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Toric Intraocular Lenses in Cataract Surgery

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1. Introduction

In modern cataract surgery, spectacle freedom is becoming more and more important. Emmetropia can be achieved for patients with myopic or hyperopic refractive errors by selecting the appropriate spherical lens power. However, approximately 20% of patients who undergo cataract surgery have 1.25 diopters (D) of corneal astigmatism or more. (Ferrer-Blasco, Montes-Mico et al. 2009; Hoffmann and Hutz 2010) Not correcting the astigmatism component at the time of cataract surgery will fail to achieve spectacle independence.

In patients with substantial amounts of corneal astigmatism several options exist to correct astigmatism during or after cataract surgery. Limbal relaxing incisions or opposite clear corneal incisions may be performed to reduce astigmatism during cataract surgery. After cataract surgery, laser refractive surgery may be used to correct residual refractive errors, including cylinder errors. However, corneal incision procedures are relatively unpredictable and laser refractive surgery may be associated with complications such as dry eyes, wound healing problems and infections. (Bayramlar, Daglioglu et al. 2003; de Oliveira, Solari et al. 2006; Kato, Toda et al. 2008; Thomas, Brunstetter et al. 2008) Toric IOLs now provide the opportunity to correct corneal astigmatism, offering patients with pre-existing astigmatism optimal distance vision without the use of spectacles or contact lenses with a cylindrical correction. Furthermore, the recent introduction of multifocal toric IOLs offers patient with pre-existent corneal astigmatism the opportunity not only to achieve spectacle independence for distance vision, but also for near and intermediate visual acuities.

2. Toric intraocular lenses

The first toric IOL was presented by Shimizu et al. in 1994. (Shimizu, Misawa et al. 1994) This was a non-foldable three-piece toric IOL made from poly-methyl methacrylate (PMMA). It consisted of an oval optic with loop haptics and was available in cylinder powers of 2.00 D or 3.00 D. Postoperatively, about 20% of the IOLs rotated 30 degrees or more and almost 50% of IOLs rotated more than 10 degrees. Rotational stability is a crucial factor in the safety and efficacy of toric IOLs, since as little as 10 degrees of axis misalignment reduces the efficacy of the astigmatic correction by 33%. Misalignment of more than 30 degrees may even induce astigmatism. (Shimizu, Misawa et al. 1994) Since 1994, many advancements have been made in toric IOL technology, including improvements in IOL material and design and refinements in surgical technique. These advances have led to an improved postoperative rotational stability and excellent visual outcomes using currently available toric IOLs. Table 1 provides an overview of the characteristics of the currently available toric IOLs.

Toric IOL	Company	Model	Material	Aspheric	IOL design	Toric surface	IOL diameter (mm)	Available Spherical powers (D)	Available Cylinder powers (D)	Incision size (mm)	Availability
Acrysof	Alcon	SN60T3 to SN60T9	Hydrophobic acrylic	Yes, but limited availability	1-Piece open loop	Posterior	13.0	+6.0 to +30.0	1.5 to 6.0 (0.75 steps)	2.2	US: SN60T3-T5 Europe: SN60T3-T9 Asia : SN60T3-T9
Acri.Comfort / AT Torbi ^	Carl Zeiss Meditec	6461LC	Hydrophilic acrylic with hydrophobic surface	Yes	Plate	Anterior + Posterior	11.0	-10.0 to +32.0	1.0 to 12.0* (0.50 steps)	<2.0	Europe, Asia
T-flex	Rayner	573T 623T	Hydrophilic acrylic	Yes	1-Piece closed loop	Anterior	12.0 (573T) 12.5 (623T)	-10.0 to +35.0	1.0 to 11.0* (0.25 steps)	<2.0	Europe, Asia
Lentis Trplus	Oculentis	LS-312 T1 to T6 / LU-313 T1 to T6	Hydrophilic acrylic with hydrophobic surface	Yes	1-Piece open loop (LS-312)/ Plate (LU-313)	Anterior	12.0 (LS-312) / 11.0 (LU-313)	0.0 to +30.0	0.5 to 12.0* (0.75 / 0.01* steps)	2.6	Europe, Asia
STAAR	Staar Surgical Company	AA4203TF AA4203TL	Silicone	No	Plate	Anterior	10.8 (TF) 11.2 (TL)	+9.5 to +23.5 (TL) +24.0 to +28.5 (TF)	2.0 or 3.5	2.8	US
MicroSil/ Torica ^	HumanOptics	6116 TU / -S^	Silicone with PMMA haptics	No	3-Piece open loop	Posterior	11.6	-3.5 to +31.0	2.0 to 12.0# (1.0 steps)	3.4	Europe, Asia

^ = Same IOL model under different name;

* = Highest cylinder powers are custom made;

= Higher cylinder powers available (customized)

Table 1. Currently available monofocal Toric Intraocular lenses

2.1 IOL material

The IOL biomaterial is of great influence on the postoperative rotation of the IOL. Older toric IOL models such as the STAAR toric IOL (STAAR Surgical Company, Monrovia, California) and the MicroSil toric IOL (HumanOptics, Erlangen, Germany) were made of silicone materials and showed relatively high postoperative misalignment rates and often required surgical realignment. As visible in Table 1, currently available toric IOLs are usually made of acrylic material.

After implantation of the toric IOL in the capsular bag, the anterior and posterior capsules fuse with the IOL which prevents IOL rotation. Therefore, strong IOL adhesion to the capsular bag is thought to prevent IOL rotation. Several *in vitro* studies have examined the interactions between different IOL materials and the capsular bag. Lombardo et al. used atomic force microscopy to determine IOL optic surface adhesiveness and found that hydrophobic acrylic IOLs showed the highest adhesive properties, followed by hydrophilic acrylic IOL, PMMA IOLs and finally silicone IOLs. (Lombardo, Carbone et al. 2009) In addition, Oshika et al. examined the adhesive forces between IOLs and bovine collagen sheets and demonstrated that acrylic IOLs formed the strongest adhesions to the capsular bag, followed by PMMA IOLs and silicone IOLs. (Oshika, Nagata et al. 1998) An animal study in which rabbits underwent phacoemulsification with IOL implantation confirmed the latter results. (Oshika, Nagata et al. 1998) Three weeks after IOL implantation, acrylic IOLs showed the strongest adhesions with the capsular bag, followed by PMMA and silicone IOLs.

Linnola et al. hypothesize that IOL materials show differences in IOL adhesion due to a different affinity to proteins in the capsular bag. (Linnola, Sund et al. 2003) Extracellular matrix proteins, such as fibronectins, vitronectin and collagen type IV, may be involved in IOL adhesion to the capsular bag. According to Linnola et al., these proteins are present in plasma but also available in the aqueous humor after cataract surgery due to break down of the blood-aqueous barrier. (Linnola, Sund et al. 2003) In an *in vitro* study in which different IOLs were incubated for 1 week with extracellular matrix proteins, each IOL material was found to have a different affinity to these proteins. (Linnola, Sund et al. 2003) Fibronectin bound significantly better to hydrophobic acrylic IOLs, whereas collagen type IV bound significantly better to hydrophilic acrylic IOLs and vitronectin to silicone IOLs. A histological study using human pseudophakic autopsy eyes also showed that fibronectin was the primary protein between acrylic IOLs and the capsular bag. (Linnola, Werner et al. 2000) In addition, acrylic IOLs explanted from human autopsy eyes contained significantly more fibronectin and vitronectin compared to silicone or PMMA eyes. (Linnola, Werner et al. 2000) These results indicate that different IOL materials use different proteins to bind to the capsular bag and that acrylic IOLs generally form the strongest adhesions with the capsular bag.

2.2 IOL design

The IOL design is of interest in avoiding postoperative IOL rotation and achieving good postoperative outcomes. The overall IOL diameter has been shown to be a major factor in the prevention of IOL rotation. (Chang 2003) Chang et al. compared two different sizes of the same toric IOL: the STAAR AA4203TF model with a diameter of 10.8 mm and the STAAR AA4203 TL model with a diameter of 11.2 mm. The longer STAAR model was found to have a much better rotational stability compared to the shorter STAAR model. Currently available toric IOLs however have a total IOL diameter ranging from 11.0 mm to 13.0 mm (Table 1),

which has been shown to be effective in avoiding IOL rotation. (Ahmed, Rocha et al. 2010; Alio, Agdeppa et al. 2010; Holland, Lane et al. 2010; Entabi, Harman et al. 2011)

Regarding the IOL haptics design, two different IOL designs are available: plate haptic IOLs, such as the Acri.Comfort and STAAR toric IOLs, and loop haptic IOLs, such as Acrysof and Rayner T-flex toric IOLs (Figure 1). Buckhurst et al. hypothesize that loop haptic IOLs have a better early rotational stability compared to plate haptic IOLs due to the longer haptics and consequently more contact between haptics and capsular bag. (Buckhurst, Wolffsohn et al. 2010) Plate haptics, however, are thought to be less susceptible to the compression of the capsular bag, which may prevent late IOL rotation. (Patel, Ormonde et al. 1999) Patel et al. compared the early (2 weeks) and late (2 weeks to 6 months) rotation of plate and loop haptic silicone IOLs in a randomised study. (Patel, Ormonde et al. 1999) Even though early postoperative rotation were comparable, late postoperative rotation was significantly higher in loop haptic IOLs compared to plate haptic IOLs: 6.8 degrees versus 0.6 degrees, respectively. However, Prinz et al. recently compared plate-haptic and loop-haptic acrylic

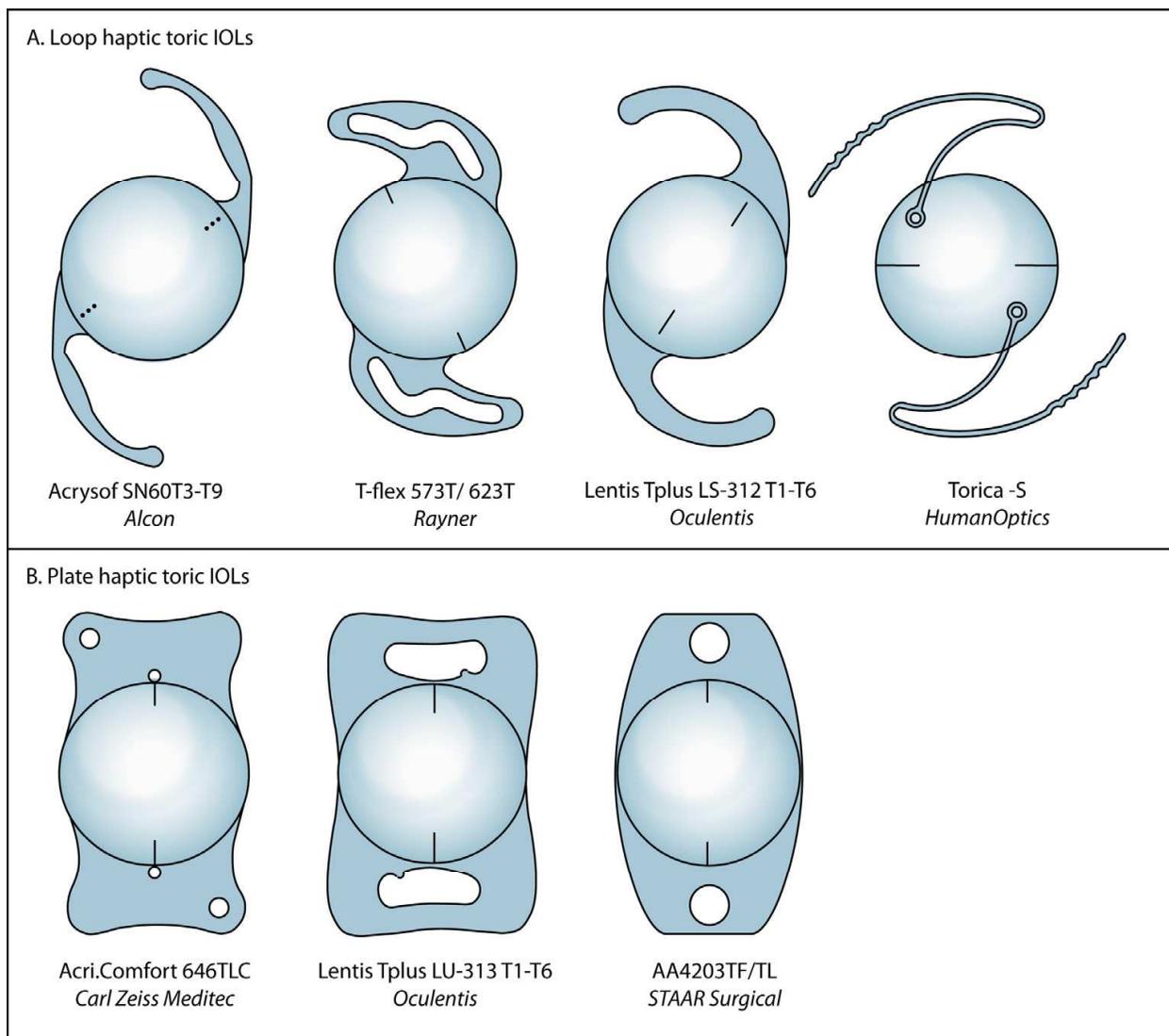


Fig. 1. Currently available loop haptic (A) and plate haptic (B) toric intraocular lenses (IOLs).

IOLs and did not find a significant difference in early and late rotation. (Prinz, Neumayer et al. 2011) Since both the plate and loop haptic IOLs in this study were made of acrylic material, it is possible that adhesion of the acrylic IOL to the capsular bag prevented postoperative rotation. This indicates that for acrylic IOLs, plate and loop haptics demonstrate equally good rotational stability.

3. Patient selection

3.1 Monofocal toric IOLs

3.1.1 Minimal astigmatism

Achieving success with toric IOLs depends on the selection of suitable patients. Depending on the toric IOL model, the minimal available toric IOL power at the IOL plane is 1.0 D for the Acri.Comfort or Rayner toric IOLs and 1.5 D for the AcrySof toric IOLs (Table 1). At the corneal plane, this corresponds to a minimal corneal power of approximately 0.75 to 1.00 D, respectively. Taking into consideration the amount of astigmatism induced by the surgery, patients must have a corneal astigmatism of at least 1.00 to 1.25 D in order to be candidates for a toric IOL.

3.1.2 Corneal astigmatism

Patients with regular bow-tie astigmatism are most suitable for toric IOL implantation. Corneal topography is therefore important for detecting irregular astigmatism and keratoconus. Two systems are available to perform corneal topography: placido-disk videokeratoscopy and Scheimpflug imaging. Even though measurements of corneal curvature obtained with both systems show moderate to good correlations, important differences exist between these two systems that may be relevant in toric IOL candidates. (Savini, Barboni et al. 2009; Symes, Say et al. 2010) A Placido-disk videokeratoscope reconstructs a curvature description of the anterior surface of the cornea based on the reflections of light-emitting Placido rings. (Jongsma, De Brabander et al. 1999) However, this does not reflect the corneal shape since it does not include information about the posterior corneal surface and the corneal thickness. (Belin and Khachikian 2009) Some corneal ectatic disorders, such as keratoconus, present with changes on the posterior corneal surface before any changes may be seen on the anterior corneal surface. (Tomidokoro, Oshika et al. 2000; Belin and Khachikian 2009) Furthermore, Placido-disk videokeratoscopy only gathers data from the central 8 to 9 mm of the cornea, which limits the detection of peripheral pathologies, such as pellucid marginal degeneration. (Walker, Khachikian et al. 2008)

Elevation-based topography uses a rotating Scheimpflug camera to capture cross sectional images of the anterior segment, which are then merged into a 3-dimensional reconstruction of the cornea, anterior chamber, iris and lens. This allows to evaluate the entire corneal surface (limbus to limbus) and allows for evaluation of the posterior corneal surface. Before conducting corneal topography or ocular biometry, ensure that the patient has refrained from contact lens wear for an appropriate time. Soft contact lenses should be discontinued for at least 1 week and hard contact lenses for approximately 2 weeks.

3.1.3 Other considerations

Other pre-existent ocular pathologies may be a contraindication for toric IOL implantation. Patients with Fuchs' endothelial dystrophy or a different corneal dystrophy might need a keratoplasty in the future and are therefore not good candidates for toric IOL implantation.

Patients with potential bag instability like patients with pseudoexfoliation syndrome or trauma induced zonulolysis are also bad candidates.

3.2 Multifocal toric IOLs

Patient selection is crucial for achieving success with multifocal toric IOLs. The first step is to determine if the patient is a suitable candidate for a multifocal IOL. The ideal patient is motivated about achieving spectacle independency for both distance and near vision, understands the limitations of multifocal IOLs and has realistic expectations. (Assil, Christian et al. 2008)

The second step is to determine possible ocular co-morbidities. Multifocal IOLs split the available light between distance and near focus. Therefore, ocular co-morbidities that affect the visual acuity or the quality of vision are a relative or absolute contraindication for multifocal toric IOLs. These include amblyopia, corneal pathology (such as keratoconus, corneal scar or Fuchs' endothelial dystrophy), maculopathy (such as macular degeneration or diabetic retinopathy), glaucoma and uveitis. (Assil, Christian et al. 2008; Kohnen, Kook et al. 2008) An extensive preoperative ophthalmic examination is therefore required, including corneal topography, endothelial cell count, ophthalmoscopy and preferably optical coherence tomography.

4. IOL calculation

4.1 Keratometry

Accurate keratometry measurements must be obtained to ensure successful astigmatism correction with toric IOLs. Clinical studies on toric IOLs describe various methods of keratometry: IOLMaster automated keratometry, manual keratometry, autokeratorefractometry, corneal topography, or a combination of these techniques. (Bauer, de Vries et al. 2008; Chang 2008; Dardzhikova, Shah et al. 2009; Ahmed, Rocha et al. 2010; Gayton and Seabolt 2010; Holland, Lane et al. 2010) Keratometry measurements obtained by automated keratometry, manual keratometry and corneal topography have been shown to have a high repeatability and are generally well comparable between devices. (Santodomingo-Rubido, Mallen et al. 2002; Findl, Kriechbaum et al. 2003; Elbaz, Barkana et al. 2007; Shirayama, Wang et al. 2009) However, differences between devices have been reported, indicating that keratometry values should not be used interchangeably. (Santodomingo-Rubido, Mallen et al. 2002; Elbaz, Barkana et al. 2007; Shirayama, Wang et al. 2009)

4.2 Surgically induced astigmatism

Another important aspect to consider in toric IOL calculation is the amount of astigmatism induced by the surgery itself. The expected amount of surgically induced astigmatism (SIA) has to be incorporated into the toric IOL power in order to select the most appropriate toric IOL model. (Hill 2008) However, the exact amount of SIA is difficult to predict and depends on several factors. The location of the incision is an important factor to consider, since corneal incisions lead to flattening of the incised meridian. An incision at the steep meridian of the cornea will flatten this meridian and will result in steepening of the orthogonal meridian due to the coupling (flattening/steepening) effect, which will reduce overall corneal astigmatism. (Borasio, Mehta et al. 2006) Consequently, an incision located at the flat meridian will increase overall corneal astigmatism. Furthermore, temporal incisions have

been shown to induce less SIA compared to superior incisions. (Tejedor and Murube 2005) This is possibly due to a higher incidence of against-the rule astigmatism in the elderly cataract population or due to a more peripheral location of the temporal incision on the cornea. (Fledelius and Stubgaard 1986; Kohnen, Dick et al. 1995) The size of the incision has also been shown to influence the amount of SIA: smaller incisions generally produce less SIA. (Kohnen, Dick et al. 1995) Other factors that are of influence are the amount of preoperative corneal astigmatism, suture use and patients' age. (Storr-Paulsen, Madsen et al. 1999) Developments in phacoemulsification techniques have led to an improved management of SIA. The shift to smaller incisions has reduced the need for suturing, thus decreasing SIA. In addition, the recent development of microincisional cataract surgery, surgery performed through incisions smaller than 2.0 mm, aims to further reduce the SIA.

Many studies have measured the amount of SIA following cataract surgery with incision sizes ranging from less than 2 mm up to 3.4 mm. However, it is difficult to compare these studies, because they use variable incision locations and sizes and variable follow-up durations. STAAR and MicroSil toric IOLs require a 2.8 and 3.4 mm incision for IOL implantation, respectively (Table 1). Incision sizes of 2.8 to 3.2 mm have been shown to induce a SIA of 0.4 to 0.8 D for temporal incisions, 0.6 D for superior incisions and 0.9 to 1.2 D for on-axis incisions. (Alio, Rodriguez-Prats et al. 2005; Borasio, Mehta et al. 2006; Moon, Mohamed et al. 2007; Morcillo-Laiz, Zato et al. 2009; Wang, Zhang et al. 2009) Acrysof toric IOLs require a 2.2 mm incision for IOL implantation. These incisions have been shown to induce a SIA of 0.2 to 0.3 D for temporal incisions and 0.4 D for superior incisions. (Lee, Kwon et al. 2009; Wang, Zhang et al. 2009; Visser, Ruiz-Mesa et al. 2011) Finally, Acri.Lisa and Rayner toric IOLs may be implanted through sub 2.0 mm incisions. Microincision cataract surgery has been shown to result in a SIA of approximately 0.3 D for temporal incisions, 0.5 D for superior incisions and 0.4 D for on-axis incisions. (Alio, Rodriguez-Prats et al. 2005; Kaufmann, Krishnan et al. 2009; Lee, Kwon et al. 2009; Morcillo-Laiz, Zato et al. 2009) In practice, the most accurate method to determine the SIA is for every surgeon to personalize the amount of SIA induced by cataract surgery in his/her patient population. This may be done by analysing preoperative and postoperative corneal astigmatism changes using a standard vector analysis. (Alpins 2001; Holladay, Moran et al. 2001)

5. IOL implantation

5.1 Marking techniques

Crucial to the efficacy of toric IOLs is exact alignment of the toric IOL at the calculated alignment axis. Accurate marking of the alignment axis should be performed with the patient in an upright position in order to prevent cyclotorsion in the supine position. Cyclotorsion of the eye from the upright to supine position is approximately 2 to 4 degrees on average, but can be up to 15 degrees in individual patients. (Arba-Mosquera, Merayo-Llodes et al. 2008; Chang 2008; Febbraro, Koch et al. 2010) Cyclotorsion is a well known aspect in refractive surgery and compensated for during laser refractive surgery. (Febbraro, Koch et al. 2010)

Most clinical studies on toric IOLs describe using a 3-step marking procedure for toric IOL implantation. The first step consists of preoperative limbal marking of the horizontal axis of the eye with the patient sitting upright to correct for cyclotorsion. This may be done with the patient seated at the slitlamp and with a coaxial thin slit turned to 0-180 degrees. (Mendicute, Irigoyen et al. 2008; Alio, Agdeppa et al. 2010; Koshy, Nishi et al. 2010) The

limbus is then marked at the horizontal position with either a sterile ink pen or a needle. Another technique to mark the horizontal axis is by using a bubble-marker, such as a Nuijts/Lane Toric Reference Marker (ASICO) (Figure 2) or a Bakewell BubbleLevel (Mastel Precision, Rapid City, US), or by using a gravity marker with a calibrated horizontal position, such as the LRI Gravity Marker (Rumex, Sint Petersburg, Florida, US). (Bauer, de Vries et al. 2008; Ahmed, Rocha et al. 2010; Gayton and Seabolt 2010) Intraoperatively, the preoperative horizontal marks are used to position an angular graduation instrument. The actual alignment axis is marked using a toric axis marker.

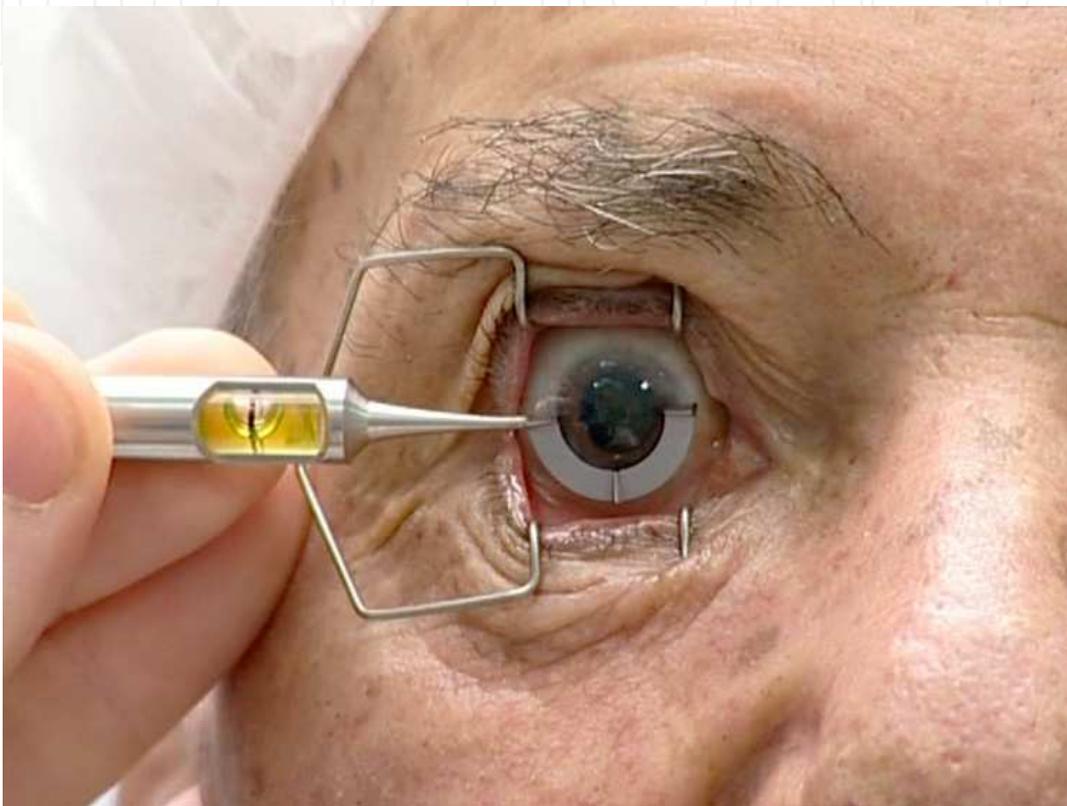


Fig. 2. Preoperative marking of the horizontal axis of the eye using the Nuijts/Lane Toric Reference Marker with bubble-level (ASICO). This is done with the patient sitting upright to correct for cyclotorsion.

One study has evaluated the accuracy of a 3-step marking procedure for toric IOL implantation. (Visser, Berendschot et al. 2011) The mean errors in horizontal axis marking, alignment axis marking and toric IOL alignment were 2.4 ± 0.8 (maximum 8.7) degrees, 3.3 ± 2.0 (maximum 7.7) degrees and 2.6 ± 2.6 (maximum 10.5) degrees, respectively. Together, these 3 errors led to a mean total error in toric IOL alignment of 4.9 ± 2.1 degrees. However, for the individual patient, this may be as high as 10 degrees. This indicates that great accuracy in toric IOL alignment is necessary in all patients in order to achieve the most optimal astigmatism correction with toric IOLs.

Currently, new techniques have become available to ensure accurate intraoperative alignment of toric IOLs. Osher has described an iris-fingerprinting technique, in which preoperative detailed images of the eye are obtained. (Osher 2010) The desired alignment axis is drawn in this image. A printout of this image is then used during surgery to align the toric IOL based on iris characteristics. A second technique to accurately align toric IOLs is by

intraoperative wavefront aberrometry (ORange, WaveTec Vision Systems). This device is connected to the operating microscope and enables intraoperative measurement of residual refraction. (Packer 2010) It allows to accurately position toric IOLs, based on actual residual refractive cylinder results. A third device, the SG3000 (Sensomotoric Instruments, Teltow, Germany) uses real-time eye-tracking, based on iris and blood vessel characteristics. (Visser, Berendschot et al. 2011) Preoperatively, a detailed image of the eye is captured, in which blood vessel and iris characteristics are visible. Simultaneously, keratometry is performed and the location of the steep and flat corneal meridians are shown in this image. Intraoperatively, the preoperative image is matched with the live surgery-image from the operating microscope, based on blood vessel and iris characteristics. Using a microscope embedded display, the overlay showing the desired alignment axis is visible in the operating microscope, allowing exact alignment of the toric IOL. In addition, this eye-tracking technology may also be used for other aspects in lens implantation surgery, including planning of the incisions and capsulorrhexis and optimal centration of multifocal IOLs.

5.2 Surgery

A standard phacoemulsification technique may be performed with a 1.5 to 3.4 mm limbal incision, depending on the toric IOL model to be implanted (Table 1). A well centered capsulorrhexis with 360 degree overlap of the IOL optics should be achieved. The optic diameter is 6.0 mm for Acrysof, Acri.lisa, MicroSil and STAAR toric IOLs and 5.75 or 6.25 mm for Rayner toric IOLs. The ideal capsulorrhexis diameter is therefore 5.0 to 5.5 mm.

After the phacoemulsification is completed and the ophthalmic viscosurgical device is injected, the foldable toric IOL is inserted through the limbal incision. The marks on the toric IOL indicate the flat meridian or plus cylinder axis of the toric IOL and should be aligned with the marked alignment axis. First, gross alignment is achieved by rotating the IOL clockwise while it is unfolding, until approximately 20 to 30 degrees short of the desired position. After the ophthalmic viscosurgical device is removed, the IOL is rotated to its final position by exact alignment of the reference marks on the toric IOL with the limbal axis marks.

In the event of a complication during surgery that might compromise the stability of the toric IOL, such as zonular damage, vitreous loss, capsulorrhexis tear, or capsular rupture, conversion to a standard non-toric IOL may be required.

5.3 Postoperative axis measurement

Postoperatively, the orientation axis of the toric IOL must be verified to confirm optimal alignment and ensure no postoperative IOL rotation has occurred. Postoperative assessment of toric IOL alignment can be achieved by several methods. The most commonly used method in the clinic is assessment using a slitlamp with rotating slit. Since the IOL marks are located at the periphery of the IOL optic, full mydriasis of the pupil is required. An objective method to determine postoperative toric IOL alignment is by wavefront aberrometry (Figure 3). (Carey, Leccisotti et al. 2010) Combined wavefront aberrometers and corneal topographers, such as the Keratron Onda (Optikon, Rome, Italy), iTrace (Tracey Technologies, Houston, TX, USA) and OPD-scan (Nidek, Gamagori, Japan), discriminate between aberrations caused by the cornea and by the internal ocular system. (Carey, Leccisotti et al. 2010; Visser, Berendschot et al. 2010) This method therefore directly determines the orientating of the toric IOL. Pupil dilation is not required.

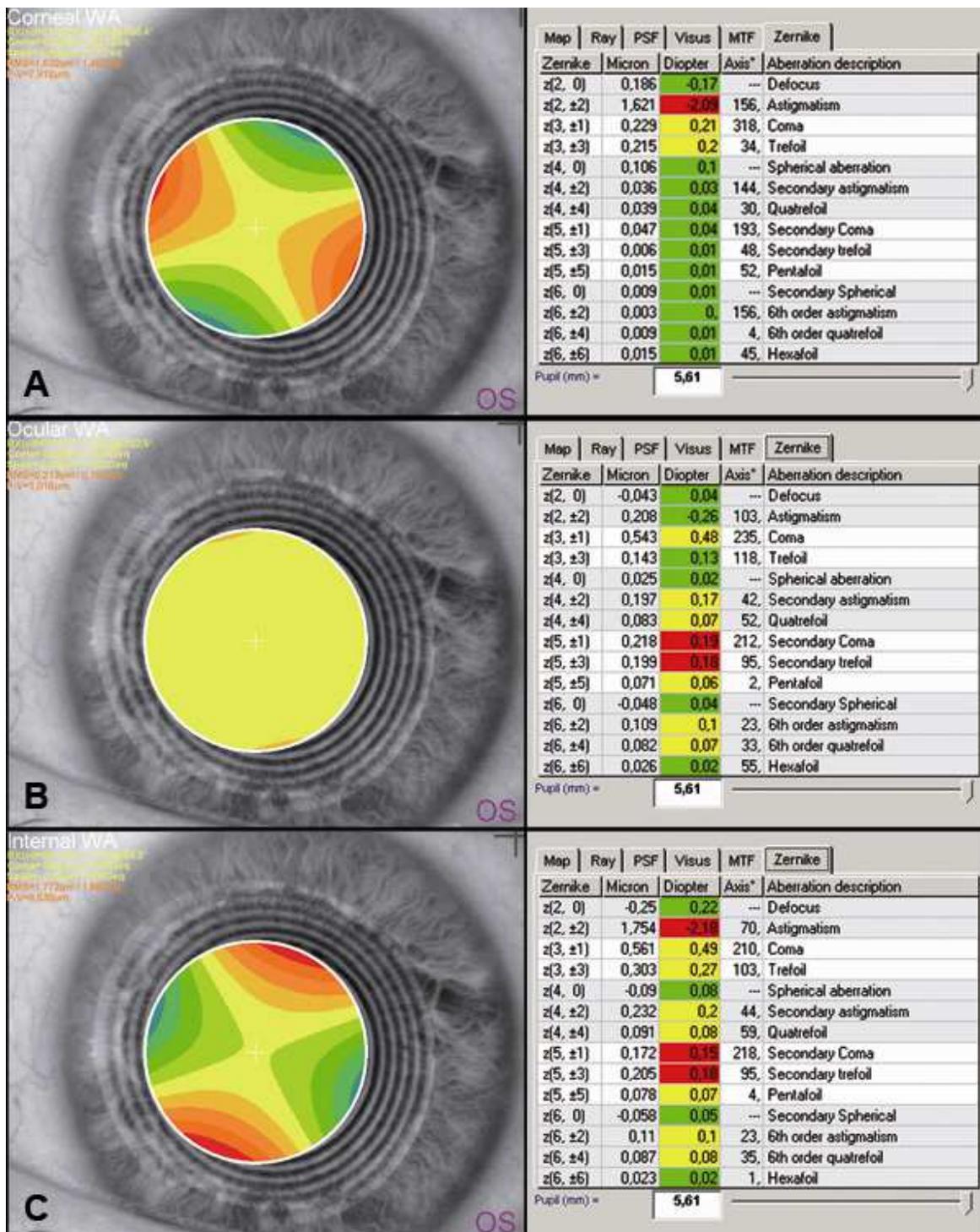


Fig. 3. Combined wavefront aberrometry and corneal topography allows to objectively determine the postoperative orientation of the toric intraocular lens axis. In this example, Corneal wavefront aberrometry (A) and Ocular wavefront aberrometry (B) were performed using the Keratron Onda (Optikon, Rome). The Internal aberrations (C) are calculated by subtracting the Corneal aberrations from the Ocular aberrations. In this example, corneal astigmatism was -2.09 diopters (D) at 156 degrees and ocular astigmatism was -0.26 D at 103 degrees. The internal astigmatism was -2.18 D at 70 degrees, which indicates that the toric intraocular lens axis is located at 70 degrees.

Realignment of a rotated toric IOL should ideally be performed as soon as possible and preferably before 2 weeks postoperatively because of the formation of adhesions between the capsular bag and IOL optics. (Linnola, Sund et al. 2003; Chang 2009)

6. Clinical outcomes

6.1 Monofocal toric IOLs

Table 2 provides an overview of the main outcomes of clinical studies on toric IOLs. In order to compare the visual outcomes, LogMAR values have been converted into Snellen values.

6.1.1 Visual outcomes

One randomized clinical trial has been conducted on toric IOLs. Holland et al. included 517 patients: 256 patients received unilateral implantation of an Acrysof toric IOL (T3, T4 or T5) and 261 patients received unilateral implantation with a spherical control IOL. (Holland, Lane et al. 2010) One year postoperatively, significantly more patients in the toric group achieved an UDVA of 20/40 or better compared to the control group: 92% versus 81% of patients, respectively. Furthermore, an UDVA of 20/20 or better was achieved in significantly more patients with a toric IOL compared to a control IOL (41% versus 19% of patients). As expected, the CDVA results in both groups were comparable: 93% of toric and 90% of control patients achieved a CDVA of 20/25 or better. Ahmed et al. have conducted a large non-randomized cohort study to evaluate bilateral AcrySof toric IOL (T3, T4 or T5) implantation in 117 patients (234 eyes). At 6 months postoperatively, 99% of patients had a bilateral UDVA of 20/40 or better and 63% of 20/20 or better. The mean binocular UDVA was 0.05 ± 0.11 LogMAR, equivalent to 0.89 ± 0.23 Snellen. In addition, the binocular CDVA was 0.03 ± 0.14 LogMAR, equivalent to 0.93 ± 0.30 Snellen. Many smaller non-randomized studies on Acrysof toric IOLs have been performed. (Bauer, de Vries et al. 2008; Chang 2008; Mendicute, Irigoyen et al. 2008; Zuberbuhler, Signer et al. 2008; Dardzhikova, Shah et al. 2009; Lane, Ernest et al. 2009; Ruiz-Mesa, Carrasco-Sanchez et al. 2009; Statham, Apel et al. 2009; Gayton and Seabolt 2010; Kim, Chung et al. 2010; Koshy, Nishi et al. 2010; Tsinopoulos, Tsaousis et al. 2010; Visser, Ruiz-Mesa et al. 2011) The majority of these studies examined the T3 to T5 toric IOLs, with low to moderately high cylinder powers. Most studies show a mean postoperative UDVA ranging from 0.63 to 0.90 Snellen. (Bauer, de Vries et al. 2008; Mendicute, Irigoyen et al. 2008; Ruiz-Mesa, Carrasco-Sanchez et al. 2009; Statham, Apel et al. 2009; Gayton and Seabolt 2010; Koshy, Nishi et al. 2010) An UDVA of 20/40 or better was reported in 81 to 95% of eyes. (Bauer, de Vries et al. 2008; Mendicute, Irigoyen et al. 2008; Dardzhikova, Shah et al. 2009; Gayton and Seabolt 2010) In addition, 26 to 36% of eyes achieved an UDVA of 20/20 or better. (Bauer, de Vries et al. 2008; Dardzhikova, Shah et al. 2009; Ruiz-Mesa, Carrasco-Sanchez et al. 2009; Gayton and Seabolt 2010) The reported BDVA ranges from 0.79 to 1.01. (Bauer, de Vries et al. 2008; Mendicute, Irigoyen et al. 2008; Zuberbuhler, Signer et al. 2008; Ruiz-Mesa, Carrasco-Sanchez et al. 2009; Gayton and Seabolt 2010; Kim, Chung et al. 2010) One study has examined the high cylinder toric IOLs (T6 to T9) and showed a mean UDVA of 0.61 ± 0.26 and an UDVA of 20/40 or better in 83% of eyes. (Visser, Ruiz-Mesa et al. 2011) In order to determine how effective toric IOLs are in achieving the maximal visual outcome, we have calculated the visual potential index (VPI), which is defined as the ratio of postoperative UDVA to postoperative CDVA. (Visser, Ruiz-Mesa et al. 2011) For the Acrysof toric IOL, the VPI in the majority of

studies ranged between 73 and 96%. This indicates that the uncorrected visual outcome with this IOL is 73 to 96% of the maximal visual outcome.

Rayner T-flex toric IOL implantation has been evaluated in two relatively small studies. (Stewart and McAlister 2010; Entabi, Harman et al. 2011) Entabi et al. evaluated Rayner toric IOL implantation in 33 eyes with a mean corneal astigmatism of 2.94 ± 0.89 D. (Entabi, Harman et al. 2011) Four months postoperatively, the mean UDVA was 0.28 ± 0.23 LogMAR, equivalent to 0.52 ± 0.28 Snellen. Stewart et al. evaluated T-flex toric IOL implantation in 14 eyes. (Stewart and McAlister 2010) Over 90% of eyes achieved an UDVA of 20/40 or better and the mean UDVA was 0.16 ± 0.16 LogMAR, equivalent to 0.69 ± 0.25 Snellen. The VPI in both studies was 80 and 91%. (Stewart and McAlister 2010; Entabi, Harman et al. 2011)

One study has examined visual outcomes following Acri.Comfort toric implantation in 21 eyes of 12 patients with moderate to high astigmatism. (Alio, Agdeppa et al. 2010) The mean preoperative corneal astigmatism was 3.73 ± 1.79 D.

At 3 months postoperatively, the mean UDVA was 0.65 ± 0.22 and 76% of eyes achieved an UDVA of 20/40 or better. The mean postoperative CDVA was 0.85 ± 0.15 and the VPI was 76%.

Several studies have evaluated the visual outcomes following silicone toric IOL implantation. Microsil toric IOL implantation has been shown to result in an UDVA of 20/40 or better in 68 to 85% of eyes. (De Silva, Ramkissoon et al. 2006; Dick, Krummenauer et al. 2006) In addition, the mean postoperative UDVA and BDVA were 0.63 ± 0.22 and 0.76 ± 0.19 , respectively. (De Silva, Ramkissoon et al. 2006) Studies using STAAR toric IOLs have shown an UDVA of 20/40 or better in 66 to 84% of eyes and a mean UDVA ranging from 0.54 to 0.62. (Ruhswurm, Scholz et al. 2000; Sun, Vicary et al. 2000; Leyland, Zinicola et al. 2001; Till, Yoder et al. 2002; Chang 2003) The VPI was 83% for MicroSil toric IOLs and 66 to 68% for STAAR toric IOLs. (Ruhswurm, Scholz et al. 2000; Leyland, Zinicola et al. 2001; De Silva, Ramkissoon et al. 2006)

6.1.2 Refractive outcomes

The randomized controlled trial on Acrysof toric IOLs has shown a significantly better refractive cylinder outcome in patients implanted with a toric IOL compared to patients with a monofocal IOL: 88% of eyes with a toric IOL achieved a residual refractive cylinder of 1.00 D or less, compared to 48% of eyes in the control group. Fifty-three percent of patients with a toric IOL achieved a residual refractive cylinder of 0.5 D or less. In addition, the mean residual refractive cylinder in the toric group was significantly lower compared to the control group (-0.59 D versus -1.22 D, respectively). Other studies on Acrysof toric IOLs show a residual refractive cylinder of 1.00 D or less in about 80 to 100% of eyes and a mean residual refractive cylinder ranging from -0.28 to -0.75 D. (Ahmed, Rocha et al. 2010; Kim, Chung et al. 2010; Visser, Ruiz-Mesa et al. 2011)

After Rayner toric IOL implantation, the mean residual refractive cylinder has been shown to range from -0.89 to -0.95 D. (Stewart and McAlister 2010; Entabi, Harman et al. 2011) Acri.Comfort toric IOL implantation resulted in a mean residual refractive cylinder of -0.45 ± 0.63 . (Alio, Agdeppa et al. 2010) Furthermore, based on a vector analysis of the refractive outcomes, the Acri.Comfort IOL has been shown to correct 91% of pre-existing astigmatism. (Alio, Agdeppa et al. 2010) (Ruhswurm, Scholz et al. 2000; Leyland, Zinicola et al. 2001; Till, Yoder et al. 2002)

Author, year	Toric IOL	Design	N	FU	Preoperative		Postoperative								
					Corneal astigmatism Mean ± SD (D)	Refractive Cylinder Mean ± SD (D)	≤1.0 D (%)	≤0.5 D (%)	Mean ± SD (D)	UDVA (%)	BDVA Mean ± SD (%)	VPI (%)	Misalign- ment Mean ± SD (°)	>10° (%)	
Holland, 2010	Acrysof T3-T5	RCT	256	12	-	-0.59	88	53	-	92	41	-	-	3.0	7
Ahmed, 2010	Acrysof T3-T5	PCS	234	6	1.7 ± 0.4	-0.4 ± 0.4	90	71	0.89 ± 0.23* (binocular)	99	63	0.93 ± 0.30* (binocular)	96	2 ± 2	0
Gayton, 2010	Acrysof T3-T5	RS	120	1.5	1.40 ± 0.70	-0.30 ± 0.40	-	-	0.63 ± 0.29* (binocular)	81	26	0.91 ± 0.15* (binocular)	69	-	-
Dardzhikova, 2009	Acrysof T3-T5	PCS	111	6	1.63 ± 0.67	-0.32 ± 0.38	94	-	-	95	36	-	-	-	5
Chang, 2008	Acrysof T3-T5	PCS	100	1	-	-0.53	-	-	-	-	-	-	-	3.4 ± 3.4	1
Lane, 2009	Acrysof T3-T5	PCS	80	6	-	-	95	60	1.07* (binocular)	-	-	1.23* (binocular)	87	-	-
Visser, 2011	Acrysof T6-T9	PCS	67	6	3.59 ± 0.80	-0.75 ± 0.49	81	-	0.61 ± 0.26 (binocular)	83	5	0.81 ± 0.21 (binocular)	75	3.2 ± 2.8	1
Bauer, 2008	Acrysof T3-T5	PCS	53	4	2.31 ± 0.72	-	91	-	0.84 ± 0.22 (binocular)	91	49	1.01 ± 0.20 (binocular)	83	3.5 ± 1.9	0
Zuberhuhler, 2008	Acrysof T3-T5	RS	44	3	2.37	-	-	-	0.98 ± 0.25* (binocular)	-	-	0.98 ± 0.25* (binocular)	-	2.2 ± 2.2	0
Ruiz-Mesa, 2009	Acrysof T3-T5	PCS	32	6	2.28	-0.53 ± 0.30	-	-	0.89 ± 0.09 (binocular)	-	56	0.95 ± 0.09 (binocular)	94	0.9	0
Koshy, 2010	Acrysof T3-T5	PCS	30	6	1.97 ± 0.58	-0.92 ± 0.43 [^]	-	-	0.63* (binocular)	-	-	-	-	2.7 ± 2.0	0
Kim, 2010	Acrysof T3-T5	PCS	30	13	1.63 ± 0.43	-0.28 ± 0.38	100	87	0.47 ± 0.19* (binocular)	-	-	0.79 ± 0.09* (binocular)	59	3.5 ± 3.4	3
Mendicuti, 2008	Acrysof T3-T5	PCS	30	3	2.35	-0.72 ± 0.43	97	80	0.69 ± 0.29* (binocular)	93	-	0.95 ± 0.11* (binocular)	73	3.6 ± 3.1	3
Tsinopoulos, 2010	Acrysof T3-T5	PCS	29	6	-	-0.64 ± 0.61	86	-	-	90	-	-	-	2.7 ± 1.5	0
Entabli, 2011	Rayner	PCS	33	4	2.94 ± 0.89	-0.95 ± 0.66	-	-	0.52 ± 0.28* (binocular)	70	-	0.65 ± 0.34* (binocular)	80	3.4	9
Stewart, 2010	Rayner	RS	14	1	1.74 ± 0.83	-0.89 ± 0.48	-	-	0.69 ± 0.25* (binocular)	93	36	0.76 ± 0.26 (binocular)	91	5.5 ± 4.7	21
Allo, 2010	Acrt Comfort	PCS	21	3	3.73 ± 1.79	-0.45 ± 0.63	-	-	0.65 ± 0.22 (binocular)	76	-	0.85 ± 0.15 (binocular)	76	1.8 ± 2.9	0
Dick, 2006	Microsil	PCS	68	3	5.30	-0.89 ± 0.70	-	25	-	68	12	-	-	3.7	2
De Silva, 2006	Microsil	PCS	21	6	3.08 ± 0.76	-1.23 ± 0.90	-	-	0.63 ± 0.22* (binocular)	85	-	0.76 ± 0.19* (binocular)	83	5	10
Sun, 2000	Staar TF	RS	130	6.9	2.57 ± 1.15	-1.03 ± 0.79	-	-	0.62 ± 0.30* (binocular)	84	-	-	-	-	33
Till, 2002	Staar TL/TF	PCS	100	5.8	2.11 ± 0.90	-	75	48	-	66	7	-	-	-	>14
Chang, 2003	Staar TL/TF	RS	61	1	-	-0.92 ± 0.87	-	-	-	-	-	-	-	-	10 (TL) 45 (TF)
Leyland, 2001	Staar TF	PCS	22	2	2.97 ± 0.88	-0.85 ± 0.66	64	-	0.54 ± 0.31 (binocular)	-	-	0.79 ± 0.26 (binocular)	68	8.9 ± 11.6	23
Rushwurm, 2000	Staar TF	RS	37	20	2.70 ± 0.88	-0.84 ± 0.63	78	49	0.61 ± 0.29 (binocular)	68	19	0.92 ± 0.24 (binocular)	66	-	45

N = number of eyes; FU = follow-up; SD = standard deviation; D = dioptres; ° = degrees; % = percentage; UDVA = uncorrected distance visual acuity; BDVA = best-corrected distance visual acuity; VPI = visual potential index; RCT = randomised controlled trial; PCS = prospective cohort study; RS = retrospective study; * = converted from LogMAR to Snellen; ^ = obtained by wavefront aberrometry

Table 2. Literature on monofocal toric IOLs

Regarding the silicone toric IOL, the postoperative residual astigmatism ranged from -0.84 to -1.23 D. (Ruhswurm, Scholz et al. 2000; Sun, Vicary et al. 2000; Leyland, Zinicola et al. 2001; Chang 2003; De Silva, Ramkissoon et al. 2006; Dick, Krummenauer et al. 2006) About 70% of eyes implanted with a STAAR toric IOLs achieved a residual refractive cylinder of 1.0 D or less and approximately 50% achieved a residual refractive cylinder of 0.5 D or less. (Ruhswurm, Scholz et al. 2000; Leyland, Zinicola et al. 2001; Till, Yoder et al. 2002)

6.1.3 Spectacle independence

Spectacle independence following toric IOL implantation has been reported in approximately 60% of patients implanted with a toric IOL, compared to 36% of patients implanted with a control IOL. (Holland, Lane et al. 2010) However, patients in this study only received unilateral toric IOL implantation. Lane et al. offered patients from the aforementioned study fellow-eye implantation with the same IOL (Acrysof toric IOL or Acrysof non-toric IOL), allowing bilateral examination of spectacle independence. (Lane, Ernest et al. 2009) Almost all patients (97%) with a toric IOL reported not using spectacles for distance vision, compared to half of the patients in the control group. Finally, Ahmed et al. examined spectacle use in bilaterally implanted patients and found that 69% of patients never used spectacles for distance vision. (Ahmed, Rocha et al. 2010)

6.1.4 Rotational stability

Crucial to the efficacy of all toric IOLs is the position of the IOL with regards to the intended alignment axis, since every degree of misalignment leads to residual astigmatism. Misalignment of the IOL may be caused by two factors: inaccurate placement of the IOL and rotation of the IOL. Currently, a misalignment of more than 10 degrees is generally regarded as the indication for surgical repositioning.

Rotational stability used to be an issue in toric pseudophakic IOLs made of silicone material. For example, STAAR toric IOLs were found to have a high incidence of eyes with more than 10 degrees of IOL misalignment: 14 to 45% for the shorter TF model 10 to 14% for the longer TL model. (Ruhswurm, Scholz et al. 2000; Sun, Vicary et al. 2000; Leyland, Zinicola et al. 2001; Till, Yoder et al. 2002; Chang 2003) Consequently, this resulted in a high rate of surgical repositioning. (Sun, Vicary et al. 2000; Leyland, Zinicola et al. 2001; Chang 2003) MicroSil toric IOLs were more rotationally stable and showed a misalignment of more than 10 degrees in 2 to 10% of eyes. (De Silva, Ramkissoon et al. 2006; Dick, Krummenauer et al. 2006)

As shown in Table 2, acrylic toric IOLs are generally more rotationally stable than silicone IOLs. For the Acrysof toric IOLs, the mean postoperative misalignment is less than 4 degrees and a misalignment of more than 10 degrees is rare. (Bauer, de Vries et al. 2008; Chang 2008; Ahmed, Rocha et al. 2010; Holland, Lane et al. 2010)

In most clinical studies, the postoperative orientation of the toric IOL axis was measured via the slitlamp. Since this measuring reticule on the slitlamp uses 5 degree steps, it is not a very accurate method to determine postoperative IOL rotation. A few studies have used digital photography to examine the postoperative IOL rotation, which is more accurate. Weinand et al. obtained digital images immediately after Acrysof IOL implantation and again at 6 months postoperatively. (Weinand, Jung et al. 2007) Rotation of the eye was compensated for by matching images based on specific blood vessel characteristics. The mean postoperative IOL rotation of Acrysof IOLs was 0.9 degree, with a maximum of 1.8 degrees.

Using a similar digital imaging technique, a different study showed that Acrysof toric IOLs rotate 2.66 ± 1.99 degrees on average in the first 6 months postoperatively. (Koshy, Nishi et al. 2010) Finally, Kwartz et al. compared the rotational stability of Acrysof IOLs and Akreos IOLs and showed that both IOLs rotate 2 to 3 degrees within a 2-year period. (Kwartz and Edwards 2010) However, both latter studies did not compensate for cyclotorsion of the eye between measurements both with the patient in an upright position, which has been shown to be approximately 2 degrees. (Viestenz, Seitz et al. 2005; Wolffsohn and Buckhurst 2010) This indicates that the postoperative rotation of Acrysof IOLs is most likely less than 1 degree. The exact postoperative rotation of other acrylic IOLs, such as the Rayner toric or Acri.Comfort toric IOLs, has not been examined yet. Finally, ocular trauma may cause rotation of a toric IOL. (Chang 2009) In human cadaver eyes implanted with a toric IOL, trauma without leakage from the old incision site resulted in IOL rotation of approximately 6 degrees. Trauma with leakage from the incision site was associated with IOL rotation of approximately 40 degrees. (Pereira, Milverton et al. 2009) However, these human cadaver eyes received post-mortem phacoemulsification with toric IOL implantation, indicating that the IOL had not fused with the capsular bag. This would have resulted in an increased IOL rotation and is possibly not an optimal model to examine toric IOL rotation following ocular trauma.

6.1.5 Economic evaluation

Two studies have performed an economic evaluation of toric IOL implantation versus monofocal IOL implantation during cataract surgery. (Laurendeau, Lafuma et al. 2009; Pineda, Denevich et al. 2010) Laurendeau et al. estimated the lifetime costs of cataract surgery with bilateral toric or monofocal IOLs in patients with pre-existing corneal astigmatism in four European countries (France, Italy, Germany and Spain). In this study, 70% of patients with bilateral monofocal IOLs needed spectacles for distance vision, compared to 26% of patients with bilateral toric IOLs. The resulting reduction in costs in patients with toric IOLs depended on the national spectacle costs and ranged from €308 for Spain to €692 for France. However, this study did not evaluate the possible non-financial benefits of toric IOL implantation, such as the patients' visual functioning and health-related quality of life.

Pineda et al. assessed the economic value of an improved uncorrected visual acuity in patients with pre-existing corneal astigmatism and cataract treated with toric or monofocal IOLs in the US. (Pineda, Denevich et al. 2010) Patient with toric IOLs saved \$34 in total costs with toric IOLs versus monofocal IOLs. These savings increased to \$393 among patients who achieved an UDVA of 20/25 or better. The costs per QALY (quality-adjusted life years; a measure of disease burden combining quality and quantity of life) for toric IOLs was \$349 compared with monofocal IOLs. This indicates that toric IOLs are highly cost-effective. (WHO 2011) In addition, toric IOLs were more cost-effective than monofocal IOLs combined with an intraoperative refractive correction such as limbal relaxing incisions.

6.2 Multifocal toric IOLs

Four different toric multifocal IOL models are currently available (Table 3): the diffractive-refractive Restor IQ toric (Alcon) with an add power of 3.0 D, the diffractive Acri.Lisa toric (Carl Zeiss Meditec) with a +3.75 D add, the refractive M-flex T (Rayner) with an add power of either +3.00 or +4.00 D, and the Lentis Mplus toric (Oculentis) with a +3.0 D

Toric IOL	Company	Model	Multifocal technology	Add power	Material	Aspheric	IOL design	Toric surface	IOL diameter	Available Spherical powers (D)	Available Cylinder powers (D)	Incision size (mm)	Availability
Acrysof IQ Restor	Alcon	SND1T2 to	Diffraction	+3.0	Hydrophobic	Yes	1-Piece	Posterior	13.0	+6.0 to +34.0*	1.0 to 3.0	2.2	Europe, Asia
		SND1T5	(centre); Refractive (outer)		acrylic		open loop				(0.5/ 0.75 steps)		
Acri.Lisa Toric	Carl Zeiss Meditec	466TD	Diffraction	+3.75	Hydrophilic acrylic with hydrophobic surface	Yes	Plate	Anterior + Posterior	11.0	-10.0 to +32.0	1.0 to 12.0 * (0.50 steps)	<2.0	Europe, Asia
M-flex T	Rayner	588F	Refractive	+3.0 or +4.0	Hydrophilic acrylic with hydrophobic surface	Yes	1-Piece closed loop	Anterior	12.0 (588F) 12.5 (638F)	+14.0 to +32.0	+1.5 to +6.0 * (0.5 steps)	<2.0	Europe, Asia
		638F											
Lentis Mplus toric	Oculentis	LU-313	Sector-shaped	+3.0	Hydrophilic acrylic with hydrophobic surface	Yes	Plate	Posterior	11.0	0.0 to +36.0	+0.5 to +12.0 * (0.75 / 0.01* steps)	2.6	Europe, Asia
		MFT	nearvision segment										

* = Highest cylinder powers are custom made;

Table 3. Currently available Multifocal Toric IOLs

sector-shaped nearvision segment. So far, two studies have been published on multifocal toric IOLs. The first study is a case series describing refractive lens exchange with Acri.Lisa toric implantation in 10 eyes of 6 patients. (Liekfeld, Torun et al. 2009) Postoperatively, the UDVA was 20/40 or better in all eyes and the mean reduction in refractive cylinder was 95%. Near and intermediate visual acuities were not evaluated. The second study is a prospective cohort study, in which 45 eyes with cataract and corneal astigmatism were implanted with an Acri.Lisa toric IOL (Figure 4). (Visser, Nuijts et al. 2011) Three months postoperatively, a residual refractive cylinder of -1.00 D or less was achieved in almost 90% of eyes. The UDVA was 0.04 ± 0.15 LogMAR (equivalent to 0.91 ± 0.31 Snellen) and 98% of eyes achieved an UDVA of 20/40 or better. The monocular UNVA and UIVA (at 60 cm distance) were 0.20 ± 0.16 LogMAR (equivalent to 0.63 ± 0.23 Snellen) and 0.40 ± 0.16 LogMAR (equivalent to 0.40 ± 0.15 Snellen), respectively. For intermediate distances, multifocal IOLs with an +3.0 D add power have been shown to lead to better uncorrected visual outcomes, compared to a multifocal IOL with a +3.75 D or +4.0 add power. (de Vries, Webers et al.; Alfonso, Fernandez-Vega et al. 2010) However, so far no studies have been published on the Restor IQ toric, M-flex T, or Lentis Mplus toric IOLs.

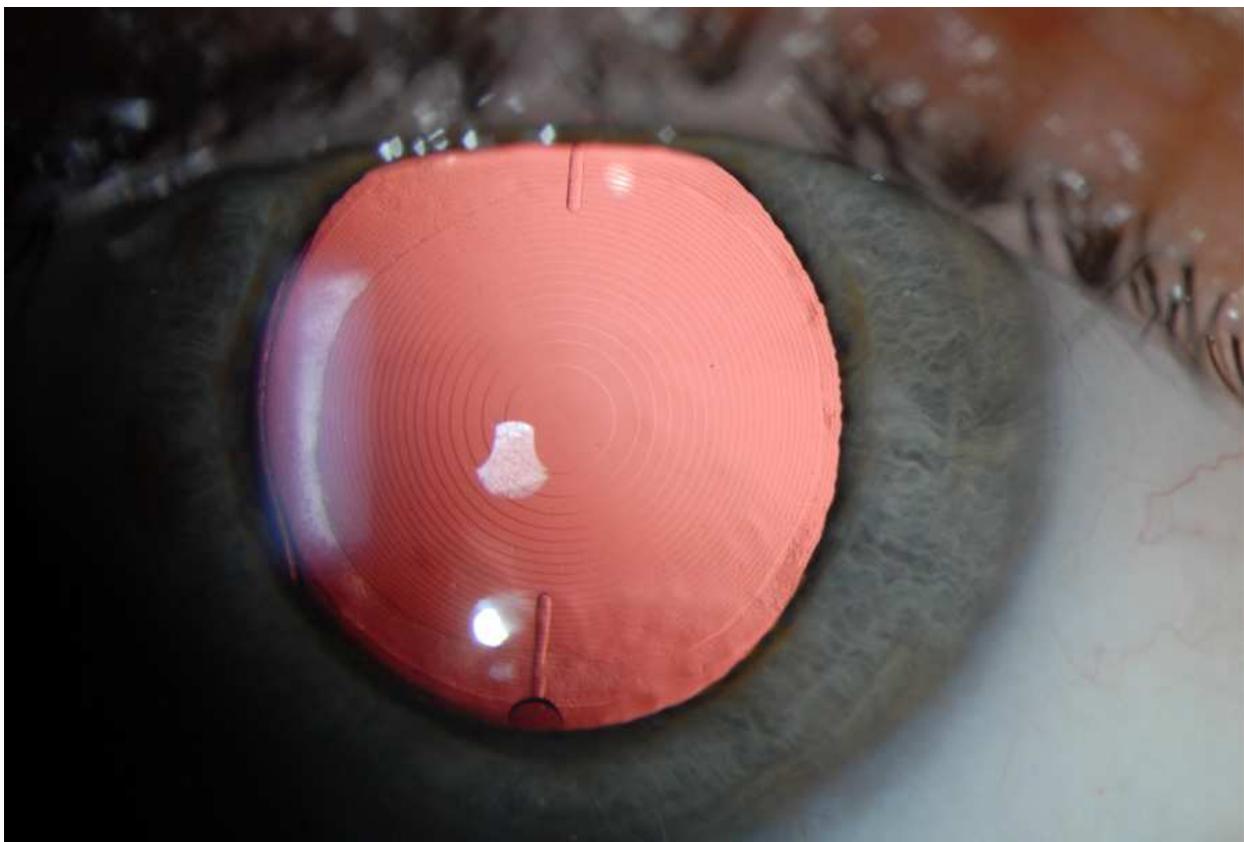


Fig. 4. Slitlamp image of the Acri.LISA toric multifocal intraocular lens.

6.3 Toric IOLs in irregular astigmatism

Even though toric IOLs are most suitable for the correction of regular bow-tie astigmatism, these IOLs have also been shown to be effective in patients with irregular astigmatism. In patients with a corneal ectasia disorder, such as keratoconus or pellucid marginal degeneration (PMD), cataract surgery or refractive lens exchange with an acrylic or silicone

toric IOL implantation has been described. (Sauder and Jonas 2003; Navas and Suarez 2009; Luck 2010; Visser, Gast et al. 2011) Two case reports have described Acrysof toric IOL implantation, with cylinder powers up to 6.0 D, in patients with keratoconus. (Navas and Suarez 2009; Visser, Gast et al. 2011) Postoperatively, there was a marked improvement in UDVA and a 70 to 80% reduction in refractive astigmatism, indicating that the toric IOLs were effective. Sauder et al. report a keratoconus patient who underwent cataract surgery with a Microsil toric IOL (cylinder power 12.0 D) implantation. (Sauder and Jonas 2003) Postoperatively, the BDVA increased from 0.4 to 0.8 with a residual refractive cylinder of -2.5 D. Luck et al. describe 1 case of a customized Acri.Comfort toric IOL implantation, with a cylinder power of 16.0 D, in a patient with PMD. (Luck 2010) Postoperatively, the residual refractive cylinder was 1.25 and the UDVA and BDVA were 20/30 and 20/20, respectively. Cataract surgery with toric IOL implantation has also been described in patients with high post-keratoplasty astigmatism. (Tehrani, Stoffelns et al. 2003; Kersey, O'Donnell et al. 2007; Statham, Apel et al. 2010; Stewart and McAlister 2010) A case series by Kersey et al. describes 7 post-keratoplasty patients who underwent cataract surgery with Microsil toric IOL (mean IOL cylinder of 10.12 D) implantation. (Kersey, O'Donnell et al. 2007) One month postoperatively, the mean UDVA and BDVA were 20/50 and 20/30, respectively, with a mean residual refractive cylinder of 2.75 D. In addition, Stewart et al. compared visual and refractive outcomes following cataract surgery with Rayner toric IOL implantation in non-keratoplasty patients ($n = 14$) and in post-keratoplasty patients ($n=8$). (Stewart and McAlister 2010) One month postoperatively, the postoperative residual refractive cylinder in post-keratoplasty patients was significantly higher compared to non-keratoplasty patients (2.88 ± 2.22 D versus 0.89 ± 0.48 D). As a result, the mean UDVA in post-keratoplasty patients was 0.50 ± 0.48 LogMAR (equivalent to 0.32 Snellen), which was significantly lower than in non-keratoplasty patients (0.16 ± 0.16 LogMAR/ 0.69 Snellen). The BDVA between both groups was comparable: 0.18 ± 0.17 LogMAR (equivalent to 0.66 Snellen) in post-keratoplasty patients and 0.12 ± 0.15 LogMAR (equivalent to 0.76 Snellen) in non-keratoplasty patients.

These case reports and case series indicate that toric IOLs may be used to correct irregular astigmatism. It should be emphasized however that toric IOL implantation is a suitable option in keratoconus patients only if the risk of progression is minimal. Therefore, before implantation of the toric IOL, the patients' risk of progression should be evaluated. In addition, toric IOLs are probably most suitable for patients with mild to moderate amounts of irregular astigmatism, who can be satisfactorily corrected using spectacles. It is possibly a less suitable option in patients whom rigid gas permeable contact lenses have been prescribed primarily to correct high levels of irregular astigmatism. (Goggin, Alpines et al. 2000)

7. Complications

7.1 Misalignment

The most important complication of toric IOLs is misalignment of the IOL with regards to the intended alignment axis. In these cases surgical re-alignment may be performed to realign the toric IOL. The overall cumulative incidence of surgical repositioning of STAAR toric IOLs in the literature is 6.6%. (Ruhsurm, Scholz et al. 2000; Sun, Vicary et al. 2000; Leyland, Zinicola et al. 2001; Till, Yoder et al. 2002; Chang 2003) The indication for surgical repositioning in studies using STAAR toric IOLs was a rotation of more than 20 to 30

degrees, whereas a misalignment of more than 10 degrees is currently considered the indication for re-alignment. Consequently, the reported incidence for surgical repositioning of STAAR toric IOLs is an underestimation. Regarding the MicroSil toric IOL, the overall cumulative incidence of surgical repositioning in the literature is 6.7%. (De Silva, Ramkissoon et al. 2006; Dick, Krummenauer et al. 2006) For acrylic toric IOLs the overall cumulative incidence of surgical repositioning was much lower: 0.3% for Acrysof toric IOLs, 2.1% for Rayner toric IOLs and 0% for Acri.lisa toric IOLs. (Alio, Agdeppa et al. 2010; Stewart and McAlister 2010; Entabi, Harman et al. 2011) However, only a few studies have been performed on Rayner and Acri.Lisa toric IOLs.

7.2 Posterior capsule opacification

Posterior capsule opacification (PCO) has been reported in several studies using Acrysof toric IOLs, but the exact incidence of PCO is unclear. (Ahmed, Rocha et al. 2010; Gayton and Seabolt 2010; Koshy, Nishi et al. 2010; Visser, Ruiz-Mesa et al. 2011) In the majority of these studies, PCO did not compromise the visual outcome and a neodymium:YAG posterior capsulotomy was not required. Too few studies have been performed with Rayner toric or Acri.Comfort toric IOLs to evaluate the incidence of PCO. Regarding the MicroSil toric IOLs, Dick et al. reported PCO in 7% of eyes and a neodymium:YAG capsulotomy in 6% of eyes within a follow-up of 3 months. (Dick, Krummenauer et al. 2006) The reported incidence of neodymium:YAG capsulotomy in patients with STAAR toric IOLs ranged from 3.8% after a follow-up of 7 months to 36.5% after a follow-up of several years. (Sun, Vicary et al. 2000; Jampaulo, Olson et al. 2008)

Both IOL material and IOL design can influence the development of PCO. Two meta-analyses and one Cochrane systematic review have been published concerning the PCO and neodymium:YAG capsulotomy rates of different IOL biomaterials and optic edge designs. (Cheng, Wei et al. 2007; Li, Chen et al. 2008; Findl, Buehl et al. 2010) Silicone IOLs were associated with lower PCO rates than acrylic IOLs, but this difference did not reach statistical significance in the Cochrane systematic review. (Cheng, Wei et al. 2007; Li, Chen et al. 2008; Findl, Buehl et al. 2010) The neodymium:YAG capsulotomy rate for acrylic and silicone IOLs was comparable. (Cheng, Wei et al. 2007; Li, Chen et al. 2008; Findl, Buehl et al. 2010) In addition, sharp-edged acrylic and sharp-edged silicone IOLs were significantly more effective than round-edged IOLs in the prevention of PCO and neodymium:YAG capsulotomy. (Cheng, Wei et al. 2007; Findl, Buehl et al. 2010) Currently available toric IOLs all have a sharp-edged design (Acrysof toric, Rayner toric, Acri.Comfort toric and MicroSil toric), or an almost sharp-edged design (STAAR toric). However, as mentioned by Nanavaty et al., considerable variation in sharp-edge design exists due to differences in sharpness of the edge. (Nanavaty, Spalton et al. 2008) If a neodymium:YAG capsulotomy has to be performed in patients with a toric IOL, the mean IOL rotation was only 1.4 degrees with a maximum of 5 degrees, indicating that IOL rotation is not an issue. (Jampaulo, Olson et al. 2008)

7.3 Other

Other complications reported in the literature are rare and are those generally associated with cataract surgery: corneal oedema, macular oedema, elevated intraocular pressure, a retinal hole or retinal detachment. (Ahmed, Rocha et al. 2010; Holland, Lane et al. 2010; Visser, Ruiz-Mesa et al. 2011)

8. Conclusion

In the last decade, many advancements have been made in toric IOL design and surgical techniques, which have led to an increased success of toric IOLs. Currently used acrylic toric IOLs demonstrate good rotational stability and a low incidence of surgical repositioning. Clinical studies on toric IOLs demonstrate excellent uncorrected distance visual outcomes and a low residual refractive cylinder. Consequently, most patients with bilateral toric IOLs achieve spectacle independence for distance vision. Toric IOL implantation has been shown to be a highly cost-effective procedure. Regarding the new multifocal toric IOLs, initial clinical results are promising with excellent uncorrected distance visual outcomes and acceptable near and intermediate visual outcomes. However, more clinical studies are required to evaluate the visual outcomes and spectacle dependency following multifocal toric IOL implantation. Toric IOL implantation has also been shown to be an effective treatment option in patients with irregular corneal astigmatism. However, care should be taken to evaluate whether a patient is a suitable candidate for this treatment option. Future developments in toric IOL implantation include the clinical use of new techniques for more accurate intraoperative alignment of toric IOLs.

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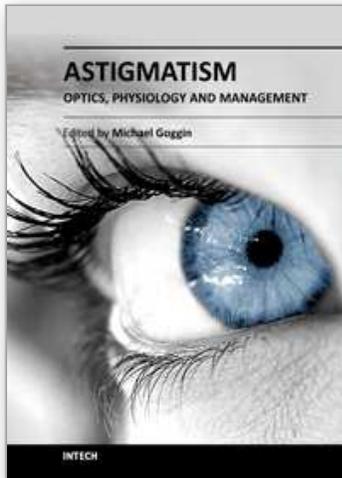
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This book explores the development, optics and physiology of astigmatism and places this knowledge in the context of modern management of this aspect of refractive error. It is written by, and aimed at, the astigmatism practitioner to assist in understanding 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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