REVIEW/UPDATE

Perioperative assessment for refractive cataract surgery

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As cataract surgery has evolved into lens-based refractive surgery, expectations for refractive outcomes continue to increase. During the past decade, advancements in technology have provided new ways to measure the cornea in preparation for cataract surgery. The increasing ability to accurately estimate corneal power allows determination of the most precise intraocular lens (IOL) for each patient. New equipment measures the anterior and posterior corneal surfaces to most accurately estimate corneal power and corneal aberrations. These measurements help surgeons make the best decisions regarding the power of the IOL to be implanted during cataract surgery. However, with all the available technology, it can be difficult to decipher which of the many technologies is necessary or best for patients and for practices. This article reviews currently available options for topography, tomography, keratometry, and biometry in preparation for cataract surgery. In addition, intraoperative aberrometry and integrated cataract suites are reviewed.

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Over the past 2 decades, we have experienced an evolution in cataract surgery from simply the removal of the cloudy lens to a refractive procedure that provides patients with increasingly higher levels of spectacle independence. With this evolution has been a parallel increase in patient expectations. Cataract surgery is now poised to compete with corneal refractive surgery, and improvements in technology are providing better ways to meet these new benchmarks. Great outcomes are not only expected but are demanded from both the premium channel patients and the standard lens patients. In addition, as the patients who have had laser in situ keratomileusis (LASIK) or radial keratotomy age, they are noticing that their once perfect vision is again being compromised with onset of incipient cataracts. This group of patients has preconceived expectations for visual perfection and the maintenance of the youthful range of vision they once experienced before the onset of cataracts and presbyopia.

During this past decade, advancements in technology have provided new ways to measure the cornea in preparation for cataract surgery. With the increasing ability to accurately estimate corneal power, we are better able to determine the most precise intraocular lens (IOL) for each individual patient. For decades, we have measured only the anterior corneal surface with the use of topographic devices; however with discovery of the impact of posterior corneal astigmatism, we can now achieve higher degrees of accuracy by taking into account the effect of the posterior corneal surface in astigmatism correction. Tomographic instruments allow 3-dimensional (3-D) measurement of the cornea to account for the impact of both the anterior and posterior corneal surfaces on total corneal power (Table 1).[1,2] This new technology also provides assessment of corneal aberrations. More and more patients have had previous corneal refractive procedures by the time they reach the point of cataract surgery. After such refractive procedures, corneal aberrations (primarily spherical aberration) are modified. Detailed analyses of the corneal aberration pattern before cataract surgery can help the surgeon make decisions on the IOL design to implant.[3–6]

This is an exciting time for us as cataract surgeons as we move toward increasing accuracy in achieving our intended refractive target individualized for each patient. However, with all of the technology available to us, it may be difficult to decipher which technology is necessary or best for our patients and for our practice. This review is designed to clarify what current technology provides us in the assessment of our patients in preparation for cataract surgery.

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Table 1. Corneal topography and tomography devices.

Device Type/Name	Manufacturer
Placido topography	
Zeiss	Atlas 9000
Keratograph 5M	Oculus
Tomey	TMS-4N
Placido + scanning slit	
Orbscan	Bausch & Lomb
Scheimplug tomography	
Pentacam	Oculus
Galilei	Zeimer
Combination*	
LED	
Cassini	i-Optics
Ray tracing	
iTrace	Tracey Technologies
Measures axial length	
IOLMaster	Zeiss
Lenstar	Haag-Streit
A Scan	
AL-Scan	Nidek
Argos	Movu Inc.
Aladdin	Topcon

LED = light-emitting diode
*Keratometer/tomographer/wavefront

PREOPERATIVE ASSESSMENT

The preoperative assessment for cataract surgery can be divided into 2 parts; that is, measurement of axial length (AL) and assessment of corneal power. Just a few years ago, the preoperative assessment consisted of a contact A-scan and manual keratometry. As technology has advanced, we have more accurate ways to directly and indirectly measure the corneal power. In addition, we have learned that the AL is more accurately measured by avoiding direct corneal contact and potential compression of the corneal surface. In many refractive cataract practices, multiple types of corneal topography and tomography are performed, compiled, and compared before choosing the final IOL type, power, and orientation.

Measurement of Axial Length

Multiple options to measure the AL are available. At present, AL measurement techniques include ultrasound (US) and noncontact optical biometers. With regard to US technology, the measurements can be performed by applanation or immersion techniques. The applanation method might compress the cornea, providing underestimation of the AL compared with the immersion technique.[7] The immersion US method provides more accurate AL measurements than obtained with applanation. However, this procedure is not widely used for routine cases because it is more time consuming and requires more technical training to ensure accuracy.

Ultrasound biometry was considered the gold standard for AL measurement until the appearance of the noncontact optical biometers in approximately 2000. This technology uses an infrared laser to measure the AL. These systems are based on partial coherence interferometry (PCI) (IOLMaster, Carl Zeiss Meditec AG) or optical low-coherence reflectometry (OLCR) (Lenstar, Alcon Laboratories, Inc.) for ocular biometry measurements. The IOLMaster device measures the AL, keratometry (K) readings, white-to-white (WTW) distance, and the anterior chamber depth (ACD) (from the corneal epithelium to the anterior lens surface). The Lenstar device measures the AL, K readings, WTW distance, central corneal thickness (CCT), and ACD (from corneal endothelium to the anterior lens surface). It also measures crystalline lens thickness and retinal thickness. Earlier studies[8–10] have shown that the IOLMaster (PCI) and the Lenstar (OLCR), despite being based on different technology, correlated very well for ocular biometry measurements. It has also been reported that PCI and OLCR provide ocular biometry measurements comparable to those provided by immersion US devices.[10]

A new noncontact optical biometer, the IOLMaster 700 (Carl Zeiss Meditec AG), was recently released. This device uses a combination of swept-source optical coherence tomography (OCT) technology and B-scan US technology to measure various ocular parameters. The devices measure the AL, ACD, CCT, crystalline lens thickness, WTW distance, and K readings. In addition, it provides a full-length OCT image showing anatomic details on a longitudinal cut through the entire eye. Several studies[11–14] have shown that this new device provides excellent repeatability and reproducibility for ocular biometry measurements, as evidenced by agreement with optical biometry measurements.

Measurement of Anterior Surface Parameters

Corneal power can be determined directly through reflected light or indirectly by analyzing elevations on the corneal surface. Direct measurements of the corneal surface can be made with a keratometer, a Placido disk–based device, or devices based on light-emitting diodes (LEDs). Indirect corneal measurements can be taken with scanning-slit beams, high-frequency US, OCT, or Scheimpflug imaging devices.[15–20,A–F]

Many devices used to measure the cornea are 2-dimensional (2-D) topography systems, such as keratometers and Placido-based devices (Table 2[15,16,A–E]), whereas others are 3-D tomographic devices that measure both the anterior and posterior corneal surfaces. Two-dimensional devices are useful in detecting abnormalities of the corneal surface in contrast to 3-D devices, which better assess total corneal astigmatism power and axis.

Placido Imaging Devices

The most common type of topography device is Placido topography (Table 2). The TMS-4N (Tomey Corp.), Keratograph (Oculus Surgical, Inc.), and the Atlas 9000 (Carl Zeiss Meditec AG) topographers are some devices that use Placido imaging. In terms of the preoperative evaluation for cataract surgery, Placido topography is especially useful with newer more advanced IOLs, such as toric or multifocal IOLs. In particular, Placido rings are helpful in

Table 2. Comparison of 3 Placido topography devices.[15,16,A–E]

	Zeiss Atlas 9000	Oculus Keratograph	Tomey TMS-4N
Rings (n)	22	22	25
Accuracy (D)	±0.05	±0.10	±0.02
Reproducibility (D)	±0.10	±0.10	NA
Working distance (mm)	70	78/100	NA
Evaluated datapoints (n)	NA	22.000	6400

NA = not applicable

detecting anterior corneal disease (eg, anterior K measurements in preparation for IOL power calculations). Poor K values are a leading cause of preoperative IOL power calculation errors.[21]

The Placido disk corneal topographers use an arc-step algorithm to reconstruct the corneal profile as a series of arcs that would reflect the rays from the mires to the keratoscope lens. The K readings are calculated by converting the measured radius into diopters (D) using a standard keratometric refractive index.

Because Placido topography is based on reflection from the tear layer, it might not be an absolute indication of the true curvature of the corneal surface; therefore, artificial tears might alter the image. Dry eyes and a compromised ocular surface can cause variability in measurements. Although 2-D topographic devices provide a very good estimate of the K values, we have realized the impact of posterior corneal astigmatism over the past several years. Three-dimensional tomographic devices have recently gained popularity for power and axis determination (Table 1).[1,22,23]

Scanning-Slit Devices

Scanning-slit technology produces multiple slitlamp images of the anterior segment using a camera moving horizontally. The Orbscan topographer works with this principle. This device uses a combination of scanning-slit and Placido topography to measure both the anterior and posterior corneal surfaces.[18,24] It records 9000 datapoints that are used to create a series of anterior and posterior corneal surface maps that can then be used to calculate corneal power. It quantifies elevation differences between the anterior and posterior corneal surface, the anterior surface of the iris, and the crystalline lens. It provides additional information including pachymetry mapping, ACD, WTW distance, and the ability to compare and contrast the front and back surfaces of the cornea. The posterior elevation (float) measurement is a good way to detect early corneal ectasia in after laser vision correction.[25] It is also an excellent screening tool for keratoconus and other corneal disease (through identification of shape and/or thickness irregularities). As with any technology, limitations exist and front-surface measurements with interpolated posterior surface measurements can produce limited diagnostics.

Scheimpflug Camera

The Scheimpflug camera is based on the Scheimpflug principle by which an obliquely tilted object can be placed in maximum depth of focus with minimal image distortion. The Pentacam (Oculus Surgical, Inc.), Sirius (Costruzione Strumenti Oftalmici), and Galilei (Ophthalmic Systems AG) systems use this technology.

The Pentacam device takes a series of 50 radially oriented sections through the center of the cornea with a rotating Scheimpflug camera. A second centrally located camera detects the size and orientation of the pupil as well as controls fixation. The cross-sectional images are then merged to create a 3-D reconstruction with a ray-tracing algorithm (Figure 1). Since the central point of each meridian is maintained, eye movement can be eliminated in these calculations. The cataract itself can also be assessed with 3-D lens densitometry software categorizing cataracts into grades 0 to 5 due to the difference in brightness between individual layers. With an objective evaluation of cataract density and volume, the surgeon can make a more tailored preoperative plan for the most appropriate phacoemulsification settings. Another advantage of this device is the use of elevation mapping as its primary data source, as opposed to other modalities such as slope (used by Placido topography). Moreover, it does not have optical distortion in calculating the anterior surface of the cornea because the tear film has no effect on measurements.[26,27] The Pentacam provides measurements of the anterior and posterior corneal surface, aberrometry, ACD, WTW distance, corneal thickness and volume, portions of the angle anatomy, and lens density.[15–18] A new model, the Pentacam AXL, combines corneal imaging by the Scheimpflug principle with AL measurements by PCI. A recent article[28] evaluated the repeatability and comparability of this device with swept-source optical biometry (IOLMaster 700, Carl Zeiss Meditec AG). The study found that both devices provided highly reproducible values. The ACD and AL measurements varied between the 2 devices; however, the difference was small and could be considered interchangeable. However, the K readings were considerably different between devices.

Similar to the Pentacam system, the Galilei device uses a combination of optical A-scan, a Scheimpflug camera system, and Placido topography methods, allowing for accurate anterior corneal surface measurements, posterior corneal surface measurements, corneal pachymetry, and anterior chamber and lens analysis.[F] The Galilei uses a dual Scheimpflug camera configuration, capturing slit images from opposite sides of the slit beam simultaneously to provide a more accurate pachymetry and elevation

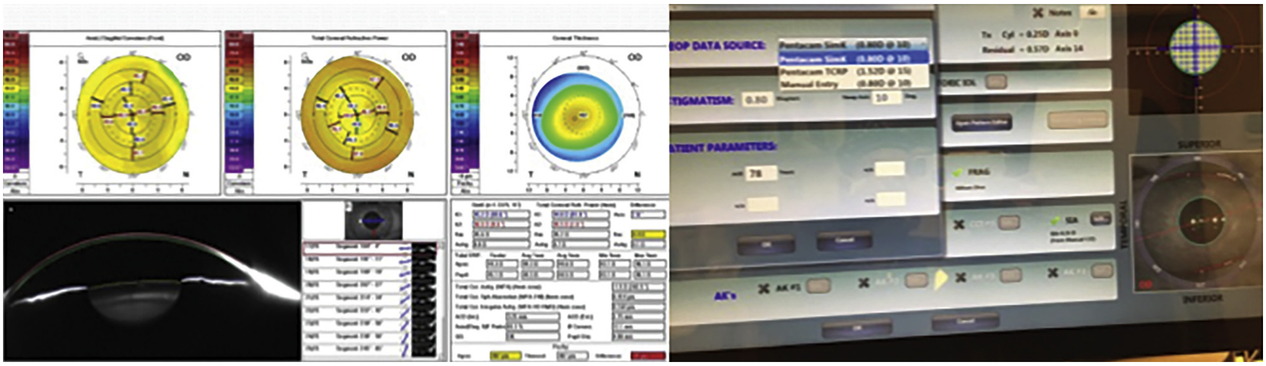

Figure 1. Pentacam streamline with Lensar.

reconstruction. The dual-camera system allows for motion correction based on iris-pattern recognition and thus is very accurate in assessing corneal thickness and elevation. This system combines multiple forms of technology used in other devices in such a way that a refractive surgeon can use 1 device to assess anterior and posterior corneal power, pachymetry, and IOL power.[25,29–32]

The Sirius topographer combines Scheimpflug and Placido disk imaging. Scheimpflug photography enables the acquisition and processing of 25 radial sections of the cornea and anterior chamber in a few seconds. The combination of a monochromatic 360-degree rotating Scheimpflug camera and a Placido disk allows full analysis of the cornea and anterior segment, providing tangential and axial curvature data of anterior and posterior corneal surfaces, the global refractive power of the cornea, a biometric estimation of various structures, a corneal wavefront map, and a corneal pachymetry map. Specifically, this system allows for the measurement of 35 632 points for the anterior corneal surface and 30 000 for the posterior corneal surface on high-resolution mode in less than 1 second.

Ray Tracing/Wavefront Aberrometry

Several devices use this technology to reconstruct the corneal shape and provide detailed information about the corneal morphology.

Cassini The Cassini corneal shape analyzer (i-Optics Corp.) measures total corneal astigmatism using multicolored LED point-to-point ray tracing to provide precise corneal mapping. This mapping can be used to create a precise corneal map to be used preoperatively or intraoperatively in the creation of a surgical plan. The Cassini device has been integrated with the Lensar femtosecond laser (Lensar, Inc.) to create and execute a treatment plan according to the preoperative tomographic measurements of the anterior and posterior corneal surfaces. Undilated preoperative iris mapping measured in the office with the Cassini system is used in the streamline process of iris registration to adjust for cyclorotation errors intraoperatively when creating femtosecond corneal astigmatic incisions with the Lensar system.

OPD-III The OPD-III Refractive Power/Corneal Analyzer (Marco/Nidek, Inc.) is a multiplatform corneal and refractive power analyzer. It performs autorefraction and K readings. The Placido disk technology collects 11 880 corneal datapoints for analysis with multiple software platforms.[33] Blue-light 33-ring Placido disk topography is gathered in approximately 1 second, making it easier to capture patient data. Wavefront aberrometry is collected using 2520 wavefront datapoints, which can help ascertain corneal spherical aberrations for IOL selections, thus providing the clinician with a diagnostic wavefront analysis. Wavefront-optimized refractions derived from data collected from the central 2.0 mm to 9.5 mm corneal area provide day-versus-night refractive analysis as an option. It also provides diagnostic mapping to evaluate diseases of the cornea (Figure 2). The ocular optical system can be subdivided into corneal, lenticular, and total-eye measurements, allowing the clinician to analyze whether the patient's refractive astigmatism is corneal, lenticular, or a combination (Figure 3). Software provides axial, instantaneous, refractive, elevation, wavefront, Zernike, point-spread function, modulation transfer function, WTW, astigmatic, optical quality, and visual acuity formats (Figures 2 and 3). The OPD Scan-III analyzer provides preoperative, intraoperative, and postoperative data to optimize patient outcomes in normal and abnormal eyes.[33,34]

The device also has simulation software that is beneficial perioperatively to help patients understand the particular differences of their individual optical systems. These maps can be helpful perioperatively for patients before surgery in determining their IOL type or postoperatively when explaining the optical reasons patients' expectations might not be met.[34]

iTrace The iTrace (Tracey Technologies) uses ray-tracing technology to measure 256 individual and consecutive light rays that enter the pupil and fall on the retina. The iTrace uses ray-tracing aberrometry to dynamically measure and analyze wavefront aberrometry while also analyzing corneal topography, allowing the surgeon to separate visual function into a corneal component and an internal optic component to calculate higher-order aberrations and refractive data.[35,36]

The iTrace's software helps evaluate crystalline lens dysfunction with the onset and progression of cataract and the progressive loss of accommodation. This software is also helpful in the screening of patients and the prediction

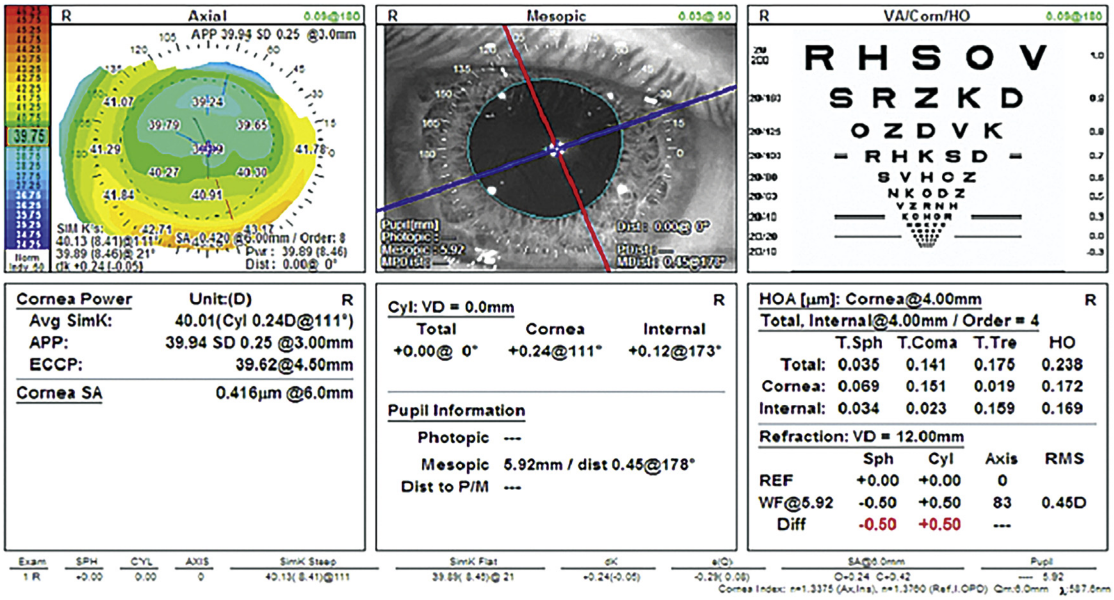

Figure 2. OPD III diagnostic mapping of disease (advanced corneal/wavefront diagnostics including pupil/angle κ measurements).

of successful outcomes with advanced IOL technologies, such as multifocal IOLs. Although previous technologies have offered similar software, the newest iTrace software and ray tracing might have advantages over current Scheimpflug technology.[36]

Agreement of the Measurements Between Devices

As explained in the previous section and shown in Table 3, ocular biometry parameters can be obtained from different devices and from various technologies. The reliability of these measurements is essential to successful cataract surgery. A wide range of studies has addressed the accuracy, repeatability, and agreement of different devices for measuring anterior segment biometry. Rozema et al.[37] published a metaanalysis based on data from 216 articles that compared 24 devices with the Pentacam (Scheimpflug technology), Orbscan (scanning-list technology and Placido disk), and IOLMaster (PCI) devices. They evaluated the agreement in the measurements of K readings, anterior and posterior cornea measurements, CCT, ACD, and AL. From this metaanalysis, the authors reached the conclusion that, as a rule, the biometry measurements taken by different devices should not be accepted as interchangeable. Hence, when using these devices clinically it is best to collect data and track results with consistency.

INTRAOPERATIVE ASSESSMENT

Two types of devices can be used intraoperatively. The first are intraoperative aberrometers, such as the ORA (Alcon Surgical, Inc.) and Holos Intraop (Clarity Medical

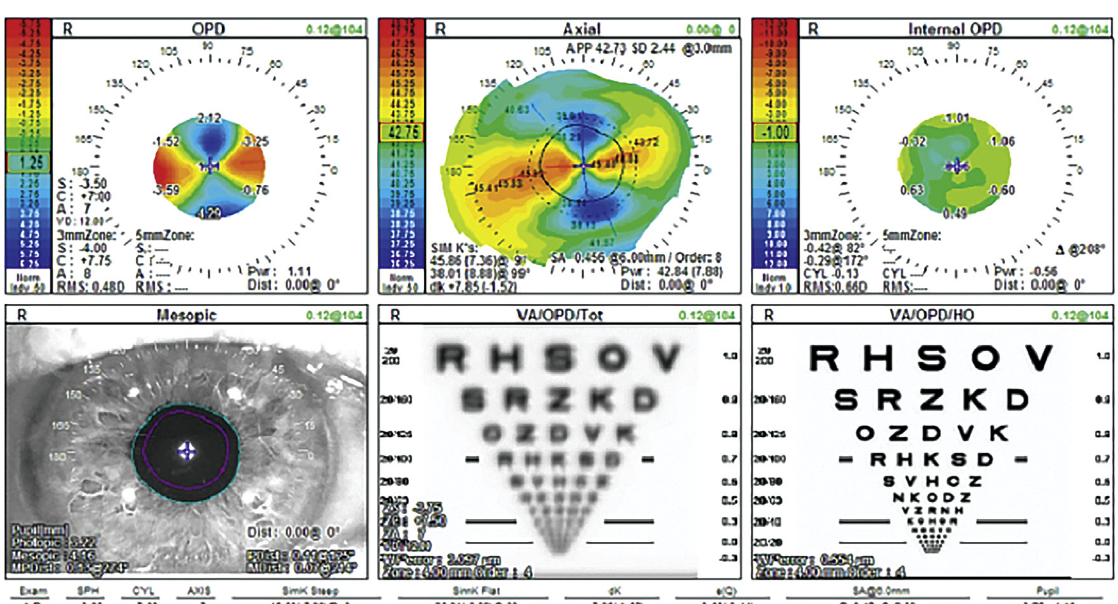

Figure 3. Cataract displays evaluating the cornea, lens, and entire-eye optical information (corneal, lenticular, and total entire eye astigmatism).

Table 3. Summary of the measurements that each device provides and the technology used by each device.

	Technology				Parameter					
Device	Placido Imaging	Scanning-Slit	Scheimpflug	Ray Tracing	Anterior corneal Surface	Posterior Corneal Surface	ACD	WTW	Corneal Thickness	Aberrometry
Tomey TMS-4N	✓	X	X	X	✓	X	X	X	X	X
Keratograph	✓	X	X	X	✓	X	X	X	X	X
Atlas 9000	✓	X	X	X	✓	X	X		X	X
Orbscan	✓	✓	X	X	✓	✓	✓	✓	✓	X
Pentacam	X	X	✓	X	✓	✓	✓	✓	✓	✓
Sirius	✓	X	✓	X	✓	✓	✓	✓	✓	✓
Galilei	✓	X	✓	X	✓	✓	✓	✓	✓	✓
Cassini	X	X	X	✓	✓	✓	X	X	X	✓
OPD-III	X	X	X	✓	✓	X	X	✓	X	✓
iTrace	X	X	X	✓	✓	X	X	X	X	✓

ACD = anterior chamber depth; WTW = white-to-white distance

Systems, Inc.). The second type comprises integrated cataract suites (detailed below). Cataract suites have been created by companies who have merged their technologies to integrate and propagate a surgical plan created in the office to be subsequently executed in the operating room through seamless communication between devices. The following cataract suites available at present:

Alcon Surgical, Inc.: Lenstar, Verion, Lensx, and Luxor (or other scope), and ORA; Carl Zeiss Meditec AG: IOLMaster, Callisto Eye (creates the overlays), and Opmi Lumera surgical microscope; Bausch & Lomb, Inc.: Cirle and Victus; Cassini corneal topographer, OPD-III, Lensar, and Trueguide system.

Intraoperative Aberrometry

Cataract surgeons are now seeing on a daily basis patients who have had previous corneal refractive surgery. After such surgery, the calculations for the IOL power are more challenging. The formulas traditionally used to calculate the IOL power assume the cornea to be more prolate than oblate; specifically, steeper in the middle and flatter in the periphery. However, patients who have had surgery to correct myopia (the majority of the corneal refractive surgery patients) have corneas that are more oblate than prolate (flatter in the center and steeper in the periphery). The reverse is true for patients who have had hyperopic treatments. To achieve the most accurate calculations for patients, surgeons use a variety of techniques and calculations for IOL measurements. These include obtaining records from before and after the refractive procedure, using online calculators (eg, American Society of Cataract and Refractive Surgery [ASCRS] online post-refractive calculator[G]), and using "fudge" factors based on the measured K readings. In addition, there are some complex formulas that can be used to help estimate the correct IOL power. In addition to these modalities, many surgeons are now using intraoperative aberrometry to increase the chance of hitting refractive targets and to give patients the best possible outcomes.[36]

In the United States, only 1 intraoperative aberrometer that is approved by the U.S. States Food and Drug Administration (FDA), the Optiwave Refractive Analysis (ORA) system (Alcon Surgical, Inc.). Another aberrometer, the Holos Intraop is manufactured by Clarity Medical Systems, Inc., is awaiting FDA approval. Both systems are designed to give real-time aphakic refraction information to the surgeon. Both are mounted on the surgical microscope. Intraoperative aberrometers can also be helpful in determining the correct axis on which to align a toric IOL and to help titrate the opening of arcuate incisions. The Holos device gives the reading in real-time, whereas the ORA essentially gives a rapidly acquired "snapshot" of the eye.

ORA One advantage of an intraoperative aberrometer is that it measures the entire refractive system of the eye, taking into account both anterior and posterior corneal astigmatism. The ORA with Verifeye+ uses infrared light and Talbot-Moire interferometry to assess the optical power of the entire eye. It takes 40 measurements in fewer than 5 seconds and then analyzes the data to determine the optimum IOL power for the eye. The ORA with Verifeye+ allows the surgeon to view the measurements as a real-time display through the right ocular of the operating microscope (Figures 4, 5, and 6).

Holos Intraop The Holos Intraop is a shifting wavefront device that provides continuous real-time intraoperative aberrometry measurements. This device incorporates a continuous real-time sequential wavefront sensor. It provides continuous refractive data and assists in the alignment of toric IOLs for the most accurate treatment of corneal astigmatism. The system shows refractive data as it changes during the cataract surgery procedure (phakic, aphakic, and pseudophakic phases).

Clinical Results Fram et al.[38] evaluated 39 eyes of 29 patients without historical data and compared them with 20 eyes of 20 patients with historical data. In the group without historical data, 49% of eyes were within ±0.25 D, 69% to 74% were within ±0.50 D, 87% to 97% were within ±0.75 D,

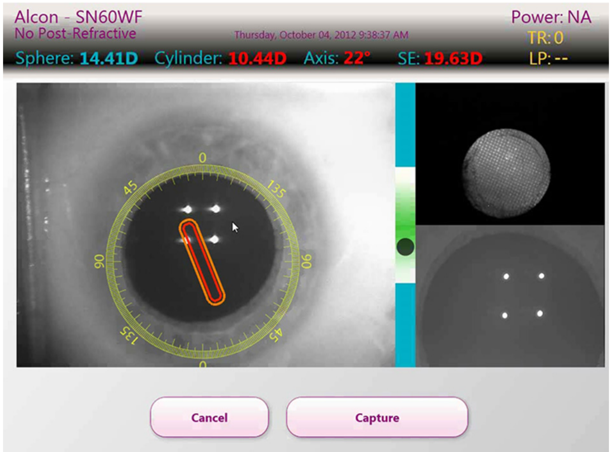

Figure 4. Representative image of what the surgeon sees on the ORA with Verifeye+ screen showing the machine is ready to capture the measurement.

and 92% to 97% were within ±1.00 D of the targeted refractive IOL power prediction error. In the group with historical data, 35% to 70% of eyes were within ±0.25 D, 60% to 85% were within ±0.50 D, 80% to 95% were within ±0.75 D, and 90% to 95% were within ±1.00 D of the targeted refractive IOL power prediction error. Based on these results, the authors concluded that newer technology, such as the ORA, used to estimate IOL power calculations in eyes after laser vision correction shows promising results compared with those obtained with established methods.[38]

Ianchulev et al.[39] performed a retrospective consecutive case series that included 246 eyes of 215 patients having cataract surgery with a history of myopic LASIK or photorefractive keratectomy (PRK). The patients had intraoperative ORA measurements, and the ORA results were compared with those of the following 3 conventional clinical practice methods: surgeon best preoperative choice (determined by the surgeon using all available clinical data), the Haigis-L,[40] and the Shammas IOL[41] formulas. In 246 eyes (215 first eyes, 31 second eyes), intraoperative refractive biometry using the ORA device achieved the greatest

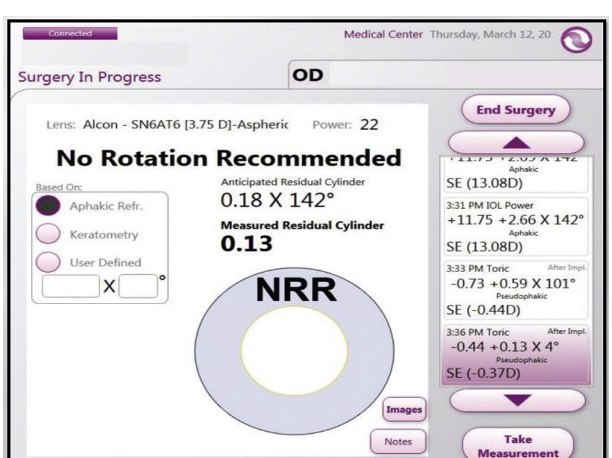

Figure 6. Toric IOL module using the ORA. This image shows that the IOL has been inserted on axis and no additional rotation of the IOL is recommended (IOL = intraocular lens).

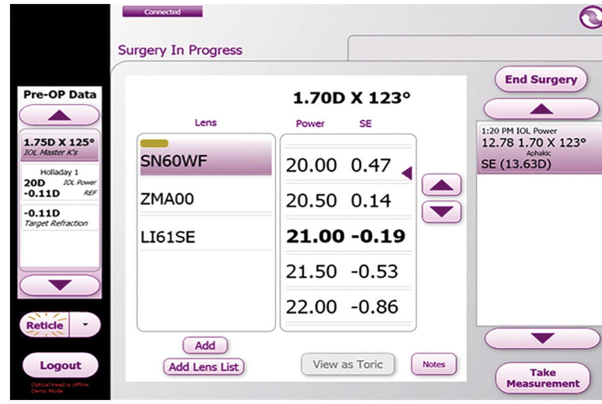

Figure 5. ORA-calculated IOL measurements. The surgeon may then choose the IOL based on the predetermined refractive error goal for the patient. (IOL = intraocular lens)

predictive accuracy ($P < .0001$), with a median absolute error of 0.35 D and mean absolute error of 0.42 D. Sixty-seven percent of eyes were within ±0.50 D and 94% were within ±1.0 D of the intraoperative refractive biometry's predicted outcome. Therefore, the authors concluded that the IOL power estimation was most accurately predicted using the ORA device in eyes with previous LASIK or PRK.[39,42–46]

Intraoperative aberrometry can be an excellent modality for helping determine the IOL power in patients who had previous corneal refractive surgery. Intraoperative aberrometers do not take the place of traditional IOL calculations because surgical factors such as corneal edema, lid speculum placement, and ocular surface irregularities can affect these measurements. Care must be taken when choosing an IOL to make sure it is consistent with the other preoperative measurements. It is important to track surgical outcomes and keep the ORA technique reproducible to increase the accuracy of the results over time.

Although intraoperative aberrometry can be useful, not all surgeons have access to this technology. However, online resources, including toric IOL and more advanced formulas, available to help surgeons accurately estimate IOL power. Among these online resources, the following should be highlighted: Barrett calculator,[H] Alcon toric IOL calculator and Restor toric IOL calculator,[I] Abbott/Johnson & Johnson toric and Symfony IOL calculators,[J] and Berdahl and Harden.[K]

Integrated Cataract Suites

Verion Image Guided System The Verion Image Guided System is designed for preoperative and perioperative planning with intraoperative applications to aid in astigmatism correction through accurate placement of limbal relaxing incisions (LRIs) and toric IOLs. There are 2 components to the system, a reference unit and a digital marker (Figure 7). The reference unit is used by the surgeon to plan incision axis and placement as well as IOL selection and power using multiple formulas, including those necessary for managing post-refractive patients (Figure 8). The reference unit captures pupillometry, keratometry, WTW horizontal distance, and the eccentricity of the visual axis

Figure 7. *Top*: Verion reference unit. *Bottom*: Verion digital marker on the Lensx laser system and the Lux or LX3.

(Figure 9). It also captures a high-resolution image of the eye for intraoperative registration with the iris, pupil, limbus, and scleral vessels. By combining the information from an optical biometry unit with that of the reference unit, the surgeon can better predict intraocular power calculations using the comprehensive case planner. The reference unit can help determine whether a patient might benefit more from a toric IOL, laser or refractive incisions, or a combination.

Few head-to-head studies exist; however, there is evidence to support that residual astigmatism should be less than 0.50 D for optimum outcomes and patient satisfaction.[47,48] In addition, residual astigmatism in eyes with a multifocal IOLs has been shown to reduce the overall quantity of vision postoperatively.[49] Integrated cataract suites, such as the Verion, are designed to help us reach these refractive goals.

Although Alcon was the first to introduce integrated cataract technology, other companies have now united to bring forth similar systems designed for surgical planning and improved astigmatism correction during cataract surgery.

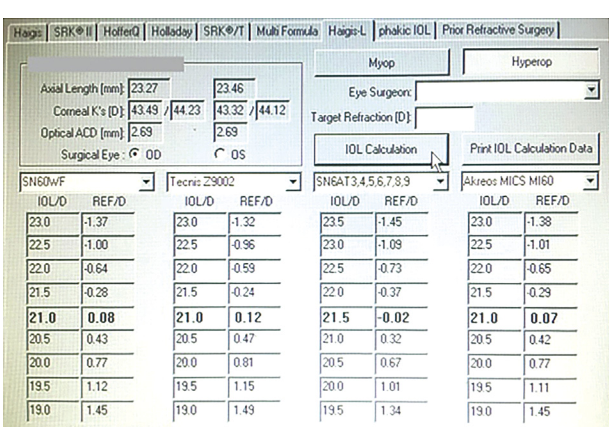

Figure 8. Example of the multiple IOL power calculation formulas for IOL power planning (IOL = intraocular lens).

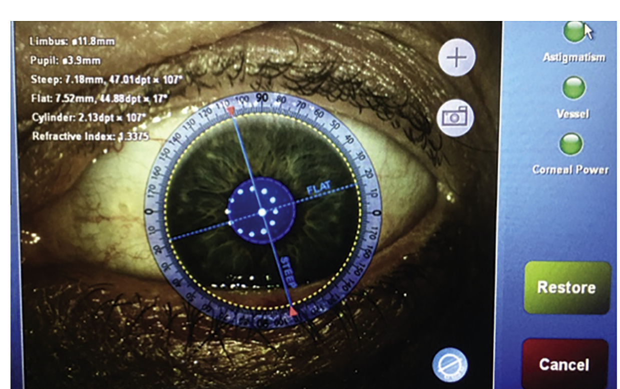

Figure 9. Data from the reference unit can be transferred to the femtosecond laser or the microscope for registration and alignment intraoperatively.

IOLMaster, Callisto Eye, Opti Lumera Surgical Microscope Zeiss has also been working to integrate technology to help with accurate toric alignment intraoperatively through the use of the Callisto imaging system, which creates the overlays to map the axis of astigmatism during surgery.

Cirle, Victus Bausch & Lomb is in the early stage of development of the Cirle system to ultimately be integrated with the Victus laser for intraoperative assessment and toric alignment during surgery.

Cassini Corneal Topographer, OPD-II and III, Pentacam HR and AXL, Lensar, and Trueguide Computer-Guided System (Truevision 3-D Surgical) The Cassini color LED corneal analyzer system, OPD-II and OPD-III scans, and Pentacam HR and AXL devices have now been integrated with the Lensar femtosecond laser for cataract surgery and the Trueguide 3-D surgical imaging system functioning through the Leica microscope (Streamline and Streamline II) (Figure 1). The Cassini, OPD, and Pentacam all allow streamlining with the Lensar for astigmatic corneal incisions and toric IOL alignment corneal and recently lenticular capsule markings by iris registration from a preoperative undilated iris map and adjusting for cyclorotation errors that can occur intraoperatively. With the Trueguide combination system, the surgeon can operate upright while viewing surgery on a separate 3-D display screen. This integrated system will theoretically provide information for increasing accuracy of toric alignment during surgery.[47,50–53]

In summary, the minimum requirement for performing refractive cataract surgery would be a 2-D corneal topography performed in all patients before cataract surgery for screening as well as diagnostic purposes. The IOL calculators available online can be used to approximate posterior corneal astigmatism using the values acquired through standard topography. However, for the highest degree of accuracy, a 3-D tomography image would be acquired that directly measures the patient's posterior corneal astigmatism. In addition, optical biometry would be performed in routine cases with noncontact immersion US for denser lenses and difficult-to-image posterior subcapsular cataracts. Fortunately, most online IOL power calculators have been updated to account for posterior corneal astigmatism. Several calculators even provide the option to calculate both with and without posterior corneal astigmatism for comparison.

POSTOPERATIVE ASSESSMENT

The period following after cataract surgery involves several aspects of patient care and outcomes optimization, including evaluation of astigmatic treatment, nomogram development, and surgically induced astigmatism (SIA) assessment. Integrated cataract suites, such as the Verion system, are equipped with software that assists the surgeon in these areas. The ORA is also equipped with a data-analysis system to analyze postoperative data and adjust surgeon nomograms accordingly. When dealing with refractive cataract patients, it is essential to analyze postoperative refractive results and adjust future surgical plans accordingly to achieve the best outcomes.

Astigmatism Treatment

Femtosecond laser–assisted arcuate incision placement allows for precise control of incision depth, arcuate length, and optical zone diameter.[54–56] These arcuate incisions, much like a femtosecond laser LASIK flap, are stuck together and can be opened for full effect. The surgeon has several options for opening these arcuate incisions. If an intraoperative aberrometry system is being used during cataract surgery, a measurement of residual astigmatism can be made in the aphakic eye or after implantation of the IOL. The surgeon may then decide to open the preplaced arcuate incisions if they are located along the axis of the residual astigmatism. If the arcuate incisions are not in the proper location to neutralize residual astigmatism, they can be left closed. If intraoperative aberrometry is not being used, the incisions can be left closed until a stable postoperative refraction and topographic assessment are obtained. Using the refraction and topography, the surgeon can assess whether the arcuate incisions are located on an axis appropriate to neutralize the residual refractive astigmatism. The incisions can then be opened using a spatula or Sinskey hook at the slitlamp up to several months after surgery.

Personalized Aberrometry and Nomogram Development

Cataract surgeons are familiar with the concept of a personalized A-constant specific to a particular IOL. By recording postoperative spherical equivalent results, a surgeon can refine the accuracy of outcomes for a particular IOL by generating a new A-constant for the SRK/T formula,[57] a surgeon factor for the Holladay 1 formula,[58] and a new ACD for Hoffer-Q[59] or Holladay 2[60] formula. In a similar way, a surgeon can refine the accuracy of intraoperative aberrometry outcomes by entering postoperative refractive results into the aberrometer software or online database. Once enough data are entered, the system will provide surgeon-specific suggestions for IOL power selection during surgery.

Refractive surgeons are familiar with the concept of excimer laser nomograms that account for surgeon- and environmental-specific factors that affect LASIK and PRK refractive outcomes. The cataract surgeon might be familiar with nomograms used for astigmatic keratotomy, which suggest specific arcuate lengths for cuts based on intended astigmatic correction, orientation of astigmatism, patient age, and other factors. Femtosecond laser arcuate incisions might be more accurate and predictable than manually placed incisions because of their precise depth, location, and arcuate extent determined by intraoperative imaging. Femtosecond laser arcuate incision nomograms are unique and separate from those designed for manual incisions and are still being debated and optimized. Several online calculators currently exist, including (1) the femtosecond laser arcuate incision nomogram and (2) the Abbott Medical Optics LRI calculator software[L] (Figure 10). For femtosecond arcuate incisions, use a

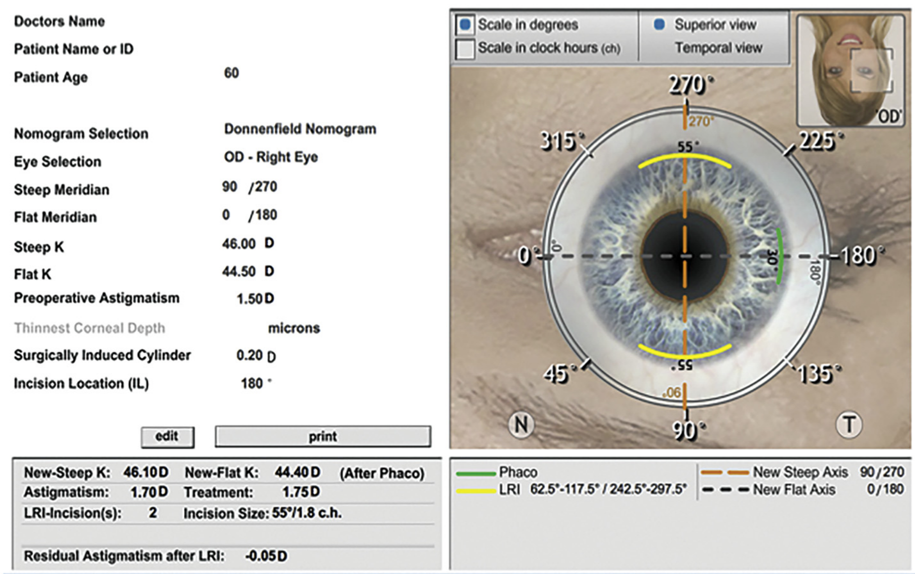

Figure 10. AMO LRI calculator.[M]

33% reduction of the arcuate length suggested by the Donnenfeld nomogram[M] and place at an 8.0 to 9.0 mm optical zone. Although many tools are available for guidance, each surgeon must evaluate their outcomes to accurately optimize their nomogram to achieve their best refractive outcomes.[61]

Surgically Induced Astigmatism

Corneal astigmatism will change according to the type, size, length, and position of the clear corneal incision (CCI). A temporal CCI, for example, will subtract from existing against-the-rule astigmatism and add to existing with-the-rule astigmatism. When treating astigmatism as part of refractive cataract surgery, it is critical for the surgeon to understand the effects of his or her CCI when planning the placement of that incision as well as the placement of astigmatic keratotomies and orientation of toric IOLs.[62]

An online resource is available for surgeons to calculate their personalized SIA.[N] The surgeon must enter preoperative and postoperative K readings and axes as well as the location and size of the incision. The calculator then uses vector mathematics to calculate the SIA. As more and more eyes are added to the database, the system calculates an average SIA for an incision of a specific size and location created by that specific surgeon.

DISCUSSION

Cataract surgery is constantly evolving and advancing with improvements in technology translating into improvements in visual outcomes. This cycle has resulted in increased expectations from patients who are paying for premium outcomes. Technology has evolved to help meet the increased need and expectation for better outcomes for patients having cataract surgery. With rapid advancements in technology and a multitude of options, it can become overwhelming to determine which type of assessment and how many different types of measurements are sufficient to provide the optimum refractive outcome for each patient.

Ultimately, integrated technology providing seamless flow of information between the office and operating room will facilitate achieving optimum outcomes. Integration of preoperative measurements and postoperative data will help optimize the process of achieving the best refractive outcomes. This process begins preoperatively and is carried through the intraoperative and postoperative course. Cataract suites that analyze postoperative outcome data can help create nomograms that guide further treatments. The nomograms theoretically become more robust as more datapoints are entered into the system. Fortunately, industry and surgeons are working together to develop and integrate the technology that will help achieve the quest toward emmetropia, ultimately resulting in happier patients and surgeons.

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