Cataract surgeons are now, more than ever, aware that pre-existing corneal astigmatism needs to be corrected in order for patients to gain the full visual benefits of cataract surgery. Astigmatism has always been difficult to treat. This is because astigmatism not only has a magnitude, but also an axis. There is constant endeavour to improve upon the existing measurement of the magnitude and axis of astigmatism to reach high level of accuracy and reproducibility.

Actually, for the eye as a whole, astigmatism as a lower order aberration has a much greater impact on visual function than higher order aberration such as spherical aberration, so that the correction of spherical aberration should be based on the full correction of astigmatism.

Sphere and cylinder are lower order aberration and it has been surprising that methods of correcting astigmatism in post-operative cataract patients have been very slow to develop. Aspheric IOLs were probably developed more quickly than toric IOLs because of the symmetry of correction. In other words, there was no axis influence on the implantation of aspheric IOLs.

Toric IOLs were conceptualized by Shimizu in 1994 to correct pre-existing astigmatism resulting from corneal toricity. Cataract surgery has now become a cataract refractive surgery. A significant number of patients have co-existing astigmatism which, if left uncorrected is likely to result in reduced post-operative visual quality. According to Dr. Barrett, the final challenge or the last frontier is toric calculations, and this is more complicated because you have magnitude as well as direction of your error.

Prevalence of astigmatism in patients undergoing cataract surgery

Visually significant astigmatic error is generally considered as ≥ 0.50 D. Almost 70% patients presenting with cataract also have astigmatism, this is a huge number but fortunately, most of them have less than 1.0 D of astigmatism. 15% - 23% of eyes exhibited more than 1.5 D of astigmatism in a series of 6000 & 7500 patients undergoing cataract surgery. Others reported that only 8% exhibited > 2.0D of corneal astigmatism and 2.6% undergoing cataract exhibited > 3.0 D.

Ideal Outcome of Toric IOL Implantation In Cataract Surgery

1. Achieving the target induced astigmatism
2. Spectacle independence.

Assessing cataract surgery success by only looking at BCVA or Spherical equivalent target will result in suboptimal refractive outcome and dissatisfied patient. E.g. of zero spherical equivalent equal are:-
- +0.50Dsph/-1.00cyl.,
- +1.00Dsph/-2.00D cyl.,
- +1.5Dsph/3.00Dcyl. etc.

Spectacle independence is now regarded by most ophthalmologist and patients as the expected desired outcome following cataract surgery.

Zero Residual Astigmatism

Holladay is of the opinion that residual astigmatism is like any other aberration and whether with the rule (WTR) or against the rule (ATR), it blurs the image particularly if you don’t wear glasses.

Hence planning for spherical and astigmatic emmetropia should be the target for all the patients when removing cataract. Small amount of residual astigmatism of 0.25D – 0.50 D WTR is goal for some surgeons like Douglas.
Koch, Warren Hill to account for the long-term ATR shift that takes place with advancing age. It is also known that occasionally patients do well with myopic astigmatism, giving them greater depth of focus, but at the expense of clear vision at any distance.

**Magnitude of Residual Astigmatism and its Statistical Distribution**

Considering 0.5D as significant astigmatic cylinder, the residual astigmatism of the same magnitude in a 2.0D astigmatism cataract patients the error would amount to 25% astigmatic power calculation error.

However 0.5D residual spherical power in patient requiring 20.00 D would amount to 2.5% IOL power calculation error. Hence it is very clear that the percentage of astigmatic power calculation error is still very significant.

In a randomized prospective multi-centre FDA trial the outcome of implantation of Acrysof Toric IOL was evaluated in 494 patients with 1 year follow up. Half of the patients were implanted toric IOL and the other half with a control IOL. The study found that 62% of toric IOL patients had 0.5 D or less residual cylinder compared with 20 % of control patients. What is significant here is that 38 % toric IOL patients had more than 0.50 D of residual astigmatism.

Dr. Barrett has developed his own toric calculator, based on his universal formula that calculates toric power on the corneal plane, and contains an algorithm to account for the posterior cornea. Using this formula, 72% patients end up with less than 0.50D of error.

The various studies in Table No.1. Shows the magnitude and the percentage of residual astigmatic error is of the same proportion as that of FDA trial.

**Parameters Causing Residual Astigmatism**

1. Total corneal astigmatism estimation error
2. Toric IOL calculator.
3. Surgically induced astigmatism
4. Rotational error.

**Total Corneal Astigmatism Estimation Error**

The outcome of all the astigmatism reducing methods depends upon accurate estimation of total corneal astigmatism.

---

### Table 1: Residual Astigmatic Error in Monofocal Toric IOL Implantation: Various Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Pre-Op Corneal Astigmatism</th>
<th>Post –Op Refractive Cylinder</th>
<th>% res. error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kosby et al (2010)</td>
<td>1.97 ± 0.50 D</td>
<td>0.92 ± 0.43 D</td>
<td>46.7%</td>
</tr>
<tr>
<td>Stewart et al (2010)</td>
<td>1.74 ± 0.83 D</td>
<td>0.69 ± 0.25 D</td>
<td>39.7%</td>
</tr>
<tr>
<td>De-silva et al (2006)</td>
<td>3.08 ± 0.76 D</td>
<td>1.23 ± 0.90 D</td>
<td>39.9%</td>
</tr>
<tr>
<td>Mendicute et al (2009)</td>
<td>1.75 ± 0.71 D</td>
<td>0.62 ± 0.46 D</td>
<td>35.5%</td>
</tr>
<tr>
<td>Arvind Eye hosp (2010)</td>
<td>2.24 ± 0.78 D</td>
<td>0.82 ± 0.53 D</td>
<td>36.6%</td>
</tr>
</tbody>
</table>


The corneal power calculations are based on certain assumptions known as Gauss’s approximation for optical formulae to be applicable.

**Gauss’s Paraxial Approximation**

Following the laws of paraxial optics we can apply to the cornea the paraxial equation of the spherical dioters:-

- \[ P = (n_2 - n_1) / r \]

Curvature can be measured in mm or Diopeters.

The curvature in mm is the actual measured parameter.

Whereas Diopteric power maps are produced by converting the radius of curvature into diopeters using various refractive indices, keratometric ref. index of \( \mu = 1.3375 \) is the most widely used refractive index.

It is based on Gullstrand’s Schematic Corneal model of 43.00 D power in which the refractive index of air, cornea,, and aqueous are 1.00, 1.376 and 1.336, respectively : where corneal thickness is 0.50mm and ratio of posterior to anterior radii is 6.8/7.7 = 0.883. It converts the measured anterior surface curvature into corneal diopteric power at the posterior vertex called back vertex power. It does not measure the posterior curvature and assumes a fixed posterior to anterior surface ratio of 0.883.

- It yields a simple relation 7.5mm = 45.00 D.

There is no consensus on the optimal area of the central part of the cornea to be taken into consideration for the purpose of calculating the corneal dioptoric power. This can be easily seen from the fact that various instruments use varying diameter of the central cornea for the corneal power measurement.

The rationale used by Alcon toric calculator is that IOL MASTER and Manual keratometer will very often give the same average central power measurement but the amount of astigmatism ( the power difference between two principal meridians) measured may be different. This is because the IOL Master K’s sample 2.5mm zone while manual keratometry sample from a larger 3.2mm zone. According to Alcon reasoning the normal prolate cornea is more like the tip of a rugby ball than the top of an orange.
and if we sample a smaller area, we may see less of a difference in the principal meridians. However, it is further added that recent study published in JCRS shows that Haag-Streit Lenstar is also an excellent choice to determining the keratometric astigmatism. All the devices here measure rings of varying diameter in the central part of cornea.

Simulated Keratometry

The keratometric dioptre is a concept intended from keratometry and is calculated simply from radii of curvature as follows:

- \( K = \frac{1.3375}{\text{radius in meter}} \)

This concept as we have seen is simplification ignoring the fact that the refracting surface is air-tear interface, and it does not account for the oblique incidence of incoming light in the corneal periphery it does not actually measure posterior surface and assume a fixed posterior to anterior surface ratio of 0.883. As a result, it miscalculates a true corneal refractive index of 1.376 to a fictitious refractive index of 1.3375 to account for some of these factors.

That is why these diopters are more correctly termed keratometric diopters to distinguish them from the diopters expressing precisely the true dioptric refractive power at certain corneal points.

Standardized Keratometric Ref. Index 1.3375 and its Relation to Posterior Corneal Astigmatism

It is assumed that:

- Radius of Posterior Curvature = 0.883 X Radius of Ant. Curvature
- Radius of Posterior Curvature \( \alpha \) Radius of Ant. Curvature.

It means that steeper the anterior curvature, steeper will be the posterior curvature. Similarly flatter the anterior curvature, flatter will be the posterior curvature.

Hence in every case of Astigmatism Power calculation based on equivalent corneal refractive index say 1.3375 to convert anterior surface measurements to total corneal power and astigmatism the following result is inevitable:-

<table>
<thead>
<tr>
<th>Instruments Used For Measuring Corneal Power And Corneal Astigmatism</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Manual Keratometer - Bausch &amp; Lomb</td>
<td>- Javal &amp; Schötz</td>
</tr>
<tr>
<td>2. Automated Keratometer</td>
<td></td>
</tr>
<tr>
<td>3. IOL Master</td>
<td></td>
</tr>
<tr>
<td>4. Lenstar</td>
<td></td>
</tr>
<tr>
<td>5. Topographer</td>
<td></td>
</tr>
<tr>
<td>6. Tomographer - Orbscan</td>
<td>- Pentacam</td>
</tr>
<tr>
<td>- Gallifey Dual Scheimpflug Analyzer</td>
<td></td>
</tr>
<tr>
<td>7. Intraoperative Aberrometer - Ora</td>
<td>- Clarity</td>
</tr>
</tbody>
</table>
1. Posterior Astigmatism is inadvertently being added in all cases of anterior corneal astigmatism.

2. Magnitude and axis of this inadvertently induced posterior astigmatism is in direct proportion & relation to anterior corneal astigmatism.

Table No. 2 shows that by using only anterior surface measurement we have inadvertently introduced posterior corneal astigmatism also, which in all the calculations are unaccounted for. This will affect the net magnitude of total corneal astigmatism as well as the error due to axis because of the vector summation with the already existing both anterior and posterior corneal astigmatism

**Corneal Power and Astigmatism Measuring Devices**

Various devices are used for measuring the corneal dioptric power and astigmatism by different methodologies, using different refractive indices, varying central zones, number of points on the cornea and certain assumptions in the calculations.

**Comparision of Various Devices Which are used for Measuring Total Corneal Diopteric Power and Astigmatic Power**

The above (Figure 1&2) shows that none of the above devices measure the posterior surface. Also nothing is known about part central and periphery to the area of the ring measured.

Hence Topographic power chart of the whole cornea is imperative to know whether the corneal astigmatism is regular or not.

Newer devices are now available for measuring both the anterior and posterior surfaces of the cornea (Table No.4)

**Galilei Dual Scheimpflug Analyzer (Zeimer Group)**

Ray tracing method is the most accurate method for calculating the corneal power and astigmatism as it does not use paraxial assumption instead it uses Snell’s Law to propagate incoming parallel rays to refract through the anterior and posterior surfaces. In a recent study by Koch et al, they found that calculating posterior corneal power using the Gaussian formula and its paraxial assumptions introduces errors in the calculation of corneal power. Recently Thomas Olsen has used the ray tracing method by the use of software called Phaco-Optics. It uses the Pentacam data of the anterior and posterior surfaces and the software uses the exact ray tracing method to calculate the accurate toric IOL power without the use of equivalent K reading.

**Comparision of Simulated Corneal Power and Astigmatism Estimation Among Various Devices**

Shiyaram, Wang et al 2009 compared 4 devices:

a) Manual keratometer,

b) IOL Master(Carl Zeiss),

c) Humphery Atlas corneal Topographer (Carl Zeiss),

d) Galilei Dual Scheimpflug Analyzer (Zeimer)

Standardized corneal refractive index of 1.3735 was used in all the devices to convert the anterior surface curvature to corneal powers. It was found that the corneal powers were highly reproducible, comparable and correlated. Regarding Astigmatic powers, IOL Master tended to give highest powers, however there were no significant differences among the devices. Repeated measurement variations were comparatively less with manual keratometer and IOL master compared to other 2 devices.

The slight variation of Astigmatic powers among the devices were perhaps due to the different area of the cornea measured, IOL Master having the smallest 2.5mm ring of area.

<table>
<thead>
<tr>
<th>Table 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tomographers</strong></td>
</tr>
<tr>
<td>1. Slit-Scanning Technology</td>
</tr>
<tr>
<td>2. Rotating Scheimpflug Devices</td>
</tr>
<tr>
<td>3. Optical Coherence Tomography</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Ray Tracing Method to Calculate Corneal Power and Astigmatism</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Galilei Dual Scheimpflug Analyzer (Zeimer Group)</td>
</tr>
<tr>
<td>2. Phaco-Optics (Thomas Olsen) software (Uses Pentacam data)</td>
</tr>
</tbody>
</table>
Intraocular Lenses

The inference from the above study is clear that as long as we are using standardized refractive index 1.3375 and not measuring the posterior curvature, all the devices have comparable corneal and astigmatic powers.

**Contribution of Posterior Corneal Astigmatism to Total Corneal Astigmatism**

One of the leading cause of corneal power and astigmatic calculation error leading to post operative residual astigmatism error is because of posterior surface curvature and posterior surface astigmatism.

**Galilei Dual Scheimpflug Analyzer (Zeimer)**

Uses a dual-Scheimpflug camera and a Placido disk to measure anterior and posterior corneal surfaces. Ray tracing is used to calculate total corneal power and total corneal astigmatism.

Whereas anterior steeper vertical meridian in young changes to horizontal steeper meridian in old age that is ATR shift with advancing age.

**Magnitude of Posterior Corneal Astigmatism Power and its Statistical Distribution**

The mean posterior astigmatism is 0.30 D ± 0.15 (Range 0.01 to 1.01). It is also seen that significant number of patients i.e 43.1% patients had negligible <0.25D (0.01 – 0.25D) astigmatism whereas we have seen that any anterior corneal astigmatism estimation using μ =1.3375 introduces inadvertent posterior astigmatism proportionally in the same axis thereby resulting in calculation error which ultimately leads to residual astigmatism. 8.3% of total patients had posterior astigmatism magnitude of ≤ 0.75 D and 0.1% had 0.75D – 1.00 D. In these patients with higher magnitude of posterior corneal astigmatism, the residual astigmatic error is inevitable if standardized ref. index of 1.3375 is used.

**Accuracy of Corneal Astigmatism Estimation by Neglecting the Posterior Corneal Surface Measurement (Jau-der Ho et al AJO 2009)**

The study compared the keratometric corneal astigmatism (KA) obtained by using the anterior corneal surface measurement and the keratometric index (1.3375) while neglecting the posterior corneal surface measurement. The Pentacam–derived total corneal astigmatism (PA) was derived by doubled-angle vector analysis of the astigmatism on both corneal surfaces. It was found that measuring only the anterior corneal surface may result in either a total corneal astigmatism magnitude estimation error of > 0.50 D or an angle estimation error of > 10 degrees in 28.8% eyes. The mean blurring strength of the cornea astigmatism estimation error caused by neglecting the posterior corneal surface measurement was 0.33 ± 0.16D (range 0 to 0.94D). Eyes with KA magnitude exceeding 1.00D (that are candidates for toric implantation), 6% had PA magnitude < 1.00 D, thereby indicating no toric IOL implantation. On the contrary KA < 1.00D (eyes that are not candidates for toric correction) 6% had PA > 1.00D, indicating a possible toric IOL implantation.

**Vector Summation of Different Angular Location of Anterior and Posterior Corneal Astigmatism**

The vector representing the anterior corneal astigmatism is usually longer than that representing the posterior corneal astigmatism (since the refractive difference across the anterior corneal surface is much larger than that across
the posterior corneal surface). Therefore, the vector sum of the vectors representing the anterior and posterior corneal astigmatism will be in a direction close to that of the vector of the anterior corneal astigmatism. When the anterior corneal surface has an oblique astigmatism and the posterior corneal surface has an against the rule astigmatism, the vector representing the anterior and posterior corneal astigmatism will be neither in nearly the same nor in nearly the opposite direction. Therefore, the vector sum of the vectors representing the anterior and posterior corneal astigmatism will have a direction that deviates more from the direction of the vector representing the anterior corneal astigmatism than when the vector representing the anterior corneal astigmatism is more parallel to (i.e in nearly the same or opposite direction) the vector representing the posterior corneal astigmatism (i.e, when the anterior cornea has a WTR or ATR astigmatism.) Thus difference in angular location of anterior and posterior corneal astigmatism will result in error of both in net magnitude and axis placement.

**Implications of Posterior Corneal Astigmatism Measurement**

1. One cannot confidently predict the amount of posterior corneal astigmatism from anterior measurement only.
2. Incorrect estimation of total corneal astigmatism
   a) May affect the outcome of astigmatic surgical interventions that are based on anterior corneal measurement only.
   b) Failure to account for a vertically steep posterior corneal curvature (causing ATR) will result in:
   - Overcorrection of eyes having WTR anterior corneal astigmatism
   - Undercorrection of eyes having ATR anterior corneal astigmatism

To assess posterior astigmatism accurately, either measure it directly by Galilei Dual Scheimpflug Analyzer, or indirectly with intraoperative aberrometry. If there is no access to these devices that measures the posterior corneal astigmatism the average values may be used.

To account for overcorrection in WTR and undercorrection in ATR corneal astigmatism, Baylor developed a toric IOL Nomogram (Table No.6). In WTR Astigmatism there is a 0.7D shift up in the toric power, thereby 0.7D lesser toric power is taken and the reverse in ATR ASTIGMATIC eyes i.e 0.7D higher toric power is recommended.

Douglas Koch is of the opinion that even Galilei Dual Scheimpflug device does not always seem to capture all of the posterior corneal astigmatism. He has developed his own nomogram which incorporates mean posterior corneal astigmatism and ATR drift with age. It is yet to be FDA approved.

**Toric Power Calculator Error (Thomas Olsen)**

Toric power can be calculated in different ways. It is a just a special case of IOL power calculation.

According to Olsen the toric power is the difference in the IOL power of steeper and flatter meridians. Most of the company based / ASCRS toric calculators do not do it right because of the following reasons:-

1. Constant relationship between corneal astigmatism and IOL toric power. It is based on fixed 1.46 times the corneal power which is based on a 22.00 D IOL power model. This figure may be different in shorter or longer eyes.
2. Effective IOL position is not taken into consideration
3. Posterior corneal astigmatism is not accounted for in Alcon and AMO Toric calculators.
4. Vector summation of anterior and posterior astigmatism in not calculated.

Alpine has introduced an on line toric calculator, which is based on incision on the steeper axis, as he is of the opinion that SIA not only has magnitude but also axis, and by placing the incision on the steeper axis this aspect is

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MEAN ± SD (D)</th>
<th>RANGE (D)</th>
<th>≤0.25D</th>
<th>0.25D TO 0.50 D</th>
<th>0.50D TO 0.75D</th>
<th>0.75 D TO 1.00 D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior Astigmatism</td>
<td>-0.30 ± 0.15</td>
<td>-0.01 To 1.10</td>
<td>43.1%</td>
<td>48.9%</td>
<td>8.3%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

**Table 5: Posterior Corneal Astigmatism Power & Statistical Distribution (Douglas D.koch Jcrs Dec 2012)**
Intraocular Lenses

Table 6: BAYLOR TORIC IOL NOMOGRAM WTR ASTIGMATISM

<table>
<thead>
<tr>
<th>ASTIGMATISM</th>
<th>TORIC IOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>= 1.69</td>
<td>0</td>
</tr>
<tr>
<td>1.70 - 2.19</td>
<td>T3</td>
</tr>
<tr>
<td>2.20 - 2.69</td>
<td>T4</td>
</tr>
<tr>
<td>2.70 - 3.19</td>
<td>T5</td>
</tr>
</tbody>
</table>

0.7 D shift : UP

Table 6: BAYLOR TORIC IOL NOMOGRAM WTR ASTIGMATISM

<table>
<thead>
<tr>
<th>ASTIGMATISM</th>
<th>TORIC IOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>= 0.39</td>
<td>0</td>
</tr>
<tr>
<td>0.40 - 0.79</td>
<td>T3</td>
</tr>
<tr>
<td>0.80 - 1.29</td>
<td>T4</td>
</tr>
<tr>
<td>1.30 - 1.79</td>
<td>T5</td>
</tr>
</tbody>
</table>

0.7 D shift : DOWN

taken into consideration. It takes into account the posterior corneal astigmatism.

Barrett toric calculator available at APACRS.ORG. takes the posterior astigmatism into its calculations.

**Surgically Induced Astigmatism Error**

Individual SIA may vary from the statistical average figures obtained through personalized data.

SIA varies in 2.2 /2.8 mm incision 0.2 D – 0.5 D

Main causes of individual variation in SIA:

- The post-operative incision reconstruction
- Biomechanical properties – elasticity gradient and strength
- Vary between individual and age,

Hence the individual true SIA remains to some extent unpredictable.

SIA is one of the causes of an unpredictable change in the astigmatic power of the cornea of eye11. Thus performing surgery in an eye with regular bow-tie astigmatism one should attempt to operate on or orthogonal to the steep axis of the cornea. This will simplify all vector calculations. If one operates on any other axis, he or she will likely induce irregular astigmatism (since the incision is placed on one side of the cornea only) that does not involve the full extent of the cornea12. The resultant vector calculation will recommend aligning the IOL to an axis not coincident with the steepest axis of the cornea which will induce a local area of irregular astigmatism and higher-order aberrations (specifically coma) at the steepest axis of the cornea on the portion located 180 degrees from the incision site.

**Marking Errors**

Manual Markers: Visser et al 20118 evaluated the accuracy of a 3- step marking procedure for toric IOL implantation.

- Mean Horz. Axis Marking error: 2.4 ± 0.8 degree (Max 8.7)
- Mean Alignment axis marking error: 3.3 ± 2.0 degree (Max 7.7)
- Mean Toric alignment error: 2.6 ± 2.6 degree(Max 10.5)
- MEAN TOTAL ERROR: 4.9 ± 2.1 degree

Markings are usually created with either a dye (e.g. gentian violet) or a surgical marking pen; both of which often smudge or “bleed”, resulting in an additional margin or error when the final angle of alignment is approximated. Alternatively splinter haemorrhages created by nicking the limbal palisades of Vogt like wise add an unnecessary margin of error.

Furthermore, these techniques focus on aligning the IOL axis with the anatomical cornea and not the visual axis or the entrance pupil, which is often not concentric with the anatomical cornea13-16.

Finally, the axis position of the IOL must be interpolated between points on the peripheral cornea or limbus using a straight instrument held above the plane of the cornea; depending on the anterior chamber depth and the depth of focus of the operating microscope, it is often not possible to keep the instrument, lens markings, and limbus in focus simultaneously17.

This error is also expected because the least count of the manual marking instruments is 5 degrees.

New techniques are available for intraoperative alignment of Toric IOL:

Osher’s iris fingerprinting technique, Sensomotoric Instruments guidance system (Verion, Alcon), I-Trace (Tracey Technology), Calisto Eye and Z Align (Carl Zeiss), intraoperative Wavefront Aberrometry (Clarity, ORA), TrueVision.

**Residual Astigmatism due to Post-Operative Rotation of Toric IOL**

Every degree of misalignment leads to residual astigmatism of 3.3% and a misalignment of 30% is as good as putting spherical IOL only.
FDA TRIAL - Mean axis rotation of Acrysof Toric IOL ≤ 4°

The new Acrylic Toric IOL’s are highly rotationally stable with 99% of Toric IOL’s within 10 degree of desired axis. Weinand et al reported rotation of currently used acrylic pseudophakic IOL’s to be less than 1 degree.

Currently, misalignment of ≥ 10 degree is generally regarded as an indication for surgical repositioning.

In those cases, Holladay IOL Consultant has a Toric Back Calculator tab that provides physicians with a second chance. It can calculate exactly how much you need to rotate that lens to the perfect position. The malpositioned lens can be optimally repositioned to a new axis, with the help of a software astigmatismfix.com, which is typically more accurate than in the initial surgery. The same can also be done by Alpine toric calculator.

**Intra-Operative Wavefront Aberrometer**

1. ORA (Wave Tech, USA)
2. CLARITY (Holos, USA)
   - Directly take refractive measurement at the time of surgery.
   - Real time confirmation of sphere and cylinder
   - Determines the axis of the cylinder
   - Confirms the proper axis and make intraoperative adjustments also.

Correlation between intraoperative refraction and 1week post op. refraction is only “moderate, to fairly weak” according to Dr. Barrette (Eye World 2013). A study presented at ASCRS. ASOA Symposium by Cionni found that in 55% of eyes ORA recommended a cylinder power change. The average cylinder reduction was 84%. Dr. Cionni concluded that ORA improved results with the toric IOL’s.

**Advantages**

1. Posterior surface astigmatism taken into account.
2. Surgically induced astigmatism considered
3. Tilting or head misalignment during pro-op testing
4. A wavefront aberrometry is generating the best-fit refraction across the entire pupillary axis.

**Drawbacks:**

Reasons for residual astigmatism with this method:

i) Not easy to determine when the eye is stable for acquisition

ii) IOP 20-30 mm Hg.

iii) Leaking incision

iv) Overhydration of the incision site

v) BSS and not Viscoelastic as it is more close to ref. Index of aqueous.

vi) Patient should be looking into the light

vii) SIA – individual variations.

Dr. Koch’s observation has been that whether it’s WTR or ATR astigmatism, for some reason they end up with more / less residual astigmatism.

- It’s possible that it may be due to the fact that WTR & ATR astigmatism have different posterior corneal astigmatisms. However Pentacam and Galilei data does not support this hypothesis.

- Other possibility is that implant is never parallel or perpendicular to the visual axis; it may be tilted a little bit and that tilt induces a small amount of astigmatism.

Dr. Holladay’s concern is that in some cases, despite the best planning the outcome is still not as desired. Even a small amount of residual astigmatism of 0.50D can cause visual blur affecting the visual quality. Hence the need to achieve total correction in Toric implantation.

The pursuit for desired ideal refractive outcome after cataract surgery still continues with respect to:

- Accurate measuring devices,
- Precise calculation and
- Acheiving surgical perfection.

### References

1. Chang DF. Comparative rotational stability of single piece open-loop acrylic and plate-haptic silicon toric intraocular lenses. JCRS; 34: 1842-47


