Chapter

Toric Intraocular Lenses

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Abstract

This chapter described a short history about the toric intraocular lenses (IOLs) and then discussed some interesting topics such as the measurement of (front and posterior) corneal astigmatism and surgically induced astigmatism; the manual marking techniques and image-guided systems and intraoperative aberrometry-based methods; the new toric lens calculation calculators and toric IOLs formulas; the post operation care of toric IOLs and re-rotation of misaligned toric IOLs; and some relevant issues on multifocal toric intraocular lens. Meanwhile, this chapter also discussed toric IOL in some special cases like keratoconus corneal ectatic disorders, post-refractive surgery and post-keratoplasty, etc.

Keywords: astigmatism, cataract, toric IOL

1. Introduction

Up to more than one-third of cataract patients have preoperative corneal astigmatism of more than 1.0 diopter (D) [1], while 26.2% have more than 1.5 D [2, 3], 8–14.9% have more than 2.0 [1, 3], and 2.6–7.4% have more than 3.0 D [1, 3]. Astigmatism is one of the most important factors that affect postoperative vision quality. More than 0.5 D of residual astigmatism can reduce visual performance and patient satisfaction [4–6]. Currently, implanting a toric lens is recognized as the most accurate form of astigmatic correction during cataract surgery, especially astigmatism of more than 1 D [7]. Actually, toric IOLs correct preexisting regular corneal astigmatism usually ranging from 0.75 to 4.75 D [8]. However, the outcomes after toric IOL implantation are still influenced by many factors including accurate preoperative measurement of corneal astigmatism, IOL selection, marking techniques, intraoperative alignment and postoperative care, etc.

2. A short history and clinical outcomes of toric IOLs

The first article reporting a toric IOL (Nidek NT -98B) was published in 1994 [9], which had a cylinder power of 2.00 or 3.00 D. In the study, Shimizu et al. had relatively positive results, although some negative results still occurred in some eyes of which the lens axis rotated more than 30° [9]. Ever since then, with the predictability increasing and the safety enhancing, toric IOLs have definitely become a considerable option to correct significant astigmatism when undergoing cataract surgery [10, 11]. At present, standard toric IOLs are available in cylinder powers of 1.0 to 6.0 D, while higher cylinder powers are also available (see **Table 1**).

Toric IOL had achieved increasingly great visual outcomes. An uncorrected distance visual acuity (UDVA) of 20/40 or better is achieved in more than 70% of

IOL	Material	Design	Aspheric	Spherical power (D)	Cylinder power (D) at IOL plane	Incision size (mm)
Acri. comfort (Carl Zeiss Meditec) [12]	Hydrophilic acrylic with hydrophobic surface	Plate haptic, 11.0-mm dialect	Y	−10.0 to +32.0	1.0–12.0 (0.50 steps)	<2.0
T-flex (Rayner) [13]	Hydrophilic acrylic	C-loop haptic with AVH technology, 12.0–12.5-mm dialect	Y	−10.0 to +35.0	1.0–11.0 (0.25 steps)	<2.0
AF-1 Toric (Hoya) [7]	Hydrophobic acrylic with PMMA haptic tips	PMMA-modified C-loop haptic, 12.5-mm dialect	Y	+6.0 to +30.0	1.5–6.0 (0.75 steps)	2.0
AcrySof (Alcon) [14–19]	Hydrophobic acrylic	C-loop haptic,13.0-mm dialect	Y	+6.0 to +34.0	1.0–6.0 (0.75 steps)	2.2
TECNIS Toric IOL (Abbott Medical Optics) [20]	Hydrophobic acrylic	"Tri-Fix" modified C haptic integral with optic, 13.0-mm dialect	Y	+5.0 to +34.0	1.5–6 (0.5–1.0 steps)	2.2
Precizon toric IOL (OPHTEC) [21, 22]	Hydrophilic acrylic	Biconvex transitional conic toric design offset-shaped haptic	Y	+1.0 to +34.0	1.0–10.0 (0.5 steps)	2.2
Morcher 89A, 92S (Morcher GmbH) [23, 24]	Hydrophilic acrylic	Bag-in-the-lens, 7.5-mm dialect	N	+10.0 to +30.0 D	0.5–8.0 (0.25 steps)	2.5
LENTIS Tplus (Oculentis) [7]	Hydrophilic acrylic with hydrophobic surface	C/Plate haptic, 12.0–11.0-mm dialect	Y	−10.0 to +35.0	0.25–12.0 (0.75–1.0 steps)	2.6
STAAR (STAAR Surgical Company) [25]	Silicone	Plate haptic, 10.8–11.2-mm dialect	N	+9.5 to +28.5	2.0 or 3.5	2.8
Light-adjustable lens (Calhoun Vision) [26]	Silicone with PMMA haptics	Modified C-loop PMMA haptics, 13.0-mm dialect	Y	+17.0 to +24.0	0.75–2.0	3.0
Microsil (HumanOptics) [27]	Silicone with PMMA haptics	C-loop haptic, 11.6-mm dialect	N	−10.0 to +35.0	1.0–15.0 (1.0 steps)	3.4

Table 1.
Summary of commercially available toric IOLs.

the cases, and spectacle independence has been reported in more than 60% of the patients in previous studies [12, 13, 15–23, 25–30], which is significantly increased compared with nontoric monofocal IOLs [31, 32]. A randomized controlled trial (RCT) compared the outcomes of AcrySof toric IOLs with conventional spherical IOLs and observed a UDVA of 20/40 or better in 92.2% of cases undergoing toric IOL implantation, with 63.4% having a UDVA of 20/25 or better. In contrast, only 81.4% of cases undergoing nontoric IOL implantation had a UDVA of 20/40 or

better and 41.4% had a UDVA of 20/25 or better [9]. Similar results were found in another high-quality RCT [29].

Compared with incisional astigmatic keratotomy, toric IOLs offered better predictability and stability of correction [17], especially in moderate to high astigmatism [30]. In a recent meta-analysis (including 13 RCTs with 707 eyes), toric IOLs provided better distance visual acuity and lower amounts of residual astigmatism, combined with greater spectacle independence, than nontoric IOLs even when relaxing incisions were used [33].

From a social cost-effectiveness perspective, toric IOLs were inferior to monofocal IOLs in a recent prospective study [34], which should be noted in healthcare decision-making.

3. The measurement of astigmatism

For a toric IOL, the keratometric astigmatism (both axis and magnitude) of the cornea must be accurately measured.

3.1 Anterior corneal curvature

Traditionally, keratometry and topography take into account only the anterior corneal curvature [35]. However, nomograms predict total corneal astigmatism based on the power and axis of the anterior corneal astigmatism, assuming a fixed ratio between the anterior and posterior curvature [36]. These methods obviously cannot take outliers and irregularities into account (e.g., post-refractive surgery eyes) [35], thus leading to significant postoperative and/or overcorrection. However, if the agreement of measurement of astigmatism between instruments of different kinds is poor (more than 10°), the selection of toric IOLs requires extra care.

3.2 Posterior corneal curvature

The astigmatism of posterior cornea is generally minus lens of against-the-rule. As mentioned above, ignoring effects of actual posterior corneal curvature may lead to inaccuracies in total astigmatism estimation in some eyes. In a recent study [36], for those eyes who received IOLs with 2 diopters of cylinder or less, a coefficient of adjustment of 0.75 for with-the-rule astigmatism and 1.41 for against-the-rule astigmatism can be applied to the corneal astigmatism power value to calculate a more appropriate IOL cylinder power than that be calculated by using unadjusted anterior corneal curvature measurements.

Since minimizing the residual refractive error is especially critical in toric multifocal IOLs [37], imaging systems that measure posterior corneal curvature, as well as the new algorithm that incorporates the effect of posterior corneal astigmatism, are increasingly being invented. For example, the Scheimpflug imaging systems, slit scanning systems, and OCT systems could measure posterior corneal curvature, besides the anterior curvature. In a comparative study [35] including a Scheimpflug tomography (OCULUS Pentacam), a Placido topographer (Tomey TMS-5 in Placido mode), a swept source/Fourier domain OCT (CASIA SS-1000), an autokeratometer (Haag-Streit Lenstar), and a hybrid topographer (Tomey TMS-5), the OCULUS Pentacam has the disadvantage of high measuring noise on posterior corneal curvature. Meanwhile, the highest precision for planning toric IOL power and axis was achieved by combining the keratometry and OCT data. In a recent study, Lu et al. found that a novel multicolored spot reflection topographer system

could provide high repeatable measurements in (both anterior and posterior) corneal power and astigmatism [38].

3.3 Surgically induced astigmatism

Besides naturally occurring astigmatism, the surgically induced astigmatism (SIA) is also an important factor for the appropriate option of a toric IOL. The SIA could be influenced by position and length of incisions [39]. Meanwhile, to achieve minimum residual refractive astigmatism for specific patients, the incisions could be determined by the magnitude and axis of preoperative keratometric astigmatism [4]. The application of femtosecond laser-assisted cataract surgery (FLACS) could minimize SIA.

4. IOL power calculation

An accurate biometry is a precondition not only for toric IOLs but also for regular IOL power calculation. The axial length may be measured by either ultrasonic biometry or optical systems, and SRK/T, Holladay 2, Hoffer Q, and Barrett formula are recommended to be used to calculate sphere power. Nguyen et al. adjusted the power of an existing hydrophobic acrylic IOL by a femtosecond laser [40], which is definitely a promising idea.

There are several toric calculators available for surgical planning that have been developed to predict postoperative cylinder power, such as Barrett toric calculator [41], Holladay toric calculator, and Alcon toric calculator(the revised Alcon toric calculator is a derivation of the Barrett calculator). In general, an ideal IOL power calculation formula should take into account the posterior corneal curvature, the effective lens position (ELP), as well as the SIA. And there are a few formulas available such as Abulafia-Koch linear regression formula [42], Baylor nomogram (a method from Koch) [43], Barrett formula, Abulafia-Koch formula, etc.

4.1 IOL power calculation considering posterior cornea

A few online toric IOL calculators have been revised to take into account the contribution of the posterior cornea in IOL power calculation, but it proved itself valuable. The Baylor nomogram which incorporates the posterior corneal curvature has been observed to be more precise than traditional Alcon and Holladay toric calculator without posterior corneal astigmatism compensation [44]. However, the revised AcrySof toric calculator incorporates the Barrett toric algorithm, which takes into account both the ELP and the posterior corneal astigmatism, and had better predictability than the Baylor nomogram as well as Holladay and traditional Alcon toric calculator [44]. Other toric IOL calculators such as TECNIS calculator also incorporate posterior corneal astigmatism compensation.

4.2 IOL power calculation considering ELP

Failing to consider the anterior chamber depth and cornea thickness may result in inaccurate calculations, especially in eyes with extremes of axial lengths [45]. As mentioned above, the revised AcrySof online toric calculator and iTrace toric planner takes into account the ELP [14, 46]. The TECNIS calculator incorporates the anterior chamber depth based on the axial length and keratometry values [46], and the Holladay formula incorporates the ELP in its calculations.

4.3 Intraoperative wavefront aberrometry

Intraoperative wavefront aberrometry is increasingly being used to estimate the toric IOL power and axis of placement based on the aphakic refraction, especially in post-refractive surgery cases. A recent study reported only a mean error of 0.43 ± 0.33 D with Optiwave Refractive Analysis (ORA; WaveTec Vision Systems Inc., CA, USA) in post laser-assisted in situ keratomileusis (LASIK) cases undergoing toric IOL implantation, which were more accurate than those obtained by the standard SRK/T formula and the online ASCRS calculator.

5. Surgery techniques

Many issues, such as accurate marking technique, clear corneal incisions, intraoperative alignment of the toric IOL, capsulorhexis, and IOL centration, play a significant role in achieving optimal outcomes.

5.1 Marking techniques

Preoperative reference and axis marking techniques could be broadly categorized as manual methods, image-guided systems, and intraoperative aberrometry-based methods.

The three-step manual technique is at present most commonly used [47], which is fairly accurate [48]. The first step is preoperative marking of the reference axis, which is commonly placed in the horizontal 3'o and 9'o clock positions. The second step is intraoperative alignment of the reference mark. The marking may be performed with a skin marking pen or needle. The patient should be sitting erect in a straight-ahead gaze while marking the reference axis. A change in patient position from sitting to supine may induce significant cyclotorsion; studies reported up to 28° of cyclotorsion in 68% of cases [49]. The manual marking methods have been limited by smudging of the dye, irregular, and broad marks.

Image-guided systems and intraoperative aberrometry have advantages compared with manual marking. The image-guided system based on the concept of landmarks to place the axis marks [50], which could be iris crypts, nevi, brush fields, etc. The systems capture a preoperative reference image and calculated the location of these marks and their distance in degrees from the target IOL axis. Then the system generated a final plan which provides simple angular directions from each reference mark to the planned axis of IOL placement.

There are a few image-guided systems at present such as CALLISTO Eye and Z Align (Carl Zeiss Meditec, Jena, Germany), VERION (Alcon, Fort Worth, Texas), TrueGuide (TrueVision 3D Surgical System, Santa Barbara, Calif), Osher Toric Alignment System (OTAS, Haag-Streit, Koeniz, Switzerland), and iTrace System (Tracey Technologies, Houston, Tx). Besides alignment, image-guided systems also contribute to planning the incisions, capsulorhexis size, and optimal IOL centration.

5.2 Intraoperative toric IOL alignment

Intraoperative IOL positioning is the key procedure to sustain rotation stability. During IOL alignment, the IOL should be left about 3–5° anticlockwise of the final desired lens position, followed by complete OVD removal and hydration of the wounds. Most open-loop IOLs can be rotated only clockwise, and a complete re-rotation will be needed if the IOL rotates further clockwise of the target axis.

The image-guided systems and intraoperative aberrometry could be definitely more useful than manual alignment. As mentioned above, the image-guided systems capture a preoperative reference image and an intraoperative image and then match the two images with respect to each other using landmarks. During the operation, a graphic overlay is then superimposed on the surgical field along the target axis, which provides a guide for toric IOL alignment. The image-guided systems and intraoperative aberrometry have improved the precision of toric IOL alignment, with <5° of deviation from the intended axis in the majority of cases.

Compared with manual marking, Elhofi et al. had observed more precise alignment with VERION image-guided system [51], which offers comprehensive astigmatism management, the incision location optimization, toric IOL power calculation, as well as decreasing SIA.

However, Solomon et al. claimed that, compared with the surgeon's standard of care, the use of the VERION combined with intraoperative aberrometry (Optiwave Refractive Analysis system with VerifEye) did not significantly optimize the outcomes [52]. The accuracy of CALLISTO Eye is also very effective [53], and it also assists in planning the position of limbal relaxing incisions.

6. Complications

Postoperative toric IOL misalignment is the major complication after toric IOL implantation. Toric IOL misalignment could harm visual quality. In a recent experimental study, 5° IOL axis rotation from the intended position determined a decay in the image quality of 7.03%, 10° of IOL rotation caused 11.09% decay, and 30° rotation caused 45.85% decay [54].

Toric IOL misalignment may be attributed to three factors: (1) inaccurate preoperative prediction of the axis of IOL alignment; (2) inaccurate intraoperative alignment; and (3) postoperative IOL rotation. IOL rotation may be observed as early as 1 hour after surgery, and a majority of rotations occur within the initial 10 days [18]. Early IOL rotation likely results from incomplete OVD removal, whereas late postoperative rotation is influenced by the IOL architecture, design, and axial length. In a recently published case report, the toric IOL was rotated more than 115° shortly after a neodymium: YAG (Nd:YAG) laser posterior capsulotomy [55].

Rotational stability of the IOL varies with design and material and strength of IOL capsular bag adhesions. Maximum rotational stability has been observed with hydrophobic acrylic lenses, followed by Hydrophobic acrylic, hydrophilic acrylic, PMMA and silicone. Loop haptic IOLs are better than plate-haptic IOLs on postoperative rotation stability when using silicone IOL, but they are similar when using acrylic IOL. A study of AT TORBI 709 M, which had one-piece hydrophilic acrylic with hydrophobic surface and a supporting four-haptic design, had rotation of more than 5° in 10% cases in 6 months [56]. Another study of AT TORBI 709 M reported 13% eyes had rotation of more than 10° [57], while another study reported 100% rotation of more than 10° [58]. Scialdone et al. found similar results in rotation stability between AT TORBI 709 M and AcrySof toric IOLs [59]. A long-term of 2-year study of AcrySof toric IOLs (hydrophobic acrylic IOL with Flexible loop haptic) reported postoperative rotation of more than 10° in 1.68% eyes, more than 5° in 23.3% eyes [18]. A recent cohort study [60] of 1273 eyes showed that AcrySof toric IOL was less likely to rotate, with 91.9% of eyes rotated 5° in AcrySof toric IOL eyes compared with 81.8% in TECNIS Toric IOL eyes ($P < 0.0001$); rotation 10° (97.8% Acrysof vs. 93.2% TECNIS, $P = 0.0002$) and 15° (98.6% Acrysof vs. 96.4% TECNIS, $P = 0.02$). Furthermore, a hydrophilic IOL with C-flex design

(Rayner 600S IOL) was reported to have excellent rotational stability: average 1.83° ± 1.44° at 6 months and no lens rotated more than 5° [61].

In cases with more than 10° of rotation, realignment of the toric IOL is needed [62]. In a study by Oshika et al., 6431 eyes are implanted with toric IOLs, and realignment was performed in 0.653% of cases [63]. An early repositioning performed after 1 week of primary cataract surgery had optical outcomes.

IOL tilt could also induce astigmatism: tilting toric IOLs aligned at 180° would decrease with-the-rule astigmatism, bringing in undercorrection, while aligned at 90° increased against-the-rule astigmatism, bringing in overcorrection [64].

Meanwhile, LASIK, customized surface ablation, or femtosecond laser-assisted intrastromal keratotomies could also be used to correct residual astigmatism [65]. Some toric rotation check, such as https://www.astigmatismfix.com/, could help determine the amount of IOL rotation, and the expected residual refraction. When the large residual cylinder not amenable to correction by rotation alone or refractive surgery, an IOL exchange, piggyback IOLs procedures may be considered.

7. Multifocal toric IOLs

Toric designs are even more required in multifocal IOLs [66] because patients undergoing multifocal IOLs may not tolerate residual astigmatism of <1 D, and multifocal IOLs without toric design perform best with less than 0.75 D of cylinder [67].

In previous studies [68–72], toric multifocal IOLs achieved good visual performance, with UDVA better than 20/40 in more than 97% of patients, uncorrected near visual acuity better than 20/40 in 100% of patients, spectacle independence in more than 80% of patients, and residual refractive astigmatism lower than 0.50 D in 38–79% of patients. Toric trifocal IOLs such as a trifocal spherical hydrophilic IOL (FineVision POD F) [73] also showed great performance.

But on the other hand, the selection of multifocal toric IOLs should be more restricted than monofocal toric IOLs, especially for the following candidates: (1) patients who had unrealistic expectations of visual quality when having related ocular comorbidities; (2) patients who may not tolerate dysphoric symptoms such as glare and halos; and (3) patients who had specific contraindications for multifocal IOLs, such as abnormal κ or α angle, etc. Thus, a comprehensive ocular examination should be undertaken to rule out any ocular comorbidities that may interfere with the postoperative outcomes.

8. Special cases

Normally, cases with irregular astigmatism, corneal ectatic disorders, post-refractive surgery, post-keratoplasty, and high myopia are not ideal candidates for toric IOL implantation, partly because they are unlikely to achieve complete refractive correction with toric IOLs. However, the amount of astigmatism may be partly reduced, decreasing spectacle dependence. And such cases may be considered for surgery after adequate counseling. As a consequence, the applications of toric IOLs are expanding to include special cases such as pellucid marginal degeneration [74, 75], mild keratoconus with cataract [76], astigmatism after keratoplasty [77–80], and high astigmatism [81]; even toric trifocal IOLs were used in high astigmatism cases [82]. In general, the indications of toric IOL are still controversial and expanding.

9. Conclusions

The outcomes after toric IOL implantation are influenced by a few factors: accurate astigmatism measurement, marking techniques, intraoperative alignment, and postoperative care. The importance of posterior corneal curvature is increasingly being recognized, and advanced toric calculators and fumulars that account for both the anterior and posterior corneal power are becoming the standard of care. The image-guided systems and intraoperative aberrometry could provide a markless IOL alignment and optimize incisions, capsulorhexis size, and optimal IOL centration. New toric IOLs with superior design are still being looked forward although they have already achieved great performance.

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Conflict of interest

The authors have declared that no competing interests exist.

Other declarations

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

Abbreviations

D	diopter
IOL	intraocular lens
RCT	randomized control trial
UDVA	uncorrected distance visual acuity
SIA	surgically induced astigmatism
FLACS	femtosecond laser-assisted cataract surgery
ELP	effective lens position
LASIK	laser-assisted in situ keratomileusis
ORA	Optiwave Refractive Analysis
UNVA	uncorrected near visual acuity

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References

[1] Hoffmann PC, Hutz WW. Analysis of biometry and prevalence data for corneal astigmatism in 23,239 eyes. Journal of Cataract and Refractive Surgery. 2010;**36**(9):1479-1485. DOI: 10.1016/j.jcrs.2010.02.025

[2] Olson RJ, Braga-Mele R, Chen SH, Miller KM, Pineda R, et al. Cataract in the adult eye preferred practice pattern ((R)). Ophthalmology. 2017;**124**(2):P1-P119. DOI: 10.1016/j.ophtha.2016.09.027

[3] Mohammadi M, Naderan M, Pahlevani R, Jahanrad A. Prevalence of corneal astigmatism before cataract surgery. International Ophthalmology. 2016;**36**(6):807-817. DOI: 10.1007/s10792-016-0201-z

[4] Holladay JT, Pettit G. Improving toric intraocular lens calculations using total surgically induced astigmatism for a 2.5 mm temporal incision. Journal of Cataract and Refractive Surgery. 2019;**45**(3):272-283. DOI: 10.1016/j.jcrs.2018.09.028

[5] Villegas EA, González C, Bourdoncle B, Bonnin T, Artal P. Correlation between optical and psychophysical parameters as a function of defocus. Optometry and Vision Science. 2002;**79**(1):60-67

[6] Villegas EA, Alcón E, Artal P. Minimum amount of astigmatism that should be corrected. Journal of Cataract and Refractive Surgery. 2014;**40**(1):13-19

[7] Kaur M, Shaikh F, Falera R, Titiyal JS. Optimizing outcomes with toric intraocular lenses. Indian Journal of Ophthalmology. 2017;**65**(12):1301-1313. DOI: 10.4103/ijo.IJO_810_17

[8] Khan MI, Ch'ng SW, Muhtaseb M. The use of toric intraocular lens to correct astigmatism at the time of cataract surgery. Oman Journal of Ophthalmology. 2015;**8**(1):38

[9] Shimizu K, Misawa A, Suzuki Y. Toric intraocular lenses: Correcting astigmatism while controlling axis shift. Journal of Cataract and Refractive Surgery. 1994;**20**(5):523-526

[10] Visser N, Bauer NJ, Nuijts RM. Toric Intraocular Lenses in Cataract Surgery. London: Intech Open Access Publisher; 2012:268-292

[11] Agresta B, Knorz MC, Donatti C, Jackson D. Visual acuity improvements after implantation of toric intraocular lenses in cataract patients with astigmatism: A systematic review. BMC Ophthalmology. 2012;**12**(1):41

[12] Alio JL, Agdeppa MC, Pongo VC, El Kady B. Microincision cataract surgery with toric intraocular lens implantation for correcting moderate and high astigmatism: Pilot study. Journal of Cataract and Refractive Surgery. 2010;**36**(1):44-52. DOI: 10.1016/j.jcrs.2009.07.043

[13] Entabi M, Harman F, Lee N, Bloom PA. Injectable 1-piece hydrophilic acrylic toric intraocular lens for cataract surgery: Efficacy and stability. Journal of Cataract and Refractive Surgery. 2011;**37**(2):235-240. DOI: 10.1016/j.jcrs.2010.08.040

[14] Savini G, Hoffer KJ, Ducoli P. A new slant on toric intraocular lens power calculation. Journal of Refractive Surgery. 2013;**29**(5):348-354. DOI: 10.3928/1081597X-20130415-06

[15] Kim MH, Chung TY, Chung ES. Long-term efficacy and rotational stability of AcrySof toric intraocular lens implantation in cataract surgery. Korean Journal of Ophthalmology. 2010;**24**(4):207-212. DOI: 10.3341/kjo.2010.24.4.207

[16] Koshy JJ, Nishi Y, Hirnschall N, Crnej A, Gangwani V, et al. Rotational stability of a single-piece toric acrylic intraocular lens. Journal of Cataract and

Refractive Surgery. 2010;**36**(10): 1665-1670. DOI: 10.1016/j.jcrs.2010.05.018

[17] Titiyal JS, Agarwal T, Jhanji V. Toric intraocular lens versus opposite clear corneal incisions to correct astigmatism in eyes having cataract surgery. Journal of Cataract and Refractive Surgery. 2009;**35**(10):1834-1835. DOI: 10.1016/j.jcrs.2009.05.037

[18] Miyake T, Kamiya K, Amano R, Iida Y, Tsunehiro S, et al. Long-term clinical outcomes of toric intraocular lens implantation in cataract cases with preexisting astigmatism. Journal of Cataract and Refractive Surgery. 2014; **40**(10):1654-1660. DOI: 10.1016/j.jcrs.2014.01.044

[19] Mendicute J, Irigoyen C, Aramberri J, Ondarra A, Montes-Mico R. Foldable toric intraocular lens for astigmatism correction in cataract patients. Journal of Cataract and Refractive Surgery. 2008; **34**(4):601-607. DOI: 10.1016/j.jcrs.2007.11.033

[20] Lubinski W, Kazmierczak B, Gronkowska-Serafin J, Podboraczynska-Jodko K. Clinical outcomes after uncomplicated cataract surgery with implantation of the tecnis toric intraocular lens. Journal of Ophthalmology. 2016;**2016**:3257217. DOI: 10.1155/2016/3257217

[21] Thomas BC, Khoramnia R, Auffarth GU, Holzer MP. Clinical outcomes after implantation of a toric intraocular lens with a transitional conic toric surface. The British Journal of Ophthalmology. 2018;**102**(3): 313-316. DOI: 10.1136/bjophthalmol-2017-310386

[22] Ferreira TB, Berendschot TT, Ribeiro FJ. Clinical outcomes after cataract surgery with a new transitional toric intraocular lens. Journal of Refractive Surgery. 2016;**32**(7):452-459. DOI: 10.3928/1081597X-20160428-07

[23] Rozema JJ, Gobin L, Verbruggen K, Tassignon MJ. Changes in rotation after implantation of a bag-in-the-lens intraocular lens. Journal of Cataract and Refractive Surgery. 2009;**35**(8):1385-1388. DOI: 10.1016/j.jcrs.2009.03.037

[24] Tassignon MJ, Gobin L, Mathysen D, Van Looveren J. Clinical results after spherotoric intraocular lens implantation using the bag-in-the-lens technique. Journal of Cataract and Refractive Surgery. 2011;**37**(5):830-834. DOI: 10.1016/j.jcrs.2010.12.042

[25] Ruhswurm I, Scholz U, Zehetmayer M, Hanselmayer G, Vass C, et al. Astigmatism correction with a foldable toric intraocular lens in cataract patients. Journal of Cataract and Refractive Surgery. 2000;**26**(7):1022-1027

[26] Chayet A, Sandstedt C, Chang S, Rhee P, Tsuchiyama B, et al. Use of the light-adjustable lens to correct astigmatism after cataract surgery. The British Journal of Ophthalmology. 2010; **94**(6):690-692. DOI: 10.1136/bjo.2009.164616

[27] De Silva DJ, Ramkissoon YD, Bloom PA. Evaluation of a toric intraocular lens with a Z-haptic. Journal of Cataract and Refractive Surgery. 2006;**32**(9):1492-1498. DOI: 10.1016/j.jcrs.2006.04.022

[28] Vale C, Menezes C, Firmino-Machado J, Rodrigues P, Lume M, et al. Astigmatism management in cataract surgery with precizon® toric intraocular lens: A prospective study. Clinical Ophthalmology. 2016;**10**: 151-159. DOI: 10.2147/OPTH.S91298

[29] Holland E, Lane S, Horn JD, Ernest P, Arleo R, et al. The AcrySof Toric intraocular lens in subjects with cataracts and corneal astigmatism: A randomized, subject-masked, parallel-group, 1-year study. Ophthalmology. 2010;**117**(11):2104-2111. DOI: 10.1016/j.ophtha.2010.07.033

[30] Roberts TV, Sharwood P, Hodge C, Roberts K, Sutton G. Comparison of Toric intraocular lenses and Arcuate corneal relaxing incisions to correct moderate to high astigmatism in cataract surgery. The Asia-Pacific Journal of Ophthalmology. 2014;**3**(1):9-16. DOI: 10.1097/APO.0b013e3182a0af21

[31] Lane SS, Ernest P, Miller KM, Hileman KS, Harris B, et al. Comparison of clinical and patient-reported outcomes with bilateral AcrySof toric or spherical control intraocular lenses. Journal of Refractive Surgery. 2009; **25**(10):899-901

[32] Ruiz-Mesa R, Carrasco-Sanchez D, Diaz-Alvarez SB, Ruiz-Mateos MA, Ferrer-Blasco T, et al. Refractive lens exchange with foldable toric intraocular lens. American Journal of Ophthalmology. 2009;**147**(6):990-996. DOI: 10.1016/j.ajo.2009.01.004

[33] Kessel L, Andresen J, Tendal B, Erngaard D, Flesner P, et al. Toric intraocular lenses in the correction of astigmatism during cataract surgery: A systematic review and meta-analysis. Ophthalmology. 2016;**123**(2):275-286. DOI: 10.1016/j.ophtha.2015.10.002

[34] Simons RWP, Visser N, van den Biggelaar F, Nuijts R, Webers CAB, et al. Trial-based cost-effectiveness analysis of toric versus monofocal intraocular lenses in cataract patients with bilateral corneal astigmatism in the Netherlands. Journal of Cataract and Refractive Surgery. 2019;**45**(2):146-152. DOI: 10.1016/j.jcrs.2018.09.019

[35] Fabian E, Wehner W. Prediction accuracy of total keratometry compared to standard keratometry using different intraocular lens power formulas. Journal of Refractive Surgery. 2019;**35**(6): 362-368. DOI: 10.3928/1081597X-20190422-02

[36] Goggin M, Zamora-Alejo K, Esterman A, van Zyl L. Adjustment of anterior corneal astigmatism values to incorporate the likely effect of posterior corneal curvature for toric intraocular lens calculation. Journal of Refractive Surgery. 2015;**31**(2):98-102. DOI: 10.3928/1081597X-20150122-04

[37] Canovas C, Alarcon A, Rosen R, Kasthurirangan S, Ma JJK, et al. New algorithm for toric intraocular lens power calculation considering the posterior corneal astigmatism. Journal of Cataract and Refractive Surgery. 2018;**44**(2):168-174. DOI: 10.1016/j.jcrs.2017.11.008

[38] Lu W, Miao Y, Li Y, Hu X, Hu Q, et al. Comparison of multicolored spot reflection topographer and Scheimpflug-Placido system in corneal power and astigmatism measurements with Normal and post-refractive patients. Journal of Refractive Surgery. 2019;**35**(6):370-376. DOI: 10.3928/1081597X-20190510-01

[39] Hayashi K, Yoshida M, Hirata A, Yoshimura K. Changes in shape and astigmatism of total, anterior, and posterior cornea after long versus short clear corneal incision cataract surgery. Journal of Cataract and Refractive Surgery. 2018;**44**(1):39-49. DOI: 10.1016/j.jcrs.2017.10.037

[40] Nguyen J, Werner L, Ludlow J, Aliancy J, Ha L, et al. Intraocular lens power adjustment by a femtosecond laser: In vitro evaluation of power change, modulation transfer function, light transmission, and light scattering in a blue light-filtering lens. Journal of Cataract and Refractive Surgery. 2018; **44**(2):226-230. DOI: 10.1016/j.jcrs.2017.09.036

[41] Gundersen KG, Potvin R. Clinical outcomes with toric intraocular lenses planned using an optical low coherence reflectometry ocular biometer with a new toric calculator. Clinical Ophthalmology. 2016;**10**:2141-2147. DOI: 10.2147/opth.s120414

[42] Abulafia A, Koch DD, Wang L, Hill WE, Assia EI, et al. New regression formula for toric intraocular lens calculations. Journal of Cataract and Refractive Surgery. 2016;**42**(5):663-671. DOI: 10.1016/j.jcrs.2016.02.038

[43] Koch DD, Jenkins RB, Weikert MP, Yeu E, Wang L. Correcting astigmatism with toric intraocular lenses: Effect of posterior corneal astigmatism. Journal of Cataract and Refractive Surgery. 2013;**39**(12):1803-1809. DOI: 10.1016/j.jcrs.2013.06.027

[44] Abulafia A, Barrett GD, Kleinmann G, Ofir S, Levy A, et al. Prediction of refractive outcomes with toric intraocular lens implantation. Journal of Cataract and Refractive Surgery. 2015;**41**(5):936-944

[45] Savini G, Hoffer KJ, Carbonelli M, Ducoli P, Barboni P. Influence of axial length and corneal power on the astigmatic power of toric intraocular lenses. Journal of Cataract and Refractive Surgery. 2013;**39**(12): 1900-1903

[46] Park HJ, Lee H, Woo YJ, Kim EK, Seo KY, et al. Comparison of the astigmatic power of toric intraocular lenses using three Toric calculators. Yonsei Medical Journal. 2015;**56**(4): 1097-1105. DOI: 10.3349/ymj.2015.56.4.1097

[47] Ventura BV, Wang L, Weikert MP, Robinson SB, Koch DD. Surgical management of astigmatism with toric intraocular lenses. Arquivos Brasileiros de Oftalmologia. 2014;**77**(2): 125-131

[48] Visser N, Berendschot TT, Bauer NJ, Jurich J, Kersting O, et al. Accuracy of toric intraocular lens implantation in cataract and refractive surgery. Journal of Cataract and Refractive Surgery. 2011;**37**(8): 1394-1402. DOI: 10.1016/j.jcrs.2011.02.024

[49] Ciccio AE, Durrie DS, Stahl JE, Schwendeman F. Ocular cyclotorsion during customized laser ablation. Journal of Refractive Surgery. 2005; **21**(6):S772-S774

[50] Osher RH. Iris fingerprinting: New method for improving accuracy in toric lens orientation. Journal of Cataract & Refractive Surgery. 2010; **36**(2):351-352

[51] Elhofi AH, Helaly HA. Comparison between digital and manual marking for Toric intraocular lenses: A randomized trial. Medicine. 2015;**94**(38):e1618. DOI: 10.1097/md.0000000000001618

[52] Solomon KD, Sandoval HP, Potvin R. Correcting astigmatism at the time of cataract surgery: Toric IOLs and corneal relaxing incisions planned with an image-guidance system and intraoperative aberrometer versus manual planning and surgery. Journal of Cataract and Refractive Surgery. 2019;**45**(5):569-575. DOI: 10.1016/j.jcrs.2018.12.002

[53] Mayer WJ, Kreutzer T, Dirisamer M, Kern C, Kortuem K, et al. Comparison of visual outcomes, alignment accuracy, and surgical time between 2 methods of corneal marking for toric intraocular lens implantation. Journal of Cataract and Refractive Surgery. 2017;**43**(10):1281-1286. DOI: 10.1016/j.jcrs.2017.07.030

[54] Tognetto D, Perrotta AA, Bauci F, Rinaldi S, Antonuccio M, et al. Quality of images with toric intraocular lenses. Journal of Cataract & Refractive Surgery. 2018;**44**(3):376-381. DOI: 10.1016/j.jcrs.2017.10.053

[55] Kaindlstorfer C, Kneifl M, Reinelt P, Schonherr U. Rotation of a toric intraocular lens from neodymium: YAG laser posterior capsulotomy. Journal of Cataract and Refractive Surgery. 2018; **44**(4):510-511. DOI: 10.1016/j.jcrs.2018.02.018

[56] Mencucci R, Favuzza E, Guerra F, Giacomelli G, Menchini U. Clinical outcomes and rotational stability of a 4-haptic toric intraocular lens in myopic eyes. Journal of Cataract and Refractive Surgery. 2014;**40**(9):1479-1487. DOI: 10.1016/j.jcrs.2013.12.024

[57] Bascaran L, Mendicute J, Macias-Murelaga B, Arbelaitz N, Martinez-Soroa I. Efficacy and stability of AT TORBI 709 M toric IOL. Journal of Refractive Surgery. 2013; **29**(3):194-199. DOI: 10.3928/1081597x-20130129-02

[58] Kretz FT, Breyer D, Klabe K, Auffarth GU, Kaymak H. Clinical outcomes and capsular bag stability of a four-point haptic bitoric intraocular lens. Journal of Refractive Surgery. 2015;**31**(7):431-436. DOI: 10.3928/1081597x-20150518-11

[59] Scialdone A, De Gaetano F, Monaco G. Visual performance of 2 aspheric toric intraocular lenses: Comparative study. Journal of Cataract and Refractive Surgery. 2013;**39**(6): 906-914. DOI: 10.1016/j.jcrs.2013.01.037

[60] Lee BS, Chang DF. Comparison of the rotational stability of two Toric intraocular lenses in 1273 consecutive eyes. Ophthalmology. 2018;**125**(9): 1325-1331. DOI: 10.1016/j.ophtha.2018.02.012

[61] Bhogal-Bhamra GK, Sheppard AL, Kolli S, Wolffsohn JS. Rotational stability and centration of a new toric lens design platform using objective image analysis over 6 months. Journal of Refractive Surgery. 2019;**35**(1):48-53. DOI: 10.3928/1081597X-20181204-01

[62] Felipe A, Artigas JM, Diez-Ajenjo A, Garcia-Domene C, Alcocer P. Residual astigmatism produced by toric intraocular lens rotation. Journal of Cataract and Refractive Surgery. 2011; **37**(10):1895-1901. DOI: 10.1016/j.jcrs.2011.04.036

[63] Oshika T, Inamura M, Inoue Y, Ohashi T, Sugita T, et al. Incidence and outcomes of repositioning surgery to correct misalignment of Toric intraocular lenses. Ophthalmology. 2017;**125**(1): 31-35. DOI: 10.1016/j.ophtha.2017.07.004

[64] Weikert MP, Golla A, Wang L. Astigmatism induced by intraocular lens tilt evaluated via ray tracing. Journal of Cataract & Refractive Surgery. 2018; **44**(6):745-749. DOI: 10.1016/j.jcrs.2018.04.035

[65] Ruckl T, Dexl AK, Bachernegg A, Reischl V, Riha W, et al. Femtosecond laser-assisted intrastromal arcuate keratotomy to reduce corneal astigmatism. Journal of Cataract and Refractive Surgery. 2013;**39**(4):528-538. DOI: 10.1016/j.jcrs.2012.10.043

[66] Waltz KL, Featherstone K, Tsai L, Trentacost D. Clinical outcomes of TECNIS toric intraocular lens implantation after cataract removal in patients with corneal astigmatism. Ophthalmology. 2015;**122**(1):39-47. DOI: 10.1016/j.ophtha.2014.06.027

[67] Braga-Mele R, Chang D, Dewey S, Foster G, Henderson BA, et al. Multifocal intraocular lenses: Relative indications and contraindications for implantation. Journal of Cataract and Refractive Surgery. 2014;**40**(2):313-322. DOI: 10.1016/j.jcrs.2013.12.011

[68] Venter J, Pelouskova M. Outcomes and complications of a multifocal toric intraocular lens with a surface-embedded near section. Journal of Cataract and Refractive Surgery. 2013; **39**(6):859-866. DOI: 10.1016/j.jcrs.2013.01.033

[69] Chen XF, Zhao M, Shi YH, Yang LP, Lu Y, et al. Visual outcomes and optical quality after implantation of a diffractive multifocal toric intraocular lens. Indian Journal of Ophthalmology. 2016;**64**(4):285-291. DOI: 10.4103/0301-4738.182939

[70] Bellucci R, Bauer NJC, Daya SM, Visser N, Santin G, et al. Visual acuity and refraction with a diffractive multifocal toric intraocular lens. Journal of Cataract and Refractive Surgery. 2013;**39**(10):1507-1518. DOI: 10.1016/j.jcrs.2013.04.036

[71] Ferreira TB, Marques EF, Rodrigues A, Montes-Mico R. Visual and optical outcomes of a diffractive multifocal toric intraocular lens. Journal of Cataract and Refractive Surgery. 2013;**39**(7):1029-1035. DOI: 10.1016/j.jcrs.2013.02.037

[72] Gangwani V, Hirnschall N, Findl O, Maurino V. Multifocal toric intraocular lenses versus multifocal intraocular lenses combined with peripheral corneal relaxing incisions to correct moderate astigmatism. Journal of Cataract and Refractive Surgery. 2014;**40**(10): 1625-1632. DOI: 10.1016/j.jcrs.2014.01.037

[73] Poyales F, Garzon N. Comparison of 3-month visual outcomes of a spherical and a toric trifocal intraocular lens. Journal of Cataract and Refractive Surgery. 2019;**45**(2):135-145. DOI: 10.1016/j.jcrs.2018.09.025

[74] Balestrazzi A, Baiocchi S, Balestrazzi A, Cartocci G, Tosi GM, et al. Mini-incision cataract surgery and toric lens implantation for the reduction of high myopic astigmatism in patients with pellucid marginal degeneration. Eye. 2015;**29**(5):637-642. DOI: 10.1038/eye.2015.13

[75] Luck J. Customized ultra-high-power toric intraocular lens implantation for pellucid marginal degeneration and cataract. Journal of Cataract and Refractive Surgery. 2010; **36**(7):1235-1238. DOI: 10.1016/j.jcrs.2010.04.009

[76] Kamiya K, Shimizu K, Miyake T. Changes in astigmatism and corneal higher-order aberrations after phacoemulsification with toric intraocular lens implantation for mild keratoconus with cataract. Japanese Journal of Ophthalmology. 2016;**60**(4):302-308. DOI: 10.1007/s10384-016-0449-x

[77] Lockington D, Wang EF, Patel DV, Moore SP, McGhee CN. Effectiveness of cataract phacoemulsification with toric intraocular lenses in addressing astigmatism after keratoplasty. Journal of Cataract and Refractive Surgery. 2014; **40**(12):2044-2049. DOI: 10.1016/j.jcrs.2014.03.025

[78] Stewart CM, McAlister JC. Comparison of grafted and non-grafted patients with corneal astigmatism undergoing cataract extraction with a toric intraocular lens implant. Clinical & Experimental Ophthalmology. 2010; **38**(8):747-757. DOI: 10.1111/j.1442-9071.2010.02336.x

[79] Wade M, Steinert RF, Garg S, Farid M, Gaster R. Results of toric intraocular lenses for post-penetrating keratoplasty astigmatism. Ophthalmology. 2014;**121**(3):771-777. DOI: 10.1016/j.ophtha.2013.10.011

[80] Allard K, Zetterberg M. Toric IOL implantation in a patient with keratoconus and previous penetrating keratoplasty: A case report and review of literature. BMC Ophthalmology. 2018;**18**(1):215. DOI: 10.1186/s12886-018-0895-y

[81] Kersey JP, O'Donnell A, Illingworth CD. Cataract surgery with toric intraocular lenses can optimize uncorrected postoperative visual acuity in patients with marked corneal astigmatism. Cornea. 2007;**26**(2):133-135. DOI: 10.1097/ICO.0b013e31802be5cc

[82] Steinwender G, Schwarz L, Bohm M, Slavik-Lencova A, Hemkeppler E, et al. Visual results after implantation of a trifocal intraocular lens in high myopes. Journal of Cataract and Refractive Surgery. 2018;**44**(6):680-685. DOI: 10.1016/j.jcrs.2018.04.037