Intraocular lens power calculation after excimer laser corneal refractive surgery: A retrospective study to compare the predictability and the efficacy of commonly used and modified formulas

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Access this article online

Quick Response Code:

Website:
www.saudijophthalmol.org

DOI:
10.4103/sjopt.sjopt_185_21

Abstract:

PURPOSE: Our article aims to assess the accuracy of modified and commonly used formulas of intraocular lens (IOL) power calculation after excimer laser corneal refractive surgery.

METHODS: This is a retrospective study, with data retrieved for 50 eyes of 32 patients who underwent uncomplicated cataract surgery after excimer laser corneal refractive surgery. The expected spherical equivalent was calculated using the American Society of Cataract and Refractive Surgeons (ASCRS) IOL power calculator for Shammas and Barrett True-K, using three-fourth generation formulas (Haigis-L, Barrett True-K no history, and Holladay 2), and using three-third generation formulas (SRKT, Holladay 1, and Hoffer Q) with single k, as a reference, and adjusting these formulas by calculating the keratometry readings by two methods (Jarade's index and formula). The mean refractive error and mean absolute refractive error (MARE) were calculated at the 1 postoperative month.

RESULTS: When all data was available (eight eyes), 13 formulas were compared. Holladay 1 as modified by Jarade's index and formula, and Hoffer Q as modified by Jarade's formula resulted in MARE <0.75D ($P < 0.05$). In the group of 25 eyes with only ablation available**,** the formulas with MARE <0.75D were Haigis L, Barrett TK (from ASCRS), Hoffer Q, and the three conventional formulas in Jarade's index ($P < 0.001$). In the group of 17 eyes with no available prerefractive data, only Haigis-L and Barret TK (no history) had a MARE <0.75 D.

CONCLUSION: The use of Hoffer Q or Holladay 1, when prerefractive data are available, gives reliable results with Jarade's index.

Keywords:

Cataract, emmetropia, formulas, intraocular lens, laser-assisted *in situ* keratomileusis, refractive

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Submitted: 31-Jul-2021
Revised: 21-Nov-2021
Accepted: 28-Feb-2022
Published: 29-Aug-2022

Introduction

The advancement in cataract extraction methods was accompanied by better visual outcomes and increased patient expectations. More and more patients are regarding cataract extraction as a way of correcting refractive errors,[1] and thus, ophthalmologists are currently prioritizing attaining target postoperative outcomes with the least refractive errors possible. As such, formulas that govern the choice of the intraocular lens (IOL) have also developed and become more accurate, taking into account multiple variables, most notably axial length (AL), keratometry (k) readings, and anterior chamber depth (ACD). Accordingly, the benchmark standard for cataract surgery in the National Health Service in 2004 recommended that 85% and 55% of patients achieve a postoperative spherical equivalent within 1 D and 0.5 D of the predicted value, respectively.[2]

Unfortunately, eyes with previous keratorefractive surgery are subject to similar or less predictable

How to cite this article: Said RB, Ghorayeb R, Akiki D, Wakim E, Sukkarieh G, Sfeir J, *et al*. Intraocular lens power calculation after excimer laser corneal refractive surgery: A retrospective study to compare the predictability and the efficacy of commonly used and modified formulas. Saudi J Ophthalmol 2022;36:177-82.

outcomes with higher patient demand.[3,4] Multiple reasons have been proposed as the root of the error. Most importantly, the relationship between the anterior and posterior surfaces of the cornea is disrupted. As a result of myopic ablation, the anterior surface is flattened, but the posterior curvature remains the same. Therefore, the relative index of refraction (Nr) generated and employed in normal corneas and used for keratometry (K) calculation from the anterior corneal radius (Ra) measurement (K = (Nr-1)/Ra) cannot be used in these eyes. Hence, keratometry measured by available methods is overestimated, leading to low IOL power choice and resultant hyperopic surprise.[5,6] Other reasons include faulty underestimation of the effective lens position after flattening of the anterior curvature. This is due to the fact that many new-generation formulas use the steepness of the cornea and the ACD to estimate the lens position. As the anterior surface of the cornea is flattened, but the AL and ACD remain unchanged, the IOL calculation using these formulas is underestimated, also leading to hyperopic error.[4,6] Another potential source of this hyperopic surprise is what is referred to as "instrument error."[6,7] Most devices used to measure the K-readings do so by extrapolation from measurements at the 3.2 mm/paracentral knee zone. Since the central zone has undergone flattening, this extrapolation leads to an overestimation of corneal power and resultant postoperative hyperopia (mainly in post radial keratotomy cases).

As there is an increase in life expectancy, more people that undergo excimer refractive surgery today will need cataract surgery sometime in future.[8,9] These patients would similarly expect flawless visual acuity following their cataract surgery. Therefore, it is crucial to select the IOL power that guarantees optimal vision.

There have been multiple proposed formulas and methods to improve the outcomes of the standard formulas, but there has been no consensus on a single best.[6] As previously mentioned, the third-and fourth-generation IOL formulas tend to result in hyperopic errors.[10] The double k method was proposed to increase their accuracy using prerefractive k values.[11] Other formulas that are more commonly used in postrefractive eyes with no available history are Haigis-L[12] and Barrett True-K (no history).[13] When the previous ablation is available, the American Society of Cataract and Refractive Surgeons (ASCRS) website can be accessed for Barrett TK[14]-and Shammas[15] – based results. The value of ablation can also be used to calculate a modified index of refraction[16] which can be utilized to calculate the k values and incorporate them in the standard formulas. Jarade *et al*. also incorporated previous topographic k readings, before refractive surgery, into a formula to calculate modified k and incorporate them as well in the standard formulas.[17]

However, the NICE guidelines adopted by the Royal College of Ophthalmologists,[18,19] do not recommend one specific formula over another for previously operated eyes. Moreover, they highlight the low refractive predictability of cataract surgery and IOL implantation in this population and the importance of informing the patient preoperatively. They also emphasize on accounting for the different relationships between the anterior and posterior curvatures of the cornea, as aforementioned, and advise surgeons to avoid using classic biometric techniques or historical data solely.

Our aim is to compare the standard IOL formulas, as well as those frequently used for postrefractive surgery IOL calculation, and the two aforementioned methods[16,17] that modify the k readings and incorporate them into the standard formulas.

Methods

This study adhered to the ethical standards of the Helsinki Declaration of 1975, and the procedure followed was in accordance with the ethical standards of the institutional review board in Beirut Eye and ENT Specialist Hospital. We retrospectively retrieved data from 2017 to 2021 on patients who underwent uncomplicated cataract surgery, who had already been operated for myopia or hyperopia, with or without astigmatism using laser-assisted *in situ* keratomileusis (Lasik) (microkeratome or femtosecond), or photorefractive keratectomy (PRK). Inclusion criteria were uncomplicated cataract surgery and postoperative follow-up, with a best-corrected visual acuity measured at 1 month postoperatively of 20/30 or better. Patients who were lost to follow-up or had other ocular pathologies were excluded from this study. Cataract extraction was done using phacoemulsification by one of two surgeons (EJ or GC) through a clear corneal incision. The IOL implanted was the monofocal RayOne Aspheric IOL 600C (Rayner Intraocular Lenses Ltd., Worthing, UK, A-constant of 118.6). Medical records were reviewed and patient characteristics were recorded. These included age, gender, operated eye, and the laser vision correction that the patient had undergone. Moreover, biometric index of refraction, measured AL, k readings, and ACD were collected from Carl Zeiss IOL Master® Advanced Technology V. 5.4 or the IOL Master 700 (IOL Master; Carl Zeiss, Jena, Germany). The Microsoft Excel program was used to collect data, calculate *P*, and analyze the data appropriately. IOL power was calculated in each eye as follows:

1. Using the ASCRS IOL power calculator for Shammas and Barrett True K (Barret TK) formulas when the refractive surgery ablation value is available (http://iolcalc. org/)[20]
2. Using three newer (fourth) generation formulas that do not require prerefractive history but have been classically used for postrefractive surgery IOL calculation (Haigis-L, Barrett TK no history, and Holladay 2)
3. Using third-generation formulas (SRKT, Holladay 1, and Hoffer Q) with single k, as a reference, and adjusting these formulas by calculating the modified keratometry readings by two methods:

Jarade's index, using a modified relative index of refraction (rN) when refractive surgical ablation is available as such:

K (postop) = (rN– 1)/(R (a-postop)), where k (postop) is the k-reading postrefractive surgery, rN is the new relative corneal effective index of refraction generated by the regression analysis formula: (rN = 1.3375 + 0.0014 × D), where D represents the amount of myopic or hyperopic ablation, and R (a-postop) represents the radius of curvature of the anterior corneal surface in meters.[16]

Jarade's formula, using keratometry readings before refractive surgery when these are available as such: K (postop) = K (preop)-[(N (c)-1) × (R (a-postop)-R (a-preop))/(R (a-postop) R (a-preop))], where k (postop) is the k-reading postrefractive surgery, K (preop) is the k-reading obtained from the topography before refractive surgery, N (c) is the index of refraction of the cornea at air-cornea interface (1.376), R (a-postop) is the radius of curvature of the anterior corneal surface after refractive surgery, and R (a-preop) is the radius of curvature of the anterior corneal surface before refractive surgery.[17]

The mean refractive error (MRE) and mean absolute refractive error (MARE) were calculated for all these formulas as follows. First, the expected spherical equivalent for each formula was subtracted from the actual resultant spherical equivalent at 1 month after the surgery (SEactual– SEexpected). The absolute value of this was then calculated. Next, the means were calculated in the study population and in the three subgroups.

Results

Fifty eyes of 32 patients were included in this study. The average age at cataract surgery was 58.14 ± 11.2 years. Around 31% of the study population were males (10 patients). Thirty-four (68%) of the 50 eyes had undergone flap corneal surgery (LASIK or IntraLase), and the remaining underwent PRK. Moreover, 34 (68%) of 50 eyes had myopic, and 16 (32%) had hyperopic, laser ablation, whether by surface ablation or flap procedures. The average AL was 25.62 mm ± 2.8. Eight eyes had prerefractive available history, including topographical k readings, manifest refraction, and ablation. These could be compared across all the formulas considered in our study. Twenty-five eyes had only prerefractive manifest refraction available, courtesy of archived files, but not prerefractive topographies. The remaining 17 eyes had no available prerefractive data and could only be analyzed within the category of standard formulas.

When all the data were available

In this group of eight eyes, 13 formulas were compared [Table 1, Figures 1 and 2]. Most formulas had a more myopic result after cataract surgery. The highest MARE was for SRKT, with a wide standard deviation. The three most accurate formulas showing MARE within 0.75 D were Holladay 1, as modified by Jarade's index and formula, and Hoffer Q, as modified by Jarade's formula, with statistically significant results ($P < 0.05$).

When only ablation was available

In this group of 25 eyes, the SRKT also had the highest MARE, and the formulas with MARE <0.75D were Haigis L, Barrett TK with available history (from the ASCRS), Hoffer Q, and the three conventional formulas in Jarade's index [Table 2, Figures 3 and 4]. All these results were highly significant ($P < 0.001$).

When no data were available

In this group of 17 eyes, only Haigis-L and Barrette TK (no history available) had a MARE <0.75 D, with the former showing a statistically significant result. The other conventional formulas showed higher MARE, most notably SRKT [Table 3, Figures 5 and 6].

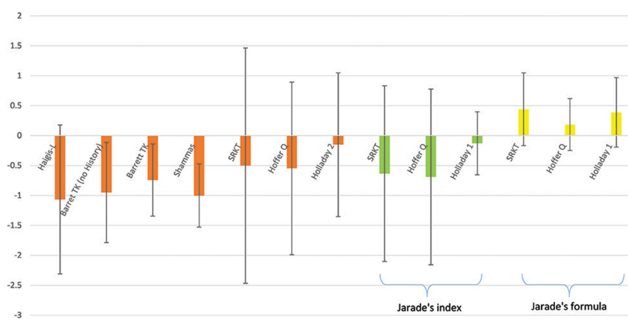

Figure 1: Chart showing the mean refractive error and standard deviation of all the formulas (when all data are available)

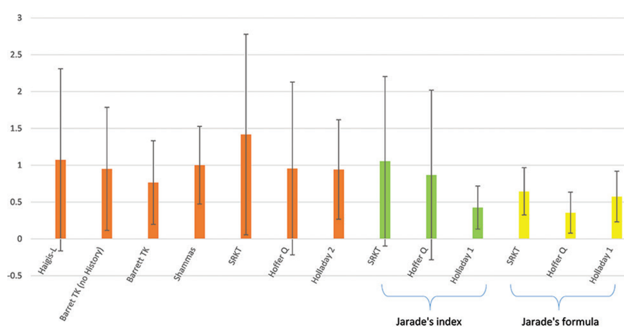

Figure 2: Chart showing the mean absolute refractive error and the absolute standard deviation of all the formulas (when all data are available)

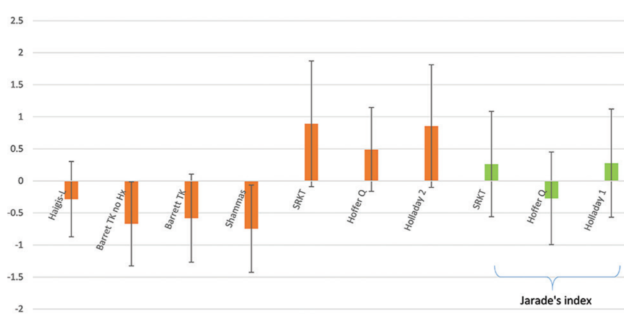

Figure 3: Chart showing the mean refractive error, and standard deviation of the conventional formulas, and Jarade's index (requiring refractive ablation)

Analyzing the data relative to refractive error targets (0.50, 0.75, 1.0 D), applied to the formulas with a bigger sample [Table 4], Haigis-L, and Hoffer Q and Holladay 1, as modified by Jarade's index, showed consistently more predictable results, with the highest percentage of eyes <0.5, 0.75, and 1.0 D. On the other hand, SRK/T showed the least predictability, with more than 50% of the eyes having a result more than 1 D from what had been expected.

Table 1: Mean Refractive Error (MRE), standard deviation, Mean Absolute Refractive Error (MARE), absolute standard deviation, and linear regression of the expected spherical equivalent correlated with the real spherical equivalent post-cataract surgery (All formulas when all data are available)

	MRE (Mean Refractive Error)	Standard Deviation	MARE (Mean Absolute Refractive Error)	Absolute Standard Deviation	*P*
Regular Formulas					
Haigis-L	-1.067	1.244	1.074	1.237	0.1367
Barret TK (no History)	-0.951	0.837	0.951	0.837	0.0710
Barrett TK	-0.742	0.602	0.765	0.568	0.0018*
Shammas	-1.001	0.527	1.001	0.527	0.0013*
SRKT	-0.502	1.965	1.417	1.361	0.7750
Hoffer Q	-0.548	1.441	0.956	1.173	0.4420
Holladay 2	-0.152	1.201	0.942	0.675	0.1070
Jarade index					
SRKT	-0.634	1.467	1.054	1.151	0.4004
Hoffer Q	-0.690	1.467	0.867	1.151	0.0105*
Holladay 1	-0.129	0.527	0.426	0.293	0.0001**
Jarade Formula					
SRKT	0.441	0.609	0.646	0.321	0.0406*
Hoffer Q	0.184	0.434	0.356	0.278	0.0104*
Holladay 1	0.388	0.580	0.576	0.344	0.0348*

$^*P<0.05$ Significant, $^{**}P<0.001$ Highly Significant

Table 2: Mean Refractive Error (MRE), standard deviation, Mean Absolute Refractive Error (MARE), absolute standard deviation, and linear regression of the expected spherical equivalent correlated with the real spherical equivalent post-cataract surgery (Conventional formulas, and Jarade's index requiring refractive ablation).

	MRE (Mean Refractive Error)	Standard Deviation	MARE (Mean Absolute Refractive Error)	Absolute Standard Deviation	*P*
Conventional Formulas					
Haigis-L	-0.286	0.588	0.499	0.413	<0.001**
Barret TK no Hx	-0.669	0.656	0.761	0.542	<0.001**
Barrett TK	-0.581	0.687	0.716	0.538	<0.001**
Shammas	-0.746	0.682	0.790	0.628	<0.001**
SRKT	0.891	0.980	1.060	0.785	0.0017*
Hoffer Q	0.490	0.654	0.627	0.519	<0.001**
Holladay 2	0.856	0.957	0.996	0.803	0.0004**
Jarade index					
SRKT	0.263	0.822	0.669	0.531	<0.001**
Hoffer Q	-0.272	0.722	0.510	0.572	<0.001**
Holladay 1	0.278	0.845	0.643	0.603	<0.001**

$^*P<0.05$ Significant, $^{**}P<0.001$ Highly Significant

Table 3: Mean Refractive Error (MRE), standard deviation, Mean Absolute Refractive Error (MARE), absolute standard deviation, and linear regression of the expected spherical equivalent correlated with the real spherical equivalent post-cataract surgery (Conventional formulas not requiring preoperative data).

Conventional Formulas	MRE (Mean Refractive Error)	Standard Deviation	MARE (Mean Absolute Refractive Error)	Absolute Standard Deviation	*P*
Haigis-L	-0.137	0.802	0.719	0.339	0.0385*
Barret TK no Hx	-0.401	0.791	0.729	0.482	0.0524
SRKT	0.343	1.335	1.133	0.738	0.3542
Hoffer Q	0.177	0.968	0.809	0.523	0.0926
Holladay 2	0.226	1.186	0.939	0.722	0.1017

* $P<0.05$ Significant

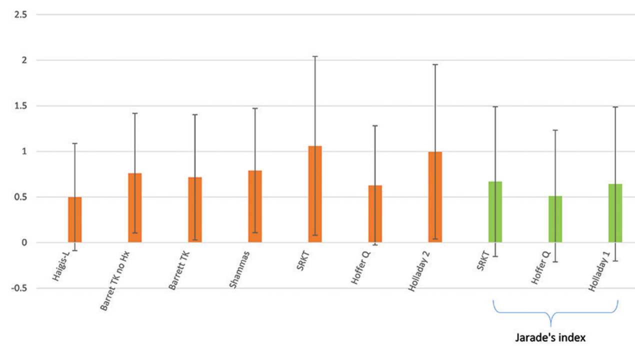

Figure 4: Chart showing the mean absolute refractive error, the absolute standard deviation of the conventional formulas, and Jarade's index (requiring refractive ablation)

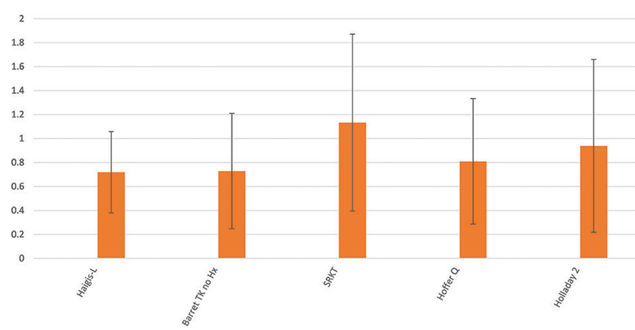

Figure 6: Chart showing the mean absolute refractive error and the absolute standard deviation of the conventional formulas (not requiring preoperative data)

Discussion

Refractive error following cataract surgery burdens the surgeon and the patient. Patients who underwent refractive surgery have higher expectations, as they have already tried spectacles for a significant proportion of their lives and then opted to spend the remaining glasses-free. Multiple formulas, or modifications of formulas, have been developed to attempt to reach the preset refractive target, and much is yet to be learned in this aspect. Our study showed that the Hoffer Q and Holladay 1 altered according to Jarade's index, as well as Haigis-L, are the most reliable methods with MARE consistently <0.75D. This goes in concordance with the study by Kang *et al*.[10] who reported the highest reliability for Hoffer Q when k readings are modified by Jarade's method if refractive information is available. Moreover, these three formulas are closest to the benchmark standard for cataract surgery in the National Health Service,(2004)[2] As a matter of fact, Hoffer Q and Holladay 1 in Jarade's index, give error within ± 0.5D in 55% of eyes, and within ± 1.0D in 79% of eyes. As for Haigis-L, this formula gives an error within ± 0.5D in 52% of eyes, and within ± 1.0D in 80% of eyes.

There have been different reports regarding the outcome of variable formulas. Savini *et al*.[21] found that the double-k clinical history method was the most accurate in IOL power calculation. On the other hand, Chen *et al*.[22] concluded that Shammas no history method with Shammas PL was superior to Haigis L, a result not shared by our study. Another report by Savini *et al*.[23] decided upon Seitz/Speicher (with or without Savini adjustment) or Masket method as the most accurate for IOL calculation in postrefractive surgery. Therefore, variable studies have given variable reports, which could be due to variability of AL and IOL types used, among other causes.[10] This study is limited by the study sample. A larger sample with potentially more eyes having available prerefractive data is warranted. Further analysis on a bigger sample would also allow subdividing the categories based on AL.

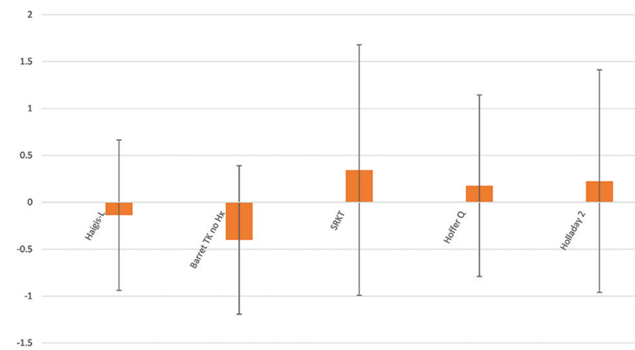

Figure 5: Chart showing the mean refractive error and standard deviation of the conventional formulas (not requiring preoperative data)

Table 4: Mean Absolute refractive error (MARE) targets (0.50, 0.75, 1.0 D), applied to the formulas with bigger samples of eyes.

Formula (total eyes where it was applied)	MARE ≤0.5D *n* (%)	MARE ≤0.75D *n* (%)	MARE ≤1.0D *n* (%)
Haigis L (50 eyes)	26 (52%)	33 (66%)	40 (80%)
Barrett TK (no History) (50 eyes)	16 (32%)	22 (44%)	36 (72%)
Barrett TK (33 eyes)	12 (36%)	20 (60%)	23 (70%)
Shammas (33 eyes)	13 (39%)	19 (58%)	21 (64%)
Jarade index			
SRK/T (33 eyes)	15 (45%)	22 (57%)	25 (76%)
Hoffer Q (33 eyes)	18 (55%)	24 (73%)	26 (79%)
Holladay 1 (33 eyes)	18 (55%)	23 (70%)	26 (79%)
Jarade formula			
SRK/T (50 eyes)	14 (28%)	18 (36%)	23 (46%)
Hoffer Q (50 eyes)	24 (48%)	29 (58%)	33 (66%)
Holladay 1 (50 eyes)	16 (32%)	22 (44%)	28 (56%)

The *n* (%) of eyes among the sample that gives an error less than a set target are shown.

Conclusion

We conclude that conventional formulas when utilized with modified k readings according to Jarade's index, give more predictable results, and postoperative refraction closer to the expected. When preoperative data are available, the use of Hoffer Q or Holladay 1 with Jarade's index provides reliable results. Most importantly, it is recommended[4,5] that potential refractive errors be explained at length before cataract surgery and that patients be given a "refractive identity" card at the time of their refractive procedure, with all the preoperative and ablation measurements, especially for patients undergoing redo procedures. Such a step would provide the cataract surgeon with as much data as needed for the use of multiple formulas to be as close as possible to the target.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

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