Original Article

Refractive prediction by various intraocular lens formulas using optical biometry and effect of ocular parameters on their accuracy

Ajay K Ambade, Rakhee A Ambade[1], Dhananjay V Raje[2]

Purpose: To assess the prediction accuracy of intraocular lens (IOL) formulas and study the effect of axial length (AL), central corneal thickness (CCT), anterior chamber depth (ACD), and lens thickness (LT) on the accuracy of formulas using optic biometry. **Methods:** This study was performed on 164 eyes of 164 patients who underwent uneventful cataract surgery. Ocular biometry values were measured using Lenstar-900, and intraocular lens (IOL) power was calculated using the SRK/T, SRK II, Hoffer Q, Holladay 2, and Barrett Universal II formulas. We evaluated the extent of bias within each formula for different ocular biometric measurements and explored the relationship between the prediction error and the ocular parameters by using various IOL formulas. **Results:** The summarization of refractive prediction error and absolute prediction error for each IOL formulation was performed after adjusting the mean refractive error to zero. The deviation in the error values was minimum for SRK/T (0.265) followed by Holladay 2 (0.327) and Barret (0.382). Further, SRK/T had the lowest median (0.15) and mean (0.198) absolute error as compared to other formulations. For the above formulations, 100% of the eyes were in the diopter range of ±1.0. It was observed that the overall distribution of error was closer to zero for SRK/T, followed by Holladay 2 and then Barrett. **Conclusion:** In summary, we found that accuracy was better in SRK/T formula. We achieved a better understanding of how each variable in the formulas is relatively weighed and the influencing factors in the refraction prediction.

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The precise and predictable IOL power calculation is essential for the predictable postoperative result. The development of optical biometry and intraocular lens (IOL) power calculation formulas have improved the refractive outcomes of cataract surgery. Advanced technologies related to optical biometry such as optical low-coherence reflectometry (OLCR), have increased the precision of biometric measurements.[1-3]

The purpose of this study was to determine which of the commonly used IOL formulas integrated to Lenstar LS900 optical low-coherence reflectometry (OLCR) system biometer are the best predictor of actual postoperative refractive outcomes. The formulas used were SRK/T, SRK II, Hoffer Q, Holladay 2, and Barrett Universal II. We also evaluated the extent of bias within each formula for different ocular biometric measurements. We assessed the relationship between the prediction error and ocular parameters such as axial length (AL), central corneal thickness (CCT), anterior chamber depth (ACD), and lens thickness (LT) to clarify the effect on the refractive accuracy by using various IOL formulas.

Methods

This is a retrospective study comprising all cataract surgeries performed during the period 2017–2019 at a tertiary eye care center from a town in central India. The study received approval from the institutional ethics committee, and all research and data collection followed the tenets of the Declaration of Helsinki. Confidentiality of the information was maintained during the data collection process. No one had access to the noncoded data except investigators, data collectors, and the supervisor. The study included consecutive patients who underwent uncomplicated phacoemulsification with an implantation of the most commonly used IOL (Alcon Acrysof IQ SN60WF) at the hospital. All patients underwent preoperative measurements by the Lenstar-900 optical low-coherenc refractometry system (OLCR) biometer. Exclusion criteria were incomplete biometry, corneal pathology, corneal astigmatism of >2.0 diopters (D), LT of <2.50 mm, complicated cataract surgery (posterior capsular rupture), additional procedures during cataract surgery (combined vitrectomy or glaucoma surgery), postoperative severe SK nonresolving, refraction performed before 4 weeks postoperatively, postoperative complications, and incomplete documentation. Patients with a history of refractive surgery, endothelial dystrophy, uveitis, and phacomorphic glaucoma were excluded. To avoid duplication/compounding of data with bilateral eyes, only one eye from each study subject was included. All surgeries were

Ambade Eye Hospital, Nagpur, Maharashtra, [1]Department of Physiology, NKP Salve Institute of Medical Sciences, Nagpur, Maharashtra, [2]Biostatistician, MDS Bio-Analytics Pvt. Ltd. Nagpur, Maharashtra, India

Correspondence to: Dr. Ajay K Ambade, Department of Ophthalmology, Ambade Eye Hospital, 1st Floor, Kamla Tower, Kamptee Road, Nagpur – 440 017, Maharashtra, India. E-mail: dr_ajayambade@rediffmail.com

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performed by a single surgeon. Fig. 1 shows an overview of the study's selection criteria. There were 430 total cataract surgeries performed during the study period. Out of these, 91 surgeries of PPV/Trab were excluded. Further, 37 surgeries of corneal pathology, 58 surgeries of nontemporal incision and 42 bilateral surgeries were excluded from the study. Finally, 38 surgeries of loss to follow up had to be ignored, resulting in a sample of 164 with complete information. The commonly used and more recent five IOL power calculation formulas, built-in software of Lenstar 900, were evaluated viz., SRKII, SRK/T, Hoffer Q, Holladay 2, and Barrett Universal II. Lens constant optimizations for the Alcon Acrysof IQ IOL were performed in collaboration with Lenstar 900, which has licensed versions of the proprietary Barrett Universal II and Holladay 2 as well as implementations of the SRK/T, SRKII, and Hoffer Q formulas. Postoperative subjective manifest refraction was measured at least 3 months after surgery, when the refraction is considered stable. The refractive prediction error was then calculated as the actual postoperative refraction minus the refractive result predicted by each formula for the IOL implanted. Medical records of patients who underwent phacoemulsification or in whom Alcon IQ implantation was revived during 2017–2019. All surgical procedures were conducted under topical 4% lignocaine with intra cameral lignocaine 1% anesthesia. A 2.2-mm-wide incision was taken in the temporal corneal limbus. Phacoemulsification and IOL implantation were performed with continuous curvilinear capsulorhexis. The IOLs were Alcon Acrysof IQ (SN60WF Alcon Laboratories, Ft. Worth, TX, USA) with their corresponding optimization constants derived from the manufacturer. The lenses were implanted in the capsular bag. Lenstar 900 was used to measure the corneal curvature, ACD, and AL. The five formulas used to calculate the refractive power of the IOLs, as well as the estimated postoperative refraction of eyes by Lenstar900 were SRK/T, SRK II, Hoffer Q, Holladay 2, and Barret. The main assessed parameters were axial length (AL), refractive error (a negative difference implied that the postoperative refractive status was myopic, whereas a positive difference indicated hyperopia), and median absolute error (MedAE).

Statistical methods

Descriptive statistics such as mean, standard deviation, and range were obtained for the continuous parameters, while frequencies and percentages were obtained for categorical parameters. The relative prediction error obtained using different IOL formulations was adjusted to mean zero and accordingly, the percentage of eyes within different diopter ranges were obtained for each formulation. After the adjustment, the mean refractive prediction error, standard deviation (SD) of prediction error, median absolute error (MedAE), and mean absolute error for each formula were calculated. The percentages of eyes within ±0.25 D, ±0.50 D, ±0.75 D, and ±1.00 D of the refractive prediction error were calculated. The mean prediction and absolute errors were compared across formulations using repeated measure analysis of variance. The analysis was performed according to the type of keratometry. The two-group analysis was performed using paired *t*-test with Bonferroni multiple testing correction. Pearson's correlation analysis was performed between ocular dimensions and the prediction errors by different formulations. All the analyses were performed using SPSS ver 20.0 (IBM Corp, USA) software and the statistical significance was tested at 5% level.

Results

The study included 164 eyes of 164 patients. The mean age of patients was 62.40 ± 8.28 years and ranged between 43 to 82 years, and females were marginally more (51.9%) than males (48.1%) [Table 1]. The mean keratometry was 44.83 ± 1.62 and ranged between 40.62 to 49.00. Based on keratometry, patients were classified into flat (<42D), normal (42D–47D), and steep (>47D). The maximum, that is, 140 (85.4%) patients had normal keratometry, followed by 18 (10.9%) with steep and only 6 (3.7%) had flat keratometry. As regards ocular dimensions, the mean axial length was 22.97 ± 1.10 mm, the mean central corneal thickness was 512.79 ± 33.96 mm, and the anterior chamber depth was 3.17 ± 0.50 mm. Moreover, the mean lens thickness was 4.35 ± 0.4 mm and mean IOL power was 21.94 ± 3.06 D. Table 2 gives the summarization of refractive prediction error (RE) and absolute prediction error (AE) for each IOL formulation after adjusting the mean refractive error to zero. The deviation in the error values was minimum for SRK/T (0.265) followed by Holladay 2 (0.327) and Barret (0.382). Further, SRK/T had the lowest median (0.15) and mean (0.198) AE as compared to other formulations, while SRK2 had the

Table 1: Descriptive statistics for various patient parameters undergoing cataract surgery

Parameter	Level	Statistic
Number of patients/Number of eyes		164/164
Age in years [Mean±SD; (Range)]		62.40±8.28; (43-82)
Sex [No. (%)]	Female	85 (51.9)
	Male	79 (48.1)
Mean keratometry [Mean±SD; (Range)]		44.83±1.62; (40.62-49.00)
Mean keratometry (<42D) [No.(%)]	Flat	6 (3.7)
Mean keratometry (42D≤ and <47D) [No.(%)]	Normal	140 (85.4)
Mean keratometry (≥47D) [No.(%)]	Steep	18 (10.9)
Axial length (mm) [Mean±SD; (Range)]		22.97±1.10; (20.05-27.15)
Central Corneal Thickness (mm) [Mean±SD; (Range)]		512.79±33.96; (432-633)
Anterior Chamber Depth (mm) [Mean±SD; (Range)]		3.17±0.50; (2.01-4.94)
Lens thickness (mm) [Mean±SD; (Range)]		4.35±0.40; (3.31-5.46)
IOL power (D) [Mean±SD; (Range)]		21.94±3.06; (7.50-28.50)

maximum parameter values. For SRK/T, Holladay 2, and Barrett, 100% of the eyes were in the diopter range of ±1.0.

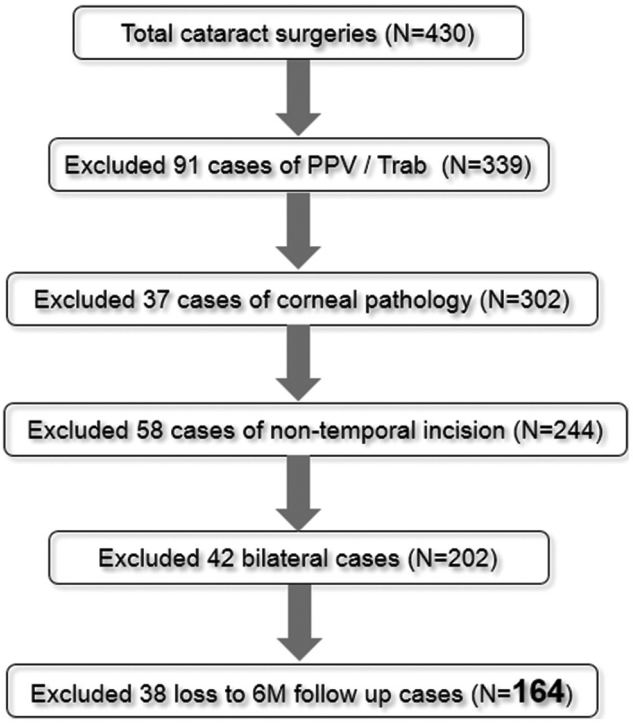

Figure 1: Sample selection process

A boxplot representation of absolute prediction error for each IOL formulation is shown in Fig. 2. It is evident that the overall distribution of error is closer to zero for SRK/T, followed by Holladay 2 and then Barrett. The error distribution was wider and away from zero for SRK2. All the five error distributions showed a positively skewed pattern. The comparison of mean prediction and absolute refractive error across different IOL formulations was performed using repeated measure analysis of variance [Table 3]. The overall comparison revealed that the mean prediction error differed insignificantly across formulations, while the mean absolute error showed significant difference with $P < 0.0001$. The paired comparison of means revealed that the mean absolute error using SRK/T was minimum (0.189 ± 0.172) and differed significantly from all the other means. The means for Holladay 2 (0.25 ± 0.208) and Barrett (0.261 ± 0.243) differed insignificantly, while the means for SRK2 (0.352 ± 0.321) and Hoffer Q (0.315 ± 0.255) were maximum and insignificantly different. The analysis according to the type of keratometry suggested that in flat type, the mean prediction and absolute errors were insignificantly different across formulas. In the normal category, the mean prediction errors differed insignificantly; however, the mean absolute error showed a significant difference with $P < 0.0001$. The mean error for SRK/T (0.191 ± 0.167) was significantly lower than all other means, followed by Holladay 2 (0.232 ± 0.199) and Barrett (0.250 ± 0.23), which differed insignificantly. The mean errors were maximum for SRK2 (0.328 ± 0.247) and Hoffer Q (0.292 ± 0.228) in this category. Further, in the steep category, the mean prediction error was insignificantly different, while mean absolute error showed a significant

Table 2: Refractive prediction error and absolute error for five different IOL formulas after adjusting the mean refractive prediction error to zero

Formula	Mean RE	SD	Median AE	Mean AE	Percentage of eyes within diopter range (%)			
					±0.25	±0.50	±0.75	±1.0
SRK/T	0.000	0.265	0.150	0.198	67.7	93.3	98.8	100.0
SRK 2	0.000	0.479	0.290	0.355	44.3	70.8	92.4	98.1
Hoffer Q	0.000	0.404	0.248	0.313	50.9	79.2	93.1	98.7
Holladay 2	0.000	0.327	0.198	0.249	57.1	88.8	96.9	100.0
Barret	0.000	0.382	0.222	0.299	54.5	80.7	93.8	100.0

RE: Refractive error; SD: Standard deviation; AE: Absolute error

Table 3: Mean refractive error using different IOL formulas as per the type of keratometry

Karatometry	Error	Mean±Standard deviation					*P**
		SRK/T	SRK 2	Hoffer Q	Holladay 2	Barret	
Overall	Prediction	−0.009±0.223	−0.015±0.477	−0.038±0.363	−0.024±0.279	0.014±0.377	0.502
	Absolute	0.189±0.172[a]	0.352±0.321[b]	0.315±0.255[b]	0.250±0.208[c]	0.261±0.243[c]	<0.0001§
	Correlation‡ (*P*)	0.007 (0.930)	−0.010 (0.905)	−0.287 (<0.0001)	−0.264 (0.001)	−0.302 (<0.0001)	
Flat	Prediction	−0.052±0.258	−0.016±0.163	0.292±0.324	0.127±0.363	0.191±0.366	0.058
	Absolute	0.205±0.139	0.127±0.087	0.328±0.281	0.292±0.22	0.253±0.318	0.133
Normal	Prediction	−0.010±0.213	−0.023±0.399	−0.021±0.326	−0.004±0.256	0.043±0.353	0.200
	Absolute	0.191±0.167[a]	0.328±0.247[b]	0.292±0.228[b]	0.232±0.199[c]	0.250±0.230[c]	<0.0001§
Steep	Prediction	0.017±0.304	0.057±1.004	−0.346±0.505	−0.274±0.331	−0.333±0.428	0.208
	Absolute	0.168±0.218[a]	0.598±0.613[b]	0.47±0.372[b]	0.367±0.227[b]	0.341±0.302[b]	0.009§

*Obtained using repeated measure ANOVA; Similar superscripts indicate statistically insignificant difference; ‡Obtained using Pearson's correlation coefficient; §Statistically significant

difference as indicated by a *P* value of 0.009. Again the mean for SRK/T (0.168 ± 0.218) was significantly lower as compared to other means. To understand if relative prediction error obtained using different IOL formulations is related to ocular dimensions, the scatter plots were obtained between each ocular parameter and the prediction error as shown in Fig. 3 (a–d). Pearson's correlation coefficient as a measure of a linear relationship and statistical significance are shown in the figure. The correlation of prediction error using SRK/T (r = −0.018) and Barret (r = −0.019) formulations with axial length were slightly negative and thus statistically insignificant [Fig. 3a]. In other words, these errors were marginally myopic with the increasing axial length. The axial length showed significant positive (r = 0.447; *P* < 0.0001) and negative (r = −0.204; *P* = 0.0103) relationship with the prediction error obtained using SRK2 and Hoffer Q formulations, respectively. Below the axial length of 23 mm, the SRK2 errors were myopic, while Hoffer Q errors were hyperopic, and vice-versa beyond this cut-off. Regarding central corneal thickness [Fig. 3b], the errors using SRK/T showed insignificantly positive relation (r = 0.04) with the increasing CCT, suggesting that the errors are marginally hyperopic with CCT, while errors using Barrett showed insignificant negative relation (r = −0.02), indicating marginally myopic errors with the increasing CCT. Similar was the observation with SRK2 (r = −0.038). The errors due to Holladay 2 (r = 0.128) and Hoffer Q (r = 0.175) were hyperopic with increasing CCT above the cut-off value of 510 mm and myopic below the cut-off. Again, the errors by SRK/T and Barrett were unaffected by the central corneal thickness. As regards anterior chamber depth [Fig. 3c], the error using SRK/T showed insignificant relation with the depth and negligible negative coefficient (r = −0.008). The errors using Holladay 2 (r = −0.058) and Hoffer Q (r = −0.082) also showed negative correlations indicating myopic errors with the increasing depth, although insignificant. SRK2 (r = 0.332; *P* < 0.0001) and Barrett (r = 0.174; *P* = 0.0363) showed significant positive correlation with ACD suggesting hyperopic tendency of errors after the value of 3.2 mm. Below this cut-off, the errors using these methods were myopic. The correlation analysis with lens thickness [Fig. 3d] revealed that the errors using Barrett are unaffected by the thickness or marginally hyperopic with the increasing thickness, as indicated by a low positive coefficient (r = 0.06). This was followed by Hoffer Q (r = 0.094) and SRK/T (r = 0.111). The errors using Holladay 2 showed significant positive relation with the thickness (r = 0.180; *P* = 0.0268) with hyperopic errors after 4.4 mm of lens thickness and myopic below this cut-off.

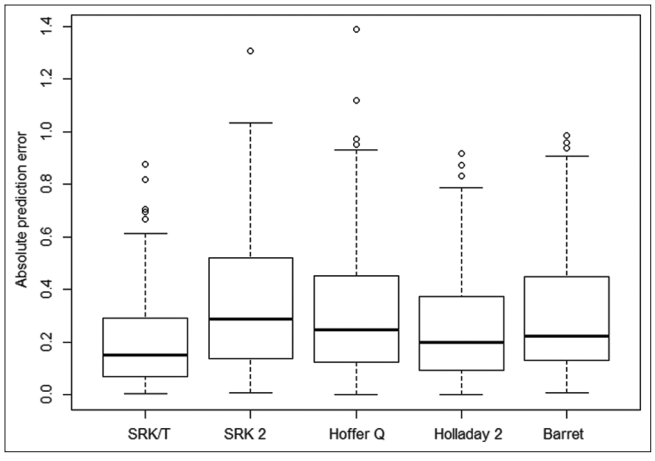

Figure 2: Boxplot showing the absolute error (D) of five intraocular lens formulations using LENSTAR

Discussion

In the present study, our results showed that SRK/T provided an overall higher predictability of IOL power calculation as compared to other formulas, after adjusting the mean refractive prediction error to zero. Approximately 67% of cases had refractive prediction error in the range of ± 0.25 D using SRK/T, which was maximum among other formulations. This was followed by Holladay 2 (57.1%) and Barrett (54.5%) with errors in the same range. This is unlike the study of Miraftab M *et al*. (2014),[4] where he predicted Hoffer Q, SRK/T, and Holladay are comparable in normal axial length. Olsen *et al*. (2007)[5] found a significant negative correlation of prediction error with keratometric reading (r = −0.23, *P* < 0.0001) using the SRK/T formula. However, our study showed an insignificant relationship of errors using SRK/T with mean keratometry. Formulations such as Hoffer Q, Holladay 2, and Barrett showed significant negative correlation with mean keratometry [Table 3]. Further, Faramarzi *et al*. (2014)[6] demonstrated that the prediction error was −0.06 ± 0.52D in eyes with steep keratometry using the SRK/T formula. Reitblat *et al*. (2017)[7] showed that myopic refractive error was seen in steep keratometry eyes; and flat keratometric eyes showed hyperopic errors with SRK/T formula. However, the findings were the opposite in our study, that is, hyperopic refractive errors in steep keratometry and myopic in flat keratometry. Although IOL power calculation began as an optical approach using theoretical formulas, the majority of methods used in clinical practice over the past 25 years are based on empirical methods that have used "fudged" formulas to compensate for the unknowns in the system.[8,9] However, the advent of better diagnostic equipment and ever-improving surgical techniques have decreased the number of unknowns, and optical methods now hold sway in IOL power calculation. For comparison, the mean numerical prediction error using the latest generation IOL power calculation formula (Olsen 2007) on the same dataset was found to be 0.00 ± 0.58D with a mean absolute error of 0.47D. Corneal power accounts for about two-thirds of the total dioptric power of eye and is an important component of the ocular refractive system. It has a profound impact on the IOL power formula. Regarding central corneal thickness [Fig. 3b], the errors using SRK/T showed insignificantly positive relation with the increasing CCT, suggesting that the errors are marginally hyperopic with CCT, while errors using Barrett showed insignificant negative relation, indicating marginally myopic errors with the increasing CCT.[10,11] Similar was the observation with SRK2.[2,4] The errors due to Holladay 2 and Hoffer Q were hyperopic, with increasing CCT above the cut-off value of 510 mm and myopic below the cut-off. Again, the errors by SRK/T and Barrett were unaffected by the central corneal thickness. Thus, while considering IOL power using SRK/T, SRK 2, and Barret, an inclination toward myopic shift was evident. Thus, the reading toward the hyperopia should be the consideration. In the study by Jeong J *et al*. (2017),[8] Barrett formula was not superior in refractive outcome prediction compared to the other IOL formulas. Iijima K *et al*. (2020)[12] showed that Barrett formula is clinically better in steep or flat corneas. Further, cornea curvature was significantly

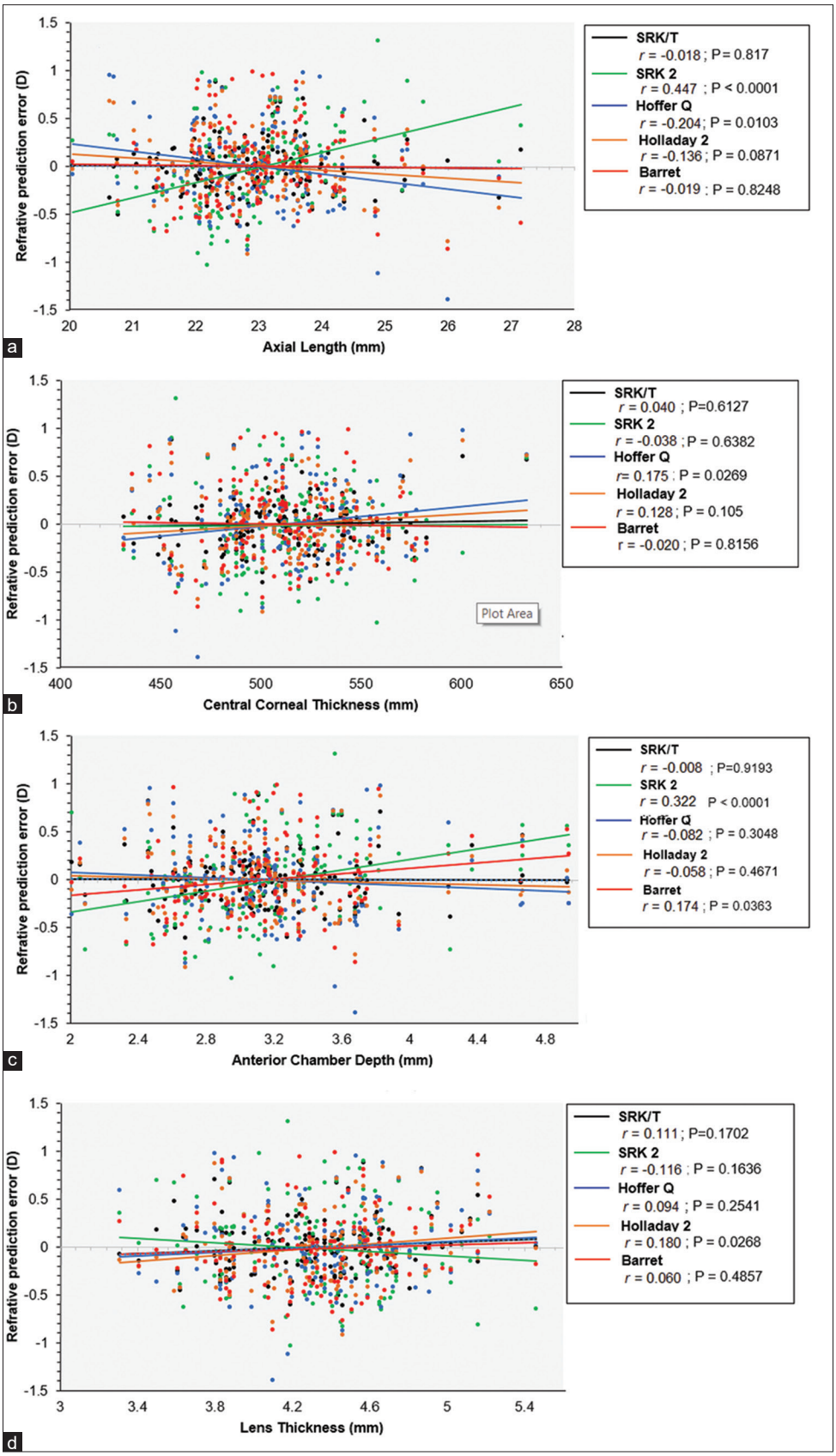

Figure 3: (a-d) Scatter plots showing the relationship between refractive prediction error determined using five IOL formulas against various ocular dimensions and lens thicknesses

correlated with the SRK/T and Holladay formulas. Also, axial length and ACD were significantly correlated with Hoffer Q, Holladay, and SRK/T formulas. The introduction of optical biometry (Drexler *et al*. 1998)[13] has significantly improved the accuracy with which axial length can be measured, but the correlation of prediction error using SRK/T and Barret formulations with axial length were slight negative [Fig. 3a]. In other words, these errors were marginally myopic with the increasing axial length. The axial length showed a significant positive ($P < 0.0001$) and negative ($P = 0.0103$) relationship with the prediction error obtained using SRK2 and Hoffer Q formulations, respectively.[14,15] Below the axial length of 23 mm, the SRK2 errors were myopic, while Hoffer Q errors were hyperopic, and vice-versa beyond this cut-off. The prediction errors were marginally myopic with the increasing axial length in SRK/T and Barret.[10,16,17] In the early stages of these theoretical formulas, very little was known about the actual position of the implant after surgery. The Binkhorst I formula (Binkhorst 1979) used a fixed ACD value to predict the position of the implant in each case.[18] It soon became obvious; however, the fixed ACD model was inappropriate because it resulted in predictions that were worse than the empirically derived formulas. Modern progress in IOL power calculation formulas largely reflect advances in methods of predicting the position of implant after surgery based on preoperative measures. There is strong evidence that postoperative ACD is positively correlated with axial length. The fixed-ACD model, therefore, predicted ACDs that were too short in long eyes and too deep in short eyes. As a consequence, a myopic error would be produced in a short eye and a hyperopic error in a long eye. As regards anterior chamber depth [Fig. 3c], the error using SRK/T showed insignificant relation with the depth and negligible negative coefficient. The errors using Holladay 2 and Hoffer Q also showed negative correlations, indicating myopic errors with increasing depth, although insignificant. SRK2 and Barrett showed significant positive correlation with ACD suggesting hyperopic tendency of errors after the value of 3.2 mm. Below this cut-off, the errors using these methods were myopic. If we accept the importance of preoperative ACD to postoperative ACD, it seems logical to assume that preoperative lens thickness also has some influence. The correlation analysis with lens thickness [Fig. 3d] revealed that the errors using Barrett are unaffected by the thickness or marginally hyperopic with the increasing thickness, as indicated by a low positive coefficient. This was followed by Hoffer Q and SRK/T. The errors using Holladay 2 showed significant positive relation with lens thickness with hyperopic errors after 4.4 mm and myopic below this cut-off.

Conclusion

In summary, we found that the accuracy was more in SRK/T formula. We achieved a better understanding of each variable in the formula. We found that AL, CCT, ACD, and LT were the influencing factor in the refraction prediction. The study has a limited sample size; thus, further evaluation on a large sample is required, which can strengthen the observations in the study.

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Conflicts of interest

There are no conflicts of interest.

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