# Comparison of predictability of intraocular lens power calculation formulas for axial hyperopic patients undergoing cataract surgery using intraocular lens master

Mohamed A. El Samadony, Tarek A. Hafez, Hany A. Helaly, Mohamed M. Rafik

Department of Ophthalmology, Alexandria University, Alexandria, Egypt

Correspondence to Tarek A. Hafez, MD, PhD, Department of Ophthalmology, Alexandria University, Alexandria, 22206, Egypt.
e-mail: tarekrazek@yahoo.com

**Received** May 2017
**Accepted** July 2017

**The Egyptian Journal of Cataract and Refractive Surgery** 2017, 23:49–53

**Purpose**

The aim of this study was to compare the predictability of different intraocular lens (IOL) power calculation formulas [Sanders–Retzlaff–Kraff (SRK) II formula, SRK-T formula, Haigis formula, Hoffer *Q* formula] in axial hyperopic patients [axial length (AL) <22 mm] undergoing cataract surgery using IOL master.

**Patients and methods**

This study comprised 40 eyes of 26 patients who presented with cataract and axial eye length less than 22 mm. Before phacoemulsification and IOL implantation, AL measurement, keratometry measurement and anterior chamber depth measurement using the IOL master were done. IOL power was calculated using four different formulas (SRK-II, SRK-T, Haigis, Hoffer *Q*). Actual stabilized postoperative refraction (spherical equivalent) 1 month after surgery was measured and the accuracy of the four different formulas was compared. Differences between actual postoperative refraction and predicted refraction using the different formulas were analyzed. *P* value less than or equal to 0.05 was considered statistically significant. Furthermore, the percentage of eyes with mean absolute prediction error (MAE) within ±0.5 and ±1.0 diopter (D) for each formula was estimated, as well as the correlation coefficient (*r*) between the AL and MAE for each formula.

**Results**

There was a significant difference between the MAE of the four formulas, except there was no significant difference between the MAE of SRK-T and SRK-II. The Haigis formula had a smallest MAE of 0.47±0.36 D, then Hoffer *Q* with a MAE of 0.87±0.51 D, and then SRK-T with a MAE of 1.38±0.89 D. The SRK-II had the largest MAE of 1.70±1.06 D. The Haigis formula predicted more eyes with MAE within ±0.5 and ±1.0 D of the predicted spherical equivalent compared with other formulas. The correlation between AL and AE has shown a negative *r* value and *P* value of less than 0.05 for all formulas.

**Conclusion**

The Haigis formula provides more accurate results concerning the postoperative target of refraction in eyes with an AL of less than 22.0 mm. Hoffer *Q* could be also used as an alternative.

**Keywords:**
ammetropia, biometry, catarct, hypermetropia, IOL, IOL master, phacoemulsifcation

Egypt J Cataract Refract 23:49–53

1687-6997

Accuracy of intraocular lens (IOL) power calculation in cataract surgery is a very important factor associated with postoperative patient satisfaction [1]. The refractive power of the human eye depends on the power of the cornea, the lens and the axial length (AL) of the eye and the axial position of the lens [2]. The aforementioned factors are crucial to obtain optimal postoperative refractive results.

IOL power is predicted preoperatively by means of several formulas. Third-generation formulas such as Holladay 1, Hoffer *Q*, and Sanders–Retzlaff–Kraff (SRK)-T attempt to predict the estimated lens power using AL, corneal curvature (K), and a constant, as the only variables. Fourth-generation formulas, like Haigis, take into account the preoperative anterior chamber depth (ACD) and use three constants (a0, a1, and a2), which are analogous to the surgeon factor, ACD, and AL, respectively [3]. Of note, inaccuracy in the measurement of ACD, AL, and K can contribute to 42, 36, and 22% of errors, respectively [4].

The measurement of AL with partial coherence interferometry (IOL Master; Carl Zeiss Meditech Inc., Dublin, California, USA) has been shown to produce significantly more precise IOL power calculation and refractive outcome in cataract surgery, thereby avoiding possible compression of the eye with applanation A-scan ultrasound and difficulty with immersion A-scan ultrasound in AL measurements [5,6].

It has been considered that IOL calculation formulas were more accurate for eyes with normal AL, but do not have the same level of postoperative refraction outcome for eyes with short AL [2]. In light of the above, the purpose of our study was to evaluate and compare the predictive capacity of four IOL power calculation formulas (SRK-II, SRK-T, Hoffer *Q*, and Haigis) in eyes shorter than 22.0 mm.

## Patients and methods

The present study was a prospective comparative analysis which included 40 eyes from 26 patients with an AL shorter than 22.0 mm and that underwent uneventful phacoemulsification with IOL implantation. Preoperative AL, keratometric power, and ACD were measured by the IOL master. The power of the implanted IOL was determined using Haigis, Hoffer *Q*, SRK-II, and SRK-T formulas calculated by the IOL master software. Postoperative refractive errors 1 month after cataract surgery were measured using automatic refractokeratometry (RKT-7700; Nidek, Hiroishi, Japan) and were compared with the predicted postoperative power. The mean absolute error (MAE) was defined as the average of the absolute value of the differences between the actual and predicted spherical equivalences of the postoperative refractive error. Ethics committe, Faculty of Medicine, Alexandria University, approved the study. Written informed consent was obtained from each patient according to declaration of Helsinki.

Cataract surgery was performed by one surgeon. Topical anesthesia with proparacaine hydrochloride (Alcaine; Alcon Labs, Fort Worth, Texas, USA) or subtenon anesthesia with 3% lidocaine was administered prior to the operation. A clear corneal incision of 2.75 mm in width was made using a microkeratome at the superior or temporal cornea according to the axis of astigmatism, and phacoemulsification was performed after continuous curvilinear capsulorhexis. Cimaflex 42 (Cima Inc., Pittsburgh, Pennsylvania, USA) foldable IOL was implanted in the 40 eyes. Cases were excluded if a posterior capsular rupture occurred during cataract surgery, if the IOL was inserted into the sulcus, or if the AL could not be measured using the IOL master. Also excluded from the present study were patients who could not be observed for at least 1 month after surgery.

The differences in the MAE according to the four IOL calculation formulas were analyzed. Furthermore, the proportions with absolute errors (AE) of less than 0.5 and 1 diopters (D) of the four IOL calculation formulas were estimated, as well as the correlation coefficient ($r$) between the AL and MAE for each formula.

SPSS version 15.0 (SPSS Inc., Chicago, Illinois, USA) was used for statistical analysis. The Mann–Whitney *U*-test was used to compare differences in the AEs of the formulas. A statistically significant difference was defined as a $P$ value less than 0.05.

## Results

A total of 40 eyes from 26 patients were included in the present study. A total of 11 patients (15 eyes) were men and 15 patients (25 eyes) were women. The mean age was 49.27±16.72 years (range: 17–72 years). The mean AL was 21.06±0.53 mm (range: 20.05–21.98 mm). The mean ACD was 2.87±0.43 mm (range: 2.26–3.54 mm). The mean $K$ was 44.89±1.64 D (range: 41.93–49.78 D).

The MAE in all formulas had a negative value except in the Haigis formula it had a positive value. A negative value indicated a tendency for myopic outcomes, whereas a positive value indicated a tendency for hyperopic outcomes. The Haigis formula had the smallest mean prediction error of +0.43 D, then Hoffer *Q* with a mean prediction error of −0.83 D, then SRK-T with a mean prediction error of −1.37 D. The SRK-II had the largest mean prediction error of −1.67 D. There was a significant difference between the mean prediction error of the four formulas, except there was no significant difference between the mean prediction error of SRK-T and SRK-II.

The Haigis formula had the smallest MAE of 0.47±0.36 D, then Hoffer *Q* with a MAE of 0.84±0.51 D, then SRK-T with a MAE of 1.38±0.89 D. The SRK-II has the largest MAE of 1.70±1.06 D. There was a significant difference between the MAE of the four formulas, except there was no significant difference between the MAE of SRK-T and SRK-II.

The Haigis formula carried the highest sensitivity of prediction at ±0.50, ±1.00 D as it measured 57.5 and 90%, respectively. No eyes were greater than ±2.00 D.

It was followed by the Hoffer *Q* formula with a sensitivity of prediction of 25 and 72.5% at ±0.50, ±1.00 D, respectively. One eye (2.5%) was greater than ±2.00 D. It was followed by the SRK-T formula with a sensitivity of prediction of 15 and 40% at ±0.50, ±1.00 D, respectively. Nine (22.5%) eyes were greater than ±2.00 D. The SRK-II formula carried the lowest sensitivity of prediction at ±0.50, ±1.00 D as it measured 12.5 and 25%, respectively. Fourteen (35%) eyes were greater than ±2.00 D.

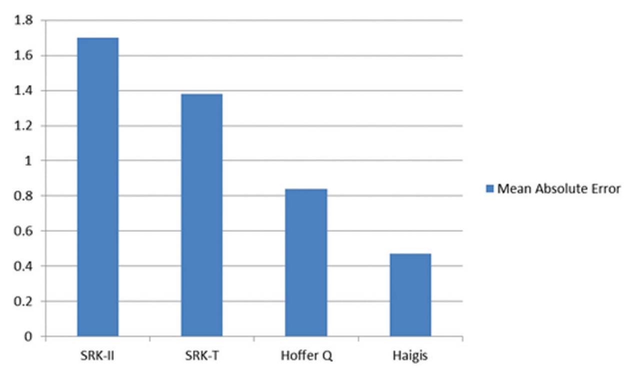
In the current study, a negative correlation between AL and MAE of the four formulas was shown. As AL increased, the MAE of the four formulas decreased (accuracy of the four formulas increased) (Table 1 and Figs 1–3).

## Discussion

The IOL master used in the present study is adapted to a noncontact method known as partial coherence interferometry. This method has a higher resolution [7,8] and more reproducible measurements [9] compared with those of standard ultrasound transducers. However, the IOL master has several shortcomings, particularly in cases of mature or hypermature cataract, severe posterior capsular opacity, or a posterior segment abnormality, such as vitreous hemorrhage, because the AL is impossible to measure [4].

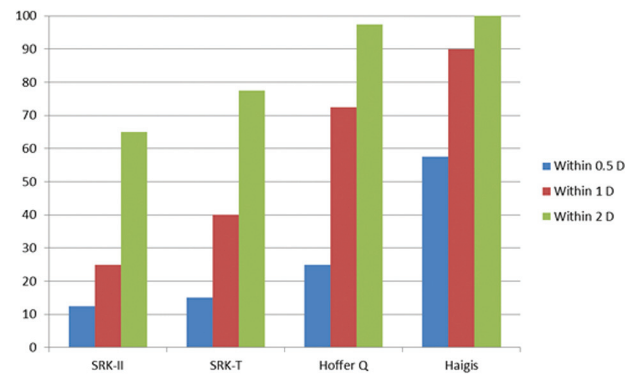
The principal message of our study is that the Haigis formula is more accurate than Hoffer *Q*, SRK-T, and SRK-II in predicting the postoperative refraction after

**Figure 1**



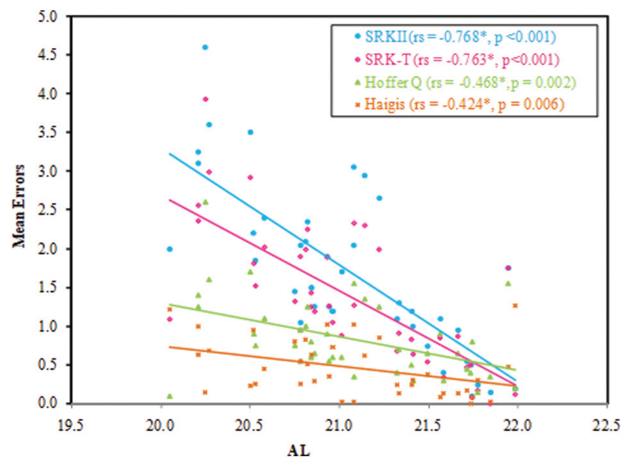

Mean absolute prediction error of the four fomulas.

**Figure 2**




Sensitivity of formula prediction at ±0.50, ±1.00, and ±2.00 D.

**Figure 3**




Correlation between axial length (AL) and mean absolute prediction error of the four fomulas.

**Table 1 Comparison between intraocular lens power calculation formulas mean absolute prediction errors in the entire studied cases (40 eyes)**

| | SRK-II ($n$=40) | SRK-T ($n$=40) | Hoffer *Q* ($n$=40) | Haigis ($n$=40) |
|---|---|---|---|---|
| Minimum–maximum | 0.10–4.60 | 0.0–3.93 | 0.10–2.60 | 0.0–1.27 |
| Mean±SD | 1.70±1.06 | 1.38±0.89 | 0.84±0.51 | 0.47±0.36 |
| Median | 1.50 | 1.26 | 0.73 | 0.37 |
| $^{KW}\chi^2$ ($P$) | | 58.216* (<0.001*) | | |
| $P_1$ | | 0.167 | <0.001* | <0.001* |
| $P_2$ | | | 0.004* | <0.001* |
| $P_3$ | | | | 0.001* |

$^{KW}\chi^2$, $\chi^2$ for Kruskal–Wallis test; $P_1$, Mann–Whitney test for comparing between SRK-II with SRK-T, Hoffer *Q*, and Haigis; $P_2$, Mann–Whitney test for comparing between SRK-T with Hoffer *Q* and Haigis; $P_3$, Mann–Whitney test for comparing between Hoffer *Q* and Haigis. *$P \leq 0.05$, statistically significant.

cataract surgery in eyes with an AL of less than 22.0 mm. It also predicted the greatest percentage of eyes that fell within ±0.5 and ±1.0 D of estimated error.

This was in agreement with Maclaren *et al.* [10] who performed a retrospective study of the refractive outcomes in 84 eyes of patients who had inserted an IOL powered more than or equal to 30 D. Maclaren *et al.* [10] have compared the Haigis formula, the Hoffer *Q* formula, the Holladay 1 formula, and the SRK-T formulas and found that the Haigis formula using single optimization was the most accurate (+0.51±0.12 D mean error) followed by the Hoffer *Q* formula (−0.70±0.14 D mean error), Holladay 1 formula (−1.11±0.13 D mean error), and finally came the SRK-T formula (−1.45±0.14 D mean error).

Szaflik *et al.* [11] have found that the Hoffer *Q* formula was the most accurate formula for IOL power prediction in hyperopic patients followed by the Holladay formula when they tested the Hoffer *Q* formula, the Holladay 1 formula, the SRK-II formula, and the SRK-T formula for IOL power prediction on 34 eyes of patients having an AL of the eye ranging from 19.6 to 21.99 mm by retrospective analysis.

Hoffer [12] compared his formula (the Hoffer *Q* formula) with the SRK, SRK-II, SRK-T, and Holladay 1 formulas in 450 eyes of patients of which only 36 eyes had an AL less than 22 mm and concluded that for shorter eyes with AL less than 22 mm, the Hoffer *Q* formula (0.52±0.53 D MAE) is superior to the Holladay 1 formula (0.61±0.55 D MAE) and rejected the other formulas from application to short eyes as the SRK-T, SRK-II, and SRK formulas had 0.76±0.55 D, 0.83±0.65 D, and 1.36±1.06 D MAEs, respectively. These results agree with the current results as the Hoffer *Q* formula is more predictable than both the SRK-II formula and the SRK-T formula.

Gavin *et al.* [13] have compared the predictability of the Hoffer *Q* formula with the SRK-T formula (without a customized ACD constant) in 41 hyperopic eyes with an AL ranging from 21.96 to 20.29 mm measured by partial coherence interferometry technique. He collected the data of the patients both retrospectively and prospectively, and noticed that the MAE of the Hoffer *Q* formula was 0.60±0.80 and that the SRK-T formula MAE was 0.87±0.829; there was a statistical significant difference ($P<0.001$) concluding that the Hoffer *Q* formula is suitable and more accurate for IOL power calculation in short eyes less than 22 mm.

Haigis [14] also concluded that the Haigis formula, the Hoffer *Q* formula, or the Holladay 2 formulas are accurate in the calculation of IOL power in eyes with high hyperopia.

However, Bai *et al.* [15] have conducted a study on 31 hyperopic eyes, he performed the biometry with both A-scan ultrasound and partial coherence interferometry and concluded the Haigis is the most accurate formula for hyperopic eyes when using the partial coherence interferometry biometry technique. It overpredicts the IOL power having a mean prediction error of 0.37±0.14 D. On the other hand, the Hoffer *Q*, the Holladay, the SRK-T, and the SRK-II formulas underpredict the IOL power as they had a mean prediction error of −0.70±0.12, −0.97±0.15, −1.25±0.14, −1.46±0.13, respectively. They noted that the Hoffer *Q* formula is the best to use for the prediction of IOL power in hyperopic eyes when using the ultrasound biometry technique.

Terzi *et al.* [16] have found that for hyperopic refractive lens exchange (AL <22.0 mm), the Haigis formula showed the smallest MAE, followed by those of the Holladay 2, Hoffer *Q*, and the SRK-T formulas, although the difference was not statistically significant.

Roh *et al.* [2] have concluded that the IOL power calculation using the Haigis formula showed the best results for postoperative power prediction in short eyes. The study was a retrospective comparative analysis which included 25 eyes with an AL shorter than 22.0 mm that underwent uneventful phacoemulsification with IOL implantation from July 2007 to December 2008 at the Seoul National University Boramae Hospital. They evaluate the predictability of IOL power calculations using the IOL master and four different IOL power calculation formulas (Haigis, Hoffer *Q*, SRK-II, and SRK-T). The MAE was the smallest with the Haigis formula (0.37±0.26 D), followed by those of SRK-T (0.53±0.25 D), SRK-II (0.56±0.20 D), and Hoffer *Q* (0.62±0.16 D) in 25 eyes with an AL shorter than 22.0 mm. The proportion with an absolute error (AE) of less than 1 D was greatest in the Haigis formula (96%), followed by those in the SRK-II (88%), SRK-T (84%), and Hoffer *Q* (80%). These results agree with the current study in that the Haigis formula shows the best results, but disagree in concluding that both the SRK-T and SRK-II formulas are better than Hoffer *Q* formula.

On the other hand, Inatomi *et al.* [17] have found that the SRK-T formula is the best formula to predict the refraction compared with the Hoffer *Q*, Holladay 1, SRK, SRK-II, S-SRK formulas in only six eyes with an AL of less than 19 mm.

In another study, Donoso *et al.* [18] have compared the predictability of different IOL power calculation formulas (SRK-II, Binkhorest II, Hoffer *Q*, Holladay 1, and SRK-T) according to the AL of the eye. They stratified the AL in three groups (short $<$22 mm, between 22 and 28 mm, and long $>$28 mm) and concluded that for short eyes the Binkhorest II and the Hoffer *Q* formulas provided the best predictive results and for long eyes the SRK-T formula was the most predictive formula.

**Financial support and sponsorship**
Nil.

**Conflicts of interest**
There are no conflicts of interest.

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