

Accuracy of corneal astigmatism correction with two Barrett Toric calculation methods

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Abstract

• **AIM:** To compare the prediction error between Barrett Toric calculator and the new online AcrySof Toric calculator which incorporated Barrett astigmatism algorithm in Chinese cataract eyes with normal axial length and anterior chamber depth (ACD).

• **METHODS:** Prospective case-control study. All the cases had axial length (21-26 mm) with ACD no less than 2.4 mm. Keratometric values were measured by LenSTAR 900. The Barrett Toric calculator was used in group 1. In group 2, SRK-T formula was used to determine the spherical power of the Toric lens, and subsequent calculation of the cylinder type was performed using the new online Alcon Toric calculator. At 1 and 3mo after surgery, a comprehensive subjective optometry was performed. The predicted residual astigmatism calculated by the two calculators was compared with that obtained by postoperative refraction, and the difference was defined as the astigmatism correction error [error of refractive astigmatism (ERA)]. The error magnitude (EM) refers to the algebraic deviation of ERA, and the error vector (EV) indicates the vector deviation of ERA. The influence of the two calculation methods on the correction accuracy of toric IOL was quantitatively analyzed.

• **RESULTS:** The |EM| obtained at 1mo after surgery were 0.21 ± 0.12 D, 0.22 ± 0.18 D in group 1 and group 2 respectively, and correspondingly turned to be 0.19 ± 0.13 D, 0.20 ± 0.19 D at 3mo after surgery, with no statistical difference ($P=0.633$, $P=0.877$). The vector analysis showed that |EV| values in two groups at 1mo after surgery were $0.29\pm 0.14@105$ (D@angle) and $0.35\pm 0.20@113$ (D@angle), respectively, whereas |EV| values 3mo after surgery were $0.27\pm 0.16@86$

(D@angle) and $0.32\pm 0.23@102$ (D@angle), respectively. The differences between the groups were not statistically significant ($P=0.119$, $P=0.261$).

• **CONCLUSION:** The clinical effect of Barrett Toric calculator has a much more accurate tendency than that of new online AcrySof Toric calculator, but is not evident in cases with normal axial length and normal anterior posterior ratio.

• **KEYWORDS:** Barrett Toric online calculator; intraocular lens; vector analysis

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INTRODUCTION

Corneal astigmatism is one of the important factors limiting uncorrected visual acuity after cataract surgery, which can considerably affect visual quality. For astigmatic correction during cataract surgery, toric intraocular lenses (IOLs) implantation has been shown to be effective and predictable^[1]. Several clinical studies have shown that toric IOL has a wide range of astigmatism correction spectrum, which can substantially reduce the residual astigmatism after cataract surgery and improve the patient satisfaction and the distant spectacle independence^[2]. However, after the toric IOL implantation, some patients still had residual astigmatism^[3-4]. The underlying reasons for this are a matter of some controversy. IOL tilt, IOL rotational misalignment, and unexpected surgically induced astigmatism (SIA) all contribute to prediction errors. However, correcting for these factors does not always explain the error of the postoperative astigmatic outcome^[4-5]. Moreover, successful correction of preexisting astigmatism requires accurate calculation for the required toric IOL cylinder power and axis of alignment. The original online toric calculator by Alcon uses a fixed ratio to calculate the estimated IOL toric power at the corneal plane^[5]. Barrett calculator is mounted in recent years, both in ASCRS and APACRS, developed by Prof. Barrett's team using a Universal II formula and adjusts the cylindrical power and axis of alignment for the IOL with the employment of a mathematic model to accommodate value of the posterior

corneal surface. To overcome the limitation of the initial calculator, Alcon Laboratories, Inc. incorporates the astigmatic algorithms in Barrett Toric calculator. However, the spherical power calculation is not recruited. Any formula can be used as doctors used to. Whether the tiny difference between the two calculators could deliver different outcome has not yet been clarified. To investigate it, the Barrett Toric calculator and new online AcrySof Toric calculator were adopted to decide the type and axis of toric IOL (Acrysof IQ), and then evaluate their influences on the astigmatic correction effect.

SUBJECTS AND METHODS

Ethical Approval The study was conducted in accordance with the Declaration of Helsinki and was approved by Tianjin Medical University Eye Hospital (TMUEC; No.ChiCTR1800019682). All patients had been fully informed of the purpose and methods of the present study and provided written informed consent from themselves or their guardians.

Patient Population Patients who underwent cataract removal by phacoemulsification were included. Preoperative measurements of corneal astigmatism with LenSTAR 900 (HAAG-STREIT, USA) were performed, and patients with corneal astigmatism greater than 0.75 D were enrolled. Corneal topography (OCULUS PENTACAM, Germany) is used to evaluate the irregular corneal astigmatism. Exclusion criteria were as followed: irregular astigmatism of cornea, axial length (AL) >27 mm, combined with staphyloma sclera, AL <21 mm, anterior chamber depth (ACD) <2.4 mm accompanied by glaucoma, uveitis, retinopathy and other eye diseases or surgeries that could compromise the visual function.

Preoperative Examination All patients had full preoperative ophthalmologic examinations, including uncorrected distance visual acuity and corrected distance visual acuity using logMAR acuity charts at 4 m under photopic conditions (85 candelas/m²), manifest refraction using the cross-cylinder method, slit lamp biomicroscopy, non-contact tonometry, and funduscopy under mydriasis. Corneal astigmatism and curvature were evaluated using the automated keratometry feature of an optical low-coherence reflectometry (OLCR) device (LenSTAR 900).

In group 1, the toric IOL is calculated by logging in APACRS and choosing Barratt Toric calculator. In group 2, the IOL spherical power was calculated using the SRK-T formula. The IOL cylindrical power was calculated using the Alcon new online calculator and automated keratometry (OLCR device). The A-constant was 119.2. The refractive goal was emmetropia.

Surgical Technique Before surgery, limbus horizontal meridian was marked by a special marker (copyright By professor Zhang H) after topical anesthesia with the patient seated to prevent cyclotorsion. Then the precalculated toric axis was marked on the basis of horizontal meridian when

the patient lay down. All surgeries were performed by an experienced cataract specialist using topical anesthesia and a micro coaxial phacoemulsification technique with a superior 2.2 mm clear corneal incision.

Postoperative Examinations At 1 and 3mo after surgery, a subjective optometry was performed by cross cylinder method, and the toric IOL axial position was examined after mydriasis.

Postoperative Calculation The refractive power was converted from the spectacle plane to the corneal plane in accordance with the vertex distance. The conversion method is as follows^[6]:

$$C_{\text{corn}} = (S_{\text{spect}} + C_{\text{spect}}) / [1 - V \times (S_{\text{spect}} + C_{\text{spect}})] - S_{\text{spect}} / (1 - V \times S_{\text{spect}})$$

[C_{corn} represents the concave-cylinder diopter of the corneal surface, S_{spect} is the spherical lens diopter of the glasses plane, C_{spec} denotes the concave-cylinder diopter of the glasses plane, and V indicates the vertex distance (in mm)].

Error of refractive astigmatism (ERA)=postoperative residual astigmatism (PRA; corneal surface) – predicted residual astigmatism (corneal surface). Error vector (EV) is the vector deviation of ERA. Error magnitude (EM) is the algebraic deviation of ERA.

Vector Analyses The PRA is decomposed into X and Y components by vector transformation.

$$X_{\text{ra}} = C_{\text{ra}} \times \cos(2 \times A_{\text{ra}}); Y_{\text{ra}} = C_{\text{ra}} \times \sin(2 \times A_{\text{ra}}) \quad (1)$$

$$X_{\text{pra}} = C_{\text{pra}} \times \cos(2 \times A_{\text{pra}}); Y_{\text{pra}} = C_{\text{pra}} \times \sin(2 \times A_{\text{pra}}) \quad (2)$$

(C_{corn} represents the diopter of the concave-cylinder, and A indicates the axial direction of the concave-cylinder.)

$$Y_{\text{EV}} = Y_{\text{ra}} - Y_{\text{pra}}; X_{\text{EV}} = X_{\text{ra}} - X_{\text{pra}}; \quad (3)$$

$$|EV| = [(X_{\text{ra}} - X_{\text{pra}})^2 + (Y_{\text{ra}} - Y_{\text{pra}})^2]^{1/2} \quad (4)$$

$$\theta_{\text{era}} = 0.5 \times \arctan(Y_{\text{EV}} / X_{\text{EV}}) \quad (5)$$

Statistics Analysis The statistical analysis was undergone by SPSS 22.0 software. The measurement data of normal distribution was expressed as mean±standard deviation. After vector analysis, the ERA, EM, and EV values between the two groups were compared using the independent sample t test. P<0.05 was considered as statistically significant difference.

RESULTS

A total of 74 cases (74 eyes) underwent phacoemulsification in Tianjin Medical University Eye Hospital were randomized to two groups. Group 1 was Barrett Toric calculator including 36 cases (36 eyes), group 2 was new online AcrySof calculator with 38 cases (38 eyes). Five patients were lost to follow-up. The cases consisted of 33 males (33 eyes) and 36 females (36 eyes) at the ages of 51-91y, with the average age of 72±10y. The difference between two groups was not statistically significant (χ²=0.357, P=0.473, t=-0.507, P=0.614), as shown in Table 1. Among 69 eyes included in this study, 11 eyes (15.94%) had with-the-rule (WTR) astigmatism, 47 eyes (68.12%) had against-the-rule (ATR) astigmatism, and 11 eyes (15.94%) had oblique astigmatism. The implantation of SN60T2, SN60T3, SN60T4, SN60T5, SN60T6, SN60T7,

Table 1 Preoperative ocular parameters of two groups

Groups	Gender		Age	AL (mm)	ACD (mm)	Corneal astigmatism (D)	IOL spherical equivalent (D)
	M	F					
Total	33	36	72±10	24.46±2.30	3.19±0.50	1.64±0.58	19.80±4.97
Barrett group	15	20	71±11	23.81±2.20	3.12±0.49	1.60±0.63	20.14±5.22
New Alcon group	18	16	73±9	24.67±2.06	3.18±0.45	1.67±0.52	19.51±4.69
t/χ^2	0.357		-0.507	-1.674	-0.592	-0.529	0.525
<i>P</i>	0.473		0.614	0.099	0.556	0.599	0.601

AL: axial length; ACD: Anterior chamber depth.

Table 2 Comparison of |EM|, EV, |X_{EV}|, and |Y_{EV}| of the two groups 1mo after surgery

Groups	EM (D)	EV (D@angle)	X _{EV} (D)	Y _{EV} (D)
Barrett group	0.21±0.12	0.29±0.14@105	0.04±0.27	0.13±0.13
New Alcon group	0.22±0.18	0.35±0.20@113	0.23±0.18	0.21±0.20
<i>t</i>	-0.480	-1.581	-3.426	-2.157
<i>P</i>	0.633	0.119	0.001	0.035

EM: Error magnitude; EV: The vector deviation of ERA (error of refractive astigmatism); XEV: X components of EV by vector transformation; YEV: Y components of EV by vector transformation.

Table 3 Comparison of |EM|, EV, |X_{EV}|, and |Y_{EV}| of the two groups 3mo after surgery

Groups	EM (D)	EV (D@angle)	X _{EV} (D)	Y _{EV} (D)
Barrett group	0.19±0.13	0.27±0.16@86	0.22±0.13	0.13±0.13
New Alcon group	0.20±0.19	0.32±0.23@102	0.22±0.22	0.18±0.17
<i>t</i>	-0.156	-1.133	-0.052	-1.442
<i>P</i>	0.877	0.261	0.959	0.154

EM: Error magnitude; EV: The vector deviation of ERA (error of refractive astigmatism); XEV: X components of EV by vector transformation; YEV: Y components of EV by vector transformation.

and SN60T8 were 1 eye (1.45%), 20 eyes (28.99%), 29 eyes (42.03%), 7 eyes (10.14%), 10 eyes (14.49%), 1 eye (1.45%), and 1 eye (1.45%), respectively. No statistically significant difference was found between the two groups in preoperative ocular biometry, such as AL ($P=0.099$), ACD ($P=0.556$), and corneal astigmatism ($P=0.599$). After surgery, IOL axis alignment in both groups were all $<5^\circ$ (Barrett group $1.89^\circ\pm 1.05^\circ$, New Alcon group $1.97^\circ\pm 0.97^\circ$), of which the difference has no statistical significance ($t=-0.349$, $P=0.729$). Table 1 shows the preoperative ocular parameter.

The ERA Comparison

Comparison of |EM| obtained by the two groups The |EM| obtained from the Barrett calculator group 1mo and 3mo after surgery were 0.21 ± 0.12 D and 0.19 ± 0.13 D, respectively. Simultaneously, |EM| in the new online AcrySof calculator group 1 and 3mo after surgery were 0.22 ± 0.18 D and 0.20 ± 0.19 D, respectively. The difference between the groups was not statistically significant ($t=-0.480$, -0.156 , $P=0.633$, 0.877), as shown in Tables 2 and 3.

Comparison of |EV| obtained by the two groups At 1mo after surgery, the total |EV| obtained from group 1 was 0.29 ± 0.14 D, whereas that of group 2 was 0.35 ± 0.20 D, which showed no statistically significant difference ($t=-1.581$, $P=0.119$). At 3mo after surgery, the total |EV| obtained by the two groups were 0.27 ± 0.16 D, 0.32 ± 0.23 D, respectively, which has no statistically significant difference ($t=-1.133$, $P=0.261$), as shown in Tables 2 and 3.

The EV of the two groups was decomposed into two vectors and compared. At 1mo after surgery, the difference in both X and Y was statistically significant ($t=-3.426$, $P=0.001$; $t=-2.157$, $P=0.035$). At 3mo after surgery, the difference was not statistically significant ($t=-0.052$, $P=0.959$; $t=-1.442$, $P=0.154$), as shown in Tables 2 and 3.

Figure 1 presented the EV distribution of the two groups in double angle plot. In group 1, patients with |EV| less than 0.5 D at 1 and 3mo after surgery accounted for 88.57% (31 eyes) and 88.57% (31 eyes), respectively. However, in group 2, patients with |EV| less than 0.5 D at 1 and 3mo postoperatively occupied 76.47% (26 eyes) and 82.35% (28 eyes), respectively.

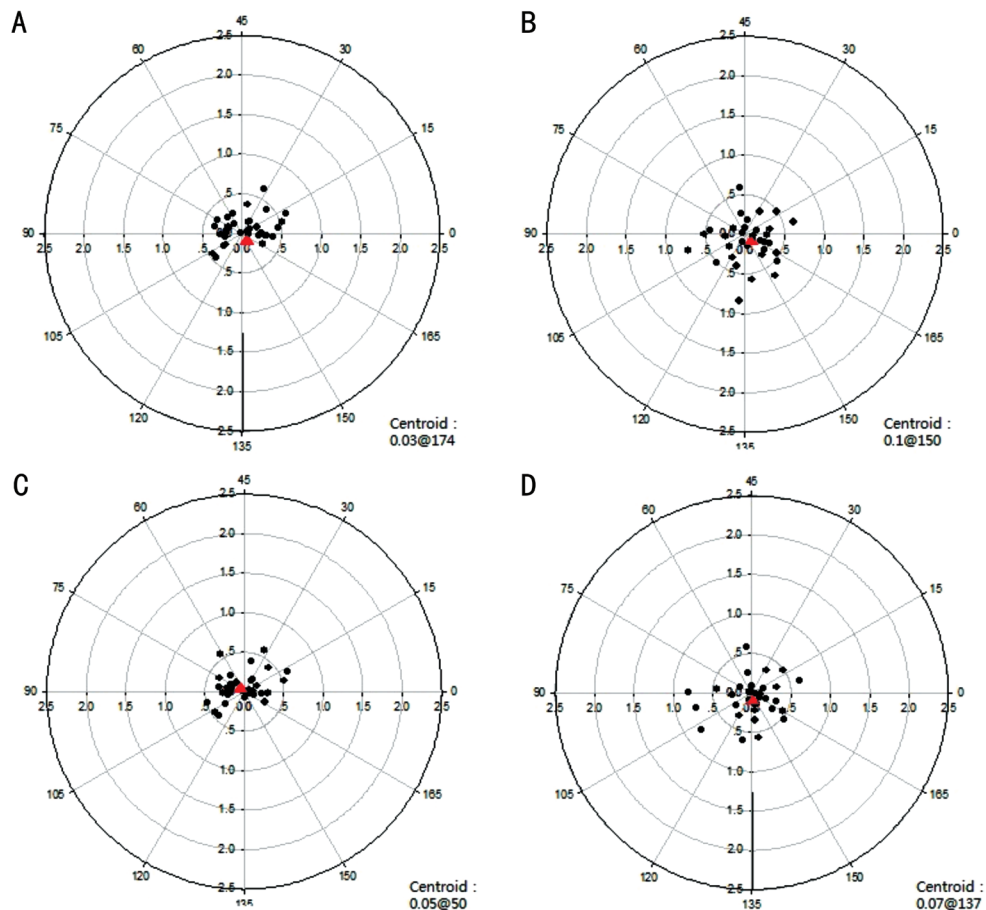


Figure 1 The EV distribution of both groups A: Barrett calculator 1mo after surgery; B: New online AcrySof calculator 1mo after surgery; C: Barrett calculator group 3mo after surgery; D: New online AcrySof calculator 3mo after surgery (The black dots represent the vector coordinates of EV of each eye, and the red dots indicate the centroids).

DISCUSSION

Corneal astigmatism can significantly impair the visual acuity in phakic and pseudophakic eyes^[7]. Corneal astigmatism is not rare in cataract patients. Between 15% and 29% of cataract patients have more than 1.5 D of keratometric astigmatism^[8-9]. Without proper correction of corneal astigmatism, postoperative vision, and visual quality of cataract patients will be considerably affected^[10].

The results toric IOL are not always predictable. Optimum correction of astigmatism requires accurate measurement, meticulous alignment of the toric IOL, and appropriate calculations. Recent studies support considering the predicted effective lens position (ELP), spherical power of the IOL, and posterior corneal surface to achieve precise results when implanting toric IOLs. To overcome the calculating pitfalls, the Baylor nomogram and Barrett Toric calculator were introduced to adjust toric IOL power to account for posterior corneal astigmatism by regression analysis and theoretical model. The ASCRS and APACRS has introduced the Barrett Toric calculator including astigmatism analysis and spherical power calculation. The Alcon initial calculator is upgraded with Barrett astigmatism algorithm which considers the posterior

corneal astigmatism. The aim of our study was to evaluate the accuracy of predicting toric IOL cylinder power by comparing the 2 toric IOL calculators.

In accordance with literature reviews, patients with |EV| less than 0.5 D who used the old AcrySof online calculator accounted for 31.3%-35.3%^[11]. In the Barrett Toric calculator group, patients with |EV| less than 0.5 D 1 and 3mo after surgery accounted for 88.57% and 88.57%, respectively. In the new online AcrySof Toric calculator group, patients with |EV| less than 0.5 D 1 and 3mo after surgery accounted for 76.47% and 82.35%. Therefore, not only by Barrett Toric calculator but also new online AcrySof calculator can achieve more accuracy than that by the old AcrySof calculator.

Several studies have discovered that the posterior corneal astigmatism is 0.26-0.78 D, with steeper curvature in vertical meridian, which will have a negative power to the total corneal astigmatism^[12-14]. Therefore, the inclusion of the posterior corneal surface in the calculation of these IOLs is now considered relevant because ignoring it results in overcorrection in eyes with WTR astigmatism and undercorrection in eyes with ATR astigmatism. The old AcrySof calculator used simulated K values (simK) derived from assumption that

the cornea is 500 μm thick and the anterior/posterior radius is fixed to 0.82, which cannot entirely reflect the overall corneal astigmatism^[15-16]. The Barrett corneal astigmatism algorithm is set up in a mathematical model based on big data. The anterior corneal astigmatism is used to estimate the posterior corneal astigmatism, so as to obtain the total corneal astigmatism, which is much more reasonable than simK theoretically. It is definite from our result that the algorithms increase the accuracy, with both centroid near to the origin, which is consistent with the other studies^[11,17]. The ray-tracing method implemented in the dual Scheimpflug analyzer uses the Snell law to calculate total corneal power and total corneal astigmatism. This approach, instead of assuming that parallel rays reach the posterior corneal surface, accounts for the refraction of rays by the anterior corneal surface and thereby more accurate in the calculation of the total corneal power and total corneal astigmatism. There are some studies about using total corneal refractive power (TCRP) from ray-tracing method in original Alcon Toric calculator which can yield better results than before as well. However, whether Barrett astigmatism algorithms is superior to the ray-tracing measurement still needs further study.

Different ELP should have produced different effect on the cylindrical power of corneal plane. AcrySof Toric IOL has eight models (T2-T9), those are 1.0, 1.5, 2.25, 3.0, 3.75, 4.5, 5.25, and 6.0 D respectively at lens plane. The manufacturer, in fact, gives a single corneal plane cylinder for each IOL cylinder power; this value is “based on the average pseudophakic eye” and depends on a fixed ratio (1.46) between the cylinder power in the IOL plane and the cylinder power in the corneal plane^[18], which means the ACD is around 3 mm. However, individual differences occur especially in short or long eyes as well as in eyes with a steep or flat cornea. The Toricity of IOL on corneal plane should vary with each individual, and this variability depends on multiple factors, which mainly includes AL and ACD^[5,19-20]. Savini *et al*^[18] found that undercorrection of corneal astigmatism can occur in eyes with a steep K value and/or a long AL; that is in eyes with a deep ACD. Overcorrection, on the other hand, can occur in eyes with a flat K value and/or a short AL; that is, in eyes with a flat ACD. Although posterior corneal astigmatism was considered in the new online Alcon calculator, other variables are not covered. In some special cases it still may cause errors. Subjects included in this study were all subjects with average ACD and AL of 21-26 mm. So that no statistical difference occurs between the two calculators. Thereafter, the study will be continued in special eyes to obtain further results.

Moreover, the Barrett Toric calculator carries formula Universal II, which is recognized to be more reasonable and accurate in IOL power calculation. In this calculator, the

influence of spherical equivalent on astigmatic power was considered, while the needed toric IOL is calculated only once including spherical and cylinder power. As for the AcrySof Toric calculator, the old and new versions must use the fourth-generation formula to calculate the IOL spherical power first. The study showed that the toric IOL spherical power of the two groups have no statistically significant difference. In the Barrett Toric calculator group, patients with $|\text{EV}|$ less than 0.5 D 1 and 3mo after surgery accounted for 88.57% and 88.57%, respectively. In the new online AcrySof Toric calculator group, patients with $|\text{EV}|$ less than 0.5 D 1 and 3mo after surgery accounted for 76.47% and 82.35%, respectively. It seemed that Barrett calculator group were slightly better than those of the AcrySof calculator, however without significant difference. Further study including more patients should be needed.

The ERA indicates the difference between the expected residual astigmatism and the actual astigmatism after surgery. The smaller the ERA, the higher the predictive precision is. In this study, the ERA of both groups was calculated, and the EM and EV of ERA were compared as well, which aimed to assess the prediction of the two calculators. In addition, astigmatism, as a vector, has magnitude and direction. The standard vector analysis method^[21] recommended by the American National Standards Institute was adopted in this study to evaluate the effect of astigmatism correction. After the astigmatism was converted to the corneal plane, the horizontal diameter line of 90° - 180° was used as a reference axis. The astigmatism was decomposed into two components of X and Y, and the coordinate system was constructed to analyze the correction effect of the two calculators. There is no statistically significant difference between the $|\text{EV}|$ values obtained by the two calculators at 1mo and 3mo after surgery. In terms of the vector analysis the difference between X and Y was statistically significant. However, at 3mo post operatively, the difference between X and Y was not statistically significant, which is related to the instability of the refraction 1mo after surgery. This outcome is similar to that of Ferreira *et al*^[11]. The EV in the center of the standard circle in coordinate system is the centroid. The closer the centroid is to the origin, the more accurate it is. At 3mo after surgery, the centroids of Barrett Toric calculator and new online AcrySof Toric calculator were 0.05 D@50, and 0.07 D@137 respectively, suggesting both of them have good prediction.

The limitation of this study is the definition of “normal” cataract eyes which included normal AL and not shallow anterior chamber with definite range. However, the ratio of anterior/posterior in normal eyes should have presented a wide change, which may result in difference between the two methods. It will be reasonable to include more eyes to reach a further conclusion.

In summary, incorporation of Barrett's astigmatism algorithm significantly improves the predictability of new online AcrySof Toric calculator. In comparison with the Barrett Toric calculator, the new online AcrySof calculator can provide the same stable and accurate results in patients with normal eye axial length and ACD. However, the Barrett Toric calculator with more variables taken into consideration still has certain advantages over the new online AcrySof Toric calculator, especially in those eyes with abnormal ACD and extremely short or long AL, which need further study.

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