Over the last decade, a vast improvement on intraocular lens (IOL) options steered cataract surgery towards a more sophisticated approach concerning the final refractive goal. On a particular note, the availability and adoption of toric IOLs, either in monofocal or multifocal platforms. This allowed for a better final quality of vision, but also addressed several complex steps, especially regarding proper diagnostic assessment during surgical planning. More than 50% of the patients who undergo cataract surgery have corneal astigmatism ≥ 0.75 diopter (D), which is within the range of surgically treatable astigmatism and may significantly limit an optimal visual outcome if left uncorrected.

When speaking of astigmatism, the main consideration is related to the anterior cornea. Its evaluation in terms of magnitude, vector, and topographic aspect is critical for toric IOL calculation.

The influence of the posterior cornea has been noted since the 19th century, as being the difference between the keratometric values from the anterior corneal surface and the total refractive astigmatism. Javal postulated an approximately linear relationship between corneal astigmatism and refractive astigmatism, which became known as Javal’s rule: refractive astigmatism equals 1.25 × (keratometric astigmatism) − 0.50×90.

In IOL calculations, the cornea is regarded as a single refractive surface with an effective refractive index, which varies from 1.332 to 1.3375, assuming that it consists of a fixed ratio between the radius of the anterior and posterior corneal surface. But this approach disregards considerations of corneal thickness and radius of the posterior corneal surface. The role of the posterior cornea was dismissed because of the small difference between the indices of refraction of the cornea and aqueous.

A 1992 study revealed that the posterior surface exhibited more toricity than the anterior surface. Another study suggested that ignoring posterior corneal astigmatism (PCA) could be a significant factor with regards to postoperative refractive astigmatism after toric IOL implantation.

To further evaluate the cornea as a whole, Scheimpflug photography and its analysis have the advantage of being a non-contact technique whereby the anterior surface, the thickness profile, and the posterior surface are determined in one step.

In a study involving 715 corneas of 435 consecutive patients who underwent analysis before cataract or refractive surgery, Koch et al. evaluated total corneal astigmatism using ray tracing, corneal astigmatism from simulated keratometry, anterior corneal astigmatism and PCA. Corneal astigmatism was measured using five devices (IOL Master, Lenstar, Atlas, Manual Keratometer and Galilei) before and three weeks after surgery.

They found that the steep axis of PCA was oriented in the horizontal meridian in approximately 87% of eyes and was not factored into what is typically measured as anterior corneal astigmatism. This would overestimate anterior corneal astigmatism by about 0.50 D for with-the-rule (WTR) anterior corneal astigmatism and underestimate...
it by about 0.30 D for against-the-rule (ATR) anterior corneal astigmatism. Selecting toric lenses based on anterior corneal measurements only could lead to overcorrection in eyes that have WTR astigmatism and undercorrection in eyes that have ATR astigmatism.

Based on these findings, Koch et al. proposed a nomogram based on a regression analysis derived from direct PCA measurements (Baylor nomogram). In eyes with WTR astigmatism, the nomogram shifts the threshold for selecting a toric IOL up 0.7 D; conversely, in eyes with ATR astigmatism, the shift of the threshold for selecting a toric IOL goes down 0.7 D. This nomogram aims for postoperative WTR astigmatism of about 0.40D to account for the gradual shift of the astigmatism axis with age from WTR to ATR. It requires surgeons to factor in their average surgically induced astigmatism (SIA), which for most surgeons is 0.2 to 0.3 D.

It is important to note that the axis of astigmatism can be flipped to achieve the lowest residual magnitude. Flipping the axis is only of concern in glasses, in which meridional aniseikonia and spatial distortion from spectacles occur due to the base curves, power, astigmatism and vertex distance.

Besides the nomogram, the study showed that even with advanced tomographic evaluation, validated ways to accurately measure PCA are still missing, with mean prediction errors of 0.57 D in the WTR group and 0.12 D in the ATR group, even when using dual Scheimpflug technology. Also, results of the total corneal astigmatism from various devices cannot be used interchangeably.

Derived from the Baylor nomogram, a hybrid algorithm was coupled with clinical outcomes of trials of AMO toric IOLs (now Johnson & Johnson Vision) and incorporated into its online toric calculator, as an optional field. Additional studies analyzed the total corneal refractive power (TCRP) astigmatism by ray tracing using a rotating Scheimpflug tomographer (Pentacam HR; Oculus) and the factors that may lead to the false calculation of total corneal astigmatism by using anterior curvature measurements only. Although using a different corneal tomograph from the work of Koch et al., they similarly concluded that ignoring posterior astigmatism could lead to miscalculation of total corneal astigmatism, and, in cases of toric IOL implantation, to significant overcorrection or undercorrection.

Studies using different devices also have shown that the steepest corneal meridian on the posterior corneal surface is vertically oriented in most cases and thus generates an ATR astigmatism. Posterior corneal astigmatism on average reduced total corneal astigmatism by 13.4% and in 28.8% of eyes total corneal astigmatism differed from anterior corneal astigmatism by >0.5 D or >10 degrees in meridian.

The Barrett formula estimates the PCA for each eye using a proprietary mathematical model, and details over its contents have not been published. The Barrett Toric Calculator (available at www.ascrs.org/barrett-toric-calculator) uses the Universal II formula to predict the required spherical equivalent IOL power. The calculator derives the posterior corneal curvature based on a theoretical model proposed to explain the behavior of the posterior cornea. The toric IOL cylinder power required to correct corneal astigmatism—that includes PCA—is calculated from the predicted effective lens position (ELP) using vector calculations for each eye.

Although the posterior cornea prediction utilizes a theoretical model as the default mode “Predicted PCA” to predict the posterior corneal astigmatism for an individual eye, it also allows the user to enter directly measured values from Scheimpflug or Swept Source OCT devices. However, it has to be noted that the Baylor nomogram offers an average adjustment for posterior astigmatism power based on the preoperative anterior astigmatic direction without addressing the possible effect on the net corneal astigmatism meridian.

The Barrett toric algorithm is also incorporated in the Alcon online calculator.

The Barrett toric formula is also available in the following optical biometers: Zeiss IOLMaster 700, HS Lenstar 900, HS Eyestar 900, Oculus Pentacam AXL, Topcon Alladin e Movu Argos.

On an additional note, an accurate preoperative SIA prediction is crucial to hitting refractive outcomes. Whereas traditional mean SIA calculation relies on magnitude alone, a more recent concept considers magnitude and direction. Using vector analysis to find the geometric mean or centroid, yields the highest prediction accuracy of any method. By applying vector analysis to a broad sample of postoperative patient astigmatism data, the usual standard value of mean SIA of 0.5 D has given place to the centroid SIA of 0.1 D (recommended for incisions between 2.2 and 2.4 mm). A centroid calculation can be carried out using a tool available at www.SIA-calculator.com.
Besides the Baylor nomogram and the Barrett Toric Calculator, PCA has also been addressed by other methods such as the subtoric IOL calculator and the Goggin et al. nomogram. Also, a new regression formula (Abulafia-Koch) was developed to calculate the estimated total corneal astigmatism based on standard keratometry measurements and significantly improved the prediction of postoperative astigmatic outcomes in the adjustment of commercial toric IOL calculators.

Pentacam

The Pentacam (Oculus Optikgeräte GmbH) measures both the anterior and posterior corneal surfaces using a rotating Scheimpflug camera. The device calculates the true net power (TNP) of the cornea by adding sagittal curvature values of the anterior and posterior corneal planes; the ray-tracing calculation is also available via the TCRP. However, because of the refractive indices used, the results cannot be applied in the conventional IOL formulas. Posterior corneal data derived from the Pentacam device also can be incorporated into standard toric IOL calculations.

As nomogram adjustments based on sample averages of the residual refractive cylinder may not be effective in all cases, the specific analysis of posterior astigmatism yields better results. Because of the variability in the contribution of the PCA in individual patients, the specific analysis of the posterior astigmatism yields better results.

Using ray-tracing technology, the corneal power of the anterior surface and posterior surface can be determined, with the result termed the TCRP. This value can be successfully applied to toric IOL calculations.

In a paper from Ho with 493 subjects comparing the keratometric corneal astigmatism with the total corneal astigmatism derived by double-angled vector analysis of both corneal surfaces with the Pentacam (Oculus), total corneal astigmatism differed from anterior corneal astigmatism by more than 0.5 D in 28.8% of eyes, and the PCA reduced total corneal astigmatism by an average of 13.4%.

In a study comparing the astigmatism prediction errors taken with the Pentacam measurements, Baylor nomogram, and Barrett formula for toric intraocular lens implantation, vector summation using anterior and posterior corneal surface power taken with the Pentacam yielded the least astigmatism prediction error.

Besides obtaining data from the posterior cornea, the Pentacam AXL incorporates the Savini Toric formula. It uses TCRP measurements from the 3mm zone, centered on the pupil.

Galilei

The Galilei (Ziemer Ophthalmic Systems AG, Port, Switzerland) is a Placido-dual Scheimpflug corneal tomographer that provides a range of data for planning cataract and refractive procedures, including anterior and posterior corneal curvature and astigmatism, total corneal power and astigmatism, elevation and pachymetry maps, keratoconus indices, anterior chamber depth (ACD) and angle kappa. Its most recent version, the Galilei G6, incorporated an optical A-scan that provides non-contact biometric measurements, besides the anterior segment parameters.

The Galilei uses a proprietary algorithm to derive anterior segment measurements from the images obtained by 20 Placido rings and two rotating Scheimpflug cameras. The two Scheimpflug cameras on opposite sides of the eye capture image simultaneously and compensate for decenteration. The device can obtain up to 60 Scheimpflug scans and 2 Placido images in one second, evaluating up to 100,000 data points. Furthermore, the current device uses an 880 nm A-scan to measure the axial length and includes IOL power calculation formulas. Its ACD measurement derives from data obtained by the Scheimpflug cameras and is defined as the distance between the corneal epithelium and the anterior lens surface.

The Galilei is a very promising device used worldwide. Previous papers have shown that some anterior segment measurements obtained by the Galilei are highly repeatable, including anterior and posterior corneal power and simulated keratometry. However, with regards to posterior corneal astigmatism measurements, moderate repeatability was observed, suggesting that hardware/software improvements are still necessary before establishing this device as the gold standard to measure posterior corneal astigmatism with the objective of inputting the exact measurement in the cataract surgical planning.

Cassini

The Cassini (i-Optics, The Hague, Netherlands) was originally launched as a corneal topographer, which acquired data based on the specular reflection of approximately 700 colored light-emitting diodes (LEDs). More recently, seven additional infrared LEDs were added to measure the posterior corneal curvature, and ray tracing began being used to calculate total corneal astigma-
There are a few papers in the literature assessing the outcomes of the Cassini. The repeatability analysis of the anterior corneal measurements has shown that the device needs improvement when compared to others routinely used by ophthalmologists. However, Klijn et al. have described a better accuracy in astigmatism measurement when using the total corneal astigmatism obtained by the Cassini, than when using its anterior corneal measurement alone. Thus, the results of this latter study are promising, and future data will show if there is a specific corneal tomographer that is accurate enough to be routinely incorporated in the cataract surgical planning.

**Perspectives**

Other advances in newer ssOCT-based biomeyometry and keratometry, using anterior and posterior corneal surfaces, corneal thickness, axial length, anterior chamber depth and white-to-white distance, led to a retrospective study in which ray tracing-based IOL power calculation was performed using retinal image quality metric (RIQM) criteria in an iterative procedure, and retinal image simulations. In the ray tracing-based method, IOL selection is based on predicted visual acuity and a neuronal weighted RIQM. After comparing the spherical equivalent outcomes of ray tracing-based IOL power calculation, using exact IOL design information, with the outcomes of a triple-optimized Haigis formula, it resulted in a 2.5% increase in outcomes within 0.5D and 0.75D of target refraction, and a 10% increase in those coming within 1.00D.

New devices, nomograms, and formulas make the posterior astigmatism consideration an exciting opportunity to better refine cataract refractive outcomes, making the diagnostic preoperative evaluation a key ingredient for success.

**References**


