·Clinical Research·

Optical biometry intraocular lens power calculation using different formulas in patients with different axial lengths

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Foundation item: This study was supported by grants of Far Eastern Memorial Hospital (FEMH-97-HHC-008), Taiwan, China

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Received: 2012-08-05 Accepted: 2013-03-20

Abstract

• **AIM: To investigate the predictability of intraocular lens (IOL) power calculation using the IOLMaster and different IOL power calculation formulas in eyes with various axial length (AL).**

• **METHODS: Patients were included who underwent uneventful phacoemulsification with IOL implantation in the Department of Ophthalmology, Far Eastern Memorial Hospital, Taipei, Taiwan, China from February 2007 to January 2009. Preoperative AL and keratometric values (Ks) were measured by IOLMaster optical biometry. Patients were divided into 3 groups based on AL less than 22mm (Group 1), 22-26mm (Group 2), and more than 26mm (Group 3). The power of the implanted IOL was used to calculate the predicted postoperative spherical equivalence (SE) by various formulas: the Haigis, Hoffer Q, Holladay 1, and SRK/T. The predictive accuracy of each formula was analyzed by comparing the difference between the actual and predicted postoperative SE (MedAE, median absolute error). All the patients had follow-up periods exceeding 3 months.**

• **RESULTS: Totally, there were 200 eyes (33 eyes in Group 1, 92 eyes in Group 2, 75 eyes in Group 3). In all patients, the Haigis had the significantly lower MedAE generated by the other formulas (*P*<0.05). In Group 1 to 3, the MedAE calculated by the Haigis was either significantly lower or comparable to those calculated by the other formulas.**

• **CONCLUSION: Compared with other formulas using IOLMaster biometric data, the Haigis formula yields superior refractive results in eyes with various AL.**

• **KEYWORDS:** intraocular lens; optical biometry; calculation formula
DOI:10.3980/j.issn.2222-3959.2013.02.08

Wang JK, Chang SW. Optical biometry intraocular lens power calculation using different formulas in patients with different axial lengths. *Int J Ophthalmol* 2013;6(2):150-154

INTRODUCTION

The accurate calculation of intraocular lens (IOL) power is essential for attaining the desired refractive outcome after cataract surgery. The accuracy of the calculation mainly depends on the accuracy of the preoperative biometric data [axial length (AL), anterior chamber depth (ACD), and keratometric value (K)] and accuracy of IOL power calculation formulas [1]. Studies based on preoperative and postoperative ultrasound biometry demonstrated that 54% of the errors in predicted refraction after IOL implantation can be attributed to AL measurement errors[2]. Therefore, precise preoperative measurement of AL is the most critical step to improve IOL power prediction[3].

Applanation ultrasonic biometry may cause erroneous measurement of AL owing to indentation of the globe and off-axis measurement of AL by the transducer [3-9]. The immersion ultrasound avoids these drawbacks to measure AL without indentation of the eyeball, having better refractive outcome than applanation A-scan in IOL power prediction[8]. The introduction of the IOLMaster commercially for IOL power calculation uses optical biometry and various formulas of IOL power calculation [10-21]. The optical biometric device measures AL, ACD, and K. The technology called dual-beam partial coherence interferometry is used to measure AL [1,10]. It measures reflected infrared laser light from internal tissue interfaces, that is, the optical path length from the anterior surface of the cornea to the retinal pigment epithelium [1,10,11]. AL in standard ultrasound biometry is from the corneal vertex to the internal limiting membrane, and the formulas built into the IOLMaster convert this optical path length into a geometric distance [11]. The readings of the IOLMaster, calibrated against immersion ultrasound by the manufacturer, were recalculated to represent the true optical length and used in the analysis of the consistency of the measurement [20]. ACD, from corneal epithelium to the anterior surface of the lens, is estimated by optical pachymetry [15]. The IOLMaster is a quick, easy-to-use non-contact device [18]. With the aid of a fixation beam, it measures AL along the visual axis [11]. No anesthesia is needed, and there is no risk of corneal trauma or infection [1,12,18]. Pupillary dilatation is also not required. The IOLMaster is less operator-dependent, compared to applanation ultrasound [4,13]. Intraexaminer and interexaminer variability of the ACD and AL is smaller when measured using the IOLMaster than when measured using applanation ultrasound, because the measurement axis is consistent with the visual axis and there is no indentation of the globe[4]. The reproducibility of the AL and ACD measurements is very high [12,15]. The precision of high resolution, partial coherence interferometry with the IOLMaster[1,22], is 10 times better than that of ultrasound [1,10]. AL measurement and calculation of IOL power by optical biometry is comparable or more accurate than that by applanation ultrasound in a normal population[1,3,4,10].

Using IOL power calculation formulas are important for postoperative refractive accuracy [23-37]. Third-generation formulas, such as the Hoffer Q, Holladay 1, and SRK/T recognize that postoperative ACD varies with AL and corneal curvature [25-27]. The Holladay 1 and SRK/T formulas use corneal height equation to predict postoperative ACD, whereas the Hoffer Q uses an independently developed formula in which the tangent of corneal power is used [25-27]. The Haigis formula, a fourth-generation formula, is different from the 2-variable formulas. It uses three constants: $a0$, $a1$ and $a2$ to calculate the effective lens position (d) where $d = a0 + (a1 \times ACD) + (a2 \times AL)$. The Haigis formula recommends IOL power based on three-variable($a0$, $a1$, and $a2$) function[11,33].

The purpose of the study is to compare the predictability of IOL power calculations by various formulas using optical biometric data regarding eyes with different AL.

SUBJECTS AND METHODS

This research was carried out in accordance with the Declaration of Helsinki and after obtaining approval from the Institutional Review Board of Far Eastern Memorial Hospital (FEMH-IRB-100027-E). From February 2007 to January 2009, the patients underwent uneventful phacoemulsification and in-the-bag implantation of one-piece soft hydrophobic acrylic posterior chamber IOL (AcrySof, SA60AT, Alcon Labs, Fort Worth, TX, USA) at Far Eastern Memorial Hospital by one surgeon (Wang JK). All patients signed informed consent forms agreeing to surgery. Eyes with pathology or operative complications affecting the refractive results and those with missing data were excluded. Preoperative AL data and keratometric values (Ks) were obtained with the IOLMaster (Carl Zeiss, Jena, Germany) by experienced technicians. Only the signal-to-noise (SNR) value more than 2.1 was recorded [20]. Patients were divided into 3 groups based on AL less than 22mm (Group 1), 22-26mm (Group 2), and more than 26mm (Group 3). The follow-up period in all patients was more than 3 months. The actual postoperative spherical equivalence (SE) was recorded 3 months following the surgery by auto-refractor (Topcon AR, Tokyo, Japan). Preoperative biometry data and the Haigis formula were used to calculate the power of the implanted IOL and predicted postoperative SE. The IOLMaster permitted calculation using four theoretical formulas: the Haigis, Hoffer Q, Holladay 1, and SRK/T. The numeric error was calculated (actual postoperative SE-predicted postoperative SE). The optimization was performed according to the prior study[30]. The mean numeric error of each formula was adjusted to zero by adjusting the IOL constant using the Excel Query/What IF function. The absolute error was the absolute value of the numeric error. Since absolute errors are not a Gaussian distribution, median absolute error (MedAE) and mean absolute error (MAE) were reported. The predictive accuracy of the formula was analyzed by comparing MedAE of the Haigis with that of the other formulas using Wilcoxon signed rank test.

RESULTS

Totally, 200 right eyes of 200 patients were included in the study. There were 109 males. The IOL power ranged from +6 to +30D. The AL varied from 20.16 to 31.16mm. The mean AL was 24.75±2.71mm, and the mean K was 43.48±1.66D in all patients. Table 1 showed the refractive results using various formulas. The smallest MedAE 0.39D was calculated using the Haigis, comparing with 0.45D using the Hoffer Q (P=0.01), 0.44D using Holladay 1 (P=0.02), and 0.43 D using the SRK/T (P=0.04).

In Group 1 (33 eyes), the mean AL was 21.52±0.47mm, the mean keratometric value was 44.64±1.97D, and the MAE and MedAE calculated by the Haigis were 0.66D and 0.57D respectively (Table 2). The MedAE generated by the Haigis was comparable to that by the Hoffer Q (P=0.13), but significant lower than that by Holladay 1 and SRK/T(P<0.05).

In Group 2 (92 eyes), the mean AL was 23.45±0.99mm, the mean keratometric value was 44.64±1.97D, and the MAE and Med AE calculated by the Haigis were 0.52D and 0.40D respectively (Table 3). The MedAE generated by the Haigis was comparable to those by the Hoffer Q, the Holladay 1, and SRK/T (P>0.05).

Table 1 Intraocular lens power calculation with various formulas by optical biometry in all patients (n =200)

	Median	Mean±SD	P
Axial length (mm)	23.68	24.75±2.71	
Keratometric value (D)	43.44	43.48±1.66	
Absolute error- Haigis (D)	0.39	0.49±0.46	
Absolute error- Hoffer Q (D)	0.45	0.55±0.46	[1]0.01
Absolute error- Holladay 1 (D)	0.44	0.54±0.46	[2]0.02
Absolute error- SRK/T (D)	0.43	0.53±0.46	[3]0.04

[1]Haigis *vs* Hoffer Q; [2]Haigis *vs* Holladay 1; [3]Haigis *vs* SRK/T. Absolute error-a IOL power calculation formula: absolute error associated with the implanted intraocular lens power calculated by the IOL formula; absolute error= | formula-predicted refractive error - actual postoperative refractive error | .

Table 2 Intraocular lens power calculation with various formulas by optical biometry in Group 1 (n = 33)

	Median	Mean±SD	P
Axial length (mm)	21.59	21.52±0.47	
Keratometric value (D)	44.76	44.64±1.97	
Absolute error- Haigis (D)	0.57	0.66±0.68	
Absolute error- Hoffer Q (D)	0.58	0.67±0.59	[1]0.13
Absolute error- Holladay 1 (D)	0.63	0.71±0.62	[2]0.01
Absolute error- SRK/T (D)	0.69	0.78±0.66	[3]0.004

Group 1: patients with axial length less than 22mm. [1]Haigis *vs* Hoffer Q; [2] Haigis *vs* Holladay 1; [3]Haigis *vs* SRK/T. Absolute error-a IOL power calculation formula: absolute error associated with the implanted intraocular lens power calculated by the IOL formula; absolute error= | formula-predicted refractive erroractual postoperative refractive error | .

Table 3 Intraocular lens power calculation with various formulas by optical biometry in Group 2 (n =92)

	Median	Mean±SD	P
Axial length (mm)	23.18	23.45±0.99	
Keratometric value (D)	43.62	44.64±1.97	
Absolute error- Haigis (D)	0.40	0.52±0.46	
Absolute error- Hoffer Q (D)	0.45	0.57±0.46	[1]0.07
Absolute error- Holladay 1 (D)	0.42	0.56±0.46	[2]0.16
Absolute error- SRK/T (D)	0.43	0.56±0.46	[3]0.15

Group 2: patients with axial length between 22 and 26mm. [1]Haigis *vs* Hoffer Q; [2] Haigis *vs* Holladay 1; [3]Haigis *vs* SRK/T. Absolute error-a IOL power calculation formula: absolute error associated with the implanted intraocular lens power calculated by the IOL formula; absolute error = | formula-predicted refractive error-actual postoperative refractive error | .

In Group 3 (75 eyes), the mean AL was 28.03±1.22mm, the mean keratometric value was 42.88±1.49D, and the MAE and Med AE calculated by the Haigis were 0.44D and 0.39D respectively (Table 4). Compared to the MedAEs generated by the other formulas, the MedAE generated by the Haigis was comparable to that by the SRK/T (P =0.1), and significantly lower than those by the Hoffer Q and Holladay 1 (P<0.05).

DISCUSSION

The IOLMaster is a non-contact, user- and patient- friendly, partial coherence interferometry device for AL determination

Table 4 Intraocular lens power calculation with various formulas by optical biometry in Group 3 (n =75)

	Median	Mean±SD	P
Axial length (mm)	28.09	28.03±1.22	
Keratometric value (D)	42.67	42.88±1.49	
Absolute error- Haigis (D)	0.39	0.44±0.39	
Absolute error- Hoffer Q (D)	0.48	0.52±0.41	[1]0.004
Absolute error- Holladay 1 (D)	0.47	0.51±0.41	[2]0.003
Absolute error- SRK/T (D)	0.41	0.45±0.1	[3]0.1

Group 2: patients with axial length more than 26mm. [1]Haigis *vs* Hoffer Q; [2] Haigis *vs* Holladay 1; [3]Haigis *vs* SRK/T. Absolute error-a IOL power calculation formula: absolute error associated with the implanted intraocular lens power calculated by the IOL formula; absolute error = | formula-predicted refractive erroractual postoperative refractive error | .

and IOL planning[11]. The IOLMaster has high precision of all the currently available diagnostic instruments in routine use for measuring AL [16]. The corneal radius measured by the IOLMaster and the automatic keratometer match closely[12,15]. Optical biometry has improved the refractive results of cataract surgery patients and is more accurate than applanation ultrasound biometry[1,3,4,10,17,18].

In eyes with medium AL, IOL power prediction results have varied, depending on the formula used for optical biometry data analysis [10,17]. A previous study found no significant difference in refractive outcome as assessed by the Holladay 1, Olsen, and SRK/T in 77 eyes [10]. In 100 eyes with average AL of 22.89mm, the IOL power calculation using the Holladay formula produced better results than did the SRK/T and Hoffer Q formulas [17]. In a study consisting 8 018 eyes, the Holladay 1 performed slightly better or equivalent as the Hoffer Q and SRK/T for AL between 22 and 26mm[5]. In our study, the Haigis formula had similar performance as the Hoffer Q, Holladay1, and SRK/T in medium eye.

Several studies evaluating the accuracy of various IOL power calculation formulas used optical biometry data obtained from assessments in eyes with long AL [5,29,31-35]. A study consisting of more than 300 long eyes, demonstrated the performance of the SRK/T better than the Holladay 1 and Hoffer Q for AL more than 27mm[5]. Roessler and associates revealed the Haigis provided the best predictability of postoperative refractive outcome than the Holladay 1 and SRK/T for 37 eye with AL more than 26.5mm [29]. In extremely myopic eyes, in which minus powered IOLs were required, there was evidence suggesting the Haigis formula performs best in these cases[31,33]. The Haigis performed better than the Hoffer Q, Holladay 2, and SRK/T formulas in 44 eyes with AL more than 26mm receiving myopic refractive lens exchange [34]. Bang and associated reported the Haigis formula was the most accurate in predicting postoperative refractive error comparing with the Hoffer Q, Holladay 1, Holladay 2, and SRK/T for 53 eyes with AL more than 27mm [35]. In our previous study, the SRK/T and Haigis performed equally well and outperformed the Hoffer Q and Holladay 1 in 34 eyes between 25 and 28mm [32]. We analyzed 34 eyes with an AL of 28mm or longer and found that the Haigis was better than the SRK/T [32]. In this study, we discovered a similar result. The Haigis and SRK/T achieved similar refractive outcomes in eyes more than 26mm, and better than the Hoffer Q and Holladay 1.

Several studies evaluating the accuracy of various IOL power calculation formulas used optical biometry data obtained from assessments in eyes with short AL [5,23,24,34,37]. Aristodemou and coauthors reported significantly more predictable refractive outcomes using the Hoffer Q for more than 600 eyes shorter than 22mm than the Holladay and SRK/T [5]. Roh and associates found the performance of the Haigis formula better than the Hoffer Q and SRK/T in 25 eyes with AL shorter than 22mm [23]. Gavin and Hammond showed the Hoffer Q had better ability to predict refractive outcome than the SRK/T in 41 eyes with AL less than 22mm [24]. MacLaren and colleagues collected 76 eye undergoing cataract surgery with IOLs ranging in power from 30 to 35 D. They found the Haigis was more accurate for open-loop, whereas the Hoffer Q was more accurate for plate-haptic lenses [37]. In this study, the Haigis and Hoffer Q yielded comparable refractive results in eyes with AL shorter than 22mm and open loop IOL, but performing better than Holladay 1 and SRK/T.

In the current study, using IOLMaster data in the Haigis formula yielded the best results when compared to the Hoffer Q, Holladay 1, and SRK/T in 200 eyes. The Haigis formula owns superior performance possibly because of its inclusion of the IOLMaster-measured ACD[35]. The Hoffer Q, Holladay 1, and SRK/T are 2-variable formulas that rely on AL and central corneal power to predict the postoperative IOL position. These formulas do not use actual measurements of the ACD; they assume that short eyes will have shallower ACDs and long eyes will have deeper ACDs. However, 80% of short eyes have large crystalline lenses but a normal anterior chamber anatomy in the pseudophakic state [36]. Another erroneous assumption is that eyes with steep corneas have deep anterior chambers and eyes with flatter corneas have shallow anterior chambers [35]. These probably were the reasons why these formulas were less accurate than the Haigis in this study. Besides, the mean preoperative refraction was on myopic side owing to the mean AL 24.75mm. This affected performance of formulas, especially better for the SRK/T (MedAE 0.43D) and worse for the Hoffer Q (MedAE 0.45D).

The quality of the AL readings of the IOLMaster was influenced by the SNR value[20]. After excluding poor quality readings (SNR <2.1), the postoperative AL measurements with the IOLMaster showed a high correlation with the preoperative measurement [20]. In the current study, the only acceptable SNR values were more than 2.1 in AL measurement with the IOLMaster.

In the current study, we use four different IOL power calculation formulas with optimized IOL formula constants and the IOLMaster device for biometry. Our findings indicate that the Haigis and Hoffer Q formula would give the best refractive outcomes in short eyes. The Haigis, Hoffer Q, Holladay 1, and SRK/T are equally good for medium eyes. For long eyes, the Haigis and SRK/T would perform best.

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