

Comparison of the clinical efficacy of AcrySof® IQ and TECNIS® toric intraocular lenses: A real-world study

JUAN-JUAN YANG*, YA-ZHOU QIN, LI QIN and JING-MING LI

Department of Ophthalmology, First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, Shaanxi 710061, P.R. China

Received December 11, 2019; Accepted May 13, 2020

DOI: 10.3892/etm.2020.9153

Abstract. Corneal astigmatism significantly compromises uncorrected visual acuity (UCVA) after phacoemulsification with implantation of traditional spherical or non-spherical monofocal intraocular lens (IOL). Toric IOL provides an effective way to gain favorable postoperative UCVA for the patients with cataracts with corneal astigmatism. There are numerous types of toric IOLs; however AcrySof® IQ toric IOL (Alcon Laboratories, Inc.) and TECNIS® toric IOL (Johnson & Johnson Vision; Johnson & Johnson) are most frequently used in our clinical practice. The purpose of the current study was to compare the clinical efficacy of AcrySof IQ with TECNIS toric IOL implantation, and to provide a clinical basis on selecting an appropriate toric IOL before cataract surgery for patients with corneal astigmatism. A total of 30 patients with cataract (44 eyes) with corneal astigmatism [0.82-7.27 diopters (D)], who have undergone phacoemulsification with toric IOL implantation between October 2012 and December 2017, were included in the current retrospective cohort study. Patients were divided into two groups: One group (26 eyes) received the AcrySof IQ toric IOL (AcrySof group) and the other group (18 eyes) received the TECNIS toric IOL (Tecnis group). The indexes of curative effect, such as uncorrected and corrected distance visual acuity (UDVA and CDVA, respectively), refractive outcomes, contrast sensitivity (CS), IOL rotation, and satisfaction, were evaluated. Both toric IOLs significantly improved UDVA and CDVA. Postoperative mean residual astigmatism was similar in the AcrySof group and in the Tecnis group (0.75 ± 0.50 and 0.78 ± 0.90 D; $P=0.896$).

There was no statistically significant between postoperative CS in the AcrySof and Tecnis groups. Rotations of $>10^\circ$ were considered to be significant and were identified in three eyes. The mean IOL rotation showed no statistically significant difference (AcrySof group, $0.24 \pm 5.54^\circ$; Tecnis group, $-0.19 \pm 6.28^\circ$; $P=0.416$). The mean patient satisfaction score was 8.46 ± 1.21 in the AcrySof group and 8.78 ± 1.44 in the Tecnis group ($P=0.260$). The results of the current study indicated that patients with cataracts with corneal astigmatism undergoing phacoemulsification with AcrySof IQ and TECNIS toric IOL implantation achieved similar clinical efficacy in term of visual outcomes, refraction correction, CS, rotational stability and satisfaction.

Introduction

Corneal astigmatism is refractive error that impairs uncorrected visual acuity (1). A previous study analyzed 2,156 eyes of 1,317 patients with cataracts and found that 73.7% of the eyes had corneal astigmatism of ≤ 1.50 D and 26.3% had >1.50 D; furthermore, 7.4% of the eyes had ≥ 3.00 D (2). Another study reported that 15-29% of patients with cataracts had refractive astigmatism of >1.50 D (3). Patients cataracts with corneal astigmatism who receive traditional spherical or non-spherical monofocal intraocular lenses (IOLs) frequently require spectacles or additional corneal refractive procedures, such as photorefractive keratectomy, peripheral corneal relaxing incisions, or laser *in situ* keratomileusis (LASIK), to achieve good visual acuity (4). However, peripheral corneal relaxing incisions have several latent disadvantages, such as lack of precision, limited cylinder correction, overcorrection, regression, wound gape, and varied healing responses (5). Moreover, potential complications of photorefractive keratectomy and LASIK include haze, keratitis, dry eye, regression, overcorrection and under-correction (6).

With the improved quality of life, cataract surgery has developed from a procedure for removing the cloudy lens safely so patients can acquire freedom from glasses and gain excellent uncorrected visual acuity (7,8). When patients undergo cataract surgery, implantation of toric IOL is deemed the most effective choice for correcting corneal astigmatism and reducing post-operative spectacle dependence (9). Nonetheless, fluctuating or inaccurate preoperative keratometry (10), undervaluation of the total astigmatism in IOL power calculations (11-13), unexpected surgically induced astigmatism (14), errors of IOL

Correspondence to: Professor Jing-Ming Li or Professor Li Qin, Department of Ophthalmology, First Affiliated Hospital of Xi'an Jiaotong University, 277 Yanta West Road, Xi'an, Shaanxi 710061, P.R. China
E-mail: jingming_li@xjtu.edu.cn
E-mail: eyeqinli@163.com

*Present address: ¹Department of Health Management, Second Affiliated Hospital of Xi'an Jiaotong University, Xi'an, Shaanxi 710004, P.R. China

Key words: toric intraocular lens, visual acuity, astigmatism, rotation, satisfaction

axis position (15), or IOL instability (16) could decrease the curative effect of toric IOL. The optimal effect of toric IOLs is dependent on the ability of the surgeon to minimize postoperative refractive error, in particular astigmatism (17).

There are numerous types of toric IOLs; however, AcrySof® IQ and TECNIS® toric IOL are most frequently used in the Department of Ophthalmology, First Affiliated Hospital of Xi'an Jiaotong University. Before cataract surgery, patients often requires help to select the optimal type of toric IOL. The objective of the present study was to compare the postoperative visual acuity, refractive outcome, contrast sensitivity (CS), rotational stability and satisfaction of patients with cataracts with corneal astigmatism following implantation of two types of toric IOLs in a tertiary hospital of northwest China, and to provide a clinical basis for selecting an appropriate toric IOL.

Patients and methods

Participants. Clinical data were collected from 30 patients with cataracts with low to high corneal astigmatism who received cataract surgery with implantation of an AcrySof IQ (Alcon Laboratories, Inc.) or TECNIS (Johnson & Johnson Vision; Johnson & Johnson) toric IOL by the same ophthalmic surgeon at the First Affiliated Hospital of Xi'an Jiaotong University (Xi'an, China). The cohort consisted of 19 females and 11 males, with a mean age of 68.87 ± 16.07 years (range, 21-90 years). Before surgery, patients were free to select their preferred type of toric IOL and were assigned to groups based on their choice. In one group, patients received the AcrySof IQ toric IOL (AcrySof group), and in the other group, patients received the TECNIS toric IOL (Tecnis group). The characteristics of these two types of toric IOLs are shown in Table I. The AcrySof IQ IOL cylinder power models include 1.00, 1.50, 2.25, 3.00, 3.75, 4.50, 5.25 and 6.00 D. The Tecnis IOL cylinder power models include 1.00, 1.50, 2.25, 3.00 and 4.00 D. Written informed consent was obtained from all patients before cataract surgery. The study protocol was approved by the Ethics Committee of the First Affiliated Hospital of Xi'an Jiaotong University (Xi'an, China). This study was conducted in accordance with the tenets of the Declaration of Helsinki. The inclusion criteria were as follows: i) Patients older than 18 years; ii) visually significant cataract diagnosis; and iii) preoperative regular corneal astigmatism >0.75 D, with corneal topography of with-the-rule astigmatism (direction of maximum refractive power, $90 \pm 30^\circ$) and against-the-rule astigmatism (direction of maximum refractive power, $180 \pm 30^\circ$). Exclusion criteria included irregular corneal astigmatism, a history of keratitis, corneal scarring, prior corneal surgeries and active corneal diseases that could compromise vision. Furthermore, patients with zonular weakness were excluded.

Preoperative assessment. In addition to collection of demographic information, all patients underwent a comprehensive ophthalmologic examination prior to surgery, including slit-lamp examination, dilated funduscopy, measurement of uncorrected and corrected distance visual acuity (UDVA and CDVA, respectively), manifest refraction, intraocular pressure, corneal topography (Carl Zeiss Meditec AG), and IOLMaster 500 partial coherence interferometry (Carl Zeiss Meditec AG). The decimal values of visual acuity obtained from the interna-

tional visual chart at 5 M were converted into logarithm of the minimum angle of resolution (LogMAR) values. The required IOL cylinder power and axis placement were calculated using online calculators from the respective IOL manufacturers. The AcrySof toric calculator (www.acrysoftoriccalculator.com; v. 3.2.3) was used with an A-constant of 119.2 for the AcrySof IQ toric IOL. The TECNIS toric calculator (www.tecnistoriccalc.com; v. 3.28) was used with an A-constant of 119.3 for the Tecnis toric IOL. In online calculator, the surgically induced astigmatism was set at 0.50 D on the axis where the main incision was made.

Operative technique. With the subject seated upright, the surgeon marked the corneal limbus of the operative eye as reference markings (0 and 180°) using a slit lamp and a marking pen. The axis marker was aligned with the corneal reference marks intraoperatively. The incision and the intended axis of the lens were inked with a surgical skin marker. Surgery proceeded as in standard cataract surgery. According to the surgeon's operation habit and experience, the primary corneal incision was 3-mm at 120° . The anterior capsule was opened with a diameter of ~ 5.5 mm through a continuous-tear capsulorhexis. After phacoemulsification and cataract removal, lenses were folded and implanted using conventional instruments. Once in the capsular bag, the toric IOL was rotated until the axis indentations of the IOL were aligned with the subject's intraoperative axis marking. All ophthalmic viscoelastic devices were completely removed to avoid further rotation of the IOL.

Postoperative assessment. Patients who have undergone surgeries were reviewed once between 1 month to 4 years postoperatively. Outcome measures included visual acuities (LogMAR UDVA and CDVA), manifest refraction (obtained by an optometrist), CS under mesopic, photopic and mesopic glare at four spatial frequencies (CSV-1000E; VectorVision, Inc.), slit-lamp examination, dilated funduscopy, toric axis using the 'Toric IOL Rotation Summary' software with OPD Scan III workstation (Nidek Co., Ltd.) under mydriasis (1.0% tropicamide; Santen Pharmaceutical Co., Ltd.), and a subjective visual quality questionnaire drafted according to a previous study (18). Rotation of the toric IOL was evaluated as follows: A clockwise rotation was counted as positive and counterclockwise rotation as negative.

Subjective visual quality questionnaire. Patients were asked yes/no questions about spectacle independence, incidence of postoperative optical or visual disturbances such as ghosting, glare, difficulty in nighttime vision, halos, visual distortion, and color vision or depth perception impairment. Furthermore, patients were asked to evaluate their satisfaction with visual improvement using a score scale from 0 to 10 at intervals of 1 (score 0, not at all satisfied; score 10, very satisfied).

Calculation of refractive astigmatism reduction. The mean percentage of refractive astigmatism reduction was calculated using the American National Standards Institute (ANSI) formula (19). The following equation was used: (Postoperative refractive cylinder-preoperative keratometric cylinder)/(target refractive cylinder-preoperative keratometric cylinder) $\times 100\%$.

Table I. Characteristics of the AcrySof® IQ and TECNIS® toric IOLs.

Characteristic	AcrySof IQ Toric IOL model SN6AT2-T9	Tecnis Toric IOL model ZCT100-400
Material	Hydrophobic acrylic	Hydrophobic acrylic
Optic diameter, mm	6.0	6.0
Overall diameter, mm	13.0	13.0
Optic shape	Biconvex, anterior toric aspheric surface	Biconvex, anterior toric aspheric surface
Haptic design	Modified L design, integral with optic	Modified C design, integral with optic
Edge design	Discontinuous 360° posterior square edge	ProTec frosted, continuous 360° posterior square edge
A-constant, mm	119.0	118.8
Refractive index	1.55	1.47
Light filtering	UV and blue light	UV
Spherical power, D	+6.0 to +30.0 (0.5 steps)	+5.0 to +34.0 (0.5 steps)
Cylinder power, D	1.0 to 6.0	1.0 to 4.0
Incision, mm	2.2	2.2

IOL, intraocular lens; UV, ultraviolet; D, diopters.

Statistical analysis. All statistical analyses were performed using SPSS for Windows (version 18.0; SPSS, Inc.). Data are presented as the mean \pm standard deviation or as frequencies. The Kolmogorov-Smirnov test was used to test the normality assumption. To assess the differences between AcrySof and Tecnis groups, Student's t-test was applied if the values presented normal distribution, and Mann-Whitney U test was performed if the values did not present normal distribution. For a mixture of paired and unpaired data comparisons, such as visual acuity and refraction, a mixed ANOVA and simple main effects with Bonferroni correction were used. The Fisher's exact test was used to analyze the gender distribution of patients. Chi-square test was used for comparisons of postoperative categorical variables. $P < 0.05$ was considered to indicate a statistically significant difference.

Results

Patients demographics and characteristics. Among the 30 patients (44 eyes) included in the current study, 18 patients (26 eyes) received the AcrySof IQ toric IOL SN6AT3-T7 and 12 patients (18 eyes) received the TECNIS toric IOL ZCT225-400. The collective characteristics and preoperative clinical data are presented in Table II. No significant difference was noted between the two groups.

Visual acuity. There were no differences between the two groups in preoperative UDVA or CDVA ($P = 0.288$ and $P = 0.116$, respectively; Fig. 1A and B). Toric IOL implantation significantly improved UDVA (AcrySof group: Preoperative, 0.68 ± 0.25 LogMAR vs. postoperative, 0.20 ± 0.14 LogMAR, $P < 0.01$; Tecnis group: Preoperative, 0.63 ± 0.27 LogMAR vs. postoperative, 0.15 ± 0.17 LogMAR, $P < 0.01$; Fig. 1A) and CDVA (AcrySof group: Preoperative, 0.36 ± 0.21 LogMAR vs. postoperative, 0.04 ± 0.06 LogMAR, $P < 0.01$; Tecnis group: Preoperative 0.28 ± 0.16 LogMAR vs. postoperative, 0.01 ± 0.07 LogMAR, $P < 0.01$; Fig. 1B). There were no differences between the two groups in postoperative UDVA or

CDVA ($P = 0.867$ and $P = 0.926$, respectively; Fig. 1A and B). For postoperative mean UDVA, 92 and 83% of the eyes achieved a value of ≥ 0.3 LogMAR in the AcrySof and Tecnis groups, respectively. For postoperative mean CDVA, 100 and 94% of the eyes achieved a value of ≥ 0.1 LogMAR in the AcrySof and Tecnis groups, respectively. These results indicated that the visual effect of both toric IOLs was statistically and clinically significant.

Refraction. No statistically significant between-group differences were noted in preoperative corneal astigmatism (AcrySof group, 2.01 ± 0.44 D vs. Tecnis group, 2.27 ± 1.35 D; $P = 0.381$; Fig. 2) and postoperative residual astigmatism (AcrySof group, 0.75 ± 0.50 D vs. Tecnis group, 0.78 ± 0.90 D; $P = 0.896$; Fig. 2). In both groups, refractive astigmatism was reduced significantly after a toric IOL implantation ($P < 0.01$). The median deviation of the postoperative residual astigmatism from the predicted residual astigmatism, based on manufactures' IOL calculators, was 0.71 D with a range of -0.25 - 1.52 D in the AcrySof group and 0.30 D with a range of -1.15 - 1.99 D in the Tecnis group. No significant difference was noted between the two groups ($P = 0.23$). Postoperative residual astigmatism was within ± 0.50 D of the predicted residual astigmatism in 12 eyes (46%) in the AcrySof group and 9 eyes (50%) in the Tecnis group, and within ± 1.00 D in 19 eyes (73%) in the AcrySof group and 14 eyes (78%) in the Tecnis group. According to the ANSI formula for % refractive astigmatism reduction, in 36 eyes (21 in the AcrySof group and 15 in the Tecnis group) with > -1.50 D preoperative corneal astigmatism, the mean percentage of refractive astigmatism reduction was $66.84 \pm 27.70\%$ in the AcrySof group and $76.63 \pm 39.12\%$ in the Tecnis group (data not shown).

CS. CS results under mesopic, photopic and mesopic glare at four spatial frequencies are presented in Table III. There was no statistically significant between-group difference in CS among the three illumination conditions at 3, 6, 12 or 18 cycles per degree.

Table II. Comparison of patient demographics and preoperative clinical data between the two groups.

Parameter	Acrysof group	Tecnis group	<i>t</i> (<i>u</i>)	P-value
Age, years ^b				
Mean ± SD	70.6±10.3	66.3±22.5	108.000	1.000
Range	48-85	21-90		
Sex, n (%) ^a				0.266
Female	13 (72)	6 (50)		
Male	5 (28)	6 (50)		
UDVA, LogMAR ^b				
Mean ± SD	0.68±0.25	0.63±0.27	-200.000	0.411
Range	0.30 to 1.20	0.40-1.40		
CDVA, LogMAR ^b				
Mean ± SD	0.36±0.21	0.28±0.17	193.500	0.329
Range	0.10-0.92	0-0.60		
Corneal astigmatism, D ^b				
Mean ± SD	2.01±0.44	2.27±1.35	230.500	0.933
Range	1.20-2.98	0.82-7.27		
IOL power, D				
Sphere ^c	19.63±6.05	21.14±3.53	-0.947	0.349
Cylinder, IOL plane ^b	2.72±0.69	3.13±0.71	167.500	0.095
Cylinder, corneal plane ^b	1.88±0.50	2.14±0.49	187.500	0.248

^aFisher's exact test; ^bMann-Whitney U test, Student's *t*-test. IOL, intraocular lens; D, diopters; UDVA, uncorrected distance visual acuity; CDVA, corrected distance visual acuity; LogMAR, logarithm of the minimum angle of resolution.

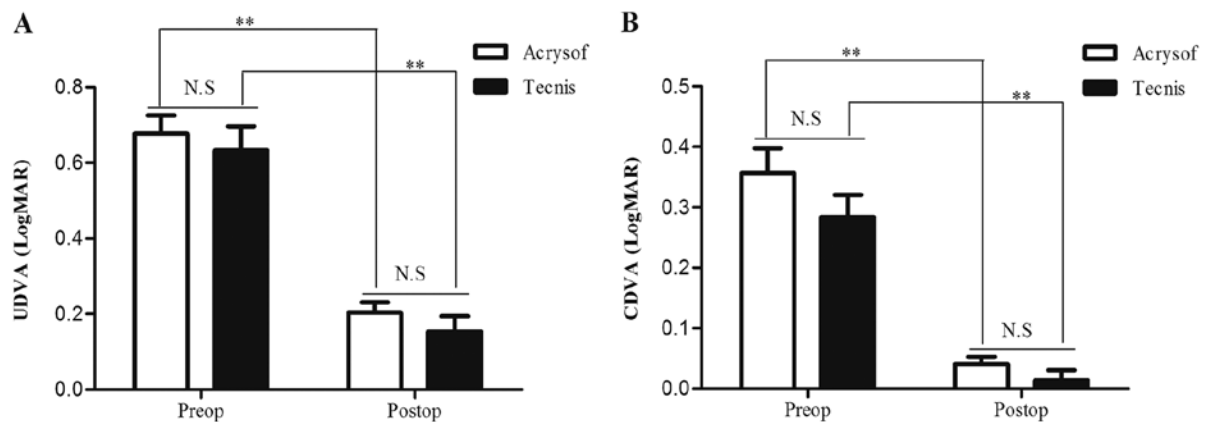


Figure 1. Comparison of preoperative and postoperative (A) UDVA and (B) CDVA between the two groups. Data were analyzed by mixed ANOVA and simple main effects with Bonferroni correction. ***P*<0.01, as indicated; NS, no significant difference. UDVA, uncorrected distance visual acuity; CDVA, corrected distance visual acuity; Preop, preoperative; Postop, postoperative.

Rotational stability. The current study evaluated the toric IOL alignment using the OPD Scan III workstation (Fig. 3). IOL rotation results are presented in Fig. 4. The overall mean deviation of intraocular lens from the target position was $0.22 \pm 5.78^\circ$ (range, -18.0 to 16.8°). The mean deviation of intraocular lens from the target position was $0.24 \pm 5.54^\circ$ (range, -7.7 to 16.8°) in the AcrySof group and $-0.19 \pm 6.28^\circ$ (range, -18.0 to 10°) in the Tecnis group (Fig. 5). There was no significant difference in IOL axis rotation between the two groups (*P*=0.416). The misalignment was within $\pm 5^\circ$ in 32 of 44 eyes (72.7%) and $\pm 10^\circ$ in 41 of 44 eyes (93.2%). However, significant rotation

with $>10^\circ$ was found in three eyes, among which two eyes received an AcrySof and one eye received a TECNIS toric IOL. One of the AcrySof IQ toric IOL misalignments was found to have rotated by 16.8° at 2 months after the operation, with a UDVA of 0.20 LogMAR, CDVA of 0.07 LogMAR and no residual refractive cylinder error. The other Acrysof IQ toric IOL misalignment was found to have rotated by 12.4° at 8 months after the operation, with a UDVA of 0.30 LogMAR, CDVA of 0.10 LogMAR and a residual refractive cylinder of -1.75 D. This eye had concomitant exotropia and had repeatedly undergone intravitreal drug injections for macular edema

Table III. Comparison of postoperative contrast sensitivity between the AcrySof and Tecnis groups.

Parameter	Mean contrast sensitivity \pm SD											
	Mesopic				Photopic				Mesopic glare			
	3	6	12	18	3	6	12	18	3	6	12	18
AcrySof group	1.61 \pm 0.30	1.67 \pm 0.18	1.41 \pm 0.46	0.87 \pm 0.43	1.66 \pm 0.26	1.74 \pm 0.25	1.31 \pm 0.25	0.82 \pm 0.39	1.54 \pm 0.28	1.65 \pm 0.39	1.15 \pm 0.36	0.76 \pm 0.37
Tecnis group	1.64 \pm 0.29	1.74 \pm 0.24	1.45 \pm 0.43	0.95 \pm 0.48	1.70 \pm 0.22	1.80 \pm 0.24	1.41 \pm 0.27	0.85 \pm 0.36	1.58 \pm 0.30	1.67 \pm 0.33	1.20 \pm 0.38	0.83 \pm 0.38
P-value	0.862 ^a	0.209 ^a	0.776 ^b	0.656 ^a	0.720 ^a	0.510 ^a	0.120 ^a	0.762 ^a	0.685 ^a	0.864 ^b	0.665 ^a	0.501 ^a

^aMann-Whitney U test; ^bStudent's t-test. SF, spatial frequency; cpd, cycles per degree.

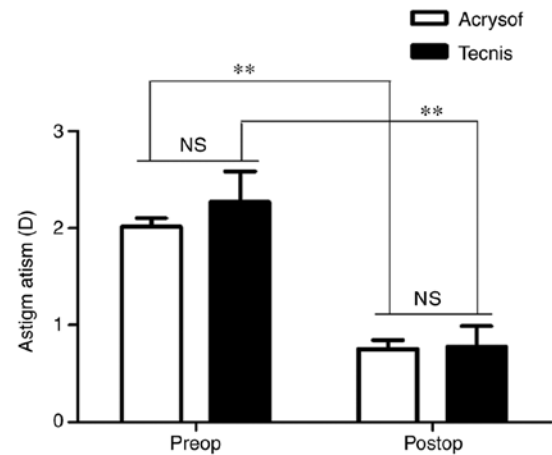


Figure 2. Comparison of preoperative corneal astigmatism and postoperative residual astigmatism between the two groups. Data were analyzed by mixed ANOVA and simple main effects with Bonferroni correction. **P<0.01, as indicated; N S, no significant difference. Preop, preoperative; Postop, postoperative; D, diopters.

resulting from diabetes prior to the operation. The TECNIS toric IOL misalignment was found to have rotated by -18.0° at 1 week after the operation, with a UDVA of 0.10 LogMAR, CDVA of 0.00 LogMAR and a residual refractive cylinder of -0.50 D. IOL repositioning was not performed for these three eyes because the patients expressed good satisfaction and refused reoperation.

Visual functioning questionnaire results. Approximately 66.7% of subjects in the AcrySof group and 100% of subjects in the Tecnis group reported a degree of spectacle independence for distance vision. No patients reported postoperative ghosting, halo, visual distortion, difficulty in color vision or depth perception in both groups. Only 2 patients (two eyes) reported slight glare and 4 patients (six eyes) reported slight difficulty in nighttime vision in the AcrySof group. Three patients (five eyes) reported slight glare in the Tecnis group. There were no differences between the two groups in the percentage of eyes without glare or slight difficulty in nighttime vision ($P=0.170$ and $P=0.081$, respectively). The mean patient satisfaction score was 8.46 ± 1.21 in the AcrySof group and 8.78 ± 1.44 in the Tecnis group ($P=0.260$). Questionnaire results are summarized in Table IV.

Discussion

The current study indicated that patients with low to high corneal astigmatism achieved comparable visual outcomes, refraction correction, CS, rotational stability and satisfaction after undergoing phacoemulsification with AcrySof and Tecnis toric IOL implantation. The current study presented data for the real-world refractive correction and rotational stability of toric IOLs in a tertiary hospital in northwest China.

Management of corneal astigmatism during cataract surgery is a routine consideration in modern clinical practice (20). Published overview data indicated that AcrySof toric IOL effectively reduced pre-existing corneal astigmatism, resulting in better UDVA and less spectacle dependence after surgery (21,22). Excellent clinical results were obtained in this

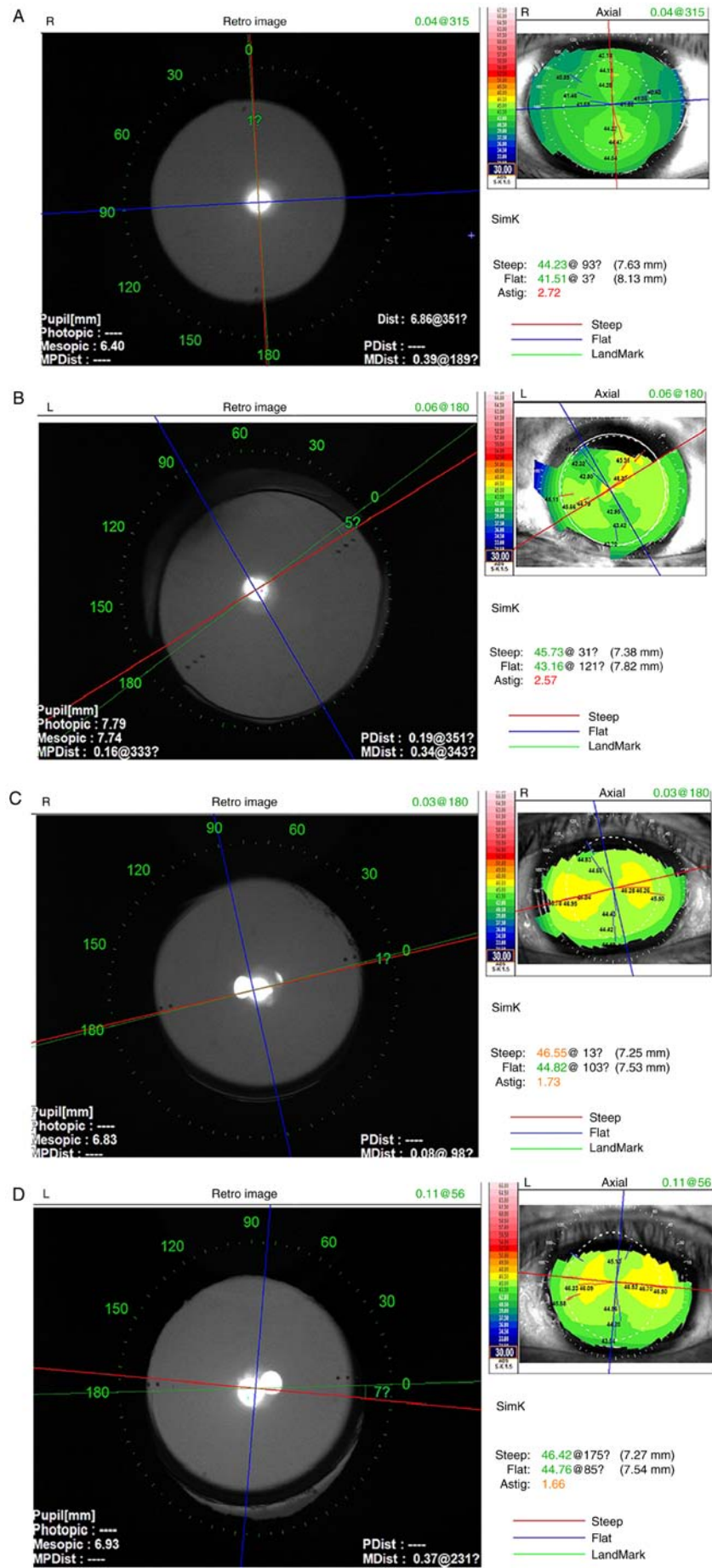


Figure 3. Postoperative toric IOL alignment from the target axis evaluated using the OPD Scan III workstation and 'Toric IOL Rotation Summary' software. (A) -1° misalignment. (B) -5° misalignment. (C) -1° misalignment. (D) -7° misalignment. Green axis, implantation axis; red axis, target axis.

Table IV. Comparison of the results of the postoperative subjective visual quality questionnaire between the two groups.

Result	AcrySof group	Tecnis group	P-value
No ghosting, %	100.00	100.00	
No glare, %	92.31	72.22	0.170 ^a
No difficulty in nighttime vision, %	76.92	100.00	0.081 ^a
No halo, %	100.00	100.00	
No visual distortion, %	100.00	100.00	
No difficulty in color vision, %	100.00	100.00	
No difficulty in depth vision, %	100.00	100.00	
Patient satisfaction score	8.46±1.21	8.78±1.44	0.260 ^b

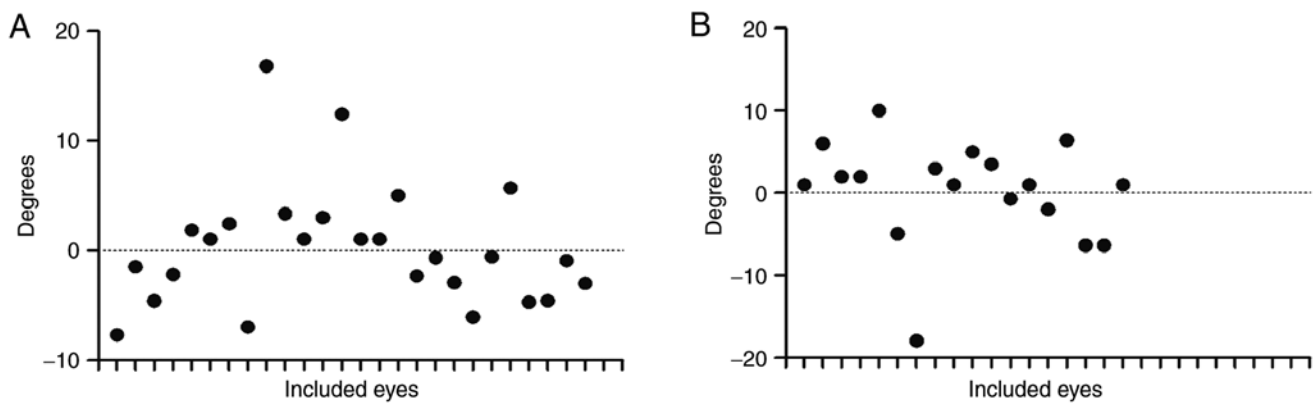
^aChi-square test; ^bMann-Whitney U test.

Figure 4. Deviation of intraocular lens from the target position in the (A) AcrySof group and (B) Tecnis group. The clockwise rotation was regarded as positive and the counterclockwise rotation was regarded as negative.

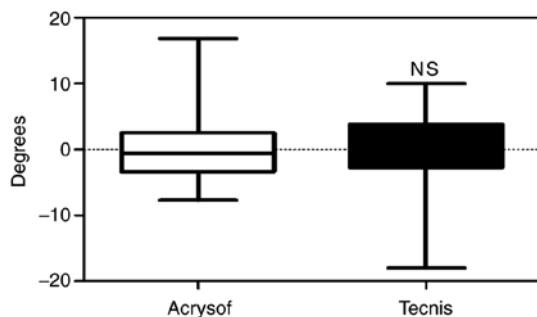


Figure 5. Comparison of intraocular lens rotation between the two groups. The clockwise rotation was regarded as positive and the counterclockwise rotation was regarded as negative. The data were analyzed by Mann-Whitney U test. NS, no significant difference.

cohort. No statistically significant between-group difference was noted in postoperative UDVA or CDVA. The majority of patients achieved highly significant UDVA and CDVA improvement. The current results are consistent with those previously reported for a number of toric IOLs, including Bi-Flex T, AcrySof, Rayner T-Flex[®] and TECNIS (1,4,9,18). There was no difference between the two groups in postoperative residual astigmatism. Patients achieved significant correction of corneal astigmatism in both groups and these results are consistent with a previous study on AcrySof Toric IOL (23,24). Waltz *et al* (19) found a

mean reduction in refractive astigmatism of 76.27±33.09% after the TECNIS toric IOL implantation at 6 months, which was comparable with the 76.63±39.12% in the Tecnis group reported in the current study.

CS represents a useful summary of functional vision and is a more sensitive index to predict performance impairment than standard acuity measurements (25). Ninomiya *et al* (26) found no difference in CS between different IOL cylinder power models of AcrySof IQ toric IOL. The current study included a comparative analysis with CS under three different illumination conditions and found no difference between the two IOL groups.

Postoperative rotational stability of toric IOL has a critical effect on the final visual outcome. Postoperative IOL rotation may be affected by several factors, such as the IOL material and diameter, design of IOL haptics, partial removal of viscoelastics from the eye or significant capsule shrinkage after surgery (27,28). In the present study, the deviation of intraocular lens rotation from the target position with an arithmetic mean postoperative misalignment was 0.24±5.54° in the AcrySof group and -0.19±6.28° in the Tecnis group. This result compared favorably with two published trials reporting on rotational stability of AcrySof toric IOL (mean values, -1.75±2.93° and 5.06±4.21°) (23,29). It can be hypothesized that a misalignment of <5° may be attributed to reference marking errors on the slit lamp, other than IOL rotation as

stated previously (30). In the current study, postoperative IOL rotation was comparable between the AcrySof and Tecnis groups. Overall, the rotational stability was consistent with good visual and refractive outcomes. Significant rotation of $>10^\circ$ was found in three eyes. In one eye, significant toric IOL rotation with -1.75 D residual cylinder appeared to have been associated with concomitant exotropia and repeated intravitreal drug injections. It has been previously reported that repeated intravitreal drug injections resulted in zonular weakness or damage, and lead to significant capsule shrinkage (31). In the other two eyes with significant toric IOL rotation, good visual acuity and low residual cylinder were achieved; therefore, preoperative measurement or calculation errors of target axis may have caused the rotation. The current study used toric IOL online calculators provided by the respective manufacturers for cylinder power and axis calculation. Nowadays, Barrett Universal II Formula was often used in studies (32,33).

The current study achieved good satisfaction scores in subjective visual quality evaluated using a questionnaire in both groups. Approximately 66.7% of subjects in the AcrySof group and 100% of subjects in the Tecnis group reported a degree of spectacle freedom for distance vision. No patient reported issues with subjective visual symptoms, such as ghosting, halo, visual distortion, difficulty in color vision and impaired depth perception. Only five eyes in the Tecnis group and two eyes in the AcrySof were affected by slight glare. Only 4 patients who received AcrySof IOLs reported slight difficulty with scotopia, which may have been caused by blue light filtration. Mainster (34) indicated that blue blocking could decrease scotopia, and conventional UV-only blocking IOLs provide higher scotopic sensitivity than blue blocking IOLs. There were no differences between the two groups in the percentage of eyes without glare or slight difficulty in night-time vision, and the patient satisfaction score was comparable in the two groups.

Finally, there were no adverse events related to the surgery or IOL during the postoperative follow-up period and secondary intervention to reposition the toric IOL was not required. Thus, all toric IOLs used in the current study were safe for patients with cataracts with corneal astigmatism. The current retrospective study had certain limitations. First, the number of cases was relatively small making it difficult to perform analyses with high statistical power. Second, the post-operative assessment period ranged from 1 month to 4 years, which may have resulted in bias. This was performed as it was intended that all clinical data was collected from patients who underwent cataract surgery with toric IOL implantation by the same one ophthalmic surgeon. Third, vector analysis of residual astigmatism to evaluate changes in refractive astigmatism was not performed in the current study; however, this will be the subject of future studies. In spite of these limitations, some conclusions may still be drawn based on careful consideration of the available data.

In conclusion, patients with cataracts with corneal astigmatism achieved comparable improvement in visual acuity, astigmatism correction, CS, rotational stability and satisfaction, following AcrySof and TECNIS toric IOL implantation in a tertiary hospital in northwest China. Both toric IOLs appear equally effective alternatives for patients with cataracts with corneal astigmatism.

Acknowledgements

Not applicable.

Funding

The present study was supported by the National Natural Science Foundation of China (grant no. 81740158), Young Talent Scholar Grant (grant no. 2016KJXX-12) and Clinical Research Grant from First Affiliated Hospital of Xi'an Jiaotong University (grant no. XJTU1AF-CRF-2016-014).

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

LQ and JML conceived and designed the study. JJY collected and analyzed the clinical data. YZQ analyzed the clinical data. JJY and JML wrote the paper. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Written informed consent was obtained from all patients before cataract surgery. The study protocol was approved by the Ethics Committee of the First Affiliated Hospital of Xi'an Jiaotong University (Xi'an, China). This study was conducted in accordance with the tenets of the Declaration of Helsinki.

Patient consent for publication

All patients provided written informed consent for the publication of any associated data and accompanying images.

Competing interests

The authors declare that they have no competing interests.

References

1. Bachernegg A, Rückl T, Strohmaier C, Jell G, Grabner G and Dexl AK: Vector analysis, rotational stability, and visual outcome after implantation of a new aspheric toric IOL. *J Refract Surg* 31: 513-520, 2015.
2. Mohammadi M, Naderan M, Pahlevani R and Jahanrad A: Prevalence of corneal astigmatism before cataract surgery. *Int Ophthalmol* 36: 807-817, 2016.
3. Hoffmann PC and Hutz WW: Analysis of biometry and prevalence data for corneal astigmatism in 23,239 eyes. *J Cataract Refract Surg* 36: 1479-1485, 2010.
4. Holland E, Lane S, Horn JD, Ernest P, Arleo R and Miller KM: The AcrySof Toric intraocular lens in subjects with cataracts and corneal astigmatism: A randomized, subject-masked, parallel-group, 1-year study. *Ophthalmology* 117: 2104-2111, 2010.
5. Horn JD: Status of toric intraocular lenses. *Curr Opin Ophthalmol* 18: 58-61, 2007.
6. Netto MV, Mohan RR, Ambrosio R Jr, Hutcheon AE, Zieske JD and Wilson SE: Wound healing in the cornea: A review of refractive surgery complications and new prospects for therapy. *Cornea* 24: 509-522, 2005.

7. Yang JJ, Liu QP, Li JM and Qin L: Comparison of visual outcomes with implantation of trifocal versus bifocal intraocular lens after phacoemulsification: A Meta-analysis. *Int J Ophthalmol* 11: 484-492, 2018.
8. Liu J, Zhao J, Ma L, Liu G, Wu D and Zhang J: Contrast sensitivity and spherical aberration in eyes implanted with AcrySof IQ and AcrySof Natural intraocular lens: The results of a meta-analysis. *PLoS One* 8: e77860, 2013.
9. Buscacio ES, Patrao LF and de Moraes HV Jr: Refractive and quality of vision outcomes with toric IOL implantation in low astigmatism. *J Ophthalmol* 2016: 5424713, 2016.
10. Kobashi H, Kamiya K, Igarashi A, Ishii R, Sato N, Wang G and Shimizu K: Comparison of corneal power, corneal astigmatism, and axis location in normal eyes obtained from an autokeratometer and a corneal topographer. *J Cataract Refract Surg* 38: 648-654, 2012.
11. Goggin M, Moore S and Esterman A: Outcome of toric intraocular lens implantation after adjusting for anterior chamber depth and intraocular lens sphere equivalent power effects. *Arch Ophthalmol* 129: 998-1003, 2011.
12. Koch DD, Ali SF, Weikert MP, Shirayama M, Jenkins R and Wang L: Contribution of posterior corneal astigmatism to total corneal astigmatism. *J Cataract Refract Surg* 38: 2080-2087, 2012.
13. Visser N, Bauer NJ and Nuijts RM: Residual astigmatism following toric intraocular lens implantation related to pupil size. *J Refract Surg* 28: 729-732, 2012.
14. Berdahl JP and Hardten DR: Residual astigmatism after toric intraocular lens implantation. *J Cataract Refract Surg* 38: 730-732, 2012.
15. Jin H, Limberger IJ, Ehmer A, Guo H and Auffarth GU: Impact of axis misalignment of toric intraocular lenses on refractive outcomes after cataract surgery. *J Cataract Refract Surg* 36: 2061-2072, 2010.
16. Chang DF: Comparative rotational stability of single-piece open-loop acrylic and plate-haptic silicone toric intraocular lenses. *J Cataract Refract Surg* 34: 1842-1847, 2008.
17. Kohnen T: Astigmatism measurements for cataract and refractive surgery. *J Cataract Refract Surg* 38: 2065, 2012.
18. Lubinski W, Kazmierczak B, Gronkowska-Serafin J and Podboraczynska-Jodko K: Clinical outcomes after uncomplicated cataract surgery with implantation of the TECNIS toric intraocular lens. *J Ophthalmol* 2016: 3257217, 2016.
19. Waltz KL, Featherstone K, Tsai L and Trentacost D: Clinical outcomes of TECNIS toric intraocular lens implantation after cataract removal in patients with corneal astigmatism. *Ophthalmology* 122: 39-47, 2015.
20. Aujla JS, Vincent SJ, White S and Panchapakesan J: Cataract surgery in eyes with low corneal astigmatism: Implantation of the AcrySof IQ Toric SN6AT2 intraocular lens. *J Ophthalmic Vis Res* 9: 324-328, 2014.
21. Visser N, Bauer NJ and Nuijts RM: Toric intraocular lenses: Historical overview, patient selection, IOL calculation, surgical techniques, clinical outcomes, and complications. *J Cataract Refract Surg* 39: 624-637, 2013.
22. Savini G, Hoffer KJ and Ducoli P: A new slant on toric intraocular lens power calculation. *J Refract Surg* 29: 348-354, 2013.
23. Alio JL, Pinero DP, Tomas J and Aleson A: Vector analysis of astigmatic changes after cataract surgery with toric intraocular lens implantation. *J Cataract Refract Surg* 37: 1038-1049, 2011.
24. Visser N, Berendschot TT, Bauer NJ and Nuijts RM: Vector analysis of corneal and refractive astigmatism changes following toric pseudophakic and toric phakic IOL implantation. *Invest Ophthalmol Vis Sci* 53: 1865-1873, 2012.
25. Plaza-Puche AB, Alio JL, Sala E and Mojzis P: Impact of low mesopic contrast sensitivity outcomes in different types of modern multifocal intraocular lenses. *Eur J Ophthalmol* 26: 612-617, 2016.
26. Ninomiya Y, Minami K, Miyata K, Eguchi S, Sato R, Okamoto F and Oshika T: Toric intraocular lenses in eyes with with-the-rule, against-the-rule, and oblique astigmatism: One-year results. *J Cataract Refract Surg* 42: 1431-1440, 2016.
27. Shah GD, Praveen MR, Vasavada AR, Vasavada VA, Rampal G and Shastri LR: Rotational stability of a toric intraocular lens: Influence of axial length and alignment in the capsular bag. *J Cataract Refract Surg* 38: 54-59, 2012.
28. Pereira FA, Milverton EJ and Coroneo MT: Miyake-Apple study of the rotational stability of the AcrySof Toric intraocular lens after experimental eye trauma. *Eye (Lond)* 24: 376-378, 2010.
29. Visser N, Berendschot TT, Bauer NJ, Jurich J, Kersting O and Nuijts RM: Accuracy of toric intraocular lens implantation in cataract and refractive surgery. *J Cataract Refract Surg* 37: 1394-1402, 2011.
30. Carvalho MJ, Suzuki SH, Freitas LL, Branco BC, Schor P and Lima AL: Limbal relaxing incisions to correct corneal astigmatism during phacoemulsification. *J Refract Surg* 23: 499-504, 2007.
31. Xue K, Jolly JK, Mall SP, Haldar S, Rosen PH and MacLaren RE: Real-world refractive outcomes of toric intraocular lens implantation in a United Kingdom National Health Service setting. *BMC Ophthalmol* 18: 30, 2018.
32. Moshirfar M, Buckner B, Ronquillo YC and Hofstedt D: Biometry in cataract surgery: A review of the current literature. *Curr Opin Ophthalmol* 30: 9-12, 2019.
33. Rong X, He W, Zhu Q, Qian D, Lu Y and Zhu X: Intraocular lens power calculation in eyes with extreme myopia: Comparison of Barrett Universal II, Haigis, and Olsen formulas. *J Cataract Refract Surg* 45: 732-737, 2019.
34. Mainster MA: Violet and blue light blocking intraocular lenses: Photoprotection versus photoreception. *Br J Ophthalmol* 90: 784-792, 2006.



This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0) License.