Clinical results using the Holladay 2 intraocular lens power formula

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ABSTRACT

Purpose: To analyze the accuracy of the Holladay 2 formula, which has been proposed as an improvement over the original Holladay formula.

Methods: This retrospective analysis comprised 317 eyes operated on by 1 surgeon using 1 technique and 1 intraocular lens style in a specialty practice. Because the Holladay 2 formula has yet to be published, its accuracy can only be analyzed using the commercially available Holladay IOL Consultant® computer program to compare it to the Holladay 1, Hoffer Q, and SRK/T formulas. Defined axial length ranges were analyzed individually.

Results: A lower mean absolute error (MAE) trend was found for the average length eye (22.0 to 24.5 mm) by the Holladay 1 and Hoffer Q formulas. For short eyes (< 22.0 mm), the Hoffer Q and Holladay 2 perform better. The SRK/T consistently showed a trend toward the lowest MAE in all long eyes (>24.5 mm) as well as the subdivisions of medium long (24.5 to 26.0 mm) and very long (>26.0 mm). The Holladay 2 trended toward the least accurate (MAE) of the 4 formulas in all ranges of axial length except the shortest and the very longest. It appears to perform poorer in average and medium long eyes.

Conclusions: Although the Holladay 2 formula has improved its MAE accuracy in short eyes, it was not more accurate than the Hoffer Q. The changes made in the formula to effect this improvement in MAE seem to have sacrificed the accuracy of the original Holladay formula in eyes with average and medium long axial lengths. *J Cataract Refract Surg 2000; 26:1233–1237 © 2000 ASCRS and ESCRS*

The Holladay 2 formula[1] for intraocular lens (IOL) power calculation was first presented for clinical use in 1996 but has yet to be published. It has been proposed as an improvement of the original Holladay formula, first published in 1988.[2] The new formula is based on a theory that postoperative anterior chamber depth (ACD) position can be more accurately estimated using anterior segment biometric measurements of preoperative ACD, lens thickness (LT), corneal diameter (CD), as well as the patient's age and preoperative refractive error (Rx). It is important to analyze the results obtained with newer formulas as they become clinically available.

Patients and Methods

There are 2 philosophies regarding the most appropriate method to evaluate the results of IOL power formulas used in clinical practice. One theory is that because the formula will be widely used by many surgeons using various IOL styles, the study should be

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made up of data from a wide variety of surgeons using a variety of IOLs in different clinical settings. However, there is difficulty in controlling the reliability and quality of the data derived from such a study. The other theory is based on standardizing all the variables in biometric data collection (A-scan unit, keratometer, technician) by using only 1 surgeon and 1 IOL style, leaving the formulas as the only variable. This study used the latter method.

Data were retrospectively and prospectively collected from 317 eyes operated on by 1 surgeon (K.J.H.) using phacoemulsification and topical, clear corneal, oblique, nonsutured 2.5 mm incisions. All the IOLs, of 1 style by 1 manufacturer, were plate-haptic silicone (AA4203). They were placed within the capsular bag after a complete 5.0 to 6.0 mm diameter curvilinear capsulorhexis was created. All axial lengths were measured using the immersion technique and a Sonometrics A-scan set at an average sound velocity of 1555 m/sec. A retinal thickness factor was not added to the result unless done so by the formula itself. All corneal powers were measured using a Bausch & Lomb manual keratometer without correcting its corneal index of refraction. No eye was included that had best corrected visual acuity of 20/50 or worse because of inaccuracies in refractions in such cases.

As the Holladay 2 formula has not been published, results using the formula can only be analyzed with the commercially available computer program made available by the formula author (Holladay IOL Consultant®). This formula requires data input of axial length, corneal power, patient age, preoperative refractive error, corneal diameter, preoperative ACD, and crystalline LT. All preoperative data were collected and entered into the computer program, and the results were obtained by using its data analysis screen.

Using the Holladay IOL Consultant program, the entire series as well as the subdivisions of axial length ranges were analyzed. These ranges were defined as short, <22.0 mm; average, 22.0 to 24.49 mm; and long, ≥24.5 mm. Long was further subdivided as medium long (24.5 to 26.0 mm) and very long (>26.0 mm). The mean absolute error (MAE) for each formula causes personalization of the formulas and eliminates consistent biases caused by the data (e.g., immersion versus applanation A-scan).

The program analysis yields the mean error (ME) and MAE in refraction of the series tested using the Holladay 2, Holladay 1, Hoffer Q,[3] and SRK/T[4] formulas. It also calculates the maximum refractive error produced by each of the formulas and the percentage of eyes with an error greater than ±2.00 diopters (D). Using the ME to evaluate accuracy is flawed in that a −10.00 D prediction error will be canceled out by a +10.00 D error, resulting in an ME of zero. The MAE of that series of 2 would be 10.00 D. Therefore, it is the MAE that is most important in evaluating the error of prediction in a series. The program also calculates a personalized ACD for each formula, which can be used in the Hoffer Q, a personalized A-constant for the SRK/T formula, and a personalized surgeon factor for the Holladay formulas.

Results

In the 317 eyes, the Holladay 1 (0.43 D), SRK/T (0.44 D), and Hoffer Q (0.45 D) formulas showed a trend to be better than the Holladay 2 (0.55 D), which was 0.12 D less accurate than the original Holladay 1 (Table 1). The maximum error was relatively the same for the Hoffer Q and Holladay 2 and ~0.15 D higher

Table 1. Holladay IOL Consultant analysis screen for all eyes in the study (N = 317).

Formula	Pers ACD	SD	A-Constant	ME (D)	MAE (D)	SD (D)	MAX (D)	>±2D (%)
Holladay 2	5.429	0.021	5.429	−0.448	0.548	0.495	−1.60	0
Holladay 1	5.673	0.025	1.910	−0.147	0.426	0.509	−1.44	0
Hoffer Q	5.748	0.026	5.748	−0.081	0.449	0.546	−1.61	0
SRK/T	5.661	0.023	119.115	−0.198	0.442	0.517	−1.45	0

Pers ACD = personalized anterior chamber depth; SD = standard deviation; ME = mean error of refraction; MAE = mean absolute error of refraction; MAX = maximum refractive error; >±2D = percentage of eyes with error greater than ±2.00 D

Table 2. Holladay IOL Consultant analysis screen for average length eyes (22.0–24.49 mm) (n = 231).

Formula	Pers ACD	SD (D)	A-Constant	ME (D)	MAE (D)	SD (D)	MAX (D)	>±2D (%)
Holladay 2	5.422	0.023	5.422	−0.491	0.563	0.485	−1.60	0
Holladay 1	5.625	0.024	1.863	−0.203	0.423	0.487	−1.44	0
Hoffer Q	5.668	0.024	5.668	−0.171	0.431	0.501	−1.61	0
SRK/T	5.640	0.025	119.083	−0.243	0.459	0.519	−1.45	0

Pers ACD = personalized anterior chamber depth; SD = standard deviation; ME = mean error of refraction; MAE = mean absolute error of refraction; MAX = maximum refractive error; >±2D = percentage of eyes with error greater than ±2.00 D

than for the other 2 formulas. No formula produced an error greater than 1.61 D.

If eyes shorter than 22.0 mm and longer than 24.5 mm are eliminated, the results in the average range of axial length can be measured. Table 2 shows that the Holladay 1 (0.42 D) and the Hoffer Q (0.43 D) had the lowest MAEs. The Holladay 2 (0.56 D) had the highest MAE and was 0.14 D higher than the Holladay 1. The maximum errors were the same as for the entire series, with no error greater than 1.61 D.

In evaluating the longer eyes, the entire series of eyes longer than 24.5 mm (Table 3) was first analyzed. The SRK/T formula had the lowest MAE (0.38 D); the Holladay 1 was higher (0.43 D). The highest MAEs were seen with the Holladay 2 and Hoffer Q (both 0.50 D). The SRK/T had the lowest maximum error (1.10 D) and the Holladay 1, the highest (1.42 D). The maximum error was plus in all formulas except the Holladay 2, in which it was minus.

When long eyes were divided into medium long (24.5 to 26.0) and very long (>26.0), the SRK/T yielded the lowest MAE (0.35 D) and the Holladay 1 a slightly higher MAE (0.37 D) in the medium long eyes (Table 4). The highest error was produced by the Holladay 2 (0.51 D). The Hoffer Q was in the middle (0.47 D). The SRK/T had the lowest maximum error (–1.06 D) and the Holladay 2, the highest (–1.31 D).

In the very long eyes (Table 5), the SRK/T had the lowest MAE (0.44 D) followed by the Holladay 2 (0.49 D). The Holladay 1 (0.56 D) and the Hoffer Q (0.58) were much higher. The Holladay 1 had the highest maximum error (+1.42 D) and the Holladay 2, the lowest (–0.90 D).

The most problematic eyes are those shorter than 22.0 mm. The Hoffer Q produced the lowest MAE in these eyes. Table 6 shows that the Holladay 2 had an MAE (0.72 D) that which was less than that of the Holladay 1 (0.85 D) by 0.13 D. The Holladay 2 equaled the Hoffer Q (0.72 D) and their maximum errors were also equivalent. The Holladay 1 (0.85) had the highest MAE in these short eyes, followed closely by the SRK/T (0.83 D). The maximum error in these short eyes was 1.24 D.

Intraocular lens power accuracy appeared to be best in medium long eyes (0.35 D) followed by average eyes (0.42 D) and very long eyes (0.44 D); the lowest accuracy was in short eyes (0.72 D) (Table 7).

Discussion

The advantage of this study is the uniformity of the biometric data collection; however, it is limited by the number of eyes collected by 1 surgeon using 1 specific IOL style. There are not enough eyes in each axial length

Table 3. Holladay IOL Consultant analysis screen for all long eyes (>24.5 mm) (n = 76).

Formula	Pers ACD	SD	A-Constant	ME (D)	MAE (D)	SD (D)	MAX (D)	>±2D (%)
Holladay 2	5.419	0.049	5.419	−0.393	0.501	0.448	−1.31	0
Holladay 1	5.851	0.085	2.083	−0.026	0.427	0.553	1.42	0
Hoffer Q	6.022	0.079	6.022	0.153	0.501	0.609	1.28	0
SRK/T	5.727	0.065	119.221	−0.120	0.375	0.465	1.10	0

Pers ACD = personalized anterior chamber depth; SD = standard deviation; ME = mean error of refraction; MAE = mean absolute error of refraction; MAX = maximum refractive error; >±2D = percentage of eyes with error greater than ±2.00 D

Table 4. Holladay IOL Consultant analysis screen for medium long eyes (24.5–26.0 mm) (n = 52).

Formula	Pers ACD	SD	A-Constant	ME (D)	MAE (D)	SD (D)	MAX (D)	>±2D (%)
Holladay 2	5.397	0.047	5.397	−0.449	0.505	0.410	−1.31	0
Holladay 1	5.592	0.056	1.832	−0.205	0.368	0.426	−1.18	0
Hoffer Q	5.820	0.076	5.820	−0.015	0.465	0.567	−1.16	0
SRK/T	5.636	0.052	119.075	−0.194	0.345	0.401	−1.06	0

Pers ACD = personalized anterior chamber depth; SD = standard deviation; ME = mean error of refraction; MAE = mean absolute error of refraction; MAX = maximum refractive error; >±2D = percentage of eyes with error greater than ±2.00 D

Table 5. Holladay IOL Consultant analysis screen for very long eyes (>26.0 mm) (n = 24).

Formula	Pers ACD	SD	A-Constant	ME (D)	MAE (D)	SD (D)	MAX (D)	>±2D (%)
Holladay 2	5.467	0.117	5.467	−0.270	0.493	0.508	−0.90	0
Holladay 1	6.412	0.198	2.627	0.361	0.556	0.607	1.42	0
Hoffer Q	6.458	0.197	6.458	0.518	0.580	0.544	1.28	0
SRK/T	5.925	0.168	119.538	0.041	0.442	0.557	1.10	0

Pers ACD = personalized anterior chamber depth; SD = standard deviation; ME = mean error of refraction; MAE = mean absolute error of refraction; MAX = maximum refractive error; >±2D = percentage of eyes with error greater than ±2.00 D

Table 6. Holladay IOL Consultant analysis screen for eyes shorter than 22.0 mm (n = 10).

Formula	Pers ACD	SD	A-Constant	ME (D)	MAE (D)	SD (D)	MAX (D)	>±2D (%)
Holladay 2	6.204	0.078	6.204	0.713	0.716	0.402	1.07	0
Holladay 1	6.264	0.054	2.483	0.849	0.849	0.282	1.24	0
Hoffer Q	6.173	0.052	6.173	0.719	0.719	0.287	1.08	0
SRK/T	6.296	0.048	120.132	0.834	0.834	0.262	1.15	0

Pers ACD = personalized anterior chamber depth; SD = standard deviation; ME = mean error of refraction; MAE = mean absolute error of refraction; MAX = maximum refractive error; >±2D = percentage of eyes with error greater than ±2.00 D

subdivision to allow for statistical significance in the extremes of axial length. This was also true in an earlier study of 450 eyes under similar conditions.[3] Although the clinical results of that study could not be shown to be statistically significant, larger series confirmed the conclusions with statistical significance.

This series differs from the previous one in that only 3% of the eyes were short compared with 8% in the earlier series, and 8% of eyes were very long compared with 5%. This affects the performance of each formula when analyzing the entire series as a whole. The previous study was of a poly(methyl methacrylate) bag-placed posterior chamber IOL inserted through a 6.0 mm superior scleral tunnel incision. The current study used a plate-haptic silicone IOL inserted through a 2.5 to 3.2 mm oblique clear corneal incision.

The results of this series appear to show that the 4 modern theoretic formulas function differently depending on the eye's axial length. My previous study[3] showed the Hoffer Q is superior for short eyes, the Holladay 1 is best for medium long eyes, and the SRK/T shows a trend toward being better in very long eyes; all 3 performed equally well in eyes with an average axial length. This study, adding the Holladay 2, showed that the Holladay 2 equals the Hoffer Q in short eyes, the Holladay 1 and Hoffer Q are equivalent in average eyes, and the SRK/T and Holladay 2 perform equally in medium long eyes, but the SRK/T produces a trend toward better results in very long eyes.

Because the Holladay 2 requires measurements and input of much more data and the Hoffer Q requires only axial length, corneal power, and ACD (or A-constant), I

Table 7. Formulas that show the least MAE in each axial length range.

Axial Length	Number of Eyes	Formula	MAE (D)	SD (D)	MAX (D)	Pers ACD	SD
Short	10	Hoffer Q	0.72	0.29	1.08	6.17	0.05
		Holladay 2	0.72	0.40	1.07	6.20	0.08
Average	231	Holladay 1	0.42	0.49	−1.44	5.63	0.02
		Hoffer Q	0.43	0.50	−1.61	5.67	0.02
Medium long	52	SRK/T	0.35	0.40	−1.06	5.64	0.05
		Holladay 1	0.37	0.43	−1.18	5.59	0.06
Very long	24	SRK/T	0.44	0.56	1.10	5.93	0.17
All long	76	SRK/T	0.38	0.47	1.10	5.73	0.07

MAE = mean absolute error; SD = standard deviation; MAX = maximum refractive error; Pers ACD = personalized anterior chamber depth

will reserve the use of the Holladay 2 formula for extremely short eyes (<18.0 mm), in which it may be more helpful. It is very difficult to garner a series of eyes that short for evaluation.

In summary, I will continue to use the Hoffer Q formula for average and short eyes (<24.5 mm), the Holladay 1 for average and medium long eyes (22.0 to 26.0 mm), and the SRK/T for very long eyes (>26.0 mm). The SRK/T may also be recommended for medium long eyes based on this study. I do not believe the extra biometric data collection (ACD, LT, CD, age, Rx) necessary to use the Holladay 2 formula is warranted based on what I see as a trend toward poorer performance in the majority of axial lengths tested (89%). The Holladay 2 did not outperform the original Holladay 1 except in short eyes and very long eyes. The effort to improve the accuracy of the Holladay 1 formula in short eyes seems to have done so at the sacrifice of accuracy in the other ranges, in which it was superior to other formulas. Other studies using multiple surgeons and various IOL styles may show different results, and larger studies may show these differences to be statistically significant.

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