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Effect of capsular tension ring implantation on intraocular lens calculation formula selection for long axial myopia

Jiaojiao Liang^{1,2}, Hong Yan^{1*}, Xue Xie^{1,2}, Jian Zhang³, Yaping Zhang¹ and Laiqiang Qu¹

Abstract

Purpose The study investigated the effect of capsular tension ring (CTR) implantation on postoperative refractive stability and accuracy of intraocular lens (IOL) formulas for axial length (AL) ≥ 27.0 mm patients.

Methods Prospective case series. The eyes of patients underwent phacoemulsification extraction combined with IOL implantation were classified as CTR implantation (A-CTR) and without CTR implantation (B-CON) groups. Refractive outcome and anterior chamber depth (ACD) were recorded at 1 week, 1 month, and 3 months post-operation. Prediction refractive error (PE) and absolute refractive error (AE) of each formula were calculated.

Results A total of 89 eyes (63 patients) were included and randomized into the CTR (A-CTR) and control groups (B-CON). Comparison of refraction at different postoperative times of the CTR group showed no statistical difference (all $P > 0.05$). The ACD in the A-CTR group gradually deepened, and that in the B-CON group gradually shallowed (all $P > 0.05$). The formulas' AE showed statistically significant differences in CTR and CON groups ($P < 0.001$). The PE of Hill-RBF 2.0 and EVO formulas in the A-CTR group were more hyperopic than that in the B-CON group (all $P > 0.05$), the other five formulas were more myopic in A-CTR group than that in the B-CON group (all $P > 0.05$).

Conclusion Patients with 13 mm diameter CTR implantation tended to have stable refraction at 1 week post-surgery and 1 month for those without it. CTR of the 13 mm diameter had no effect on the selection of formulas. Additionally, it is found that Kane and EVO formulas were more accurate for patients with AL ≥ 27.0 mm.

Keywords Cataract, Capsular tension ring, Long axial myopia, IOL calculation formula, Refraction

Introduction

Long axial myopia is usually defined as an axial length (AL) of 26.0 mm or longer [1]. Population-based studies have found a direct association between long axial

myopia and cataract characterized as early onset, large nuclear sclerosis, and rapidly progressive cataract usually need cataract surgery during their working ages [2, 3]. The anterior chamber depth (ACD) is often unstable and deeper than the normal one, with a relatively floppy and loose capsule [4], and more likely forming the posterior capsular opacification (PCO) [5]. Capsular tension ring (CTR) allows surgeons to approach zonular weakness during surgery with improved safety as well as provides long-term intraocular lens (IOL) stabilization [6], inhibiting the migration and proliferation of the cells and avoiding IOL rotation, as a result of the shrinkage of the capsular sac [7].

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Notably, accurate IOL power calculations for long axial myopia are inconsistent, often resulting in an unsatisfactory hyperopic surprise [4]. New IOL formulas are constantly optimized to gain a more accurate prediction of postoperative refraction [8]. The representative Barrett Universal II (BU II) [9] showed improved prediction in long axial myopia compared to formulas of prior generations (SRK/T, Haigis, and Holladay II) [10, 11]. Recently, artificial intelligence-assisted new formulas (BU II, Hill-RBF 2.0 [12], Emmetropia Verifying Optical (EVO) [13], and Kane [14]) have indicated promising outcomes [8, 15, 16].

However, these studies [8, 15, 16] mainly focused on comparing the accuracy of IOL calculation formulas. It is still unclear whether CTR implantation will affect the prediction accuracy of the IOL calculation formula, especially for the new generation. Therefore, the current study observed the effects of CTR on postoperative refractive stability and the prediction accuracy of seven IOL calculation formulas, providing valuable reference for the application of CTR and the selection of IOL calculation formulas for long axial myopia.

Methods

The Institutional Review Board, Shaanxi Eye Hospital, Xi'an People's Hospital, approved this prospective study (No.20200035). The study was conducted in accordance with the principles of the Declaration of Helsinki. All patients were given detailed information about the perioperative and possible surgical complications and were not blinded to treatments. All patients signed written informed consent, and anonymized clinical data were analyzed and published for study purposes. This study was registered in the Chinese Clinical Trial Registry (identifier: ChiCTR2300067653, Date: January 16, 2023) (<https://www.chictr.org.cn/>).

Participants with long axial myopia with cataract who underwent phacoemulsification cataract surgery with in-the-bag IOL implantation at Shaanxi Eye Hospital (Xi'an People's Hospital), Northwest China, between December 2020 and September 2021 were eligible for enrollment if age ≥ 18 years, patients had an AL ≥ 27.0 mm, as measured by swept-source optical coherence tomography (Master 700, Carl Zeiss Meditec, Oberkochen, Germany), the refraction of astigmatism ≤ 1.50 D, the number of corneal endothelial cells was greater than 2000/mm², patients were eligible for phacoemulsification surgery with IOL implantation alone or combined with CTR implantation, patients can complete postoperative follow-up for 3 months. Exclusion criteria included severe corneal scar, keratoconus, ocular inflammation, a history of prior ocular surgery or trauma, vision-limiting retinal or optic nerve disease or ocular inflammatory conditions, Intraoperative complications such as iris prolapse,

irregular tearing of the anterior or posterior capsule of the lens, posterior capsule rupture, suspension ligament relaxation rupture, nuclear sedimentation, vitreous prolapse, postoperative corneal persistent edema, postoperative IOL deviation, tilt, postoperative corrected distance visual acuity (CDVA) worse than 20/40 (i.e., 0.3 logarithm of the minimum angle of resolution [logMAR]). The AL of the three eyes were 35.10 mm, 35.12 mm, and 35.75 mm, respectively, and were not within the boundaries of the Hill-RBF 2.0 and Kane formulas online calculator, therefore, they were excluded from the two formulas. The participants were randomly assigned to the A-CTR group (CTR implantation) or B-CON group (without CTR implantation) based on a computerized random number.

Preoperative examinations

The routine preoperative examinations included a slit-lamp examination, intraocular pressure (CT-80, Topcon, Tokyo, Japan), corneal endothelium calculation (SP-3000P, Topcon, Tokyo, Japan), ultrasound biometry (Aviso A/B, Quantel Medical, Paris, France), ultrasound biomicroscopy (SW-3200L, Solvay, Tianjin, China) and optical coherence tomography (Cirrus HD-5000, Carl Zeiss Meditec, Oberkochen, Germany). Corneal curvature, ACD, AL, white-to-white (WTW), and lens thickness were measured by the same examiner using swept-source optical coherence tomography (Master 700, Carl Zeiss Meditec, Oberkochen, Germany). The BU II formula was used to calculate the required IOL power, and all patients used the same brand of IOL (AR40E, Johnson&Johnson, USA). The predicted error (PE) and absolute refractive error (AE) were calculated using seven different formulas (1) SRK/T, (2) Holladay II, (3) Haigis, (4) BU II, (5) Hill-RBF 2.0, (6) EVO, and (7) Kane. The constants used for the seven formulas were those recommended by the User Group for Laser Interference Biometry (ULIB) database [17]. The IOL power that yielded a predicted refraction value closest to minors 3.0 diopters (D) was chosen.

Surgical technique

All surgeries were performed by the same experienced surgeon (H.Y) using topical anesthesia. All patients underwent a 2.8 mm clear corneal primary incision approximately 11 clock hours above the temporal side of the right eye or approximately 11 clock hours above the nasal side of the left eye.

The phacoemulsification was performed and an IOL was implanted in the bag. Patients assigned to the A-CTR group received CTR following phacoemulsification and those assigned to the B-CON group did not receive CTR. CTR (OPHTEC, Groningen, the Netherlands) of the

13 mm diameter was placed with manual forceps. All patients were treated with levofloxacin eye drops (Santen Pharmaceutical Co., Ltd.), pranoprofen eye drops (Senju Pharmaceutical Co., Ltd.), and tobramycin and dexamethasone eye drops (s.a. ALCON-COUVREUR n.v.) dosed three times a day. Sodium hyaluronate eye drops (Santen Pharmaceutical Co., Ltd.) were used 4 times a day. All eye drops were used for 2 weeks.

Postoperative examinations

Manifest refraction measurements were performed by the same technician at 1 week, 1 month, and 3 months after surgery. The logMAR corrected distance visual acuity (CDVA) were recorded. The postoperative refractive error (PE) was defined as the actual refractive outcome minus the refraction predicted by that formula using the IOL power implanted, and the absolute refractive error (AE) was compared.

Statistical analysis

Statistical analysis was performed using SPSS 25.0 software. The Shapiro-Wilk test was used to confirm the normality of the measurement data, including age, AL, ACD, PE, AE, and postop logMAR CDVA. Data with normal or approximately normal distribution were described by Mean ± SD, and the two groups were compared using *t*-test analysis. Data with skewed distribution were described by median and interquartile range, and the two groups were compared using Mann–Whitney-U test analysis. The Kruskal–Wallis rank sum test was used for data that did not conform to normal distribution. The percentages of AE within ± 0.50D, ± 1.00D, ± 1.50D, and ± 2.00D for the seven IOL formulas were calculated. When *p*-values were less than 0.05, the difference was considered statistically significant.

Results

A total of 89 eyes (63 patients) were included and randomized into the CTR (A-CTR) and control groups (B-CON). The mean age was 55.93 ± 10.17 years (range 35 to 82 years), and preoperative mean AL in all eyes was 30.30 ± 2.18 mm (range 27.05 to 35.75 mm), and preoperative mean ACD was 3.43 ± 0.35 mm (range 2.71 to 4.81 mm). Table 1 shows the baseline characteristics of the patients. There were no statistically significant between group differences in age, AL, ACD, or CDVA 1 month post-surgery.

Comparison of refraction at different postoperative times of the A-CTR group showed no statistical difference (*P* = 0.07, *P* = 0.82, *P* = 0.83), indicating that the refraction of patients with CTR implantation tended to be stable 1 week post-surgery. Comparison of refraction

Table 1 Baseline characteristics of patients

Parameter	A-CTR	B-CON	t/z	p	
n	43	46	-	-	
Sex	Male	14(32.6%)	18(39.1%)	-	-
	Female	29(67.4%)	28(60.9%)	-	-
Age(yr)	55.26 ± 9.62	56.57 ± 10.72	-0.61	0.55	
AL(mm)	30.36 (28.33, 32.42)	30.10 (28.33, 31.97)	0.63	0.53	
ACD(mm)	3.42 ± 0.31	3.44 ± 0.40	-0.24	0.81	
Postop CDVA (log-MAR)	0.21±0.13	0.21±0.19	-0.29	0.83	

ACD Anterior chamber depth, AL Axial length, CDVA Corrected distance visual acuity, IOL Intraocular lens, logMAR logarithm of the minimum angle of resolution, CTR Capsular tension ring group, CON Control group

Table 2 Comparison of refractive and ACD at different time after surgery (D)

Parameter	Refraction(D)		ACD(mm)	
	A-CTR (n = 43)	B-CON (n = 46)	A-CTR (n = 21)	B-CON (n = 24)
After 1 week	-2.72 ± 0.62	-2.59 ± 0.74	4.75 ± 0.28	5.00 ± 0.38
After 1 month	-2.71 ± 0.66	-2.46 ± 0.68	4.82 ± 0.52	4.91 ± 0.40
After 3 months	-2.70 ± 0.66	-2.43 ± 0.71	4.87 ± 0.47	4.86 ± 0.39
<i>p</i> ^a	0.70	< 0.001*	0.36	0.12
<i>p</i> ^b	0.82	< 0.001*	0.11	0.11
<i>p</i> ^c	0.83	0.45	0.55	0.41

CTR capsular tension ring group, CON control group

^aThe refractive at 1 week and 1 month after surgery were compared by independent sample *t* test; ^bThe refractive at 1 week and 3 months after surgery were compared by independent sample *t* test; ^cThe refractive at 1 month and 3 months after surgery were compared by independent sample *t* test

* Statistically significant

at 1 week and 1 month, 1 week and 3 months post-surgery of B-CON group showed statistical difference (*P* < 0.001). There was no statistical difference between 1 and 3 months post-surgery (*P* = 0.45), indicating that the refraction of the control group tended to be stable 1 month post-surgery (Table 2).

The changes of ACD in the A-CTR and B-CON groups at 1 week, 1 month, and 3 months post-surgery were compared, respectively (Table 2). The Master 700 was affected by the anterior optical surface of IOL when measuring postoperative ACD, and the repeated measurement of ACD was not detected in some patients. Therefore, the patients without ACD measurement were excluded. A total of 45 eyes with ACD before operation, 1 week, 1 month, and 3 months post-surgery were continuously measured, including 21 eyes in the A-CTR group and 24 eyes in the B-CON group.

Table 3 Pairwise comparison of AE values of 7 formulas in A-CTR group and B-CON group

Formula	A-CTR n=43 P	B-CON n=46 P
EVO~Hill-RBF 2.0	1.00	1.00
EVO~BU II	1.00	1.00
EVO~Kane	1.00	1.00
EVO~Haigis	0.93	0.09
EVO~SRK/T	0.21	<0.001*
EVO~Holladay II	<0.001*	<0.001*
Hill-RBF 2.0~BU II	1.00	1.00
Hill-RBF 2.0~Kane	1.00	1.00
Hill-RBF 2.0~Haigis	1.00	0.97
Hill-RBF 2.0~SRK/T	0.31	0.02*
Hill-RBF 2.0~Holladay II	0.01*	<0.001*
BU II~Kane	1.00	1.00
BU II~Haigis	1.00	1.00
BU II~SRK/T	1.00	0.12
BU II~Holladay II	0.09	<0.001*
Kane~Haigis	0.51	1.00
Kane~SRK/T	0.11	0.33
Kane~Holladay II	<0.001*	<0.001*
Haigis~SRK/T	1.00	1.00
Haigis~Holladay II	1.00	0.03*
SRK/T~Holladay II	1.00	1.00

BU II Barrett Universal II, EVO Emmetropia Verifying Optical; Mann-Whitney-U Test

* Statistically significant

Evidently, the ACD in the A-CTR group gradually deepened and that in the B-CON group gradually shallowed. However, there was no statistical difference in the ACD between the two groups at each time post-surgery ($P>0.05$).

The refraction of all patients tended to be stable at 1 month post-surgery. Therefore, the refractive outcomes of patients at 1 month post-surgery were selected and compared with the refraction predicted by the seven formulas to calculate the PE and the AE of the seven formulas were further compared.

The Kruskal–Wallis rank sum test confirmed statistical differences between the AE for the various formulas in the A-CTR and B-CON groups, respectively ($P<0.001$). Therefore, the difference between the two groups is further analyzed (Table 3). In the A-CTR group, the Holladay II formula differed significantly from Hill-RBF 2.0, EVO, and Kane formulas. However, there was no statistical significance among the other formulas. In the B-CON group, Holladay II formula was statistically significantly different from BU II, Hill-RBF 2.0, EVO, Kane, and Haigis formulas. While there was a statistically significant difference in SRK/T formula compared to Hill-RBF 2.0 and EVO formulas, there were no statistical significances among other formulas.

Figure 1 show the AE distribution of the A-CTR and B-CON groups at 1-month post-surgery, respectively. In the A-CTR group, the median AE of Kane formula was the smallest, in the B-CON group, the median AE of the EVO formula was the smallest. However, when Kane and

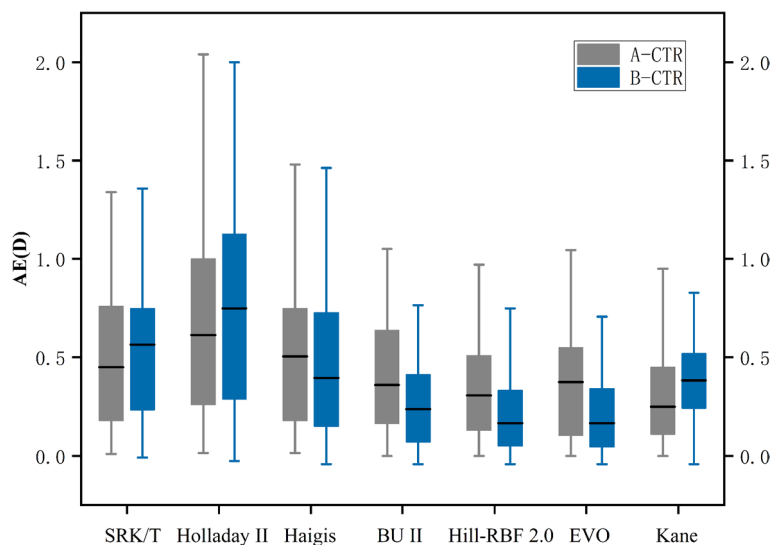


Fig. 1 AE distribution of the 7 formulas in A-CTR and B-CTR groups at 1 month after surgery. AE = absolute refractive error; BU II = Barrett Universal II; EVO = Emmetropia Verifying Optical

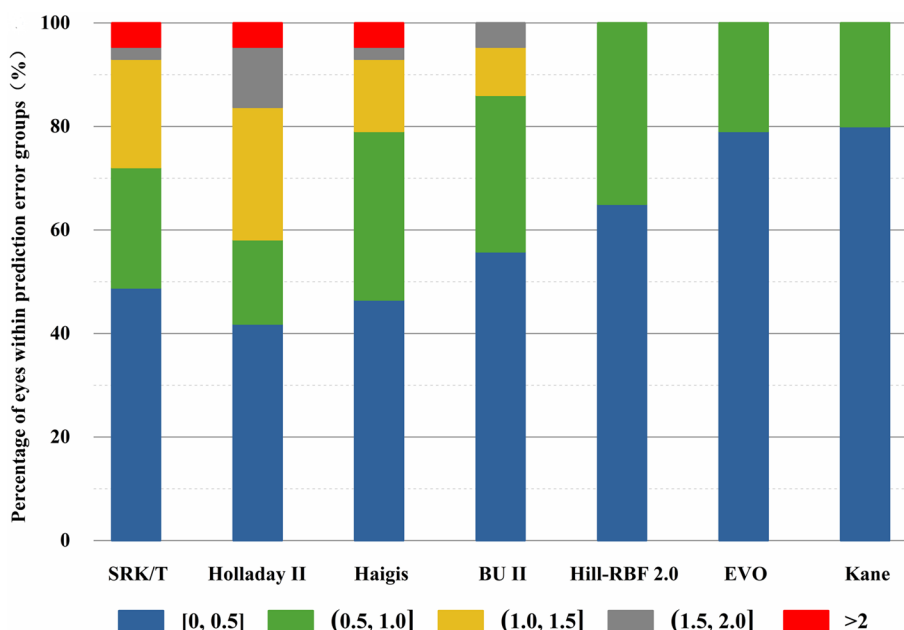


Fig. 2 Stacked histogram comparing the percentage of cases within a given diopter range of predicted spherical equivalent refraction outcome. A-CTR group stacked histogram of AE distribution of seven formulas. BU II=Barrett Universal II; EVO=Emmetropia Verifying Optical

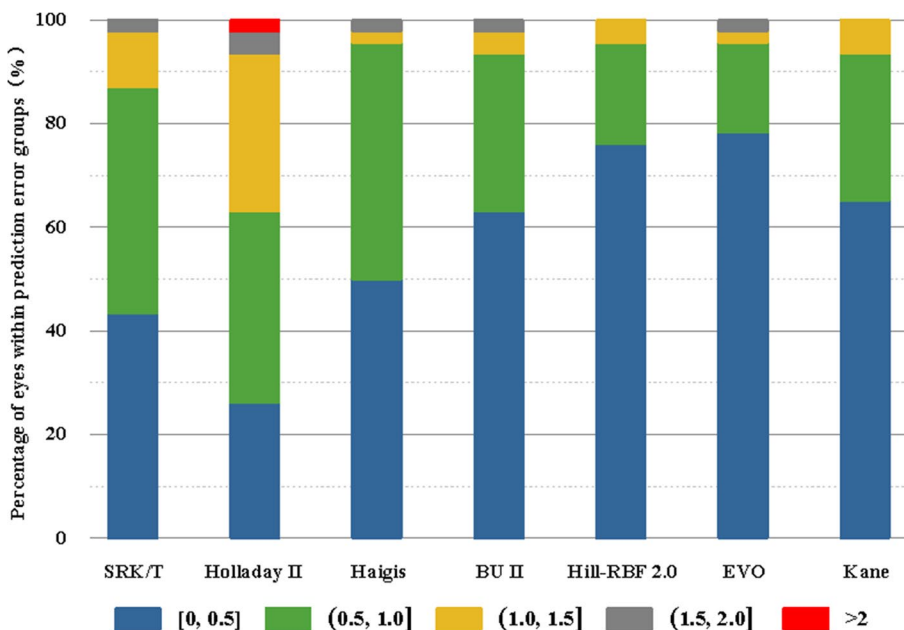


Fig. 3 Stacked histogram comparing the percentage of cases within a given diopter range of predicted spherical equivalent refraction outcome. B-CON group stacked histogram of AE distribution of seven formulas. BU II=Barrett Universal II; EVO=Emmetropia Verifying Optical

EVO were compared in the same group, there was no statistical significance ($P=1.0$).

The percentages of AE for the seven formulas within $\pm 0.5D$, $\pm 1.0D$, $\pm 1.5D$, and $\pm 2.0D$ in the A-CTR and B-CON groups at 1 month post-surgery were

described. Figure 2 shows that the proportion of AE in the A-CTR group in $\pm 0.5D$ is Kane > EVO > Hill-RBF 2.0 > BU II > SRK/T > Haigis > Holladay II. Figure 3 shows that the proportion of AE in the B-CON group

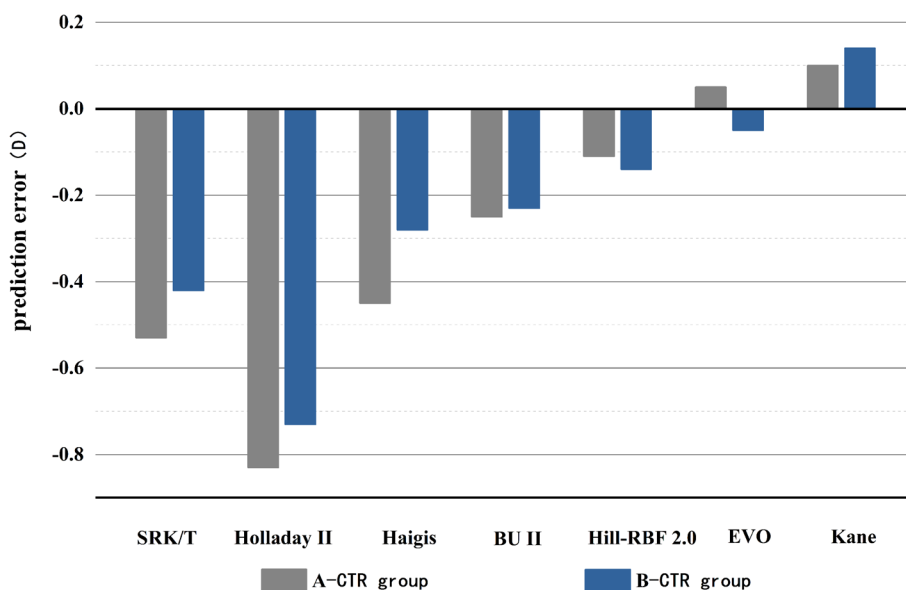


Fig. 4 Distribution of PE of seven formulas in A-CTR group and B-CON group. AE= absolute refractive error; BU II=Barrett Universal II; EVO= Emmetropia Verifying Optical

Table 4 PE of the same formula after surgery were compared between the two groups

Parameter	Group	Mean ± SD	MNE (95% CI)	T-test	
				t/z	P
SRK/T	A-CTR	-0.53 ± 0.74	0.14	-0.83	0.41
	B-CON	-0.42 ± 0.59	(-0.40–0.16)		
Holladay II	A-CTR	-0.83 ± 0.70	0.14	-0.67	0.50
	B-CON	-0.73 ± 0.64	(-0.38–0.19)		
Haigis	A-CTR	-0.45 ± 0.67	0.13	-1.15	0.25
	B-CON	-0.29 ± 0.59	(-0.42–0.11)		
BU II	A-CTR	-0.13 ± 0.49	0.11	0.99	0.33
	B-CON	-0.23 ± 0.51	(-0.11–0.32)		
Hill-RBF 2.0	A-CTR	-0.03 ± 0.46	0.11	1.62	0.11
	B-CON	-0.20 ± 0.55	(-0.04–0.40)		
EVO	A-CTR	0.05 ± 0.42	0.09	1.04	0.10
	B-CON	-0.05 ± 0.45	(-0.09–0.28)		
Kane	A-CTR	0.10 ± 0.39	0.10	-0.33	0.74
	B-CON	0.14 ± 0.51	(-0.23–0.16)		

BU II Barrett Universal II, EVO Emmetropia Verifying Optical, CTR Capsular tension ring group, CON Control group, CI Confidence interval

in ± 0.5D is EVO > Hill-RBF 2.0 > Kane > BU II > Haigis > SRK/T > Holladay II.

The PE of the same formula was compared between the A-CTR and B-CON groups, and the effect of CTR implantation on the prediction accuracy of the seven formulas was studied (Fig. 4, Table 4). The PE of Hill-RBF 2.0 and EVO formulas in the A-CTR group was more

hyperopic than in the B-CON group. However, there was no significant difference between the two groups ($P=0.11$, $P=0.10$). The PE of the other five formulas was more myopic in the A-CTR group than in the B-CON group. There was no significant difference in the PE of the five formulas between the two groups ($P=0.41$, $P=0.50$, $P=0.25$, $P=0.33$, $P=0.74$). The results indicated that CTR implantation could affect the PE of the formula, and the deviation of myopia or hyperopia was not statistically significant. Therefore, CTR implantation had no clinically significant effect on the prediction accuracy of the seven calculation formulas.

Discussion

The stability time of refraction in conventional phacoemulsification cataract surgery is 2–4 weeks post-operation [18]. Combined implantation of CTR can improve the stability of the capsule during and after surgery of myopia patients and make the IOL position more centered [19]. However, there were few studies on the stability time of refraction in long axial myopia patients with CTR implantation. In the present study, we demonstrated that the refraction of patients with implanted CTR tended to be stable 1 week post-surgery, and that of patients without implanted CTR is 1 month post-surgery. This indicates that CTR implantation is beneficial to the early stability of refraction for long axial myopia patients. CTR implantation could act on the loose capsule of long axial myopia at an early stage, lead to the even distribution and stability of the capsule, and also enhance the

adhesion force between the posterior capsule and the posterior surface of the IOL [20, 21].

The stability of effective lens position (ELP) after cataract surgery is a key factor affecting the stability of refraction, and the ELP can be indirectly reflected by postoperative ACD [22]. The results of this study showed that the CTR implantation did not have a clinically significant impact on the position of the IOL within 3 months after surgery, and therefore it is unlikely to affect the calculation results of the formula. However, the ACD observed in this study only represented the linear distance from the corneal apex to the front surface of the IOL optical center, while the actual IOL position includes the plane position of the IOL optical part and angle between the optical center and the optical axis [22, 23]. Therefore, ACD only indirectly reflects ELP. The observation of ELP post-surgery should include more comprehensive effective positions of IOL except for ACD; therefore, our results require further research to confirm this notion.

The refraction prediction of cataract surgery has been steadily improved, and the latest IOL calculation formulas are generally superior to previous generations. Numerous previous studies have compared BU II with the third-generation formulas, and BU II is proven to be the most accurate formula [24–27]. Compared with new formulas, Kane could more accurately predict the actual postoperative refraction [28, 29]. The published researches suggest that the formulas of BU II [15, 8, 25, 30, 31], Kane [31, 32] and Hill RBF 2.0 [30, 33] exhibit good performance when $AL \geq 26.0$ mm. It is not surprising that differences in research results may be related to the selection of patients with different anterior ocular conditions, measurement instruments, and implanted IOL types. In the present study, BU II, Hill-RBF 2.0, EVO, and Kane formulas are suitable for myopic eyes, whether CTR is implanted or not, but that might be more accurate in extremely myopic eyes ($AL \geq 27.0$ mm).

The retrospective case control study on 19 patients with implanted CTR and 24 patients without implanted CTR by Boomer and Jackson found that CTR implantation did not impact the prediction accuracy of SRK/T and Holladay II formulas [32]. Saadet et al. [33] believed that the CTR implantation did not affect the prediction accuracy of the SRK/T formula. In this study, the CTR implantation was shown to affect the PE of the calculation formula, causing myopia or hyperopia changes, but it seems to have no clinical significance. Therefore, the CTR implantation will not affect the prediction accuracy of the seven formulas. However, there are not many studies with larger samples to observe the influence of CTR implantation on the accuracy of the new formulas in

cataract patients with $AL \geq 27.0$ mm. Our current study may not suitably compare with previous studies.

This study has some limitations. Refraction and ACD were observed until 3 months post-surgery. Use CTR of the same length only. Whether long-term postoperative complications such as PCO and capsule shrinkage affect the correlation between CTR implantation and refraction stability or IOL location is unclear. Posterior staphyloma and other complications are common in extremely myopic eyes, and its influence on the prediction accuracy of the calculation formula needs further analysis. To the best of our knowledge, this work is the first report to compare the predictive accuracy of four new formulas, BU II, Hill-RBF 2.0, EVO, and Kane, for refraction in patients with long axial myopia using 13 mm diameter CTR implantation as an intervention factor. We found that BU II, Hill-RBF 2.0, EVO, and Kane formulas performed equally well; Kane and EVO formulas were more accurate for patients with long axial myopia. It is beneficial to implant a 13 mm diameter CTR for early refractive stability. No effect on the prediction accuracy and selection of the seven formulas is evident for patients with $AL \geq 27.0$ mm combined with cataracts.

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Authors' contributions

JJL wrote the main manuscript text. XX and JJL completed patient follow-up and data collection. HY participated in project design, data analysis and interpretation. JZ, LQQ and YPZ participated in the revision of the key results and conclusions in the paper. All authors reviewed the manuscript.

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Availability of data and materials

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The Institutional Review Board, Shaanxi Eye Hospital, Xi'an People's Hospital, approved this prospective study (No.20200035). All patients signed written informed consent, and anonymized clinical data were analyzed and published for study purposes.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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