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Astigmatism: A New Standard of Care

Bridging the Gap to Cataract Refractive Surgery

A high proportion of cataract patients are significantly astigmatic (1) – and this can compromise their quality of vision post-surgery (2). There are diverse methods to address astigmatism at the time of the cataract surgery, but not all are equally effective (3). Could advanced instrumentation and toric IOLs change the standard of care? The consensus at Alcon Axis Advanced Workshop, held in Barcelona, Spain, on October 26, 2018, is that it can – even in patients with only mild astigmatism.

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Part I: The importance of astigmatism correction

Andrzej Dmitriew, Poland

Why bother correcting astigmatism in cataract surgery patients? Because as little as 0.5D post-surgical astigmatism can significantly affect patients' functional vision (2) – and toric IOLs can now address not just 2D astigmatism and over, but 1D and below (4). We can completely change our attitude to mildly astigmatic patients: it is no longer necessary to accept compromises that leave them with poor functional vision.

And this change in attitude is well overdue: consider the prevalence data, based on the real-world recent studies. Among cataract patients, 70 percent or more showed ≥0.5D of corneal astigmatism and may benefit from astigmatism correction (1, 5); furthermore when a non-toric IOL is implanted in an astigmatism patient, the astigmatism magnitude might be higher after cataract surgery than before worsening then the visual acuity (1). This conclusion was based on very significant patient numbers: 110,000 pre-operative readings and 40,000 post-operative readings. Similarly, data from the Swedish Cataract Registry indicate that 60 percent of patients remain with 0.5D of corneal astigmatism after surgery (Sidebar 1 (6)).

In Dmitriew's opinion, therefore, it is misguided to apply arbitrary cut-offs beneath which astigmatism is left untreated; I advise all surgeons to move towards correcting astigmatism wherever possible, even where post-operative astigmatism is predicted to be under one diopter. It really should be part of the standard of care!

"As little as 0.5D post-surgical astigmatism can significantly affect patients' functional vision." – Andrzej Dmitriew

Sidebar 1. post operative astigmatism results (1); patients implanted with non-toric IOLs

Pre-operative corneal astigmatism:

- 78% (n=85 650) ≥0.5 D
- 42% (n=46 003) ≥1.0 D
- 21% (n=22 899) ≥1.5 D
- 11% (n=11 651) ≥2.0 D

Post-operative refractive astigmatism results:

- 90% (n=35907) ≥0.5 D
- 58% (n=22886) ≥1.0 D
- Visual acuity tended to worsen postoperatively with increased astigmatism ($\rho = -0.44$, $P < 0.01$)

Part II: Astigmatism treatment

Kjell Gundersen, Norway

Preoperative astigmatism is common and is not reduced by cataract surgery and monofocal IOL implantation (1). Therefore, to improve visual outcomes, we must correct astigmatism when we treat cataracts. Unfortunately, many cataract surgeons simply don't care about astigmatism! But the rest of us do have some options (Sidebar 2).

Limbal relaxing incisions will reduce astigmatism in most cases, but are not as effective, precise and predictable as toric IOLs (3). Laser vision correction can be useful in patients with high astigmatism, but is not universally applicable: those with stable keratoconus and 6D astigmatism or above may be better served by use of toric IOLs. Furthermore, remember the ocular surface (Sidebar 5); most cataract patients are over 50 years of age – either they have a dry eye problem, or the laser will create one! Leaving a mild refractive error is far preferable to instigating chronic dry eye disease.

Toric IOLs, however, give better outcomes than relaxing incisions or laser surgery (3), and better uncorrected distance vision. Even at very low values of astigmatism, toric IOLs provide better functional outcomes and spectacle independence – and fewer post-operative complications – than combinations of non-toric IOLs and relaxing incisions (3). And the impact on workflow is minimal – it takes only a little more surgeon time to implant a toric as opposed to a non-toric lens. In my opinion, therefore, the toric lens is unquestionably the best option (Sidebar 3).

Sidebar 2. Astigmatism treatment options

- Toric lens
- Laser vision correction
  - PRK
  - LASIK
  - SMILE
- Limbal relaxing incisions
  - Arcuate (manual or FLACS)
  - Opposite clear corneal incision (pay attention to nomogram)

Sidebar 3. Benefits of astigmatism correction with toric IOLs (3)

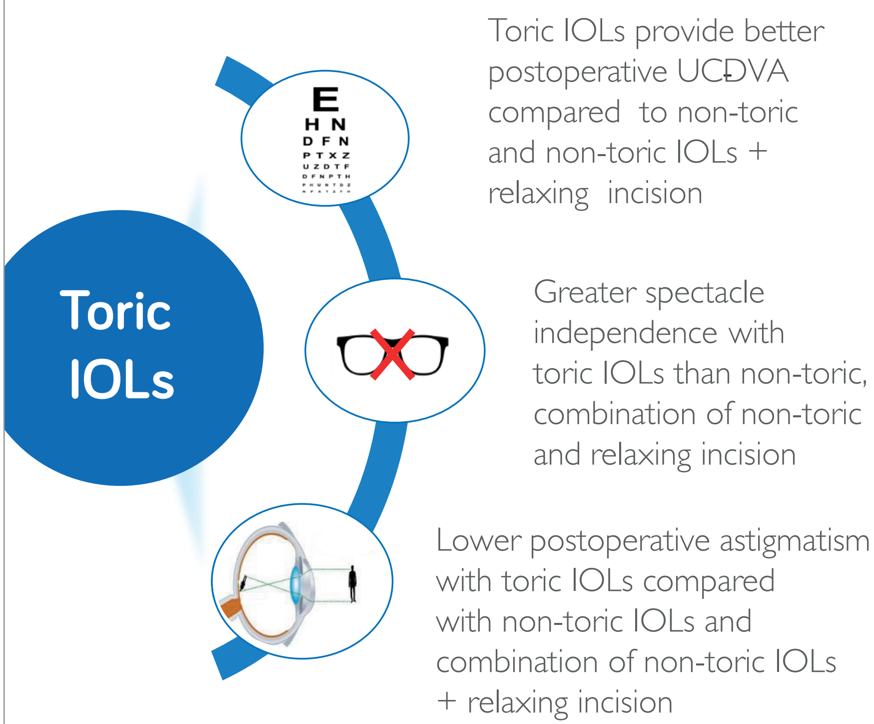


Figure 1. Benefits of astigmatism correction with toric IOLs (3)

Andrzej Dmitriew, Poland

But how exactly should we manage cataract patients with astigmatism? First, we should appreciate that predictable results require a stable platform. A history of over 100 million procedures provides abundant evidence for the rotational stability of the AcrySof® IQ Toric IOL: mean Acrysof rotation is 2.72 degrees, versus 3.79 degrees for TECNIS® Toric (7). Similarly, 91.9 percent of AcrySof® IQ Toric implantations rotate by 5 degrees or less versus 82.8 percent for TECNIS® Toric (Table 1 (7)).

Second, we should be aware of new concepts in astigmatism treatment – not least, work on posterior corneal astigmatism (PCA). The large difference between with-the-rule (WTR) and against-the-rule (ATR) patients, in terms of refractive outcomes, is due to PCA. Ignoring posterior corneal astigmatism may yield incorrect estimation of total corneal astigmatism. Failure to account for it in toric IOL calculations may result in significant residual astigmatism due to overcorrection in eyes with WTR astigmatism and undercorrection in those with ATR astigmatism. Using the devices that calculate total corneal astigmatism based on anterior corneal measurements only, WTR astigmatism was overestimated by 0.5 to 0.6 D and ATR astigmatism was underestimated by 0.2 to 0.3 D (8).

The old Alcon calculator didn't allow for PCA, and therefore wasn't ideally predictive; The new Barrett calculator theoretically accounts for PCA in WTR and ATR eyes (9), axial length and anterior chamber depth in ELP estimates permitting more precise astigmatic prediction (10).

Based on the Douglas D. Koch and Li Wang theory, Surgically Induced Astigmatism (SIA) is a vector; it has both magnitude and angular direction, and both vector components must be included when calculating the median or mean SIA in a group of cases (11). Previous approaches to SIA calculation were based only on the numerical average for a specific meridian or axis, and hence only accounted for an incision's effect on a specific axis. Cornea, however, is a living biomechanical structure; it does not react to incisions as if it were a simple monofocal lens, and therefore older formulas cannot always predict its behavior. Barrett toric calculator utilizes centroid vector calculations for improved SIA accuracy.

Therefore, I strongly recommend the new Alcon Online Toric Calculator, not least because it is based on the Barrett algorithm, which is superior to ray-tracing software and other formulae (Figure 2, Table 2 (8, 9)).

"Because SIA is a vector, it has both magnitude and angular direction, and both vector components must be included when calculating the median or mean SIA in a group of cases... It is critical to account for posterior corneal astigmatism in cataract patients to achieve optimal post-operative outcomes." (11)

"It is important to consider posterior corneal astigmatism in toric calculations as the posterior cornea acts as a minus lens ... Both the anterior and posterior corneal surfaces contribute to the total corneal astigmatism." (12)

"Posterior corneal astigmatism can impact astigmatic correction and visual outcomes... Failure to account for posterior corneal astigmatism in toric IOL calculations can lead to overcorrection in eyes that have WTR anterior corneal astigmatism and under correction in eyes that have ATR anterior corneal astigmatism." (13)

Accounting for PCA is also assisted by advances in instrumentation. But what option should we choose? I believe that the best keratometry tool is the one that works best for you. I use VERION™ for measuring axis and astigmatism magnitude, and a Scheimpflug camera and Pentacam as a control approach. This approach helps avoid significant surprises; for example, by identifying patients with posterior keratoconus or other corneal pathology that could cause deviation from pre-operative predictions. Feel free to use any biometer for K values, but you must always remember to optimize lens constants for each device separately – that's very important.

Accurate location of the principal meridian is very important in irregular corneas, and is the main reason to use topography, but you can also use

	AcrySof® IQ Toric	TECNIS® Toric
IOL rotation, degrees (95 percent CI)	2.72 (2.35-3.08)*	3.79 (3.36-4.22)*
Rotation ≤5 degrees	91.9 percent*	81.8 percent*
Rotation ≤10 degrees	97.8 percent*	93.2 percent*
Rotation ≤15 degrees	98.6 percent*	96.4 percent*
Rotation ≤20 degrees	98.9 percent	97.4 percent
Rotation ≤30 degrees	99.5 percent	99.4 percent
Rotation >30 degrees	0.50 percent	0.60 percent

CI = confidence interval; IOL = intraocular lens

*P < 0.05.

Table 1. Toric intraocular lens rotation: percentage of eyes demonstrating rotational stability (7).

topography to distinguish between regular and symmetrical astigmatism.

Take-home messages

- Understand that the significant burden of preoperative corneal astigmatism can now be addressed with toric IOLs.
- The role and impact of low cyl astigmatism is profound; patients with under one diopter of astigmatism represent a large number of potential toric IOL recipients.
- Adopt the new Alcon Online Toric calculator and the vector (centroid) SIA method; Barrett's Toric calculator predicts residual astigmatism more accurately than other approaches, and accurate PCA adjustment provides optimal outcomes.
- Consider refining your outcomes by SIA personalization.
- Toric IOLs are clearly the best option for correcting astigmatism within cataract surgery, but not all IOLs are equal; understand the importance of choosing a rotationally stable IOL platform.

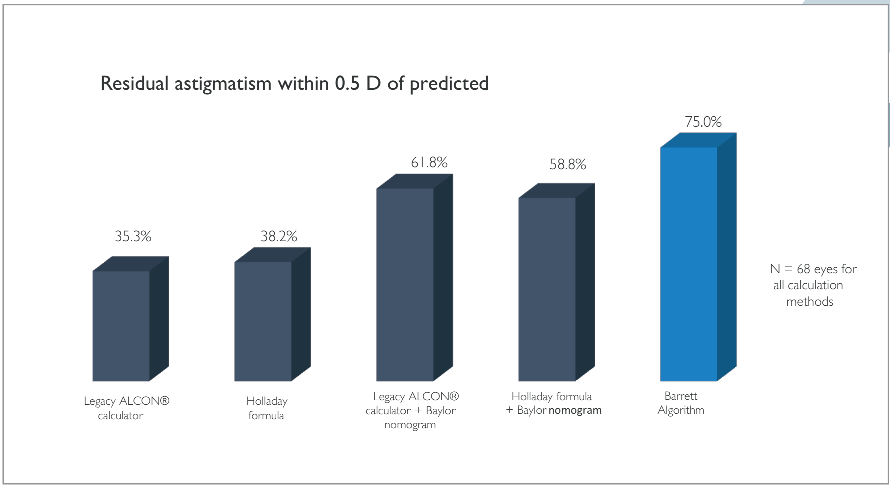


Figure 2. Proportion of eyes with absolute error in predicted residual astigmatism below or equal to 0.50 DD by measuring with optical low-coherence reflectometry and different methods of calculation (9).

Sidebar 4. Tools for measuring PCA

- Scheimpflug imaging: calculates total corneal power using ray tracing (8)
- Intraoperative aberrometry: measures sphere, cylinder and axis (14) - total refractive astigmatism in the eye in the aphakic phase, which accounts for the anterior and posterior curvature of the cornea (15)
- OCT: Calculates anterior and posterior corneal powers by curve-fitting over the central area
- Colour LED: Assesses corneal topography by anterior and posterior corneal measurements

	Method of Calculation				
Measuring Device	Alcon Toric Calculator	Holladay Toric Calculator	Alcon Toric Calculator (Baylor Nomogram)	Holladay Toric Calculator (Baylor Nomogram)	Barrett Toric IOL Calculator
OLCR					
Mean ± SD (D)	0.64 ± 0.28	0.65 ± 0.30	0.47 ± 0.23	0.47 ± 0.23	0.39 ± 0.19
Range (D)	0.03, 1.28	0.09, 1.33	0.05, 1.12	0.02, 1.11	0.09, 0.86
Median (D)	0.6	0.64	0.45	0.46	0.35
Centroid ± SD (D)	0.53 @ 1 ± 0.33	0.54 @ 180 ± 0.33	0.21 @ 4 ± 0.34	0.22 @ 2 ± 0.33	0.01 @ 119 ± 0.31

OLCR = optical low-coherence reflectometry

Using the Barrett toric calculator, the PCI device had the lowest median absolute error in predicted residual astigmatism (0.35 D).

Table 2. Absolute error and centroid errors in predicted residual astigmatism by method of calculation (9).

Kjell Gundersen, Norway

Patient selection for toric IOL

Broad indicators for IOLs are known (Box 1). My view is that general indications include regular corneal astigmatism (WTR, but especially ATR, or in the oblique axis); and all cases where good biometry and the Barrett calculator recommend a toric lens down to T2.

Specific indications include stable keratoconus and post-keratoplastic patients; note that "stable" is the keyword. If the conus is inferiorly positioned, such that the central part of the optical axis is not too involved, we can expect excellent outcomes. If the conus is involved with the central optical axis, however, outcomes won't be as good (though still better than without toric lenses).

Contra-indications and situations where the surgeon should proceed with care include irregular astigmatism with a short history; always be cautious if you are not certain of the stability. All irregular cases should be handled with extreme care, and perhaps treated with other modalities.

Choosing tools

Precision of measurement is more important than the precise measurement instrument: the best technologies are those that identify outlier patients who might cause problems. Don't use too many different instruments: Scheimpflug, OCT and the Placido-based system are adequate. Ray tracing may be useful in the future – the idea of calculating a specific lens for a specific patient is certainly attractive – but is not yet ready for routine use.

Above all, adopt modern algorithms that account for PCA. Several toric calculators are available, but only the Barrett takes into account both toricity and effective lens position, and offers a number of advantages (9):

- accounts for PCA in both WTR and ATR eyes
- improves SIA accuracy (centroid vector calculations incorporate both magnitude and direction)
- predicts T-power more accurately (accounts for axial length and anterior chamber depth in ELP estimates)

"We all hate outliers – but examine the ocular surface before you blame Barrett."
– Kjell Gundersen

Finally, consider image-guided technology; in my clinic, it has revolutionized the precision and practicality of toric lens implantation, with virtually no impact on workflow. Notably, using a toric IOL adds only seconds to the total procedure time.

Clinical results with Totic IOLs

In my experience, clinical outcomes with toric IOLs are excellent (Figure 3, 4).

Detailed analysis, however, showed

Sidebar 5. Don't forget dry eye

Kjell Gundersen has set up a dedicated dry eye lab at his clinic, and routinely screens patients prior to surgery. Why?

- To manage astigmatism, we must accurately measure it.
- But a compromised ocular surface may skew keratometric measurements by up to 2.5D (17).
- Furthermore, over 50 percent of patients reporting for cataract surgery have abnormal tear osmolarity, and more than 60 percent have abnormal inflammatory markers (18).

Box 1. Thoughts on identifying toric IOL candidates: Andrzej Dmitriew

A key consideration is the difference between WTR and ATR patients; the latter may have much higher residual astigmatism than the former. Due appreciation of this will significantly increase the number of patients eligible for toric IOLs. Important to remember that a given measurement may indicate implantation of a toric IOL in WTR but not ATR patients. Don't forget age-related ATR drift: for patients below 65, we can accept a target of 0.25D WTR astigmatism, but for patients over 80, we should have zero tolerance of astigmatism (16).

that although my centroid was good, I had some ATR outliers (Figure 5). These were probably related to known IOL rotational stability differences (91.9 percent of AcrySof® IQ Toric eyes rotate by <=5 degrees at first follow-up, versus 81.8 percent of TECNIS® Toric eyes ($P < 0.0001$) (7). Similarly, we had two large rotational errors in TECNIS® Toric eyes, but none in AcrySof® IQ Toric eyes.

Take-home messages

- Toric IOLs give better astigmatism correction than non-toric IOLs with or without relaxing incisions (3)
- Toric advantages include better visual acuity (3, 19, 20); less post-operative refractive astigmatism (3, 19, 20); higher ratings of clarity of vision (21); greater spectacle independence for distance (3); and higher patient satisfaction after surgery (20, 22, 23).

3 months post op	Total	Spherical	Toric
Efficacy	0,964	0,962	0,967
Safety	1,089	1,076	1,110

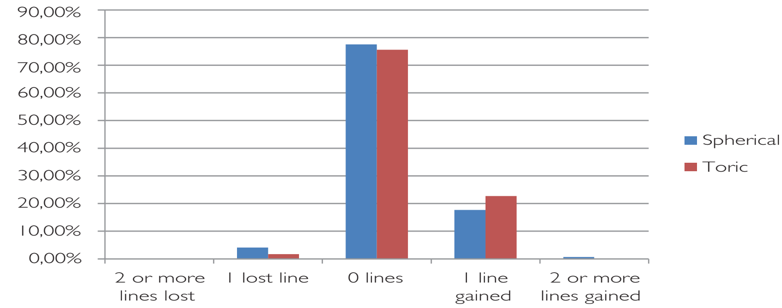


Figure 3. Summarized data from a series of 348 eyes treated during 2016-2017. Virtually all eyes were within 1D of astigmatism; over 80 percent were within +/- 0.5D, and almost 60 percent were within +/- 0.25D. Source: clinician's personal experience.

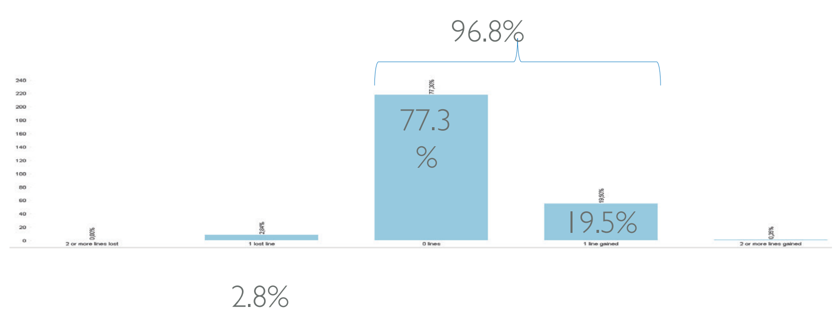


Figure 4. Virtually all toric IOL recipients (96.8 percent) lost zero lines or gained one line; only 2.5 percent lost one line; Source: clinician's personal experience.

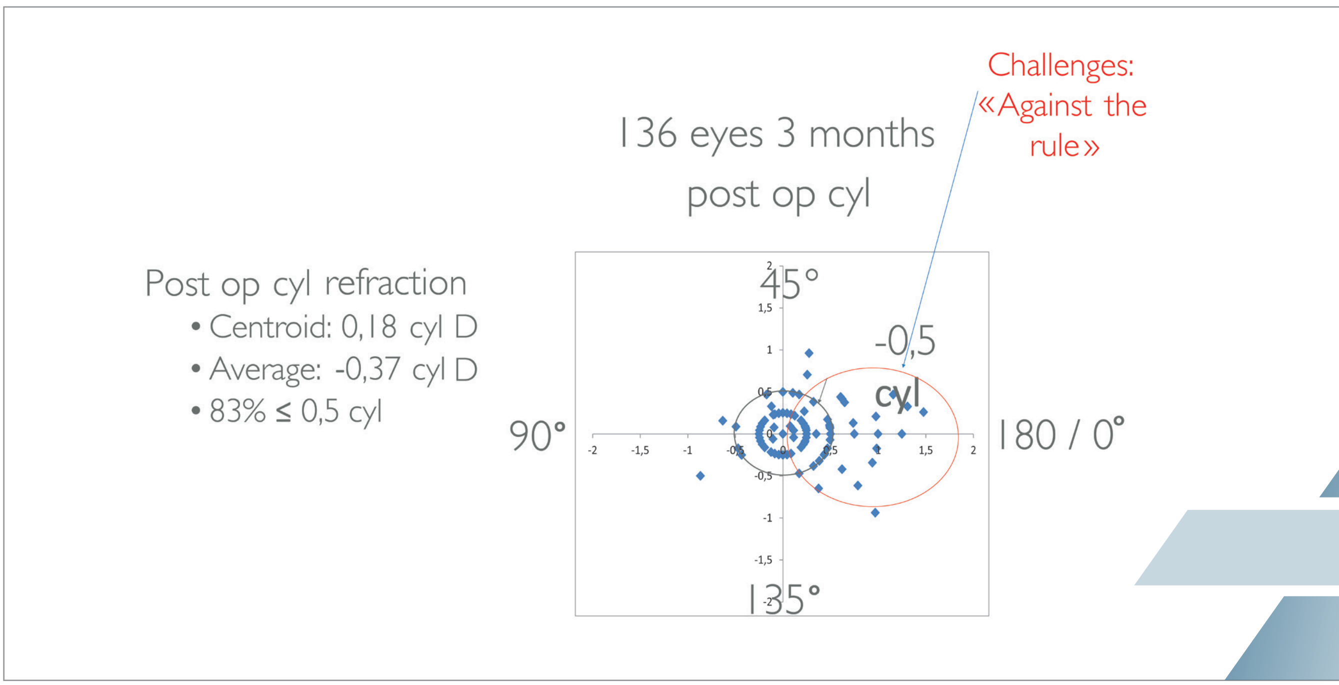


Figure 5. Centroid outliers thought to be caused by TECNIS® Toric IOL rotational stability issues, clinician's personal experience.

Part III. VERION™ 3.1 Image Guided System in astigmatism management

Norbert Pesztenlehrer (Hungary)

Mean absolute error in predicted residual astigmatism

Calculator	Mean ± SD (Range) (D)	P[a]
Barrett toric calculator	0.34 ± 0.23 (0.03 to 1.04)	
Holladay calculator + Abulafia-Koch formula	0.43 ± 0.34 (0.04 to 1.49)	0.139
Panacea	0.59 ± 0.29 (0.13 to 1.35)	<.001
PhacoOptics	0.64 ± 0.34 (0.15 to 1.44)	<.001

SD = standard deviation; D = diopters

[a]Comparison with the Barrett toric calculator

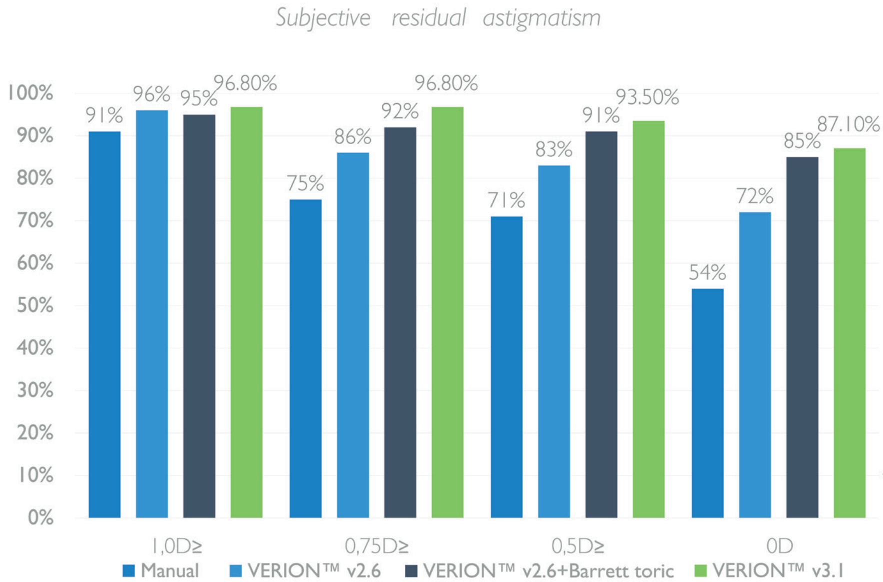
Table 3. The Barrett toric calculator yielded the lowest mean absolute error of all calculators (25).

Refractive surprises mainly arise from inaccurate measurements or poor patient selection, and so can be avoided by better preoperative assessments. Instrumentation options include swept-source OCT, topography, Scheimpflug devices, ray tracing.

Always optimize the constants used by different calculators and formulas, including personal constants: this is a key element of outcome optimization. Also, use appropriate sphere IOL power formulas, which work best in your hands for different axial length. The new VERION™ 3.1 version integrates Barrett Algoritm, including Barrett Toric calculator, Barrett Universal II and Barrett True-K formulas. According with the recent study, the Barrett Universal II formula had the lowest mean absolute prediction error over the entire AL range ($P < .001$, all formulas). Holladay Ishowd best results for eyes below 22 mm, however no statistically significant difference was seen between formulas in the short AL subgroup. Overall, the Barrett Universal II formula resulted in the highest percentage of eyes with prediction errors between 0.25D, 0.50D, and 1.0D groups. (24).

For residual astigmatism prediction, the Barrett Toric calculator is clearly superior to alternatives, including Panacea and PhacoOptics ray-tracing systems (Table 3) and the Holladay / Abulafia-Koch formula.

Digital marking is superior to manual methods: VERION™ (26) guidance delivers better outcomes than slit-lamp assistance in terms of induced astigmatism (mean deviation from target: 0.10 versus 0.2); and postoperative toric IOL misalignment (mean 2.4 degrees versus 4.3 degrees) (21). Furthermore, the VERION™ can deal with intraoperative challenges, such as bleeding, chemosis and subconjunctival edema; even with a huge suffusion in the conjunctiva, the VERION™ accurately guides toric IOL implantation. Hence, I use VERION™ in every procedure – multifocal, toric, and spheric lenses – in over three thousand patients a year. With that throughput, it helps that the VERION™ 3.1 requires



Residual Cyl Refraction (n=31)	Subjective	Objective
MEAN	0,10D	0,49D
SD	0,31D	0,33D
SEM	0,06D	0,09D
CI95%	-0,01-0,22D	0,31-0,68D

Barrett Universal II + Barrett toric calculator
Verion ™ v3.1, Vision Planner, digital alignment
Own results .

Figure 6. Outcomes improve alongside technology advances, Source: clinician's personal experience.

less than forty seconds for measurement and imaging, versus 1.5 minutes per eye in the earlier version.

Other welcome features of the new VERION™ 3.1 (26) include the ability to drag and reposition the incision site to modulate post-operative astigmatism. The 'compare formulas' option is also extremely convenient; with a click we can compare, at a given spherical equivalent, post-operative refraction predictions of different formulae. Reassuringly, VERION™ 3.1 automatically warns us if predicted post-operative astigmatism exceeds preselected values. Futhermore, the system's SIA calculator accounts for incision site effects, and permits optimization of constants per surgeon and per incision size (different constants apply to 2.2 mm and 2.8 mm incisions).

My experience with VERION™ 3.1 is highly satisfactory (Figure 6). Before VERION™, I was using manual marking: only 54 percent of my patients achieved zero subjective astigmatism. Adoption of VERION™ 2.6 improved our results significantly (72 percent in the zero diopter group); but we wanted to do better. Last year, we began using VERION™ 2.6, with the new Barrett Toric calculator; 85 percent of patients achieved a zero diopter outcome. Now, we are using VERION™ 3.1 with integrated Barrett Algorithm and we see 87 percent in the zero diopter group. But that is with fewer than 40 cases – we hope to exceed 90 percent zero diopter outcomes as our dataset grows. Interestingly, keratometry shows that VERION™ 3.1 achieves mean post-operative subjective astigmatism of 0.10, and objective astigmatism of 0.5D. So those who criticize a zero-astigmatism objective, on the grounds that 0.5D astigmatism is the natural physiological state, should know that, in fact, we have retained that physiological value.

Take-home messages

- Optimal outcomes require:
  - optimal hardware (accurate biometry, digital marking, good rotational stability)
  - optimal software (accurate formulae for surgically-induced astigmatism, either centroid or optimized constants).
- Used together in one system, these will provide excellent results.

Part IV. Plan, Guide, Verify with ORA VerifEye Lynk™ System

Humberto Carreras, Spain

The Optiwave Refractive Analysis (ORA) system is an intraoperative aberrometer that measures aphakic and pseudophakic refraction during surgery. By allowing verification of IOL selection and toric alignment, it enhances refractive outcomes and minimizes refractive surprises (15), ORA System™ measures lower order aberrations of the wave front; calculate intraoperatively total eye refraction; calculates lens power using a refractive vergence formula derived from outcomes logged by ORA System™ users worldwide (27). This formula, known as the WaveTech Factor (WTF), is informed by data from over 1,000,000 cases.

A key part of ORA System™ is AnalyzOR™ Technology – a secure, web-based data system that stores and analyses clinical data, thereby helping users to optimize both personal constants and IOL constants. Surgeons input patient information via the touchscreen, including pre-operative measurements and keratometry-relevant data (for example, prior to refractive surgery). Surgery begins after data input is complete.

After taking measurements, ORA System™ displays data (Figure 7), including aphakic refraction, planned IOL power, and the recommended IOL, and recommends a sphere. After sphere selection, ORA System™ recommends a toricity value.

Following IOL implantation and pseudophakic measurement, ORA System™ recommends and guides IOL rotation (Figure 8) until the lens reaches the "no rotation recommended" position of optimal refractive outcome.

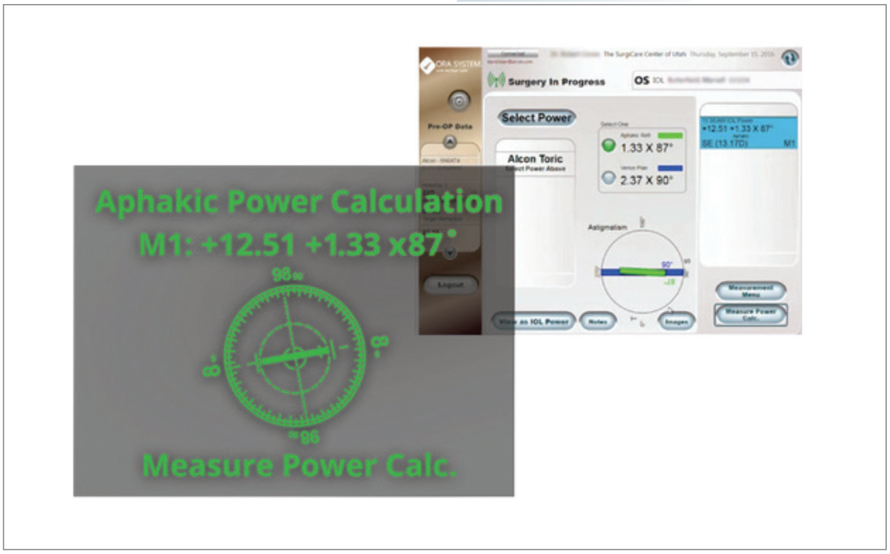


Figure 7. ORA displays guidance including recommended IOL and sphere.

ORA System™'s ability to provide real-time, optimized guidance for IOL sphere, cylinder and LRIs, as well as its ability to recommend a precise IOL power based on the individual eye anatomy, largely depends on AnalyzOR™. This unique system draws on the ever-expanding global database of real-world IOL outcomes to continually refine the four ORA System™ formula regression coefficients (related to axial length, mean K, white-to-white and aphakic SE, respectively). The user-friendly display distinguishes clearly between IOL recommendations based on global optimization (signaled by a gold indicator) and personally optimized IOL values (based on the surgeon's own real-world outcomes, and signaled with a platinum indicator).

Additionally, AnalyzOR™ supports individual performance assessment via analysis of cases over the preceding 18 months. Features including refractive accuracy or astigmatism management can be assessed in standard or customized formats.

Clinical data

ORA also improves biometry predictability. Data from over 30,000 eyes indicate better spherical equivalent outcomes with ORA System™ versus pre-operative calculations (30).

It is increasingly accepted that astigmatism correction with toric IOLs can provide the best outcomes. However, we should remember that achieving these outcomes depends on: correct biometry; adequate management of PCA; implantation at the correct axis; competent surgery; and rotational stability. ORA System™ is associated with a 12 percent improvement in the proportion of astigmatism below 0.5D (31), and 67,3% reduction in off-target post-op outcomes in cases of high pre-operative cylinder (30).

Intra-operative pseudophakic calculations, based on real-time refractive measurements, inform ORA System™ guidance regarding toric IOL rotational adjustment (Figure 8). This feature is also very useful when you need to make Relocation of Toric IOL, as you can avoid time-consuming calculation and have the real-time guidance from ORA System™ System.

Take-home messages

- The combination of VERION™ 3.1 with the next-generation ORA™ VrifEye Lynk™ allows surgeons to plan, measure, operate and verify using a single, seamlessly integrated technology set.
- Enhanced data flow between VERION™ 3.1 and ORA System™, and between ORA System™ and AnalyzOR™, allows ORA System™ VerifEye LynkTM to compare your pre-operative plans with ORA System™ intra-operative recommendations.
- ORA System™ remains very user-friendly – entirely controllable with the Centurion foot-pedal.
- A microscope integrated display shows high-resolution images and multiple measurements in the ocular view. Real-time axis tracking, toric alignment, and streaming of refractive data allows ORA System™ to guide surgeons as to axis and IOL power.
- The new ORA VerifEye Lynk™ helps surgeons achieve optimal refractive results by integrating planning, guidance and intraoperative aberrometry (31).

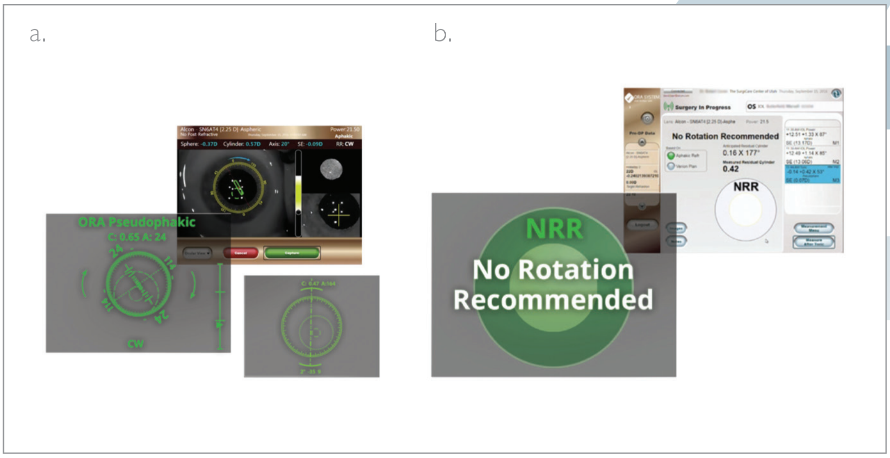


Figure 8. ORA prompts surgeon to rotate lens until optimally positioned.

Figure 9. ORA System™ allows surgeons to assess their performance against the global database.

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