



# IOL calculation using six formulas in children undergoing lens extraction and primary IOL implantation with and without posterior optic capture

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## Abstract

**Purpose** To evaluate formulas for intraocular lens (IOL) calculation in children undergoing lens extraction and IOL implantation.

**Methods** Retrospective, consecutive case series at the Department of Ophthalmology, Goethe University Frankfurt, Germany. We included eyes that received lens extraction and IOL implantation (SN60AT, Alcon, Fort Worth, TX) due to congenital or juvenile cataract. Preoperative assessments included biometry (IOLMaster 500/700, Carl Zeiss Meditec, Germany). To evaluate the measurements, we compared the mean prediction error (MPE), mean and median absolute prediction error (MAE, MedAE) of six different formulas, and number of eyes within  $\pm 0.5$ ,  $\pm 1.0$ ,  $\pm 2.0$ D of target refraction. Postoperative spherical equivalent was measured by retinoscopy 4–12 weeks after surgery.

**Results** 66 eyes matched our inclusion criteria with a mean age of 6.3 years  $\pm 3.2$ . MedAE was lowest in SRK/T ( $0.55\text{D} \pm 1.08$ ) followed by Holladay I ( $0.75\text{D} \pm 1.00$ ), EVO 2.0 ( $0.80\text{D} \pm 0.89$ ), Barrett Universal II (BUII,  $0.86\text{D} \pm 1.00$ ), Hoffer Q ( $0.97\text{D} \pm 0.94$ ), and Haigis ( $1.10\text{D} \pm 0.95$ ). Regarding eyes within  $\pm 0.5$ D SRK/T (45.5%, 30 eyes) performed best, followed by Holladay I (36.4%, 24 eyes), EVO 2.0 and BUII (each 34.8%, 23 eyes). There was a myopic shift seen in all formulas (MPE:  $-0.21$  to  $-0.90\text{D}$ ).

**Conclusion** Using modern formulas, or even AI formulas, for IOL calculation in children's eyes does barely improve predictability of the postoperative refraction. A myopic shift can be found for all formulas. However, specific formulas like SRK/T seem to better anticipate this.

## Key messages

### What is known:

- IOL calculation in children comes with a reduced predictability of postoperative refraction.
- Modern formulas can improve the IOL calculation not substantially.

### What is new:

- SRK/T seems to anticipate the myopic prediction error best.
- Eyes without optic capture show less myopic shift regarding the IOL calculation.

**Keywords** IOL calculation · Congenital cataract · Juvenile cataract · Optic capture

## Background

Cataract surgery, in terms of lens extraction with IOL implantation, is nowadays the widely accepted treatment for not only age related cataract, but juvenile or congenital cataract as well.

Even though being a rare condition with a prevalence ranging from 0.3 to 22 per 10,000 for childhood and 0.6 to

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9.7 per 10,000 for congenital cataract [1], it is a treatable cause of blindness or visual disability in children worldwide. However, taking the lens out of the eye is only half the cure [2]. Depending on the age of the patient and if the cataract is uni- or bilateral [3], leaving the eye aphakic is not an ideal option due to possible anisometropia, need of aphakia glasses or contact lenses and known risk of glaucoma [4]. This underlines the importance of the IOL implantation itself, but especially the calculation of the IOL, which is hardly comparable to IOL calculation in adult eyes due to various reasons. First of all one has to notice that children eyes are shorter and with a steeper cornea, measurements are possibly less reliable due to reduced compliance and the target refraction is usually hyperopic to anticipate the axial growth of the eye [5, 6]. At last the procedure of the surgery is different itself since often primary posterior capsulorhexis and posterior optic capture are performed. Older formulas produce mixed results [5, 7], but even modern formulas that perform well in short eyes [8–10], only reach modest results in pediatric patients [11, 12]. A modern formula that seems to perform well in short eyes would be the emmetropia verifying optical (EVO) 2.0 formula, which is a thick-lens formula using an “emmetropia factor” and is available online ([www.evoiolcalculator.com](http://www.evoiolcalculator.com)) [13]. However to the best of our knowledge only few publications on IOL calculation in pediatric eyes using it are available [14]. Additionally, most trials do not report if eyes underwent posterior optic capture. This is why we conducted this retrospective case series to evaluate the IOL calculation of third, fourth and newer generation formulas including the EVO 2.0 formula in pediatric eyes that received a primary IOL implantation during cataract surgery at the University Hospital of Frankfurt, Germany and compared eyes with and without intraoperative optic capture.

## Methods

### Study design

The study protocol was approved by the local Ethics Committee of the University Frankfurt, Germany and followed the tenets of the Declaration of Helsinki.

The medical records of all patients of 13 years or younger that underwent lens extraction and intraocular lens (IOL) implantation for congenital or juvenile cataract from January 2011 to October 2022 were screened.

### Inclusion and exclusion criteria

Eyes meeting the following criteria were included: Pseudophakia with a monofocal IOL implanted primarily after lens

extraction, maximum age of 13 years at the time of surgery, complete pre- and postoperative data, no intra- or postoperative complications. *Exclusion criteria* were pseudophakia with a lens other than a monofocal IOL, ocular pathologies that could possibly influence the postoperative refraction, IOL implantation in a second procedure, missing pre- or postoperative data, and biometry under general anesthesia. Patients older than 13 years were excluded since they do not reflect the pediatric eye anatomy as much as younger children. There was no minimum age for inclusion.

### Preoperative and postoperative assessment

Keratometry, axial length (AL), anterior chamber depth (ACD), lens thickness (LT), and white to white distance (WTW) were collected with the IOL Master 500 or 700 (Carl Zeiss Meditec, Germany) in all eyes we included. Literature shows that the measurements of the IOL Master 500 and 700 are comparable in terms of simulated *k* values, anterior chamber depth, and axial length measurements [15], therefore both were included. A trained ophthalmologist, using retinoscopy while the pupil was dilated, performed preoperative and postoperative objective refraction. The postoperative refraction (spherical equivalent = SE; diopters = D) was taken 4–12 weeks after surgery.

### Intraocular lenses, calculation, and surgery

Only patients with the following monofocal IOL were included: SN60AT (Alcon, Fort Worth, Texas, USA). The used IOL constants were Sanders-Retzlaff-Kraff third generation formula (SRK/T) A constant 118.8, Hoffer Q 5.44, Haigis A0 -0.111, A1 0.249, A2 0.179, Barrett Universal II (BUII) 118.53, Holladay 1.67, EVO 2.0 118.8, which are the commonly used constants for our regular practice.

Lens extraction was performed under general anesthesia by the same surgeon (TK) using a temporal 2.2 mm clear corneal incision. The lens was always implanted into the capsular bag, with or without posterior optic capture and primary posterior capsulorhexis to reduce risk of posterior capsule opacification [16]. If no optic capture was done, an anterior vitrectomy was performed.

All surgeries were performed at the Department of Ophthalmology, Goethe University, Frankfurt am Main, Germany.

### Calculation of the prediction error

The formulas evaluated were: SRK/T, Hoffer Q, Haigis, BUII, Holladay I, and EVO 2.0. All formulas were used in their latest version, calculation was performed in November 2022. Formulas like Kane or radial basis function (RBF3.0)

**Table 1** Patient demographics ( $n=66$ )

	Mean	SD	Min	Max
Age (years)	6.3	3.2	1	13
AXL (mm)	22.24	1.19	19.15	25.85
Kmean (D)	43.20	2.11	37.69	50.59
ACD (mm)	3.49	0.39	2.59	4.71
LT (mm)	3.34	0.31	3.92	2.78
IOL power (D)	24.98	5.1	6	36
Preop SE (D)	-0.68	4.49	-17.88	6.13
Postop SE (D)	-1.19	1.24	-3.75	3.5
Preop VA (decimal)	0.26	0.17	0.014	0.6
Postop VA (decimal)	0.52	0.31	0.025	1.0

*D* diopter, *Kmean* mean keratometry, *ACD* anterior chamber depth, *LT* lens thickness, *IOL* intraocular lens, *SE* spherical equivalent, *VA* visual acuity

formula were excluded since hyperopic target refraction was only available up to a certain amount and therefore a calculation of some eyes wouldn't have been possible.

The predicted residual refraction at the spectacle plane for the implanted IOL was calculated with each formula and by using actual postoperative refraction the prediction error was calculated. A positive value would be a hyperopic, a negative value a myopic prediction error.

## Outcome measures

The percentage of eyes within  $\pm 0.5D$ ,  $\pm 1.0D$  and  $\pm 2.0D$  of target refraction, mean prediction error (MPE), standard deviation (SD), mean absolute error (MAE), median absolute error (MedAE), and maximum respectively minimum (range) were calculated and evaluated for each formula.

## Statistical analysis

Available data was tested for normal distribution by a Kolmogorov Smirnov test. To compare differences in MPE and MedAE a Friedman test was used and, if a significant difference was found, a post hoc analysis with a Wilcoxon signed-rank test or paired t-test was performed (depending on distribution). The percentage of eyes within  $\pm 0.5D$  and  $\pm 1.0D$  was compared with a Cochran Q test. The *p* values were Bonferroni corrected if needed, *p* values under 0.05 were considered statistically significant. Statistical analyses were performed using Excel 2011 (Version 14.7.7; Microsoft, WA) and SPSS (Version 29.0; IBM, NY).

The sample size estimation was based on a previous paper published by us [31] and was performed with the G\*Power 3.1 Software (Heinrich Heine University Duesseldorf, Germany). Based on a difference between the groups of 0.1D with a standard deviation of 0.2D at least 47 eyes were needed to reach power of at least 80%.

**Table 2** Mean prediction error, mean and median absolute prediction error

All eyes ( $n=66$ )				
	MPE $\pm$ SD	MedAE	MAE	Range
SRK/T	-0.21 $\pm$ 1.08	0.55	0.93	0.00 / 5.35
Holladay I	-0.41 $\pm$ 1.00	0.75	1.01	0.01 / 4.87
EVO 2.0	-0.41 $\pm$ 0.89	0.80	1.00	0.02 / 4.73
BUII	-0.60 $\pm$ 1.00	0.86	1.08	0.02 / 5.1
Hoffer Q	-0.75 $\pm$ 0.94	0.97	1.13	0.01 / 4.81
Haigis	-0.90 $\pm$ 0.95	1.10	1.31	0.05 / 5.3
Optic capture eyes ( $n=47$ )				
SRK/T	-0.29 $\pm$ 1.17	0.52	0.93	0.00 / 5.35
Holladay I	-0.60 $\pm$ 1.08	0.72	0.99	0.05 / 4.87
EVO 2.0	-0.41 $\pm$ 0.97	0.62	0.97	0.02 / 4.73
BUII	-0.69 $\pm$ 1.10	0.70	1.07	0.02 / 5.1
Hoffer Q	-0.75 $\pm$ 0.98	0.95	1.13	0.01 / 4.81
Haigis	-1.03 $\pm$ 1.00	1.11	1.35	0.01 / 5.32
Non optic capture eyes ( $n=19$ )				
SRK/T	0.01 $\pm$ 0.78	0.86	0.93	0.01 / 2.86
Holladay I	-0.13 $\pm$ 0.79	0.89	1.04	0.01 / 2.85
EVO 2.0	-0.41 $\pm$ 0.64	1.03	1.11	0.02 / 2.99
BUII	-0.37 $\pm$ 0.71	0.92	1.12	0.02 / 2.59
Hoffer Q	-0.21 $\pm$ 0.79	1.01	1.15	0.12 / 2.99
Haigis	-0.56 $\pm$ 0.76	1.07	1.24	0.06 / 3.39

*MPE* mean prediction error, *MAE* mean absolute prediction error, *MedAE* median absolute prediction error

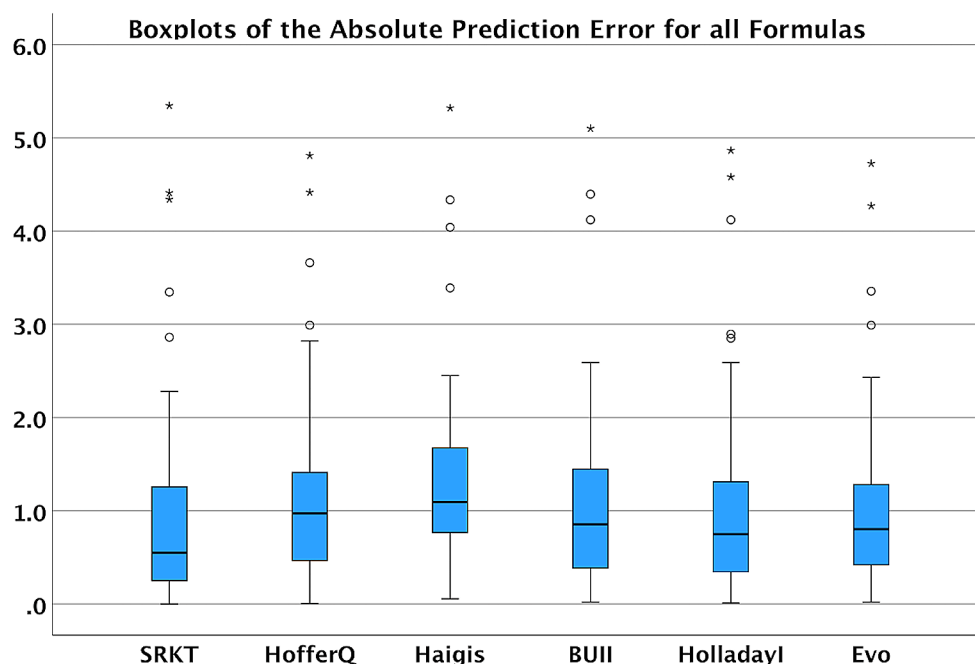
## Results

### Preoperative data

We included 66 eyes from 53 patients with a mean age of 6.3 years  $\pm$  3.2. Mean axial length was 22.24 mm  $\pm$  1.19. Mean preoperative spherical equivalent was  $-0.68D \pm 4.49$  and mean postoperative spherical equivalent (SE) was  $-1.19D \pm 1.24$ . Mean implanted IOL power was 24.98D  $\pm$  5.1. The complete preoperative data is shown in Table 1. The follow-up took place at least one month postoperative in all patients. Forty-seven eyes received an intraoperative optic capture (71%).

### Mean and median absolute error

The MedAE (Table 2; Fig. 1) was lowest in the SRK/T formula (0.55D, SD  $\pm$  1.08) followed by Holladay I (0.75D, SD  $\pm$  1.00), EVO 2.0 (0.80D, SD  $\pm$  0.89), BUII (0.86D, SD  $\pm$  1.00), Hoffer Q (0.97D, SD  $\pm$  1.13), and Haigis (1.10D, SD  $\pm$  0.95 each). All of those were significantly above zero ( $p < 0.001$ ). There was a statistically significant difference using the Friedman test with Bonferroni correction ( $p < 0.001$ ) and after pairwise testing comparing the SRK/T to Hoffer Q ( $p = 0.035$ ) and comparing all formulas to the Haigis formula ( $p = 0.020$  to  $< 0.001$  depending

**Fig. 1** Boxplots of the absolute refraction error of all formulas

on the formula). When excluding eyes that did not receive intraoperative optic capture the MedAE was shown to be lower (Table 2). This difference was not significant from a statistical and clinical point of view.

Specifically having a look at the 5 outliers that show an AE of above 3.0D for all or some formulas does not seem to show a correlation to lower axial length or steeper corneas. By looking at the biometric data of them the AL ranges from 19.15 to 25.85 mm and the keratometric values (k mean) from 40 to 50D. The age ranges from one to seven years and the implanted lens from 6.0 to 33.0D. Screening those files for intra- or postoperative anomalies did not reveal anything special as well. There was a significant, correlation between Age and AE ( $p=0.070$  to  $0.046$ ) but non between AL and AE ( $p=0.066$  to  $0.177$ ).

### Mean prediction error

The MPE is shown in Table 2 including standard deviation and range. The MPE was myopic for all formulas ( $-0.21$  to  $-0.90$ D). Since the MPE does not describe the performance of the calculation formula as precisely as the MedAE, we deliver only descriptive data without  $p$  values [17]. Optic capture eyes had more myopic outcome compared to those without optic capture for all formulas except EVO 2.0.

There was no correlation between PE and AL ( $R^2=0.03-0.05$ ) or age at surgery ( $R^2<0.01$  for all formulas).

**Table 3** Eyes within  $\pm 0.5$ D,  $\pm 1.0$ D, and  $\pm 2.0$ D of target refraction all eyes ( $n=66$ )

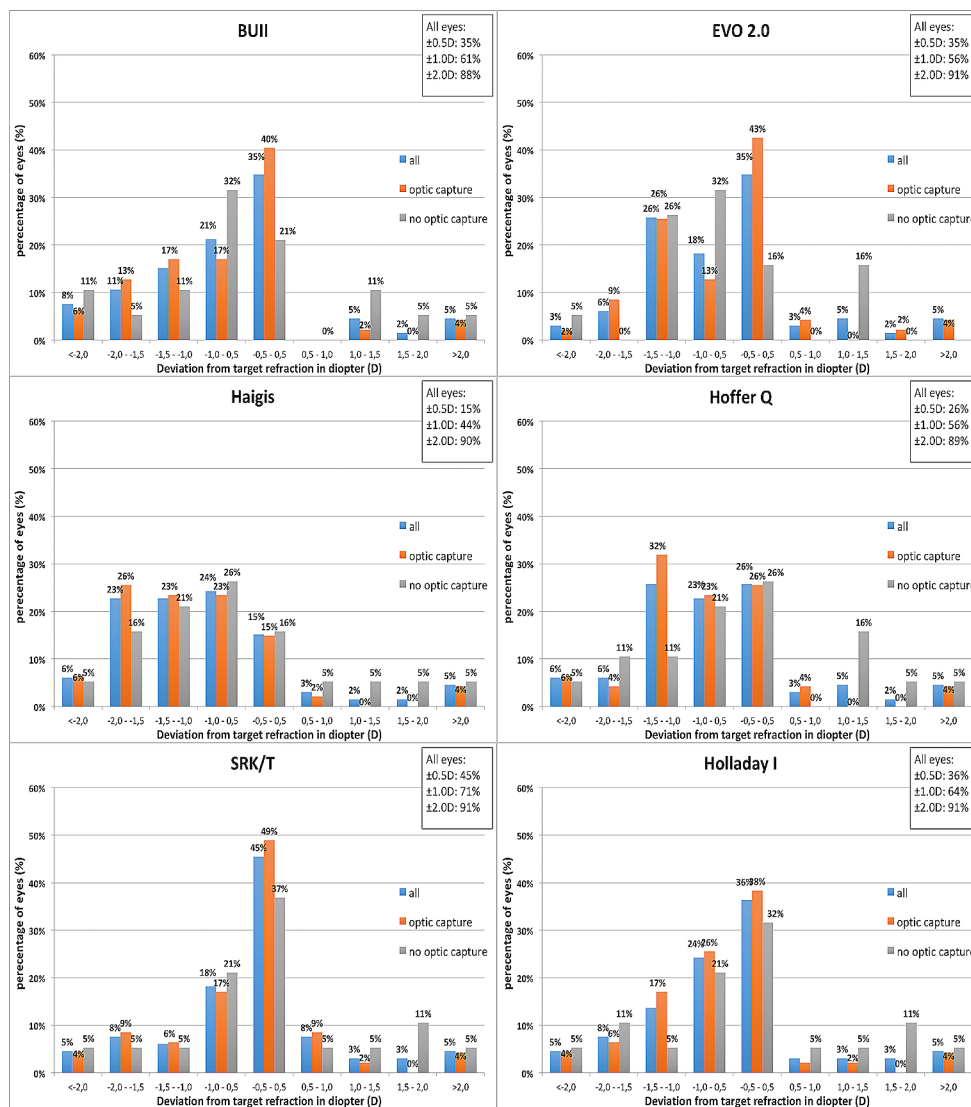
	$\pm 0.5$ D	$\pm 1.0$ D	$\pm 2.0$ D
SRK/T	30 (45.5%)	47 (71.2%)	60 (90.9%)
Holladay I	24 (36.4%)	42 (63.6%)	60 (90.9%)
EVO 2.0	23 (34.8%)	37 (56.1%)	61 (92.4%)
BUII	23 (34.8%)	37 (56.1%)	58 (87.9%)
Hoffer Q	17 (25.8%)	34 (51.5%)	59 (89.4%)
Haigis	10 (15.2%)	28 (42.4%)	59 (89.4%)
optic capture eyes ( $n=47$ )			
SRK/T	23 (48.9%)	36 (76.6%)	43 (91.5%)
Holladay I	18 (38.3%)	32 (68.1%)	43 (91.5%)
EVO 2.0	20 (42.5%)	28 (59.6%)	45 (95.7%)
BUII	19(40.4%)	28 (59.6%)	42 (89.4%)
Hoffer Q	12 (25.5%)	25 (53.2%)	42 (89.4%)
Haigis	7(14.9%)	19(40.4%)	42(89.4%)
no optic capture eyes ( $n=19$ )			
SRK/T	7 (36.8%)	13 (68.4%)	17 (89.5%)
Holladay I	6 (31.5%)	12 (63.2%)	17 (89.5%)
EVO 2.0	3 (15.8%)	12 (63.2%)	17 (89.5%)
BUII	4 (21.1%)	12 (63.2%)	16 (82.4%)
Hoffer Q	5 (26.3%)	12 (63.2%)	17 (89.5%)
Haigis	3 (15.8%)	10 (52.6%)	18 (94.7%)

D diopter

### Percentage within Target Refraction

Taking into account the number of eyes within  $\pm 0.5$ D of the target refraction (Table 3; Fig. 2) the best performing was again the SRK/T (45.6%, 30 eyes), followed by Holladay I, (36.4%, 24 eyes), EVO 2.0 and BUII (each 34.8%, 23 eyes). The lowest number of eyes within  $\pm 0.5$ D was found using Hoffer Q (25.8%, 17 eyes) and Haigis (15.2%,

**Fig. 2** Histogram of all formulas regarding the deviation from target refraction



10 eyes). This difference was statistically significant using the Cochran Q test ( $p=0.026$ ). A higher rate of eyes within  $\pm 0.5D$  and  $\pm 1.0D$  was found for some formulas for eyes with optical capture compared to those without.

### Discussion

We present the results of a retrospective case series comparing six different formulas for IOL calculation in children eyes that underwent primary IOL implantation during lens extraction with and without optical capture. The used formulas were the SRK/T, Haigis, Hoffer Q, BUII, Holladay I, and the EVO 2.0.

To our knowledge studies with similar number of eyes using new formulas like BUII in children eyes are rather rare and we found no study evaluating the EVO 2.0 formula

in children at all. Additionally, we compared results in eyes with and without posterior optical capture.

We included 66 eyes from 53 patients and the lowest MedAE was found in SRK/T (0.55D) followed by Holladay I (0.75D), EVO 2.0 (0.80D), BUII (0.86D), Hoffer Q (0.97D), and Haigis (1.10D). All of those were significantly above zero ( $p<0.001$ ). This is similar to other trials that evaluate the IOL calculation in pediatric eyes like Nihalani et al. who evaluated SRK II, SRK/T, Hoffer Q and Holladay formula and found MAE of 0.76–1.11D [18], but with the Hoffer Q formula performing best in contrary to our result. However, this trial is from 2009, which could reduce comparability to our data. Similar results are found for SRKII or an online calculator for pediatric eyes [19]. A trial comparing the BUII with SRK/T, Holladay, Hoffer Q, and Haigis reported similar results as well with MAE ranging from 0.95–1.11D [12]. Similar results reported the same group in a trial adding the Kane formula with MAE ranging from

0.88D to 0.98D, with worse results for the SRK/T formula but better results for the rest [11]. Other trials reported worse results compared to ours for all formulas with MAE ranging from 1.19D (SRK/T) to 1.37 (Hoffer Q) even when using optimized IOL constant [20]. Reported as well was that the prediction error seems to decrease in older children [21] which could be caused by reduced predictability in young kids due to steep corneas and short eyes in early childhood. Chang et al. reported that SRK/T shows higher predictability in short (<21.0 mm) eyes, while BUII and Haigis perform better in eyes above 21.0 mm [22]. This was not found in our trial with very low correlation between the prediction error, patient age, and axial length. This can be found in other published results as well [23]. Others reported worse results with MedAE of up to 2.0D for Haigis and MedAE ranging from 1.16D to 1.34D for other formulas like BUII, Olsen, Hoffer Q, SRK/T, SRKII, and Holladay [24] or MAE ranging from 1.08D (Hill RBF) to 1.28D (Holladay I) [25]. Still one has to keep in mind that most of the cited trials used different IOLs or formulas and therefore comparison in between is limited.

The prediction error in our study tended to be more myopic in eyes with posterior optic capture. The reason for this however remains unclear since one would expect a more hyperopic outcome due to a more posterior effective lens position (ELP). However, possibly the IOLs with no primary posterior optic capture could have an even more posterior ELP due to anterior vitrectomy, which would explain the outcome. Prospective trials measuring the postoperative position of the lens could explain how the ELP is affected by the posterior optic capture.

Looking at the number of eyes within  $\pm 0.5D$  of the target refraction the SRK/T (45.5%, 30 eyes) performed best, followed by Holladay I, EVO 2.0 and BUII. These results are comparable to other trials that report 43% of eyes being within  $\pm 0.5D$  using the SRK/T formula [23] or 41.5% for SRK/T but better results for Hoffer Q and Holladay compared to ours (each 43%) [18]. Results reported by Chang et al. show a similar amount of eyes within  $\pm 0.5D$  like ours for BUII (36.7%) and Hoffer Q (29%), but worse for SRK/T (38%) and better for Haigis (38%) [22]. Comparing the SRKII formula against an online tool for pediatric IOL calculation resulted in similar amount of eyes within  $\pm 0.5D$  as well (46%) for the online calculator but worse results for the SRKII formula (18%) [19]. Others reported worse results for the SRK/T (32%) compared to ours but better results for the other formulas (42–52%; except EVO 2.0 which was not included) [12]. Similar results were reported by the same authors when adding the Kane formula which performed well with 47% of eyes being within  $\pm 0.5D$  and therefore comparable to our results for the SRK/T formula [11]. This is similar to Lin et al. that report comparable

results for SRK/T but better results compared to ours using EVO [14] in short (<21.00 mm) eyes or patients younger than 24 months. In older patients or longer eyes BUII, Kane and EVO performed better than SRK/T. Lower prediction error for eyes >22.0 mm using BUII or Hofer Q compared to SRK/T was found by Shmueli et al. [26]. This trend was also seen by Wang et al. comparing multiple formulas in 101 eyes of 68 patients [27]. We had a similar trend in our study group with a significant correlation of age and AE but no significant correlation with AL. However, this was not found for PE and AL or age respectively. This could indicate that the reduced prediction accuracy in young patients is a multifactorial issue and not only AL based. Interestingly, eyes with optic capture had a higher chance of being within  $\pm 0.5D$  and  $\pm 1.0D$  from target refraction. However, due to the imbalance of the sample size in this subgroup analysis this could be an accidental finding as well and needs to be verified in further trials. Nevertheless, it is noteworthy and stands in contradiction to other trials reporting no difference in eyes with and without optic capture [28]. The same does account for the pronounced myopic shift in optic capture eyes.

We would like to point out the possibility of bias in our reported trial, such as its retrospective setting. We were not able to include other formulas like RBF3.0 or Kane, since those do not allow hyperopic target refraction of a certain amount in their online calculators. For some patients we included both eyes. However, this was done in thirteen patients and therefore shouldn't significantly influence the results from our point of view. We did not optimize the lens constants for the IOL, however using established constants does reflect the everyday practice for most clinicians. Additionally, the sample size was too small for a sufficient IOL constant optimization, since for single constant IOL formulas 80–100 and for Haigis 200–300 eyes would be needed [29]. Even in their guidelines for clinical reporting on IOL formula Hoffer and Savini state, that in specific cases like short eyes or post refractive corneal surgery eyes it is acceptable to not optimize the IOL constants [17]. This can be transferred to pediatric cataract surgery as well. Additionally, when comparing our results to other trials reporting prediction error after IOL constant optimization, this does not seem to grant a major improvement given by new constants [12]. This was reported by Vasavada et al. as well, who compared MAE with the manufacturers IOL and personal IOL constants and reported that no significant difference was found [20].

Another possible bias could be that some of the patients were measured with the IOL Master 500 and therefore lacking lens thickness as optional parameter for IOL calculation using the BUII or EVO formula. For all other parameters literature shows that the measures are comparable between

both devices [15]. Nevertheless, using IOL Master in all eyes of awake patients (even very young children, at age of 1 year) is one upside of our study, since AL and keratometric measures using an ultrasound biometer and a handheld keratometer under general anesthesia seem to reduce predictability [30]. Only including one IOL type is a strength of our trial as well, but results may not be transferable to other IOL types.

## Conclusion

In our retrospective case series of 66 eyes receiving IOL implantation during lens extraction due to juvenile or congenital cataract, we were able to show that IOL calculation in those patients is challenging compared to healthy eyes. However, using specific formulas, especially SRK/T in our patients, grants higher predictability of postoperative refraction and lower variance of error.

This could substantially improve postoperative refractive results and lead to less spectacle dependence and less anisometropia.

**Funding** None.

## Declarations

**Ethical approval** The study protocol was approved by the local Ethics Committee of the University Frankfurt, Germany (2022 – 899) and followed the tenets of the Declaration of Helsinki.

**Patient consent** Due to the retrospective nature of this trial no patient consent was needed.

**Conflict of interest** T. Kohnen: Consultant and Research for Alcon/Novartis, J&J, Lensgen, Oculentis, Oculus, Presbia, Schwind, Zeiss. Consultant for Allergan, Bausch & Lomb, Geuder, Med Update, Santen, Staar, Thieme, Ziemer. All other authors have no financial interests to disclose.

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