



Assessment of Accuracy of Different Intraocular Lens Formulas in Aphakic Children for Secondary Implantation

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Abstract: Purpose: to evaluate the accuracy of pediatric intraocular lens (IOL) calculation formulas in predicting refractive outcome in aphakic eyes for secondary implantation with axial lengths (AL) equal to or less than 22.0mm and under the age of six years. **Aim of the study:** This study was intended to assess the most accurate intraocular lens calculation formula in pediatric aphakic cases doing secondary intraocular lens implantation. **Methods:** A prospective study was conducted on 30 eyes of 20 patients (8 males and 12 females), 10 unilateral and 10 bilateral. They underwent secondary IOL implantation after obtaining an informed and written consent from the parents. Preoperative keratometry was done by a portable autorefractometer. Axial length and anterior chamber depth was measured using A-scan of Pac Scan 300AP. Patients were divided into two groups. According to the axial length (AL), group A with $AL \leq 20$ mm and group B ($> 20, < 22$ MM). According to the age, group C ≤ 2 years and group D ($> 2, < 6$ years). IOL calculation was made using the three formulas (Holladay 1, Hoffer Q, Haigis) for each eye, IOL was implanted according to one of them and the refractive outcome was compared with the other two formulas. Estimation error (E) and Absolute Error (AE) were calculated at one and half months for each eye. The predictive accuracy of each formula in each group was analyzed by comparing the Absolute Error (AE). The Kruskal Wallis test was used to compare differences in the (AE) of the formulas. A statistically significant difference was defined as p -value <0.05 . **Results:** In group A, the Hoffer Q had the lowest mean absolute error. In group B, there were no statistically significant differences in mean absolute error between the three formulas. In group C the percentage of target refraction within $\pm 1D$ was higher with Hoffer Q (P -value ≤ 0.05) but in group D the percentage of target refraction within $\pm 1D$ was also higher with Hoffer Q but (P -value > 0.05) which means that there are no difference between the three formulas in this age group. **Conclusion:** Hoffer Q was the most predictable in axial length group ≤ 20 mm but in axial length $> 20, < 22$ mm the three formulas were equally predictable. In age group ≤ 2 years we detect a significant difference as Hoffer Q was the most predictable formula but in age group > 2 and < 6 years the three formulas were equally predictable.

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1. Introduction:

Recent advances in pediatric cataract surgery have resulted in an increase of usage of intraocular lenses (IOLS) in children.(1)

With improved surgical equipments and techniques, the acceptable age for intraocular lens implantation is becoming progressively younger.(2)

It is critical for the surgeons to have the ability to predict post-operative refraction and implant an intraocular lens with an accurate power in pediatric eye.(3)

Implantation of intraocular lenses in children involves several unique challenges not present in adult cataract surgery as children eyes continue to grow significantly. The change of axial length during post-

operative years will result in refractive changes that complicate the predictive refractive power of intraocular lens after surgery.(4, 5)

In addition, errors in intraocular lens power selection are more likely to occur in pediatric age group due to inaccuracy in measurement of axial length or keratometric power.(6)

Pediatric cataract surgery usually has a postoperative refractive goal that may aim for a significant amount of residual hyperopia to accommodate for the anticipated growth and refractive shift of the postoperative eye.(1)

The complex situation of needed hyperopia is further compounded by the use of intraocular lens calculation formulas that generally are designed for

adult and not reliable for young children who have steeper, less diameter cornea, shorter axial length and correspondingly shallower anterior chamber.(1)

Currently the pediatric ophthalmologist must depend on accurate formulas which are designed for adult which formula to use is still a matter of discussion.(6)

2. Patients and methods:

This prospective study was carried out on 30 eyes of patients attending Ophthalmology outpatient clinic in Tanta University Hospitals from March 1, 2018 to March 1, 2019.

Inclusion criteria:

- Axial length less than 22 mm.
- Aphakia for secondary implantation.
- Age: below 6 years.
- Both sexes enrolled.
- Clear cornea.
- Presence of posterior capsular support.

Exclusion criteria:

- Aphakia after traumatic cataract extraction.
- Pre-existing ocular condition such as:
 - Corneal opacities, scars.
 - Microcornea, Microphthalmos.
 - Glaucoma, uveitis, optic nerve diseases.
 - Congenital colobomas.

Statistical analysis

Data entry was done in Microsoft Excel 2016. Mean, Median and Standard deviation (SD) was calculated. Postoperatively, patients were examined after one and half months postoperatively. Estimation error (E) was defined as the difference between the actual postoperative refraction after one and half months follow up and the predicted postoperative refraction. The (AE) defined as the absolute value of

error. Mean AE was calculated for each formula. The differences in the mean AE of the three formulae were analyzed. Furthermore, the percentage of eyes with AEs within ± 1.00 and > 1 D for each formula was estimated.

3. Results:

Sample selection

The present study included 30 eyes of 20 patients (8 males and 12 females), 10 cases were unilateral and 10 cases were bilateral who underwent secondary IOL implantation after congenital cataract extraction.

Table 1: Age distribution of patients at time of surgery (in years)

Age at time of surgery	No. of eyes
Age ≤ 2 years	14
Age > 2 - < 6 years	16
Total	30

Statistical analysis

A- The cases were included in the study were divided in two categories.

- **First category according to the axial length:**

- Group A: 20 eyes. ($AL \leq 20$ mm).
- Group B: 10 eyes ($AL > 20$, $- < 22$ mm).

- **Second category according to the age:**

- Group C: 14 eyes. (age ≤ 2 years)
- Group D: 16 eyes. (age > 2 , < 6 years)

B- For the first category: Kruskal Wallis test which is a nonparametric ANOVA test was used to compare differences in the AEs of the formula.

C- For the second category: ANOVA test which is a parametric test was used to compare differences in the AEs of the formulas.

Table 2: Descriptive statistics of patients of group A & B.

Group A			
Formula	Haigis	Hoffer-Q	Holladay I
Mean Estimation, Error (E) \pm SD	0.93 \pm 0.47	0.68 \pm 0.54	0.90 \pm 0.80
Range of Estimation Error (E)	-0.25 to 2.00	-0.50 to 1.80	-1.50 to 1.90
Mean Absolute Error (AE) \pm SD	0.93 \pm 0.47	0.75 \pm 0.45	1.10 \pm 0.47
Range of Absolute, Error	0.25 to 2.00	0.20 to 1.80	0.25 to 1.90
Median Absolute Error	0.85	0.60	1.1
Group B			
Formula	Haigis	Hoffer-Q	Holladay I
Mean Estimation, Error (E) \pm SD	0.96 \pm 0.47	0.68 \pm 0.55	1.12 \pm 0.60
Range of Estimation Error (E)	0.25 to 1.50	-0.50 to 1.40	-0.25 to 1.90
Mean Absolute Error (AE) \pm SD	0.95 \pm 0.472846	0.78 \pm 0.37	1.12 \pm 0.60
Range of Absolute, Error	0.25 to 1.50	0.20 to 1.40	0.25 to 1.90
Median Absolute Error	0.90	0.75	1.15

Analysis of Group A results

The mean AL was 20.317 ± 1.033 mm. The mean E (\pm SD) for Haigis, Hoffer Q and Holladay I was 0.93 ± 0.47 , 0.68 ± 0.54 and 0.90 ± 0.80 , respectively. The mean AE (\pm SD) for Haigis, Hoffer Q and Holladay I was 0.93 ± 0.46 , 0.75 ± 0.44 and 1.10 ± 0.47 , respectively.

The median AE for Haigis, Hoffer Q and Holladay I was 0.85, 0.60 and 1.10, respectively.

Analysis of Group B results.

The mean AL was 21.591 ± 0.75 mm. The mean E (\pm SD) for Haigis, Hoffer Q and Holladay I was 0.95 ± 0.47 , 0.68 ± 0.55 and 1.12 ± 0.60 , respectively. The mean AE (\pm SD) for Haigis, Hoffer Q and Holladay I was 0.95 ± 0.47 , 0.78 ± 0.37 and 1.125 ± 0.60 , respectively.

The median AE for Haigis, Hoffer-Q and Holladay I was 0.90, 0.75 and 1.15, respectively.

Table 3: p-value in group A & B.

Group A	
Comparison (Mean AE)	p-value (Kruskal Wallis Test)
Haigisvs Hoffer Q	0.001
Haigisvs Holladay I	0.493
Hoffer Qvs Holladay I	0.005
Group B	
Haigisvs Hoffer Q	0.9
Haigisvs Holladay	0.35
Hoffer Q vs Holladay	0.4

P-value of Group A

The Holladay formula had statistically significant higher mean AE in comparison to Hoffer Q ($p < 0.05$), Haigis formula had statistically significant mean AE in comparison to Hoffer Q ($p < 0.05$), Holladay I formula had no statistically significant higher mean AE in comparison to Hoffer Q ($p > 0.05$). Thus, Haigis and Holladay I formulas were equally accurate in predicting postoperative refraction after secondary IOL implantation of $AL \leq 20.00$ mm. while accuracy of the Hoffer Q formula was significantly higher than Haigis and Holladay I.

P-value of Group B.

There was no statistically significant difference in mean AE of Haigisvs Hoffer Q and Holladay formulae ($p > 0.05$).

Thus, Haigis, Hoffer Q and Holladay formulae were equally accurate in predicting postoperative refraction after secondary IOL implantation of $AL > 20 - < 22$ mm.

The percentage of eyes with absolute error (AEs) within ± 1 and > 1 D for each formula was estimated.

D- Group A & B:

The Percentage of specified target refraction within ± 1 D in group A ranges between 50% and 75%. The highest percentage is Hoffer Q, where (P-value ≤ 0.05), which means that the Hoffer Q is the highest prediction Value, consistent with significant P-value.

The Percentage of specified target refraction within ± 1 D group A ranges between 50 % and 70%. The highest percentage is Hoffer Q, where (P-value > 0.05), which means that there are no differences between three formulae.

Table 4: Analysis of eyes within specified target refraction for each formula in Group A & B.

Group A				
Formula	AEs within ± 1		AEs > 1	
	No. of eyes	percentage	No. of eyes	percentage
Haigis	13	65%	7	35 %
Hoffer Q	15	75%	5	25 %
Holladay I	10	50%	10	50 %
Group B				
Haigis	6	60%	4	40 %
Hoffer Q	7	70%	3	30 %
Holladay	5	50%	5	50 %

Group C & D:

The Percentage of specified target refraction within $\pm 1D$ in group C ranges between 57% and 86 %. The highest percentage is Hoffer Q, where (P-value ≤ 0.05), which means that the Hoffer Q is the highest prediction Value, consistent with significant P-value.

The Percentage of specified target refraction within $\pm 1D$ in group D ranges between 50% and 69 %. The highest percentage is Hoffer Q, where (P-value >0.05), which means that there are no differences between three formulae.

Table 5: Analysis of eyes within specified target refraction for each formula in Group C & D.

Group C				
Formula	AEs within ± 1		AEs > 1	
	No. of eyes	percentage	No. of eyes	percentage
Haigis	9	64%	5	36 %
Hoffer Q	12	86%	2	14 %
Holladay	8	57%	6	43 %
Average		69%		31 %
Group D				
Haigis	10	63%	6	37 %
Hoffer Q	11	69%	5	31%
Holladay	8	50%	8	50 %
Average		60%		40 %
P-value =0.044 using (ANOVA measurement test)				

4. Discussion:

Calculation of the appropriate IOL power in children is not well established specially in the younger age group. (1)

Pediatric eyes not only have smaller axial lengths, but also they usually have smaller and steeper corneas, shallower anterior chambers, and disproportionately smaller posterior segment/axial length ratio. In addition, there is no reliable method of predicting this frequently anomalous growth curve, and there is no agreement on the suitable post-operative refractive goal, even in those eyes that would follow a standard growth curve. Added to these facts, there are no specific formulas for pediatric age group. (1)

This study included 30 eyes of 20 children under the age of six years comparing three IOL power calculation formulas (Holladay 1, Hoffer Q, Haigis) to detect the most predictable formula and we found that there was no statistically difference between them in axial length group >20 and < 22 mm. but Hoffer Q formula was the most predictable in $AL \leq 20$.

As regards the short AL group, Carifi et al., (2015) (7) compared 6 formulas (Hoffer Q, Holladay 1, Holladay 2, Haigis, SRK-T, and SRK-II), including 28 short eyes, and found that the Hoffer Q formula resulted in a good or fair refractive results in less than two thirds of the cases. Holladay 1 and 2 and Haigis

formulas, the results would not have been significantly different and their (p value = 0.245) meaning that there is no statistical difference between the different formulas included in the study.

Also Kane et al., (2016)(8) compared 7 formulas (Universal II, Haigis, Hoffer Q, Holladay 1, Holladay 2, SRK/T, and T2) including 156 short eyes of axial length less than 22.00 mm showing that (p value =0.210) which means that there was no statistical difference between them.

Also Gokce et al., (2017)(9) compared 7 formulas (Barrett Universal II, Haigis, Hill-RBF, Hoffer Q, Holladay 1, Holladay 2, and Olsen) including 67 patients with axial lengths (AL) equal to or less than 22.0 mm in predicting refractive outcome and they found that their (P value=0.076) which means that there is no significant differences between the prior formulas in predicting refractive outcome.

Also Aristodemou et al., (2011)(10) reported in their study that in short eyes, the Hoffer Q and Holladay1 had a lower median absolute error (MAE) than the SRK/T for axial lengths ranging from 21.00 to 21.49 mm and There were no statistically significant variations in MAE for axial lengths from 21.50 to 21.99mm.

Gavin et al., (2008)(11) investigated 41 eyes with AL less than 22 mm, The Hoffer Q formula showed a mean prediction error of 0.61 D (SD 0.80) compared

to the SRK-T, which showed a mean prediction error of 0.87 D (SD 0.829). A paired t-test found that the Hoffer Q was significantly more accurate than the SRK-T formula ($P < 0.001$) and concluded that the Hoffer Q formula was more accurate in axial length less than 22 mm.

In the contrary to our study, MacLaren et al., (2007)(12) reported in their study that the Haigis formula was the most accurate followed by the Hoffer Q, including 76 eyes with mean AL 20.79 mm, while Holladay 1 and SRK / T were the least accurate.

Also contrary to our study, Roh et al., (2011) (13) study comparing four different formulas (Haigis, Hoffer Q, SRK II, and SRK/T) including 25 eyes with an AL shorter than 22.0 mm and found that The Haigis formula showed the best results for postoperative power prediction in short eyes.

Unfortunately, in our study children were under the age of 6 years, IOL Master was not used as our patients were not cooperative so AL was measured using ultrasonic contact biometry that makes errors more likely.

Any measurement error in the axial length of a short eye will have a greater impact on the final refraction as a given measurement error is a much bigger proportion of the axial length in a short eye and could therefore be a significant cause of error. This is particularly important in applanation ultrasound biometry, as this technique is known to have the disadvantage of possibly depressing the cornea during use leading to a falsely short axial length measurement.

Regarding to biometry technique, In a study comparing Contact technique versus immersion A-scan biometry in Prediction error after pediatric cataract surgery with intraocular lens implantation, Trivedi et al., (2011) (14) found that there was a statistically significant difference between them (P value $< .001$) and that the immersion technique was better in predicted refraction.

As regard to age group, In this study, we found that 69% of children younger than 2 years old had refractive result within 1 diopter of their post-operative refractive target, in children older than 2 years old the percentage was 60 %.

Neely et al., (2005) (1) compared 4 formulas (SRK II, SRKT, Hoffer Q, Holladay I) in a study 101 eyes of 76 patients They noted that the proportion of children below 2 years of age had a refractive outcome within 1 diopter was 61 %, while the proportion of children older than 2 years of age increased to 81%. That proportion was worse than ours.

That low accuracy result may reflect the implantation of IOL in very young age as the number of patients under 2 years of age was 23, and 17 of them were under 1 years old. This causes consequent

problems such as high post-operative refractive goals and the high incidence of increased rate of refractive growth in relation to his age group.

In this study, we found in age below 2 years that the average of refractive result within 1 diopter in eyes of children under 2 years of age was 69 % and the Hoffer Q was significantly the most predictable formula (p value $< 0.05\%$).

That result changed in another age group, as the formula Hoffer Q was the most predictable, but that was found to be insignificant.

In agreement with our study what Nihalania et al., (2010) (15) found in their study including 135 eyes compared the absolute prediction error with the 4 formulas in each patient, the Hoffer Q formula was the most predictable as it gave the minimum prediction error.

Limitation of our study is that the immersion technique of AL measurement was not used and the contact technique was only used that could carry the risk of error in measurement.

Also another limitation was that the sample size is small to allow further analysis taking into account that short AL is not very widespread.

Recommendations:

- Ophthalmology surgeons should recognize the anatomical, physiological and technical variations in pediatric developing eyes which add sources of errors in estimated IOL power, and should be taken in consideration.
- The need for development of new IOL calculation formulas that satisfy needs of pediatric population.
- The need to support the development of new devices (e.g. a portable IOL MASTER) that will decrease the sources of errors in estimated IOL power.

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