Original Article

Accuracy of the Barrett Universal II formula integrated into a commercially available optical biometer when using a preloaded single-piece intraocular lens

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Purpose: To compare the commonly used formulas for intraocular lens (IOL) selection using IOLMaster®700 (Carl Zeiss Meditec) and to evaluate the Barrett Universal II (BU-II) formula accuracy when using the Vivinex™ iSert® XY1 IOL (Hoya Corporation Medical Division). **Methods:** A retrospective chart review was performed that included patients who underwent uneventful cataract surgery with in-the-bag insertion of Vivinex™ iSert® XY1 IOL. Prediction errors at 3 months postoperative of IOLMaster® 700 with Haigis, Holladay 1, SRK/T, and BU-II formulas were compared. As a subgroup analysis, we focused on the axial length (AL) and IOL power. AL subgroup analysis was based on the following AL subgroups: short (<22.5 mm), medium (22.5–25.5 mm), and long (>25.5 mm). IOL power subgroup analysis was based on the following IOL power subgroups: low (≤18.0 diopters [D]), medium (18.5–24.0 D), and high (≥24.5 D). **Results:** This study included 590 eyes of 590 patients. Overall, the four IOL calculation formulas appeared to be similarly accurate. In the long AL subgroup, the BU-II formula had a significantly lower absolute error (AE) than the Holladay 1 formula. In the low-power subgroup, the BU-II formula had a significantly lower AE than the Holladay 1 and SRK/T formulas. On the other hand, in the high-power subgroup, the BU-Ⅱ formula was significantly less accurate than the SRK/T formula and also appeared to be worse than the Holladay 1 formula (P = 0.052). **Conclusion:** The BU-II formula might be less accurate when using a Vivinex™ iSert® XY1 IOL of 24.5 D or greater.

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The evolution of intraocular lens (IOL) power calculation formulas and the optical biometry both contribute to achieving better refractive outcomes. Among several IOL power calculation formulas, the Barrett Universal II (BU-II) formula has been considered to be one of the most accurate formulas.[1-7] Using IOLMaster® 700 (Carl Zeiss Meditec AG, Jena, Germany), cataract surgeons can now easily obtain refractive prediction, including with the BU-II formula. To the best of our knowledge, there have been no previous reports on the comparison of the accuracy of the IOL power calculation formulas for the Vivinex™ iSert® XY1 IOL (Hoya Corporation Medical Division, Tokyo, Japan). The purpose of this present study was to compare the commonly used formulas for IOL selection and to evaluate the accuracy of BU-II formulas for the Vivinex™ iSert® XY1 IOL.

Methods

In this study, a retrospective chart review was performed that included patients who underwent uneventful cataract surgery with in-the-bag insertion of Vivinex™ iSert® XY1 IOL. Approval of the study protocol was obtained from the institutional review board. Five surgeons performed all surgeries by 2.4-mm clear cornea temporal incision phacoemulsification using the Centurion® Vision System (Alcon Laboratories, Inc., Fort Worth, Texas, USA). All patients were measured preoperatively with the IOLMaster® 700. Approval of the study protocol was obtained from the Institutional Review Board of Machida Hospital. And the date of the approval was March 28th, 2020.

This study included the patients who had subjective refraction within 45 to 135 days after surgery. The exclusion criteria were patients with incomplete biometry, a postoperative best-corrected visual acuity of worse than 20/40, a keratometric cylinder of more than 4.0 diopters (D), and a lens thickness measurement of less than 2.50 mm. If both eyes were eligible, the eye with better visual acuity was selected. If the visual acuity was equal in both eligible eyes, the eye closer to 90 days after surgery was selected. No patients received bilateral surgeries on the same day.

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With the software built into the IOLMaster® 700 (Software Version 1.70), the IOL power was calculated using the Haigis, Holladay 1, SRK/T, and BU-II formulas. The IOL constants were used for the reference value provided by the manufacturer, that is, a0, −1.047, a1, 0.081, and a2, 0.261 for the Haigis formula; surgeon factor, 2 for the Holladay 1 formula; A constant, 119.2 for the SRK/T formula; and lens factor, 1.99 for the BU-II formula. Lens factor was determined by converting the optimized A constant of the SRK/T formula using the calculation tool of the BU-II formula (available at https://www.apacrs.org). Subjective refraction was evaluated at 3 months postoperative. Using each formula, the prediction error was calculated by the actual postoperative spherical equivalent refraction minus the predicted preoperative refraction.

The mean prediction error (ME), standard deviation (*SD*) of prediction error, mean absolute error (MAE), and median absolute error (MedAE) were calculated for each formula. The percentages of eyes within ± 0.25 D, ±0.50 D, ±0.75 D, and ± 1.00 D of the refractive prediction error were also calculated.

As a subgroup analysis, we focused on axial length (AL) and IOL power. AL subgroup analysis was based on the following AL subgroups: short (<22.5 mm), medium (22.5–25.5 mm), and long (>25.5 mm). IOL power subgroup analysis was based on the following IOL power subgroups: low (≤18.0 D), medium (18.5-24.0 D), and high (≥24.5 D). The IOL power subgroup was divided into three groups with similar proportions as the AL subgroup.

All statistical analyses were performed with the open-source Easy R (EZR) statistical software, which is based on R and R commander.[8] It is a modified version of R commander designed to add statistical functions frequently used in biostatistics, and all analyses were performed in accordance with the editorial.[9] The differences in absolute error between the formulas were assessed using the Friedman test. In the event of a significant result, *post hoc* analysis was performed using the Wilcoxon signed-rank test with Bonferroni correction. Adjusted *P* values (by Bonferroni correction) less than 0.05 were considered statistically significant.

Results

In this study, 590 eyes of 590 patients are enrolled. The demographic and biometric characteristics of the enrolled

Table 1: The demographic and biometric characteristics of enrolled patients (*n*=590)

Demographics	Count (%)		
Left eye	296 (50.2)		
Female sex	337 (57.1)		
	Mean (SD)		
Age	75.0 (8.76)		
Postoperative days	96.5 (14.3)		
Axial length	23.78 (1.42)		
Mean keratometry	44.19 (1.47)		
Anterior chamber depth	3.08 (0.46)		
Lens thickness	4.58 (0.47)		
Corneal white-to-white value	11.83 (0.42)		
IOL power	21.02 (3.35)		
	Count (%)		Count (%)
Axial length subgroups		IOL power subgroups	
Short (<22.5 mm)	89 (15.1%)	Low (6.0-18.0 D)	84 (14.2%)
Medium (22.5-25.5 mm)	432 (73.2%)	Medium (18.5-24.0 D)	436 (73.9%)
Long (>25.5 mm)	69 (11.7%)	High (24.5-27.5 D)	70 (11.9%)

IOL, intraocular lens; D, diopter

Table 2: Prediction errors of all patients for each formula

Formula	Haigis	Holladay 1	SRK/T	Barrett universal II
ME	–0.115	0.024	0.045	0.176
SD	0.439	0.443	0.448	0.402
Mean AE	0.359	0.347	0.354	0.345
Median AE	0.288	0.293	0.293	0.285
Eyes within prediction error (%)				
±0.25 D	44.2	44.7	43.2	45.3
±0.50 D	73.2	76.1	74.4	75.3
±0.75 D	90.3	91.4	92.2	92.0
±1.00 D	96.9	96.4	96.8	97.8

ME, mean prediction error; SD, standard deviation of mean prediction error; AE, absolute prediction error; D, diopter

Table 3: Prediction errors in each axial length subgroup of each formula

Formula	ME±SD (D)	Mean AE	Median AE	Eyes within±0.50 D prediction error (%)
Short axial length (*n*=89)				
Haigis	−0.080±0.428	0.344	0.280	75.3
Holladay 1	−0.097±0.421	0.334	0.295	77.5
SRK/T	−0.028±0.446	0.352	0.320	71.9
Barrett universal II	0.215±0.439	0.398	0.340	66.3
Medium axial length (*n*=432)				
Haigis	−0.126±0.439	0.360	0.285	73.6
Holladay 1	0.005±0.416	0.326	0.270	78.9
SRK/T	0.057±0.446	0.350	0.280	75.7
Barrett universal II	0.184±0.392	0.337	0.278	76.6
Long axial length (*n*=69)				
Haigis	−0.093±0.458	0.365	0.340	68.1
Holladay 1	0.306±0.521	0.500	0.410	56.5
SRK/T	0.064±0.464	0.386	0.350	69.6
Barrett universal II	0.079±0.406	0.327	0.300	78.3

ME, mean prediction error; SD, standard deviation of mean prediction error; AE, absolute prediction error

Table 4: Prediction errors in each IOL power subgroup of each formula

Formula	ME±SD (D)	Mean AE	Median AE	Eyes within ±0.50 D prediction error (%)
Low power (*n*=84)				
Haigis	−0.020±0.394	0.318	0.288	77.4
Holladay 1	0.259±0.511	0.454	0.370	63.1
SRK/T	0.055±0.490	0.400	0.358	67.9
Barrett universal II	0.126±0.372	0.308	0.280	78.6
Medium power (*n*=436)				
Haigis	−0.133±0.478	0.362	0.283	73.6
Holladay 1	−0.013±0.412	0.323	0.270	78.9
SRK/T	0.025±0.437	0.342	0.280	76.6
Barrett universal II	0.164±0.391	0.332	0.278	77.3
High power (*n*=70)				
Haigis	−0.123±0.486	0.388	0.298	65.7
Holladay 1	−0.021±0.462	0.371	0.310	74.3
SRK/T	0.157±0.457	0.378	0.340	68.6
Barrett universal II	0.310±0.475	0.471	0.418	58.6

ME, mean prediction error; SD, standard deviation of mean prediction error; AE, absolute prediction error; D, diopter

patients are shown in Table 1. The mean AL was 23.78 ± 1.42 mm, and the mean IOL power was 21.02 ± 3.35 D. The Vivinex™ iSert® XY1 IOL is manufactured in the range of 6.0 of 30.0 D by 0.5 D steps. In this study, none of the patients were implanted with an IOL of greater than 27.5 D.

Table 2 shows the ME, *SD* of prediction error, MAE, MedAE, and the percentages of eyes within ±0.25 D, ±0.50 D, ±0.75 D, and ±1.00 D prediction error by each formula in all 590 eyes. There was no significant difference in absolute error between the formulas. The BU-II formula achieved the lowest *SD* of prediction error, MAE, and MedAE. However, the difference of MedAE was only within 0.01 D in the four formulas, and the percentage of eyes within ± 0.50 D prediction error varied from 73.2% to 76.1%. Overall, the four formulas appeared to have a similar accuracy of IOL calculation.

The results of the AL subgroup analysis are shown in Table 3. In the short AL subgroup, although the Friedman test confirmed a statistically significant difference in absolute error between the four IOL power formulas ($P = 0.043$), the Wilcoxon signed-rank test with Bonferroni correction showed no significant difference in any two groups. In the medium AL subgroup, there was a statistically significant difference in absolute error between the four formulas ($P < 0.01$). The Holladay 1 formula had a significantly lower absolute error than the Haigis formula ($P < 0.01$) and the SRK/T formula ($P = 0.024$). However, the difference of MedAE was only within 0.015 D in the four formulas, and the percentage of eyes within ± 0.50 D prediction error varied from 73.6% to 78.9%. The lowest *SD* of prediction error was achieved by the BU-II formula. In the long AL subgroup, there was a statistically significant difference in absolute error between the four formulas ($P < 0.01$). The BU-II

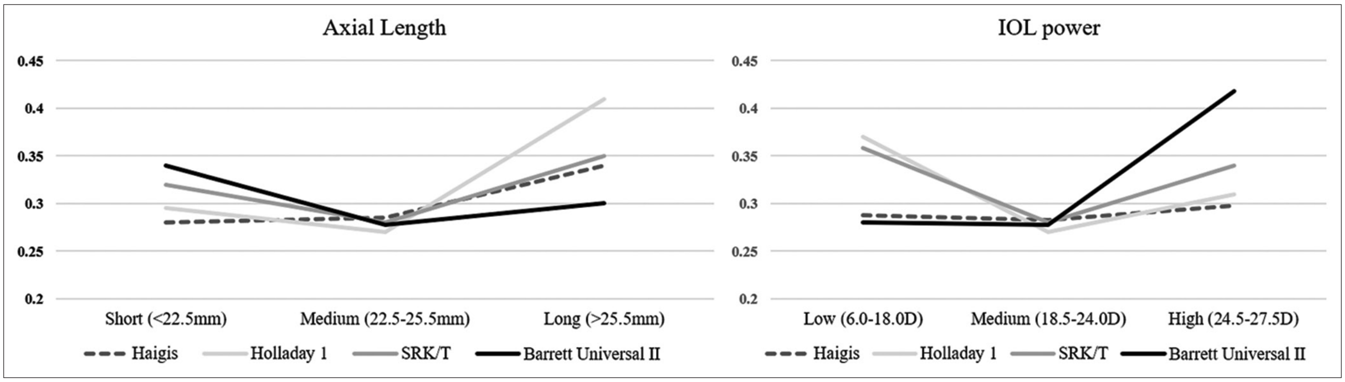

Figure 1: Median absolute error for each formula plotted according to the axial length and intraocular lens power subgroups

formula performed better than the Holladay 1 formula ($P < 0.01$). The SRK/T formula also had a significantly lower absolute error than the Holladay 1 formula ($P < 0.01$).

The results of the IOL power subgroup analysis are shown in Table 4. In the low-power subgroup, there was a statistically significant difference in absolute error between the four formulas ($P < 0.01$). The BU-II formula had a significantly lower absolute error than the Holladay 1 formula ($P < 0.01$) and the SRK/T formula ($P = 0.023$). The Haigis formula also performed better than the Holladay 1 formula ($P = 0.021$). In the medium-power subgroup, there was a statistically significant difference in absolute error between the four formulas ($P < 0.01$). The Holladay 1 formula was significantly more accurate than the Haigis formula ($P < 0.01$). However, the difference of MedAE was only within 0.013 D in the four formulas, and the percentage of eyes within ± 0.50 D prediction error varied from 73.6% to 78.9%. The BU-II formula achieved the lowest *SD* of prediction error. In the high-power subgroup, there was a statistically significant difference in absolute error between the four formulas ($P < 0.01$). The BU-II formula was significantly less accurate than the SRK/T formula ($P < 0.01$) and also appeared to be worse than the Holladay 1 formula ($P = 0.052$). Moreover, the BU-II formula had the lowest percentage of eyes within ± 0.50 D prediction error at 58.6%.

The MedAE for each formula plotted according to the AL group and IOL power group is shown in Fig. 1. In both AL and IOL power, the MedAE was similar in the medium group for any formula. Focusing on the BU-II formula, in the long AL eyes and the eyes with low-power IOL insertion, it had a lower MedAE than the other three formulas. On the other hand, in the short AL eyes and the eyes with a high-power IOL insertion, it had a higher MedAE than the other three formulas. In these subgroups, MedAE was the lowest to the highest in the Haigis, Holladay 1, SRK/T, and BU-II formulas, respectively.

Discussion

The Vivinex™ iSert® XY1 IOL is a preloaded single-piece hydrophobic acrylic blue-light filtering IOL with ultraviolet–ozone (UV–O_3) treatment on the posterior surface. UV–O_3 irradiation creates active binding sites and introduces oxygen-containing functional groups on the surface material, thus enhancing protein adsorption and cell adhesion.[10] This contributes to preventing posterior capsule opacification (PCO), likely by increasing the adhesion between the posterior capsule and the IOL while retaining uveal biocompatibility.[11] Leydolt *et al*. recently reported that the Vivinex™ iSert® XY1 IOL showed significantly lower PCO rates and lower yttrium aluminum garnet (YAG) laser rates compared with the AcrySof® IQ SN60WF IOL (Alcon Laboratories, Inc., Fort Worth, Texas, USA) over a 3-year follow-up period.[12]

The findings in the present study are the first to reveal the accuracy of the specific IOL calculation formulas for the Vivinex XY1 IOL. In the standard eyes, four formulas in this study appeared to have a similar accuracy of IOL calculation; however, the BU-II formula had the lowest *SD* of prediction error. *SD* represents the precision or consistency in the formula predictions. In the long AL eyes, the BU-II formula was found to be significantly more accurate, as previously reported.[1,2,5,7,13,14] Moreover, the BU-II formula appears to stably provide less refractive errors for the Vivinex™ iSert® XY1 IOL. On the other hand, and quite surprisingly, in the eyes with high-power IOL insertion, the BU-II formula was significantly less accurate.

One of the possible reasons for this lesser accuracy is the influence of IOL thickness. The BU-II formula is classified as a "thick lens" formula.[15] Design factor is taken into account in low-power meniscus IOL. On the other hand, in biconvex IOLs, although the thickness of the IOL increases with the higher power IOL, the same lens factor is used for calculation. Kane and Melles recently reported the accuracy of IOL power calculation formula predictions when using the AcrySof® IQ SN60AT IOL (Alcon Laboratories) of 30 or greater D power.[16] In that study, they compared 10 formulas (i.e. BU-II, EVO 2.0, Haigis, Hill-RBF 2.0, Holladay 1, Holladay 2, Hoffer Q, Kane, Olsen, and SRK/T) and found that the Kane formula had the lowest prediction error. According to their findings, among the four IOL formulas investigated in our study, the order of both MAE and MedAE was Haigis, Holladay 1, SRK/T, and BU-II, from the lowest to the highest. This finding is consistent with MedAE order in our high-power IOL insertion subgroup. Thus, the accuracy of the BU-II formula may be affected by IOL power.

Another possible reason is the influence of short AL. Generally, in the eyes of short AL, high-power IOL is inserted. The accuracy of the BU-II formula for the short AL is controversial. Melles *et al*. reported that the BU-II formula had the lowest MAE and MedAE for short AL eyes among seven formulas (i.e. BU-II, Haigis, Hoffer Q, Holladay 1, Holladay 2, Olsen, and SRK/T).[2] On the other hand, Kane *et al*. reported that the Holladay 1 formula had the lowest MAE for short AL eyes among seven formulas (i.e. BU-II, Haigis, Hoffer Q, Holladay 1, Holladay 2, SRK/T, and T2).[1] Shrivastava *et al*. reported that the Haigis formula had the lowest MAE and MedAE for short AL eyes among six formulas (i.e. BU-II, Haigis, Hoffer Q, Holladay 2, RBF Method, and SRK/T).[17] Connell and Kane also reported that MAE of the BU-II was higher than those of the Holladay 1 and the Haigis for short AL eyes.[18] In our study, the Holladay 1 had the lowest MAE, and the Haigis had the lowest MedAE for short AL eyes. No studies, including this one, have shown that the BU-II formula for short AL eyes is statistically less accurate; however, there still may be room for discussion.

It has been reported that newer IOL power calculation formulas have achieved better results.[18-20] However, these formulas currently require third-party software or an online calculator and cannot be easily used in the general clinical setting. On the other hand, the BU-II formula is integrated into the commercially available optical biometer; so it is a formula that can be easily applied, thus contributing to a reduction of the refractive prediction error after cataract surgery in the general clinical setting.

It should be noted that this present study did have some limitations. First, since we used the reference value provided by the manufacture as the IOL constants, lens constant optimization was not performed. Since this study was conducted in a single facility, the cause of these errors may have included the problem of systematic error (Personal A constant). However, the MAE of SRK/T formula in this study is 0.045, which can be regarded almost as zero. Since the details of the BU-II formula have not yet been made public, the lens factor of the BU-II formula is generally determined by converting the optimized A constant of the SRK/T formula. Therefore, it is thought that the lens constant optimization would not have changed the conclusions in this study. Second, because none of the patients in this study were implanted with an IOL greater than 27.5 D, we could not investigate the accuracy of the IOL calculation formulas when using the highest power IOLs. Moreover, we were unable to evaluate the eyes that had not been measured preoperatively with the IOLMaster® 700. Third, only the Vivinex™ iSert® XY1 IOL was evaluated in this study, and those findings may not apply to other IOL models. In a previous study on AcrySof® IQ SN60WF IOL implantation, the BU-II formula provided better results, even in the eyes with high-power IOL insertion.[2] Therefore, further investigation is needed to evaluate the accuracy of the BU-II formula in the eyes with a high-power IOL insertion or a short AL.

Conclusion

In conclusion, the BU-II formula appears to stably provide less refractive errors; however, it might be less accurate when using a Vivinex™ iSert® XY1 IOL of 24.5 D or greater.

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Conflicts of interest

There are no conflicts of interest.

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