PERSPECTIVES

# Consensus on the management of astigmatism in cataract surgery

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**Abstract:** This project was aimed at achieving consensus on the management of astigmatism during cataract surgery by ophthalmologists from Latin America using modified Delphi technique. Relevant peer-reviewed literature was identified, and 21 clinical research questions associated with the definition, classification, measurement, and treatment of astigmatism during cataract surgery were formulated. Twenty participants were divided into seven groups, and each group was assigned three questions to which they had to respond in written form, after thoroughly reviewing the literature. The assigned questions with corresponding responses by each group were discussed with other participants in round 4 – presentation of findings. The consensus was achieved if approval was obtained from at least 80% of participants. The present paper provides several agreements and recommendations for management of astigmatism during cataract surgery, which could potentially minimize the variability in practice patterns and help ophthalmologists adopt optimal practices for cataract patients with astigmatism and improve patient satisfaction.

**Keywords:** management of astigmatism, astigmatism correction during cataract surgery, cataract patients with astigmatism, measurement and treatment of astigmatism, consensus on managing astigmatism

## Introduction

Ocular astigmatism is a refractive condition which occurs because of unequal curvatures of the cornea and the crystalline lens, decentration or tilting of the lens, or unequal refractive indices across the crystalline lens,[1] and in some cases, alterations of the geometry of the posterior pole. Several studies have reported the prevalence of corneal astigmatism in cataract patients of different age groups. In general, nearly 35%–40% of the cataract patients have astigmatism $\geq 1.0$ D and 19%–22% have astigmatism $\geq 1.5$ D.[2–4]

The advances in intraocular lens (IOL) designs and surgical technique have increased the patient expectations after cataract surgery. Since resultant astigmatism after phacoemulsification can leave the patient spectacle-dependent and significantly decreases patient satisfaction, it is important to address astigmatism as well during cataract surgery, so as to achieve optimal postoperative refractive outcomes and/or spectacle independence.

There are several ways to measure and treat astigmatism at the time of cataract surgery. Techniques to measure astigmatism include keratometry (manual or automated), corneal topography (eg, placido-based or based on the reflection of multicolor light-emitting diode [LED] points), and corneal tomography (eg, slit-scan imaging, Scheimpflug imaging).[5] Additionally, the use of intraoperative aberrometry has been documented to improve the astigmatic outcomes.[6] Some of the techniques used to

correct astigmatism during cataract surgery include selective positioning of the phacoemulsification incision, corneal relaxing incisions, limbal relaxing incisions, and toric IOL implantation.[7] Every procedure has its own limitations, advantages, and disadvantages. As such, no single device/surgical approach has been identified as the most accurate for measuring and correcting astigmatism during cataract surgery. Since there is a lack of well-defined approach to astigmatic planning and treatment, there is a necessity to develop a consensus on the best practices to manage astigmatism during cataract surgery.

The purpose of this paper is to present the consensus achieved on the evaluation and correction of astigmatism during cataract surgery by a panel of experts in the Latin American region using a modified Delphi method. The consensus covers the most relevant questions regarding the definition, measurement, and treatment of astigmatism during cataract surgery.

## Methods

We used a modified Delphi technique to obtain consensus on the management of astigmatism during cataract surgery. The Delphi method[8,9] is a technique used to collate the opinions of the panelists through iterations with multiple rounds of a structured questionnaire. As a modification to the Delphi method, we included an additional round of presentation of findings, in which the participants presented their responses to the assigned questions, which were discussed and approved by the panelists using the voting method.

The Colombian Association of Cataract and Refractive Surgeons (ASOCCYR), a nonprofit organization that promotes academic research of general interest in cataract and refractive surgery, was the leader of the project. Consensus process began with the development of a research question using the PICOT methodology[10] in the first round. This means population (P) – patients diagnosed with cataract and preexisting corneal astigmatism, intervention (I) – surgical management of both cataract and astigmatism, comparison (C) – surgical methodologies, outcomes (O) – postoperative astigmatism and cataract outcomes, and time (T) – postoperative 3 months. Using this methodology, appropriate search words were used to identify relevant peer-reviewed literature.

The second round involved the formulation of clinical research questions, based on the base question developed in the previous round. Overall 21 questions associated with the definition, classification, measurement, and treatment of astigmatism during cataract surgery were prepared. Ophthalmologists from different countries of Latin America with

experience in the field of cataract and/or astigmatism and scientific publications in ophthalmic journals were enlisted as potential panelists. The criteria to determine experience were number of cataract surgeries performed using toric and multifocal IOLs, number of cataract surgeries performed using relaxing incisions, experience in a clinical setup that has all the preoperative and intraoperative technologies required to do premium surgery, university professor position, and experience in research. An e-mail invitation was sent to these experts requesting their participation, explaining the aim of the study and the methodology. Twenty experts who were willing to comply with the initial question rounds and the final round involving presentation of findings were selected to participate in this project. Considering the multiplicity of themes, the participants were divided into seven groups with two or three participants in each. The groupwise distribution of the panelists with their respective countries is shown in Table 1.

In the third round, the participants were provided with the bibliography and literature regarding the diagnosis and management of astigmatism. The experts of each group were assigned three questions (of the total 21), and they were required to respond to those questions in written form after thoroughly reviewing the literature.

In the fourth round, each group of participants presented their assigned questions with corresponding responses,

**Table 1** Groupwise distribution of the panelists

| Group | Panelists | Country |
|---|---|---|
| Group 1 | Virgilio Centurion | Brazil |
| | Guadalupe Cervantes | Mexico |
| | Claudio Orlich | Costa Rica |
| Group 2 | Arnaldo Espaillat | Dominican Republic |
| | Oscar Guerrero | Mexico |
| | José Miguel Varas | Ecuador |
| Group 3 | Bruna Ventura | Brazil |
| | Eduardo Viteri | Ecuador |
| | David Flikier | Costa Rica |
| Group 4 | Maria A Henriquez | Peru |
| | Eduardo Mayorga | Argentina |
| Group 5 | Lyle Newball | Colombia |
| | Juan Guillermo Ortega | Colombia |
| | María Ximena Núñez | Colombia |
| Group 6 | Miguel Srur | Chile |
| | Jose Luis Rincón | Venezuela |
| | Claudia Blanco | Colombia |
| Group 7 | Luis Escaf | Colombia |
| | Luz Marina Melo | Colombia |
| | Juanita Londoño | Colombia |

which were discussed with the remaining panelists. The consensus on each statement was obtained by voting method (raising hands in favor of the statement). The consensus was considered to be achieved if at least 80% of the participants approved the statement. In case of a disagreement, the statement was revised, and a new voting was performed.

## Results and discussion

All participants responded to their assigned questions and attended the last round of presentation of findings. The items addressed throughout the rounds and the consensus obtained are hereby presented by their major topic.

## Classification of cataract and astigmatism

The first set of questions was aimed at discussing the methods used to classify cataract and astigmatism. To evaluate cataracts, different methods have been described in the literature, such as the Lens Opacities Classification System (LOCS)[11] and the Age-Related Eye Disease Study System.[12] Some objective methods for measuring nuclear density have also been described;[13–19] however, the experts agreed that in the absence of a validated classification system, such methods do not add much value to the clinical decision making. Despite the technical limitations related to the slit lamp and subjectivity of the evaluator, LOCS III remains the most established subjective method for cataract grading.[14,15] The experts suggested that the LOCS III can be complemented with the Barraquer Cataract Nuclear Classification (BCN 10),[20] which divides the nuclear cataract progression into a baseline clear lens (N0) and 10 grades of opacification (N1 to N10), where N10 corresponds to a completely dark lens (cataracta nigra). The grading chart shows a large slit-lamp cross-sectional image, a smaller frontal view image, and the relative color for each stage of cataract development.

The panelists also agreed on the different ways described in the literature to classify ocular astigmatism based on the refractive component, magnitude, orthogonality, anatomy, and location of the steepest meridian, and in terms of wavefront aberrations (Table 2).

## Measurement of corneal astigmatism in cataract patients

Several devices based on different technologies are available to measure corneal power and astigmatism, which include manual keratometers, automated keratometers, placido-based corneal topographers, point-source color LED topographers, Scheimpflug image-based topographers, low-coherence reflectometers, and scanning-slit corneal topographers.[21–26]

## Anterior corneal astigmatism: devices and calculators

Manual keratometers, automatic keratometers, and placido ring-based topographers offer direct measurements of the anterior cornea.[23–26] Since each device has its own characteristics, measurements obtained from different devices may not be comparable due to the use of different refractive indices or measurement area. Measurements can also be influenced by unstable tear film, ocular surface disease, etc.[27,28] These factors may compromise the accuracy of measurements. Therefore, evaluating the quality of each measurement before using it to plan the surgery is critical to obtain precise postoperative results.

Some investigators have suggested that combining keratometry techniques may improve the precision of preoperative keratometry. For example, Browne and Osher demonstrated that measurement errors can be substantially reduced by carefully taking measurements with a manual keratometer and an automated keratometer, and then averaging the measurements.[29] It was found that using the average of the measurements reduced the outliers and led to more precise results. It is important to note that axis location and magnitude of astigmatic measurements should be obtained with at least three different measurement methods (manual keratometry, automated keratometry, and topography/tomography). If no two measurements are fairly consistent, there can be ambiguity in deciding correct measurement and calculating toric IOL power. In such conditions, toric IOL should be avoided.

Conventionally, only anterior corneal surface was measured, assuming that the posterior cornea induces minimal refractive astigmatism.[30] However, recent studies have demonstrated that both the anterior and posterior corneal surfaces contribute to the total corneal astigmatism (TCA), and that ignoring posterior corneal astigmatism may induce errors in astigmatic treatment calculations.[31,32] Koch et al determined that the posterior corneal astigmatism (average −0.3 D) affects the value of TCA. This value may decrease (in cases of with-the-rule [WTR] astigmatism) or increase (in cases of against-the-rule [ATR] astigmatism) TCA.[30,32–35] If the posterior corneal astigmatism is not considered, it may overestimate WTR astigmatism by 0.5–0.6 D and underestimate ATR astigmatism by 0.2–0.3 D.[30] It has also been documented that ignoring the astigmatism of the posterior cornea can produce an axis error of 7.4°±10.3°.[36] The panel agreed that in addition to the evaluation of the anterior corneal surface, posterior corneal surface should be considered in patients undergoing astigmatism correction during cataract surgery.

**Table 2** Classification of astigmatism

| Based on refractive component | Regular | Simple | Simple myopic | One meridian is myopic and the other emmetropic |
|---|---|---|---|---|
| | | | Simple hyperopic | One meridian is hyperopic and the other emmetropic |
| | | Compound | Compound myopic | The two meridians are myopic but with different gradient |
| | | | Compound hyperopic | The two meridians are hyperopic but with different gradient |
| | | | Mixed | When one of the meridians is myopic and the other hyperopic |
| Based on magnitude | Low | 0.25–1.5 D | | |
| | Medium | >1.5 to <3 D | | |
| | High | >3 D | | |
| Based on orthogonality | Regular | | | The main meridians are placed at 90° from one another and/or maintain the same power along the meridian |
| | Irregular | | | The main meridians are not placed at 90° from one another and/or do not maintain the same power along the meridian |
| Based on anatomical location | Corneal | Anterior | | Astigmatism originating from the anterior face of the cornea |
| | | Posterior | | Astigmatism originating from the posterior face of the cornea |
| | Intraocular | | | Astigmatism originating from the anterior and posterior face of the lens |
| Based on location of the steepest meridian | With the rule | | | When the steepest meridian is ≥60° and ≤120° |
| | Against the rule | | | When the steepest meridian is ≥0° and ≤30° or ≥150° and ≤180° |
| | Oblique | | | When the steepest meridian is >30° and <60° or >120° and <150° |
| Based on wavefront aberrations | Low-order astigmatism | | | Equivalent to the astigmatism found during refraction |
| | High-order astigmatism | | | Secondary astigmatism of fourth order |

Various nomograms, adjustment coefficients,[35,37] and calculators[37–39] are being used to factor in the effect of posterior cornea in the anterior corneal measurements. The Koch et al[30] and Goggin et al[37] nomograms are being used for selecting the toric power for astigmatic correction that factors in posterior corneal astigmatism. The Baylor nomogram recommends a 0.7 D shift in toric IOL threshold to compensate for posterior corneal astigmatism. However, the method is likely to suffer from inaccuracies due to inherent problems with the measuring device and/or by assuming a fixed location of the steep meridian of the posterior corneal astigmatism. The Goggin nomogram adjusts the anterior corneal astigmatism based on the orientation of the anterior cornea (ie, WTR or ATR) and on the toric lens power for astigmatism

correction up to 2.0 D.[37] According to this nomogram, the cylindrical component is multiplied by an adjustment factor of 0.75 for WTR astigmatism and by 1.41 if the astigmatism is ATR. Although these methods may improve the accuracy of the surgical planning, they remain inherently inaccurate for not using vector analysis to determine TCA.

Barrett's toric calculator uses the Universal II formula[40] to calculate effective position of the lens and predicts posterior corneal astigmatism based on a theoretical model to provide toric IOL power.[40] The Abulafia–Koch formula aims to adjust the measured anterior corneal astigmatism to factor in posterior corneal astigmatism; the net corneal astigmatism thus calculated is used for toric IOL calculations. The Abulafia–Koch formula and Barrett's

toric calculator provide net corneal astigmatism using vector analysis.[38,39]

## Posterior corneal astigmatism and TCA: devices and calculators

The point-source color LED topographer and Scheimpflug image-based tomographers measure both anterior and posterior cornea. Devices based on these technologies, which include the Galilei (Ziemer Ophthalmic Systems AG, Port, Switzerland), the Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany), and the Cassini (i-Optics BV, Hague, the Netherlands) provide TCA by directly measuring the anterior as well as the posterior corneal astigmatism. The total corneal power can be used to determine corneal topographic astigmatism (CorT) value,[41] which is calculated using summated vector mean of the astigmatism values using all the valid data captured during topography. Additionally, toric calculators, such as Panacea IOL & Toric Calculator, consider real measurements of anterior and posterior toricity with the correction from keratometric to real corneal refractive index.[42] Although the use of direct measurements of the anterior and posterior cornea is helpful in decreasing resultant astigmatism after toric IOL implantation,[33,43,44] there are studies demonstrating that the outcomes achieved using these measurements or software are not better than those achieved with the Barrett's toric calculator.[24,45]

Recently, to obtain net corneal power measurement, intraoperative methods were made available, such as the ORA (Alcon Laboratories, Inc., Fort Worth, TX, USA) and the Holos (Clarity Medical Systems, Inc., Pleasanton, CA, USA). During aphakic measurements, intraoperative aberrometry provides net corneal astigmatism that incorporates posterior corneal astigmatism, thus allowing for better estimation of toric IOL power and its axis of implantation. Although variables such as eyelid speculum pressure, intraocular pressure, corneal hydration, and the viscoelastic used to fill the anterior chamber can influence the net corneal power measurements, several studies have shown promising results.[6,46]

Although none of the methods is perfect, surgical results have improved over the years. The experts agreed that there is no gold standard technique for measuring posterior corneal astigmatism until now. While the direct measurements of anterior and posterior cornea are helpful, these do not demonstrate high reliability. The panel also agreed that the use of predictive nomograms that use vectorial analysis, such as

Barrett's toric calculator and Abulafia–Koch formula, is safe and reliable, as was demonstrated in a study by Ferreira et al.[47]

## Treatment of corneal astigmatism during cataract surgery

Among various surgical techniques used for cataract extraction, phacoemulsification continues to be the universal choice. It can be either manual or femtosecond laser assisted. However, several investigators have reported that femtosecond laser-assisted cataract surgery (FLACS) does not yield better visual or refractive outcomes than conventional phacoemulsification.[4,48] Although the increasing use of robotics is highly anticipated as an effect of technification in the field of health care, the panelists believed that the FLACS is still evolving and will take time to become the mainstream cataract procedure.

The prevalence of preoperative astigmatism in cataract patients has been reported to be 86.6%, of which 35%–40% of the cataract patients have astigmatism ≥1.0 D and 19%–22% have astigmatism ≥1.5 D.[2–4] While preexisting astigmatism of <0.5 D does not need correction,[49] resultant astigmatism should be <0.75 D in patients seeking spectacle independence after cataract surgery especially with multifocal IOLs.[50–52] The experts agreed that, whether manual or femtosecond assisted, the following intraoperative techniques are currently being used to correct astigmatism during cataract surgery: 1) creating clear corneal incision (CCI) on the steepest meridian, 2) paired opposite clear corneal incisions (POCCIs) on the steepest meridian, 3) corneal relaxing incisions, and 4) toric IOL implantation. It is important to recognize that these treatment options correct regular astigmatism; as such, it is important to do thorough preoperative work-up to identify and rule out the presence of corneal conditions that cause irregular or asymmetric astigmatism. Corneal tomographic imaging, in addition to topography, is valuable for decision making.[53,54]

### CCI on the steepest meridian

During cataract surgery, the placement of CCI on the steep meridian has a flattening effect on the corneal curvature, which helps control astigmatism.[55] The total astigmatic effect of an incision on the corneal astigmatism is quantified by its surgically induced astigmatism (SIA) vector.[56] Conceptually, SIA can be calculated as a double-angle vector difference between the postoperative astigmatism and the preoperative astigmatism at the corneal plane. This SIA can be decomposed into a component with a pure flattening/steepening effect, which changes the magnitude of the astigmatism,

and a component that induces torque, which changes the orientation of the preoperative astigmatism.[57]

The incision on the steep meridian has been reported to correct astigmatism of 0.85±0.75 D.[58] The mean surgically induced astigmatism for a 3.0–3.2 mm CCI may range from 0.50 to 0.67 D.[7,59,60] The superior incisions tend to produce greater SIA than the temporal incisions, due to greater proximity of the superior incisions to the corneal center than the temporal incisions because of the oval shape of the cornea.[61] With the advancing technology, the width of CCI has been decreasing. While there are reports that a CCI of 2.2 mm produces some flattening effect,[62] the panel agreed that incisions smaller than 2.4 mm (SIA 0.35±0.21),[60] whether created manually or with femtosecond laser, do not produce much astigmatic effect.

## Paired opposite corneal incisions at the steepest meridian

Performing an additional CCI opposite (180°) to the first CCI to enhance the flattening effect has also been reported.[63] This method is called POCCI. When compared to the single CCI, POCCIs (3.2 mm incision) have been documented providing an enhanced effect of 1.66±0.50[58] and 1.3±0.9 D[64] for correcting preexisting corneal astigmatism during cataract surgery using POCCIs of 3.2 mm.[58,63,64] The experts agreed that POCCI on the most curved meridian has the potential to correct preexisting regular astigmatism of up to 1.5 D and is more effective than performing a single CCI.[61,64] However, the technique has not become popular due to its lack of predictability, absence of nomogram, and increased risk of endophthalmitis.[65]

## Corneal/limbal relaxing incisions

Corneal/limbal relaxing incisions flatten the cornea in the incised meridian; therefore, they are created on the steepest meridian. Additionally, these incisions produce a coupling effect on the meridian 90° away.[66–68] Although relaxing incisions can be performed manually employing inexpensive instrumentation, the efficacy of reducing astigmatism is limited to low keratometric astigmatism as compared to procedures using an excimer laser or toric lens implantation.[69,70] The maximum length of relaxing incision suggested in different nomograms is 90°.[71,72] This type of incision can be single or paired and can potentially correct up to 1.5 D of astigmatism. The corneal/limbal relaxing incisions are associated with transient effects of foreign body sensation, decreased corneal sensitivity, and increased ocular dryness after surgery.

The clinical application of the femtosecond laser for creating relaxing incisions of precise length, depth, and radius presumably improves clinical outcomes.[73–75] With integrated optical coherence tomography/Scheimpflug imaging, the depth of the incision can be controlled accurately, which allows making precise incisions at a depth equivalent to 85%–90% of the corneal thickness. While some surgeons choose to open the incisions at the time of surgery, it can be done up to a month later, in the office, depending on visual acuity, refraction, and topography.[76] When existing nomograms[71,72] of manual incisions were attempted for femtosecond laser-assisted corneal relaxing incisions, tendency for hypo-correction was observed. As such, there is a need to refine the nomograms to optimize the outcomes of laser-assisted corneal relaxing incisions.

The experts agreed that although corneal relaxing incisions are helpful in correcting astigmatism, they do not offer the predictability and stability provided by a toric IOL.[69] As such, the panelists recommend performing corneal relaxing incisions only in select cases, particularly those with low astigmatism (<1.5 D), without exceeding 90° arc. Furthermore, they should not be performed in corneas which have suspicious topographic features of ectasia.[59]

## Toric IOL implantation

Toric IOL implantation can correct preexisting astigmatism as low as 0.75 D and is the method of choice for correcting high levels of astigmatism. In addition, it is considered the most predictable method to correct astigmatism in cataract surgery, as was demonstrated in a multicenter study involving five centers, three in Europe and two in South America.[77] Monofocal and presbyopia-correcting (extended depth of focus, bifocal, and trifocal) toric IOLs are available, offering high patient satisfaction and significantly reducing spectacle dependence for distance as well as near vision, when using the latter lens.[78] However, they are not suitable for cases with irregular astigmatism or zonular instability. In addition, toric IOL implantation should be avoided in patients with severe dry eye, not responding to treatment. Although toric IOLs have been documented to yield promising results, a review of the literature reveals that there is high variability in visual outcomes. The prevalence of spectacle independence for distance vision following unilateral toric IOL implantation ranges from 60% to 85%,[79–82] and following bilateral toric IOL implantation from 69% to 97%.[30,83,84] The experts believed that this high variability in postoperative visual and refractive outcomes is due to the several factors affecting preoperative planning, surgical technique, and postoperative IOL rotation.

The experts agreed on the key factors affecting resultant refractive astigmatism following toric IOL implantation. They are shown in Table 3.

Differences in the magnitude and axes of preoperative corneal astigmatism from different devices are fundamental to the high variability of resultant astigmatism observed in the literature. For example, difference between the standard keratometric astigmatism and the Scheimpflug-derived readings can be up to 0.5 D and 10° in 25% of the population.[85] Similarly, the comparison of keratometric findings obtained using Lenstar LS 900 and IOL Master 500 has shown that the differences are significant.[86] Likewise, the findings obtained using Lenstar LS 900 and IOL Master 500 or Topcon auto-keratometer KR-8100 are found to be different.[87] The axes of astigmatism measured using different devices can be highly variable. For example, a difference of >20° has been demonstrated between the measurements obtained using the Verion™ and IOL Master 500 in 21% of cases and between Verion™ and Topcon KR-8900 in 17% of cases.[88] Incorrect position of the patient's head while performing keratometry may be a possible reason for variable keratometric measurements. In addition, increased tear osmolarity due to the presence of dry eye in the patient may produce variability in mean keratometry and in astigmatism of the anterior corneal surface.[27]

Further, some instruments, such as Verion™ (Alcon Laboratories, Inc.), use only anterior corneal measurements for the calculations and others like Oculus Pentacam or Galilei consider an integrated value of the anterior and posterior power of the cornea.[89] Ignoring posterior corneal astigmatism may yield incorrect estimation of TCA.

The panel agreed that it is important to accurately estimate SIA for optimal correction of astigmatism during cataract surgery. SIA can be influenced by several factors, such as corneal radius, size, depth, and location of the incision.[90–93] Other factors include suture use, patient age, biomechanical properties of the cornea, intraoperative complications of the incision, previous surgeries in the cornea,[94] and the laterality of the eye. Commonly used vector methods for calculating SIA are the polar value system,[95] the Alpins method,[56,96] the Holladay method,[97,98] and the Thibos method.[99,100] The most accepted method to calculate SIA is the vectorial sum method described by Alpins.[56,96] When analyzing SIA for a case series (aggregate analysis), two methods are commonly used. One of the methods determines the mean vector magnitude by

**Table 3** Factors associated with postoperative secondary astigmatism after toric IOL implantation

| Errors associated with the selection of IOL power | Inadequate keratometric reading/biometry | Altered corneal surface (dry eye, scars, or leukomas) |
| --- | --- | --- |
| | | Deficient keratometric/biometric information collection technique |
| | | Discrepancy between readings of devices/equipment |
| | Incorrect toric calculations | Incorrect input of information (keratometry, axial length, anterior chamber depth, surgeon-induced astigmatism, incision location) |
| | | Posterior corneal astigmatism not considered |
| | | Effective position of the lens not considered by the calculators |
| | Inadequate patient selection | Irregular astigmatism |
| | | Eye dryness |
| | | Zonular instability |
| Surgical errors during toric IOL implantation | Inadequate presurgical marking | |
| | Misalignment of the IOL cylinder with respect to the planned corneal meridian | |
| | Defective capsulorhexis | Size (rhexis >6.0 mm, rhexis <4 mm) |
| | | Shape (noncircular rhexis) |
| | | Poor centration |
| Rotation and/or unpredictable postoperative effective lens position of the toric IOL | Remnants of viscoelastic behind the IOL | |
| | Hypotonia due to postoperative leakage and rotation of the secondary IOL | |
| | Inadequate design and materials of some models of toric IOLs | |
| | IOL-to-capsular bag size ratio | Axial length >24 mm and large capsular bag |

**Abbreviation:** IOL, intraocular lens.

calculating arithmetic mean and disregarding the orientation of the vectors.[96] In the second method, the magnitudes of the vectors are added with regard to each vector's orientation to determine a summated vector mean of the group. This analysis is done by converting the polar values (power and axis) into Cartesian values (x/y). The centroid, thus obtained, provides the power and axis of the induced astigmatism in the aggregate of patients.[98]

Accurate alignment of the toric IOLs intraoperatively, after correcting for any cyclorotation, is fundamental to achieving good refractive astigmatism outcomes. This can be guided by making ink marks on the corneal limbus using the horizontal light beam on the slit lamp or the advanced manual markers (eg, pendulum marker), or using automated references in iris patterns or conjunctival vessels of the limbus. A comparative study of three types of presurgical marking methods – iridian pattern references, a pendulum marker, and a three-point corneal marker – found comparable results between the first two, which were better than the three-point corneal marker, particularly in eyes with ATR astigmatism.[101] Insufficient visibility due to either dissolution of the ink or marks that are too wide and imprecise may also alter refractive astigmatism accuracy. Manual methods are also prone to corneal epithelial damage by involuntary movement of the patient.[102]

To overcome such problems with conventional marking system, automated image-guided systems, such as Verion™ and Callisto (Carl Zeiss Meditec AG, Jena, Germany), are helpful. Verion™ is an image-guided system, which is designed to accurately measure the eye, image anterior segment landmarks, perform IOL calculations including astigmatic corrections, and then guide the surgeon in the placement of corneal incisions and toric IOL alignment. In a single step, it measures both keratometry and pupil size and captures a high-resolution reference image of the eye, detecting anatomical landmarks (scleral vessels, limbus, pupil, and iris features) that are used for intraoperative tracking and registration. The data are automatically transferred to the Verion™, which is compatible with the LenSx Laser system (Alcon LenSx Lasers Inc., Aliso Viejo, CA, USA) and most surgical microscopes. In addition, the system tracks for eye movement and automatically adjusts for cyclotorsion. By eliminating the need for manually placed, astigmatic ink markings and the imprecisions inherent with that technique, the Verion™ system increases the accuracy of toric IOL alignment resulting in less postoperative deviation from targeted induced astigmatism.[103] However, major disadvantages with this technique are that it uses an image divider in the microscope, which reduces the amount of light intended for the surgeon's visualization. In addition, this technique does not consider posterior corneal measurements for IOL power calculation.

Callisto is another device available for precise and markerless alignment of toric IOL. Unlike Verion™, it does not require an additional planning station for data transfer from biometry to surgery. It also does not require an external image divider but is rather designed to be used directly under the microscope. However, with Callisto, it is required to have an IOL Master 700 to use the necessary images for the identification of the axis of implantation and a Zeiss Lumera microscope.

The use of intraoperative aberrometers in the aphakic state provides net corneal power, which helps to guide the selection of the IOL toric power and alignment.[104] However, as was previously mentioned, factors such as edema of the incision during surgery and intraocular pressure at the time of measurement may affect its final outcome.

Toric IOLs can rotate after implantation, especially in the early postoperative period. The toric IOL offset or inclination effect may induce high-order aberrations that negatively impact the patient's postoperative visual outcomes.[105] This may be due to several reasons, which include presence of residual viscoelastic between the IOL and the posterior capsule at the end of the surgery, postoperative changes in pressure (hypotonia) that destabilize the anterior chamber, capsulorhexis size and centering, the design and material of the toric IOL, axial lengths >24 mm, and large capsular bag. There is a sinusoidal relationship between resultant cylinder and meridional misalignment of toric IOL.[57] However, within 15° of off-axis rotation of the toric IOL, there is loss of astigmatic correction of ~3.5% per degree.[104] If the IOL rotates by 30°, the astigmatism remains unchanged, but aligned at a meridian different from the original steep meridian.

The longer the axial length of the eye, the greater is the size of the capsular bag, which may decrease the equatorial friction on the lens, potentially reducing the IOL rotational stability. While some studies have reported a positive correlation of IOL rotation with axial length ≥24 mm,[106] this relationship has not been found in other studies.[107] Additionally, high myopia is associated with weak zonules, which may also affect rotational stability of the IOL.[108] The IOLs with smaller diameter tend to rotate more.[104,109]

There are very few studies which compared the rotational stability of IOLs with regard to haptic design and optic material. Patel et al compared two IOLs with silicone optic but different haptic designs (plate and "C" loop) and found that rotational stability was higher in plate haptic IOLs as

compared to loop haptic IOLs.[110] Another study compared open-loop, hydrophobic acrylic IOL, and plate haptic hydrophilic acrylic IOL and found that both the IOLs had similar rotational stability.[111] As such, there is not enough evidence to conclude if IOL material or haptic design affects the rotational stability of lens.

Some authors have suggested that epithelial cells of the anterior capsule should be left in situ while implanting a toric IOL.[108] The fibrotic contraction of the capsular bag decreases the free space between the capsule and the lens, which may increase the rotational stability of the IOL. In addition, the panel recommended that single-piece acrylic toric IOLs must be implanted in the capsular bag; if implanted in the sulcus, there is a higher risk of iris chafing[112] and rotation of the IOL, resulting in loss of astigmatism correction.

The panel concluded that the most predictable method to correct preexisting astigmatism is toric IOL implantation. However, the postoperative outcomes depend on several factors related to the measurement accuracy of the preoperative meridian and magnitude of astigmatism, type and location of CCI, accurate estimation of surgeon's SIA, precise alignment of IOL intraoperatively, absence of IOL rotation postoperatively, etc. There are different platforms of toric IOLs that have proven to be effective and predictable; however, there are not enough prospective, randomized studies that demonstrate the superiority of one platform over another. Regarding the matter of astigmatism that must be corrected with a toric IOL, the panel recommends putting every case of cataract surgery through toric IOL calculator taking into account the type and location of the incision, the surgeon's SIA, the existing astigmatism, and the sphere of the lens to be implanted. Finally, we should choose the suggested toric IOL, such that the resultant astigmatism is close to 0 without flipping the astigmatism axis and knowing that resultant astigmatism should be <0.75 D especially in multifocal IOLs.

## Use of toric IOLs in specific conditions
### Glaucoma
Several studies have suggested that glaucoma affects contrast sensitivity to a greater extent than visual acuity.[113] In fact, contrast sensitivity has been found to inversely correlate with visual field loss. In glaucoma patients undergoing cataract surgery, contrast sensitivity may potentially be improved with aspheric IOLs; however, if these lenses decenter, they may induce more aberrations than non-aspheric IOLs.[114] For the management of astigmatism in such patients, aspheric monofocal toric IOLs can be used. However, caution must be taken when performing combined cataract and filtering surgery.[115]

### Pseudoexfoliation (PXF) syndrome
Patients with PXF have zonular weakness and may not respond to pharmacologic pupil dilation preoperatively.[116] These patients are also predisposed to intraoperative zonular dialysis. Toric IOL implantation in such patients may not be successful, as the lens and bag may rotate, or tilt once implanted, altering the patients' vision.[117] For this reason, the use of toric IOL in patients with PXF should be avoided.

### Fuchs' dystrophy
Although toric IOL implantation has been used successfully for astigmatism correction at the time of triple Descemet's membrane endothelial keratoplasty procedure in patients with Fuchs' dystrophy, the use of toric IOL is less predictable in such patients.[118] As such, the authors recommend avoiding toric IOL implantation in such cases.

### Maculopathy
When there is a risk of retinal/macular disease, toric IOL should be avoided due to unpredictable stability over time.

### Keratoconus
As discussed above, postoperative outcomes after toric IOL implantation depend on the repeatability of keratometric measurements. Since keratoconus is a progressive disorder, toric IOL implantation should only be considered in patients with stable corneal topography over a period of at least 1 year. Hashemi et al compared the repeatability of keratometry measurements with five different devices in keratoconus eyes and reported that in cases with maximum keratometry reading >55.0 D, all devices had reduced repeatability.[119] As such, toric IOL implantation should be avoided in keratoconus eyes with maximum keratometry >55 D.

## Management of resultant astigmatism
Despite the use of advanced technology and the best efforts to plan and execute the surgery, resultant astigmatism may still occur. The experts recommended that resultant astigmatism (≥0.75 D) should be corrected if it generates significant patient dissatisfaction with symptoms, such as blurred vision, dysphotopsia, photophobia, and diplopia.[120] Alpins et al have described several reasons of refractive surprises after toric IOL implantation, which include incision effect, incision position, IOL power, and IOL orientation.[121] Understanding these factors may enable surgeons to choose appropriate

methods of managing resultant astigmatism. Online toric calculators, such as ASSORT (http://www.assort.com/assort-vector-calculator-0; accessed October 5, 2018), can be used for rotational analysis of the implanted toric IOL to calculate any required rotation that may minimize the refractive cylinder postoperatively. The panel agreed that for correction of resultant refractive error post-cataract surgery, corneal ablation procedures,[122–124] arcuate keratotomy, or IOL replacement can be considered. Of the ablative procedures, although both photorefractive keratectomy (PRK) and LASIK yield similar outcomes, LASIK is the preferred option as it offers faster visual rehabilitation along with good results.[125–129] However, LASIK should only be performed if the patients are younger than 60 years, do not have dry eye symptoms, have a healthy cornea without corneal ectasia or secondary irregular astigmatism, and sufficient estimated residual bed thickness. Additionally, the refraction should be stable; usually, about 3 months is a prudent and appropriate period after cataract surgery.[130] The experts recommended that if a patient is not eligible for LASIK, PRK is the second option. Arcuate keratotomy can also be considered to correct resultant astigmatism; however, the predictability of this procedure is relatively low. Replacement of the IOL should be considered in cases of high refractive surprises, and in such cases, the replacement should be immediate. If a patient is eligible neither for corneal ablation nor for IOL replacement, a piggyback IOL can be considered.

## Astigmatism and dysfunctional lens syndrome (DLS)

With the advancing technology and increasing awareness about DLS, interest in offering clear lens extraction (CLE) for DLS is increasing. Some authors even classify this syndrome as stages 1, 2, and 3 based on degree of loss in accommodation, optical aberrations, and densitometry of the crystalline lens.[131]

Given that the treatment of DLS stage 2 is essentially the same as cataract, that is, implantation of IOL but following extraction of clear (yet dysfunctional) lens, it was pertinent to ask whether DLS with preexisting astigmatism can be treated with same methods as cataract with preexisting astigmatism. The experts felt that although the technologies that currently exist for the treatment of cataract with preexisting astigmatism can also be used for the treatment of DLS, ophthalmic surgeons are advised to make extensive preoperative assessments for appropriate patient selection weighing the risks vs the benefits of the procedure. For example, DLS patients with preexisting high myopia with long axial length and partial posterior vitreous detachment have an increased risk of retinal detachment (ranging from 0.0% to 7.3%),[132–140] as compared to cataract patients (ranging from 0.005% to 0.0179%).[141–144] In addition, the use of premium IOLs, in general, leads to a reduction in contrast sensitivity especially at high spatial frequencies.[145–148] In such cases, exhaustive questioning about the family history may reveal individual risk factors which could predict possible future occurrence of the retinal, corneal, or glaucomatous diseases. Such patients should be treated cautiously. It is important to note that following CLE surgery, patients report greater discomfort in their daily lives postoperatively due to secondary visual effects compared to patients with cataract surgery, probably, due to the absence of photic phenomenon preoperatively.[147] Such patients need substantial preoperative counseling to reinforce the notion that most of these symptoms cause discomfort at the beginning of the process and tend to decrease or disappear after 6 months. Due to the abovementioned challenges associated with CLE, the panelists recommend that such surgeries should be performed by experienced surgeons who have adequate technology available to achieve satisfactory visual outcomes.

Practice patterns related to measurement and treatment of preexisting astigmatism during cataract surgery vary across the world. This project provides several agreements and recommendations for the measurement and treatment of astigmatism during cataract surgery, which would help ophthalmic surgeons adopt optimal practices for cataract patients with preexisting astigmatism and improve patient outcomes.

## Disclosure

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