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Surgical Correction of Astigmatism During Cataract Surgery

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1. Introduction

Naturally occurring (idiopathic) astigmatism is frequent, with up to 95% of eyes having detectable astigmatism. It is estimated that approximately 70% of the general cataract population has at least 1.00 D of astigmatism, and approximately 33% of patients undergoing cataract surgery are eligible for treatment of preexisting astigmatism.1,2

Today, cataract surgery is regarded as a refractive surgery, aiming pseudophakic emmetropia, which makes eliminating corneal astigmatism critical.3-8

Ferrer-Blasco et al studied prevalance of corneal astigmatism before cataract surgery and found that; in 13.2% of eyes no corneal astigmatism was present; in 64.4%, corneal astigmatism was between 0.25 and 1.25 diopters (D) and in 22.2%, it was 1.50 D or higher.9

This finding implies that, when planning a surgery, both the spherical and the astigmatic components should be taken into account to achieve post-operative outcomes as close to emmetropia as possible.

Due to new developments in phacoemulsification devices, changes in operation techniques and the use of small incisions in cataract surgery which reduce the operation-induced astigmatism or make an inconsiderable change in the existing corneal astigmatism, the general aim of cataract surgery has gone from simple cataract extraction to ensuring the best visual acuity and quality without spectacle dependence. With the wide-spread use of phakic, aphakic, bifocal, multifocal and accommodative intraocular lenses (IOLs); all surgeons aim to eliminate any small ametropia, especially astigmatism, existing before or after cataract surgery.

There are several techniques for dealing with the pre-existing astigmatism intraoperatively as well as postoperative approaches for dealing with residual or induced astigmatism. However; the most important and critical step in treating the astigmatism is to find out the exact source, magnitude and axis of the astigmatism and making the decision about which technique is appropriate for that patient. The cylindrical component is evaluated by automated and/or manifest refraction, placido ring reflections, keratometry and/or corneal topography and wavefront aberrometry primarily, but other factors need to be taken into account, such as age of the patient and the corneal characteristics of both eyes.

Refractive astigmatism; also called total astigmatism; as determined by retinoscopy or by subjective refraction, is made up of both corneal and internal astigmatism. *Corneal astigmatism* occurs due to unequal curvature along the two principal meridians of the anterior cornea and *internal astigmatism* is due to factors such as the toricity of the posterior surface of the cornea, unequal curvatures of the front and back surfaces of the crystalline lens, or tilting of the crystalline lens with respect to the optic axis of the cornea. The combination of the corneal and the internal astigmatism gives the eye's *total(refractive) astigmatism*. Corneal astigmatism is often classified according to the axis of astigmatism as being either with-the rule (WTR), oblique or against-the-rule (ATR).

It is well accepted that there is some relationship between the eye's corneal and internal astigmatism. In 1890, Javal proposed a rule that predicted the *refractive (total) astigmatism* of the eye based on the corneal astigmatism.10

Javal's rule states: $A_t = k + p(A_c)$ where A_t is the *refractive (total) astigmatism* and A_c is the corneal astigmatism. The terms k and p are constants approximated by 0.5 and 1.25, respectively. This rule relies on the fact that residual astigmatism is thought to be constant and ATR in most people (that is, -0.50 D ATR). Keller and colleagues investigated the relationship between corneal and total astigmatism by measuring corneal astigmatism with a computer-assisted videokeratoscope and the results from this study supported Javal's rule.11 To quantify the discrepancy between corneal and refractive astigmatism measurements, the corneal astigmatism value measured by topography or keratometry is substracted from the refractive cylinder measured by wavefront or manifest refraction and the vectorial difference is known as the ocular residual astigmatism (ORA), which is expressed in diopters.12,13

Keratometry, topography, and refraction, all provide useful information regarding the astigmatic status of patients. If the astigmatism measured by these tools is not in agreement either in magnitude, axis, or both, then the surgeon needs to evaluate all the datas again in order to optimise the visual outcome. Corneal topography provides a qualitative and quantitative image map based on evaluation of the corneal curvature14. Most topographers evaluate 8,000 to 10,000 specific points over the entire cornea and center the acquisition on the corneal apex. Topographers that incorporate scanning slit photography also measure the power and the astigmatism of the posterior corneal surface, which may improve correlation with the refractive astigmatism.15 In contrast to topography measurements, manual keratometry has only four data points within 3 mm to 4 mm of the central anterior surface of the cornea. An other device, automated keratometer, although not sensitive for accuracy of axis with low magnitudes of astigmatism, may be useful in screening astigmatism. Corneal topography and keratometry are considered "objective" measures of corneal refractive power. Although cataract surgery relies primarily on keratometry or topography and subjective refraction data; corneal or limbal incisional precedures to correct pre- or postoperative astigmatism have to involve keratometry, topography, refraction or a combination of corneal and refractive parameters using vector planning due to the fact that treatment of refractive astigmatism without regard to corneal astigmatism may result in a significant amount of remaining corneal astigmatism or even an increase in corneal astigmatism.

The history of surgical treatment for astigmatism dates back to the late 1800s. Various authors tried various techniques including limbal and corneal incision in the steep meridian, anterior transverse incisions, and nonperforating corneal incisions.16-25 The use of keratotomy to correct refractive error, facilitated in the mid-nineteenth century when

Snellen suggested that a corneal incision placed perpendicular to the step corneal meridian might induce flattening along that meridian.16 In 1885, Schiötz placed a 3.5 mm limbal penetrating incision in the steep meridian to reduce iatrogenic astigmatism of 17 D occurred after cataract surgery.17 Faber performed perforating anterior transverse incisions to reduce idiopathic astigmatism18. Lucciola reported the first cases of non-penetrating corneal incisions in 1886, where he also attempted to reduce astigmatism by flattening the steep corneal meridian in ten patients19. In 1894, Bates described 6 patients who developed flattening of the cornea in the meridian after a surgical or traumatic scar was intersected20. Later, Lans first appreciated that the flattening that occurs in a corneal meridian after placing a transverse incision was associated with steepening in the opposite meridian.21 He also demonstrated that the deeper and the longer incisions had more effect.21 In 1940s, Sato began an extensive investigation of radial and astigmatic keratotomy.22-25

However, early and late investigations of the techniques for astigmatic keratotomy are attributed to the works of Thornton, Buzard, Price, Nordan, Grene, Lindstrom, Troutman and Nichamin.26-36

Nordan proposed a relatively simple method of straight transverse keratotomy, with target corrections in the range on 1-4 diopters.29 Lindstrom developed a technique, as well as a nomogram, including an age factor.30

Thornton proposed a technique that included up to 3 pairs of arcuate incisions in varying optical zone sizes and with consideration of age and timing after surgery, respectively.26 Consequently, Troutman, who fancied wedge resection for reduction of postcorneal transplant astigmatism, also discussed the benefits of corneal relaxing incisions to decrease residual astigmatism.31 Corneal transplant surgery and radial keratotomy surgery both stimulated the development of astigmatic keratotomy. Thornton's technique involved making paired arcuate incisions placed at the 7.0 mm and 8.0 mm optical zones, following a curve on the cornea, while Chayez et al recommended optical zone sizes as small as 5.0 mm. 26,37

Nichamin developed an extensive nomogram for AK at the time of cataract surgery; titled "*Intralimbal relaxing incision nomogram for modern phaco surgery,*" which has age adjustments for correction of against-the-rule astigmatism and with-the-rule astigmatism. It utilizes an empiric blade-depth setting of 600 µm. 32-36

A detailed look in those various techniques for correcting pre-existing corneal astigmatism at the time of cataract surgery are discussed below.

2. Correction with incisions

2.1 Creating a clear corneal phacoemulsification incision on the steep axis of astigmatism

Improved spherical and astigmatic outcomes are now well-recognized benefits of modern small incision cataract surgery. Although standard 2.8-3.2-mm phacoemulsification provides satisfactory results in terms of safety, efficiency, and refractive outcomes, studies have shown that microincision cataract surgery (MICS) -defined as cataract surgery performed through an incision of less than 2 mm-, is a minimally invasive procedure with increased safety and less surgically induced astigmatism.38-45 Also a recent study has shown that biaxial microincisional cataract surgery with enlargement of one incision to 2.8 mm is not astigmatically neutral, demonstrating a statistically significantly larger Surgically induced astigmatism SIA than that attributable to measurement error.46 During cataract surgery it is

possible to reduce the pre-existing astigmatism by modifying the length, shape, type and the localization of the incision.37-39,47-54 The simplest way to do this, is to create a clear corneal incision at the steep corneal axis, whether superiorly, temporally, or obliquely, to profit the flattening effect of the incision which can help to reduce the astigmatism along that axis. This approach is usually sufficient for most eyes.3-5,15,49,54 However, a small incision can correct only astigmatism up to 1 D and sometimes this technique may not be easy due to localization of the steep meridian such as the difficulty while creating superonasal or inferonasal incision at the left eye. For this technique, identifying and marking the axis of the astigmatism preoperatively is critically important to ensure the exact placement of the surgical incision to flatten the cornea. Mild to moderate corneal astigmatism can be corrected or reduced by modifying the length of the corneal incision, as well as its depth and distance from the corneal center. 15,54

A study by Giasanti et al, indicated that a clear corneal incision of 2.75 mm for cataract surgery induced little change of astigmatism in eyes with low preoperative corneal cylinder, regardless of the incision site.55 However, a retrospective study describes larger changes induced by superior rather than temporal 2.8-mm incision, which had been considered nearly astigmatism neutral.56 A similar result was obtained by Borasio et al, when comparing the 3.2 mm clear corneal temporal incisions(CCTI) with clear corneal on-axis incision(CCOI) results in terms of surgically induced astigmatism, that CCTI induced less SIA than CCOI.57

However, recent evidence revealed that incisions between 1.6 to 2.3 mm had better outcomes in terms of induced astigmatism, focal wound related flattening of the peripheral cornea and corneal surface irregularity than small-incision cataract surgery. 41,58,59

Surgically induced astigmatism (SIA) is the condition in which a patients' preoperative and postoperative values differ. The methods used to determine the SIA are; Jaffe and Cleymans vector analysis method and Fourier polar and rectangular vector analysis methods as described by Thibos et al.60,61 However, if the pre and postoperative axes are identical and the sign convention is preserved, a simple substraction may also be used. Several studies have shown that temporal incisions result in with-the-rule (WTR) astigmatism, whereas superior incisions result in against-the-rule (ATR) astigmatism. 41,62-65

Altan-Yaycioglu et al compared superotemporal incisions in the right eye versus superonasal incisions in the left eye and have shown that superotemporal incisions yielded less against-the-rule astigmatism and surgically induced astigmatism values compared to superonasal incision group ($p < 0.001$).51

Various experts reported surgically induced astigmatism values with small incisions between 0.6-1D induced with 3.5 and 4mm incisions.66-68 Kohnen et al. reported a statistically significant difference in surgically induced corneal astigmatism after temporal and nasal unsutured limbal tunnel incisions.69 Ozkurt et al. investigated the astigmatism outcomes of temporal versus nasal clear corneal 3.5-mm incisions and found that temporal incisions yielded less total and surgically induced astigmatism.70

It is not clearly identified why temporal incisions create lesser astigmatic affect compared with the superior, but it may probably be due to the fact that the temporal limbus is farther from the visual axis than the superior limbus. In addition, the pressure the eyelid exerts on the superior incision may be another factor increasing or creating astigmatism on that localization.

In summary, temporal incisions should be used for negligible astigmatism, and nasal and superior incisions should be used when the steep axis is located at approximately 180° and 90°, respectively.

2.2 Opposite side clear corneal incision (OCCI)

In this technique, the corneal incisions are made on opposite sites 180 degrees apart, on the steepest meridian of cornea. It is based on the assumption that a healing tissue forms between those incisions, and this tissue-adding effect results with flattening of the cornea. The incisions were facilitated by creating two biplanar 3.2mm incisions 180 degrees from each other along the steep meridian of the cornea, 1.5-2mm inside the edge of the limbal vessels. They require no additional expertise, instrumentation, time, or cost.

Lever and Dahan were the first to apply a pair of OCCI on the steep axis to correct pre-existing astigmatism during cataract surgery.71 They modified the standard approach of clear corneal incision, adding an identical incision on the opposite side (180 degrees away). In their series of 33 eyes, mean keratometric astigmatism changed from 2.80 D preoperatively to 0.75 D postoperatively.71 Other studies found similar reductions. 72,73

This method is effective for correction of mild to moderate corneal astigmatism, but in eyes with higher degrees of astigmatism it is recommended to use an alternative method or a combination of two or more methods.74 Disadvantages of this method include the increased risk of endophthalmitis due to the penetrating nature of the incisions as compared to non-penetrating methods. For control of leakage in this method nylon sutures may be used for wound closure.71

In conclusion, paired OCCIs on the steep axis are useful for correcting mild to moderate pre-existing astigmatism during cataract surgery. Employing this technique during routine phacoemulsification using a 3.2 mm incision does not require additional instruments and therefore can be performed without altering the surgical setting.

2.3 The limbal relaxing incision (LRI) technique

This technique consists of performing two small curvilinear incisions at the limbus which produce a flattening of meridian along which they are performed due to the tissue addition effect along with steepening of the orthogonal meridian.(*fitting together effect*).

Performing LRIs is a preferred technique to reduce pre-existing astigmatism at the time of cataract surgery in eyes with low to moderate, and even high, astigmatism. They also appear to have potential advantages over corneal relaxing incisions or arcuate keratotomy by being a quick, easy to perform technique with low technology and low cost, causing less distortion and irregularity on corneal topographies and less variability in refraction as they are placed at the limbus. They can provide earlier stability in postoperative vision and have been found to produce less glare and patient discomfort with lower risks of corneal perforation and overcorrection of astigmatism.1,74-76 Kaufmann et al compared LRI and on-axis incisions(OAI) and found that, the flattening effect was 0.41 D in the OAI group and 1.21 D in the LRI group ($p = 0.002$). 77 The amount of astigmatism reduction achieved at the intended meridian was significantly more favorable with the LRI technique, which remained consistent throughout the follow-up period.77

The disadvantages are that LRIs are surgeon dependent resulting in some degree of variability and unpredictability and have less flattening effect due to their localization far from the optical center of the cornea. This means, they must be large to have any substantial effect on corneal curvature. However limbal incisions over 120 degrees of arc, especially when placed nasally or temporally, may denervate the cornea at that location, creating dry eye and healing problems. Furthermore, they are contraindicated in ectatic corneal disorders since the results are unpredictable and they may further destabilize the cornea.

Corneal pachymetry can be helpful but most surgeons empirically treat at 500-600 microns with a preset diamond or disposable metal blade.
With LRI technique the decrease in the mean astigmatism is reported to be between 25-52% by various authors.74,77-80.
Nichamin et al. recommended that the proper incision depth for LRIs is approximately 90% of the thinnest corneal depth around the limbus.1 The cutting depth of an empiric blade is commonly set to 600 μm.1 However Dong et al adjusted the cutting depth according to the preoperative corneal thickness considering that patients have variable corneal thicknesses, and showed that a cutting depth of less than 90% also achieved an acceptable correction effect on astigmatism.81
Asymmetrical incisions (e.g. single LRI) have a higher coupling ratio than symmetrical incisions (e.g. paired LRIs). Dong et al also stated that, performing the single LRI with CCI appears to produce similar effects to performing the paired LRI with CCI.81
Nichamin has developed two nomograms, which specify the use of LRIs according to the type of astigmatism and the patient's age. The standard Nichamin nomogram does not use pachymetry or adjustable blade-depth settings, but rather an empirical blade depth of 600 micrometers.32,33
For higher orders of astigmatism, a combination of CRI's and LRI's may be used. The length, depth, and placement of these incisions, as well as the age of the patient, will all affect the outcome of these incisions.

2.4 Single or paired peripheral corneal relaxing incisions (CRIs)

Corneal relaxing incisions(CRIs) run parallel to the limbus which can be single or paired, straight or arcuate, may treat slightly greater amounts of astigmatism (about 1-3D) as LRIs. They straddle the meridian of the steepest corneal curvature. These can be placed either at the time of surgery or post-operatively. They may be necessary when implanting multifocal intraocular lenses in eyes with more than 1 diopter of astigmatism.
Early investigations of the corneal incision techniques for astigmatism reduction included surgeons Thornton, Buzard, Price, Grene, Nordan, and Lindstrom in the early 1980s.26-30
Osher and Maloney described straight transverse keratotomy incisions in combination with cataract surgery while some others made variations on incision length, depth, number and their localization on the optical zone.76,82-86 In 1994, Kershner, coined the term *'keratolenticuloplasty'* meaning simultaneously reshaping the cornea through relaxing incisions and implanting an IOL to correct refractive error.87-92
Corneal relaxing incisions couple which refers to changes in corneal curvature occuring in the incised meridian and in the unincised orthogonal meridian 90 degrees away. Along the meridian of the incision and central to the incision, cornea flattens, while the meridian 90 degrees away steepens. The combination of flattening of the steeper axis with steepening of the flatter axis yields the total amount of astigmatism correction. This is called *coupling or flattening/steeping ratio*.30 If the amount of flattening in the steep meridian is equal to the amount of steeping in the flat meridian, then the *coupling ratio* is accepted to be 1, and no change in the spherical equivalent value occurs.30,83 Lindström found that coupling ratio was 1:1 when a straight 3-mm keratotomy or a 45 to 90 degree arcuate keratotomy incision facilitated at 5 to 7 mm-diameter optical zones; showing that the coupling ratio depends on the length, location and the depth of the incision. 30
Thornton described that, all transverse or arcuate corneal incisions will flatten the cornea in the meridian in which they are placed and treat astigmatism by acting as if tissue had been

added to the keratotomy site.83 However, he also stated that a true 1:1 coupling ratio can only occur when the corneal incisions act as tissue added but at the same time the corneal circumference is not changed; which is achieved only with short, concentric and arcuate incisions.83

Although the corneal relaxing incision technique is a quick and easy procedure - despite worldwide accepted nomograms - the results of this technique are still less predictable, especially with higher levels of astigmatism, and can change the axis of the astigmatism or induce irregular astigmatism.

The maximal effect of incisions occurred when they are placed around the 5 to 7mm-diameter optical zone. Clinical use of paired arcuate incisions should be avoided in optical zones of 5 mm or less. Optical zones of 6, 7,8, and 9 mm offer technically easier surgery and less risk of glare to the patient by staying far from the visual axis.

The biggest effect is obtained by the first pair of incisions and the second pair may add only 20-30% flattening effect. Effect can not be increased by adding more pairs than 2 pairs of incisions. There is some debate about the acceptable maximum length of these incisions but the approach accepted by most surgeons is that incisions should not be made greater than three clock hours long.14

If we summarize the basic concepts for corneal incisions;

- Larger incisions, create greater flattening. The larger the arc length of the corneal incisions, the more effect it will have in flattening the cornea at that meridian. Due to the coupling effect, arc lengths of more than 90° are ineffective.
- Incisions nearer to the optical center reveal greater flattening.
- A shorter tunnel length in a penetrating incision creates greater flattening while a longer creates smaller effect.
- A deeper incision creates greater flattening.
- It may be kept in mind that incisions more than 90% of pachymetry –although the fact they may create greater flattening effect- may result in corneal perforation.
- Arcuate incisions are easier to perform and produce more flattening with less surgery, besides they do not make a change in the circumference of the cornea.
- When learned well and applied accurately, the time-tested techniques of astigmatic keratotomy may produce more predictable outcomes.88-92.

3. Corrections with intraocular lenses

3.1 Toric IOL (T-IOL) implantation

T-IOLs are popular for advantage of being precise, predictable, and reliable correction of moderate to high astigmatism, requiring no new skills for the surgeon. They offer the possibility of correcting not only spherical equivalent refraction, but also the astigmatism during phacoemulsification cataract surgery.

The toric IOL was first devised by Shimizu et al. in 1992.93 At the same year Grabow and Shepherd implanted the first foldable silicone toric plate haptic IOL. 94,95

Implanting a toric IOL is a single-step, reliable, small-incision approach with a result that is independent of the postoperative tissue healing response. They have distinct advantages compared with treatments involving corneal or limbal tissue incisions.3,27,30,72,78,87,95-102 Toric IOL implantation is accepted as procedure that correct higher degrees of cylinder

than can corneal procedures.93,103,104 However a recent study by Poll et al, demonstrates that toric IOL implantation and peripheral corneal relaxing incisions yielded similar results regarding surgical correction of astigmatism at the time of phacoemulsification cataract surgery achieving comparable results with mild-to-moderate astigmatism.105

Their effective correction of astigmatism relies on performing accurate keratometry, choosing appropriate lens as in any cataract surgery, and perfect insertion technique with no postoperative rotation. The success of a toric IOL can be judged not only by its ability to reduce refractive astigmatism, but also by its ability to maintain a stable position in the capsular bag in the longer term. The most frequent cause of T-IOL rotation following an uncomplicated cataract surgery is because of capsular bag shrinkage due to fibrosis. 106

By taking serial fundus photographs, Viestenz et al documented that rotation (or torsion) of an eye by 3 degrees was present in 36% of patients which may lead to overestimation or underestimation of the presumed spontaneous rotation of an implanted toric IOL.107 Their results show that 11.5 degrees of toric IOL rotation would lead to residual astigmatism that is 40% of the initial astigmatic power and 3 degrees, 10% of the initial power.107 Rotation of the lens by 15 degrees reduces the astigmatic correction by about 50%. With 30 degrees of rotation, all the toric power is nearly lost.108 Kershner has demonstrated that this problem may occur in only fewer than 6% of cases.96

The first study evaluating the rotational stability of a toric IOL(STAAR 4203T; STAAR Surgical Company,USA) showed this plate-haptic design to undergo rotations of more than 30 degrees in fewer than 5% of cases.106 Results from the phase1 FDA trial, showed that, in 95% of cases, the toric IOL was within 30 degrees of the intended axis, with a mean achieved reduction in refractive cylinder of 1.25D. 109

De Silva et al. showed in a series of 21 MicroSil 6116TU toric IOLs with Z-haptics (HumanOptics, Germany) that the mean rotation of this lens was 5.2 degrees and the maximum rotation was 15 degrees.110

Chang demonstrated in a series of 50 STAAR TL toric IOLs (STAAR Surgical Company,USA) a maximum rotation of 20 degrees and 72% of the IOLs were within 5 degrees of the intended axis.111 A smaller diameter version of this STAAR IOL (STAAR TF toric IOL) demonstrated rotation of up to 80 degrees and required subsequent repositioning in 50% of cases.111 Other currently used toric IOLs include the T-flex 573T and T-flex 623T (Rayner, United Kingdom), and the Acri.LISA Toric 466TD and AT TORBI™ 709M (Acri.Tec, Germany).

Holland et al compared the AcrySof Toric intraocular lens (IOL) and an AcrySof spherical IOL to investigate the rotational stability of the AcrySof Toric IOL (Alcon Laboratories, Inc., Fort Worth, TX) in subjects with cataracts and preexisting corneal astigmatism and found out that Acrisof toric IOL showed favorable efficacy, rotational stability and distance vision spectacle freedom with a mean rotation of <4 degrees (range, 0-20 degrees).112

As with all plate-haptic IOLs, the T-IOLs should only be implanted with an intact capsule and a complete, continuous curvilinear capsulorhexis. The careful removal of viscoelastic from between the posterior capsule and the lens is important to prevent the early rotation of the IOL. Although some eyes may require an Nd:YAG capsulotomy for posterior capsular opacification, there have been no reports of subsequent off-axis deviation of the IOL. Jampaulo et al evaluated 115 eyes in which Staar toric IOL models AA4203TF and AA4203TL (Staar Surgical Co, Monrovia, California, USA) were implanted and found out that the mean difference in axis alignment was 1.36 degrees and no case had axis change more than 5 degrees after Nd:YAG capsulotomies.113

Some studies showed that T-IOL implantation is more effective than limbal relaxing incisions(LRIs) and that it is reliable in reducing postoperative refractive astigmatism, consistent in producing a uncorrected visual acuity(UCVA) of 20/40 or better, has a low incidence of early positional problems with long-term stability.96,114-118 Other clinical studies have used the T-IOLs to correct excessive astigmatism by combining the lens with LRIs or using multiple T- IOLs in a piggyback fashion.74,119,120

Methods of marking the cornea during surgery and insertion techniques have been published, aiming to minimize any further error.121,122 Cyclotorsion may occur when the patient is supine, so it is essential to mark the patient's eye in an upright position prior to surgery.

3.2 Piggy-back toric-IOLS (piggy-back T-IOLs)

Piggybacking system for IOLs is a combination of two IOLs implanted together to treat residual refractive error. These IOLs can be implanted during cataract surgery or clear lens extraction and IOL insertion (primary piggyback implantation) or as a secondary procedure following the initial IOL implantation (secondary piggyback implantation). Although the availability of the toric intraocular lens (IOL) provided the opportunity to correct some astigmatism; the limited power of lenses available, resulted in significant undercorrection in patients with high astigmatism.120

Piggyback T-IOLs are a combination of two toric IOLs implanted in the same fashion as spherical IOLs to provide satisfying vision for the high astigmatic patient. The only difference between piggyback implantation with spherical silicone IOLs and toric silicone IOLs, relate to the axis of implantation.120

As rotation is the main complication for one toric IOL, it is obvious that implantation of two IOLs together may exaggerate these problems; including rotation of both IOLs in opposite directions. Although rotation is rare, to avoid counter-rotation problems, Gills sutured 2 toric lenses together and implanted them through a 6.0 mm scleral incision in a patient with high astigmatism.119

The other concerns about piggybacking IOLS are; pupillary capture of the optic, interlenticular opacification(ILO), pigment dispersion, iridocyclitis, glaucoma and hyphema.123-129

Pigment dispersion and pigmentary glaucoma have been reported with placement of IOLs with sharp anterior optic edges in the ciliary sulcus.126,127 IOLs with rounded anterior optic edges are required for piggybacking.124 An unusual and rare complication of piggyback IOL insertion is posterior capsular rupture (PCR).129

Proper preoperative planning along with IOL type and patient selection are the most critical steps for performing this technique successfully. Orienting the toric lens by using preoperative keratometry or corneal topography to determine the steep axis of cylinder may not produce accurate results due to possibility of the cylinder changes induced by the cataract incision.117

Multiple peer-reviewed publications have demonstrated the effectiveness of both primary and secondary placement of piggyback spherical and toric IOLs as well as their possible complications.119,120,123-132

With the proper evaluation of the patient and excluding cases with pigment dispersion, elevated intraocular pressures, loose zonules from trauma or pseudoexfoliation, posterior synechia, and low endotelial cell values; implanting piggyback T-IOLs can achieve

acceptable results and may represent a good choice for correcting high astigmatism or residual cylindrical ametropia in eyes that falls outside the range for accurate correction with other surgical procedures, or with a history of previous corneal or limbal keratotomies and/or T-IOL implantation and in eyes that are not good candidates for LASIK or PRK due to ocular surface disease or suspicious corneal topography.

4. Conclusion

There are numerous techniques for dealing with astigmatism both during and after cataract surgery. Good uncorrected postoperative distance visual acuity can be obtained for a high percentage of cataract patients with preexisting corneal astigmatism. Corneal astigmatism can be treated effectively at the time of cataract surgery with either toric IOLs, corneal or limbal relaxing incisions or combination of all. There are advantages and disadvantages to each method. The appropriate patient-based plan of either one or a combination of these different surgical techniques, can provide a greater ability to correct cylindrical errors intraoperatively, achieving improved visual acuity and visual quality independent of spectacles. It should be kept in mind that postoperative keratorefractive surgery may also be available to enhance the condition of patients who achieve less-than-optimal astigmatic results.

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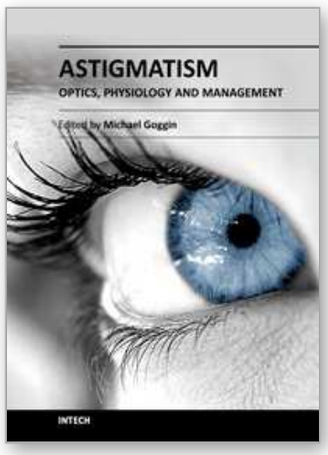
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This book explores the development, optics and physiology of astigmatism and places this knowledge in the context of modern management of this aspect of refractive error. It is written by, and aimed at, the astigmatism practitioner to assist in understanding astigmatism and its amelioration by optical and surgical techniques. It also addresses the integration of astigmatism management into the surgical approach to cataract and corneal disease including corneal transplantation.

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