performed with SAS software (Version 9.3).

Results

From Aug. 1, 2013 to Aug. 31, 2016, a total of 3258 eligible cataract patients (3258 eyes) aged from 33.9 to 88.4 years old were recruited in the present study. The axial length varied from 18 mm to 32.42 mm and IOL power ranged from + 5.22D to + 38.1D. The mean horizontal (K1) and the vertical (K2) readings were 7.72±0.28 and 7.53±0.27 respectively (**Table 1**).

The distribution of eyes by various predicted errors for all formulas was shown in **Table 2**. Most of the eyes had MAEs value between-1 and 1, and no eye had an error of refraction more than 2D. As compared with 3rd generation formula, the 4th generation formula had less proportion (Holladay 2: 6.59%; Haigis: 4.18%) of MAE more than 1D and they had less proportion (Holladay 2: 6.04%; Haigis: 4.25%) of MAE less than -1D as well.

The comparisons of MAEs between various formulas were stratified by axial length. For average length eyes (23≤ axial length <27) no difference was observed between Holladay 1, Hoffer Q, SRK/T and Haigis, which means, for those eyes with average axial length, the formula of Holladay 1, Hoffer Q, SRK/T and Haigis had the same accuracy to calculate the IOL power. By the abnormal axial length the MAE of Haigis is 0.58±0.28D, 0.50±0.23D, 0.55±0.24D and 0.59±0.25D for group of axial length shorter than 21 mm, 21 to <23 mm, 29 to <31 mm and longer than 31 mm respectively and they were less than those of other third generation formulas. The difference was statistical significant with *P* value lower than 0.05.

Table 2. Percent (%) of eyes by predicted error (D) by various formulas

	MAE	MedAE	-2~-1	-1~-0.5	-0.5~0	0~0.5	0.5~1	1~2
SRK/T	0.66±0.30	0.71	10.75	16.67	23.02	20.07	18.97	10.52
Hoffer Q	0.63±0.29	0.59	8.25	16.41	23.30	23.36	17.15	11.53
Holladay 1	0.63±0.30	0.56	9.16	16.59	22.88	24.30	15.98	11.08
Holladay 2	0.56±0.23	0.46	6.04	18.06	25.58	27.89	15.84	6.59
Haigis	0.51±0.24	0.40	4.25	17.44	27.11	28.56	18.46	4.18

Table 3. Mean absolute errors (MAEs) for all eyes by various formula

AL (mm)	Eyes (%)	SRK/T	Hoffer Q	Holladay 1	Haigis	p
<21	139 (4.27)	0.82±0.40	0.84±0.38	0.81±0.37	0.58±0.28	<0.001*
21 to <23	225 (6.91)	0.79±0.37	0.82±0.38	0.81±0.37	0.50±0.23	0.045
23 to <25	1007 (30.91)	0.56±0.25	0.57±0.26	0.63±0.29	0.50±0.23	0.072
25 to <27	1340 (41.13)	0.62±0.30	0.61±0.27	0.64±0.29	0.49±0.21	0.134
27 to <29	307 (9.42)	0.59±0.28	0.60±0.27	0.64±0.29	0.55±0.26	0.071
29 to <31	154 (4.73)	0.74±0.35	0.77±0.35	0.66±0.30	0.55±0.24	0.047**
≥31	86 (2.64)	0.85±0.40	0.87±0.39	0.69±0.30	0.59±0.25	0.033***
	3258	0.63±0.30	0.64±0.29	0.66±0.30	0.51±0.24	0.057

*p value of Friedmann test; ***p* value of Friedmann test; ****p* value of Friedmann test.

Table 4. Mean absolute errors (MAEs) for all eyes by Holladay 2 and Haigis

AL (mm)	Eyes (%)	Holladay 2	Haigis	*p*
<21	139 (4.27)	0.71±0.24	0.58±0.23	0.048*
21 to <23	225 (6.91)	0.65±0.22	0.50±0.22	0.094
23 to <25	1007 (30.91)	0.52±0.19	0.50±0.18	0.165
25 to <27	1340 (41.13)	0.53±0.19	0.49±0.19	0.972
27 to <29	307 (9.42)	0.57±0.22	0.55±0.21	0.969
29 to <31	154 (4.73)	0.63±0.24	0.55±0.24	0.038**
≥31	86 (2.64)	0.72±0.27	0.59±0.25	0.029***
	3258	0.56±0.18	0.51±0.24	0.980

*p value of Friedmann test; ***p* value of Friedmann test; ****p* value of Friedmann test.

However, there was no difference between those formulas for MAEs by group of 27 to <29 mm axial length (P = 0.071). For all eyes without stratification by AL, there was no significant difference of MAEs between Haigis and other formulas (P = 0.057) as well (**Table 3**).

The MAE comparison between Holladay 2 and Haigis was shown in **Table 4**. Generally, no significant difference of MAEs between Holladay 2 (MAE: 0.56±0.18D) and Haigis (0.51±0.24D) was observed (P = 0.980). By the shorter (<21 mm) or extreme longer (≥29 mm) eyes, the difference of MAEs between them was statistically significant and showed that Haigis was more accurate than Holladay 2 on these eyes.

In most cases, the MAEs across all formulas were similar for eyes with axial length ranged from 21 to 29 mm. In the present study, based on 11.62% of the eyes (shorter or extreme longer) that Haigis formula was found to be more accurate than the other formulas.

Discussion

In our study, the consistency of five IOL power calculation formulas in 3258 eyes was compared. The optimized Haigis formula is found to be more accurate than other formulas on shorter (<21 mm) or extreme longer (≥29 mm) eyes. Although Haigis formula showed a lower MAE on average axial length eyes, no statistically significant was observed in the present study.

Although the accuracy of IOL power calculation is related to lens style [5] and measuring equipment [8, 9], lots of studies, that used different lens style and even various equipment, had reported that most of formulas performed same effect and no statistically significant difference seemed to be found among their estimation on the normal or medium or average AL eyes [10-12].

There is no consistent conclusion about the prediction error of long eyes (AL more than 29 mm). Our results have showed that optimized Haigis formula performed better than others. Although Aristodemou *et al.* suggested another formula performed better in their study based on 8018 eyes, we firmly believed the present study achieved the best results according to our study design.

Unlike other studies, the subgroups in the present study had not been classified according to Hoffer's reference, because of potential difference of average AL between European and Chinese eyes [13-14]. The subgroups of eyes were divided every 2 millimeters of AL into one group. Another advantage of this study was the consistency of biometric data collection, which has been collected by one optometrist using one equipment (IOL Master), operated by one surgeon using one intraocular lens type (AA4203) and one technique (Phacoemulsification). Furthermore, the study did not include two genetically identical eyes. We are not sure of the exact effect of two genetically identical eyes in the analysis, but it is possible that two genetically identical eyes in data could strongly enlarge or decrease the working effect of formulas. In another study, in which there was only one eye per patient, Cook et al. reported a consistent result that Haigis performed better than Holladay 1 and 2, SRK/T and Hoffer Q on long AL eyes with more than 1000 eyes [12]. Besides, Cook et al. Also showed that Haigis performed better than Holladay 1 and 2, SRK/T and Hoffer Q on short eyes [11].

The association between myopia and shorter AL is difficult to be explained [15, 16], most of the formulas has more predicted error than they did for normal AL eyes. The ELP, which cannot be measured before operation, becomes the key error source after using PCI technology by IOL Master [17]. The reason that Haigis formula had good results seemed to be associated with its three constants, particularly a2, which could be optimized by data collected from the operation before [12].

One of the possible limitations in this study is that the IOL power estimation of Holladay 2 formula is not used lens thickness (LT) because it is unable to be measured by the IOL master. To avoid measurement error between two devices, only IOL Master was used. Moreover, the results for Holladay 2 with or without LT was reported to be no statistically significant difference [18], and that seemed to be little problem for our results. Our surgical and refractive techniques may lead to some bias, though this is very unlikely.

In this study, the absolute predicted error was used to be compared among formulas. But whether the predictive value was more or less than postoperative refraction, whether the positive or negative difference is consistent within formulas and whether there is some relationship between hyperopic and the positive or negative difference, were not further and deeply discussed.

In conclusion, our preliminary results suggest that the Haigis formula have more satisfied estimation of IOL power than others among Chinese and then should be used on cataract surgery in the clinic as the first option in China. Even if Haigis Formula is not available, the other formula like Holladay 1&2, Hoffer Q and SRK/T can also get acceptable results on medium eyes.

Disclosure of conflict of interest

None.

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