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Wavefront Examination and
Digital Refraction to Create a
Rapid and Accurate Approach
(XFractionSM) for a Total
Visual System Assessment for
Intraocular Lens Selection**

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Abstract

Following advances in intraocular lens technology in recent years, greatly increased options are now available to the ophthalmic surgeon. However, there is a need for improved diagnostic technologies to optimize outcomes and select the best treatment strategies. A process combining multimodal wavefront examination and digital refraction, wavefront optimized refraction or 'XFractionSM,' has been recently developed to address this requirement. This novel fusion of techniques increases the amount of data that can be captured from each eye by orders of magnitude and is completed in much less time than former separate methods or manual refraction alone. The result is a process that enhances current procedures, provides superior patient diagnosis over previous techniques through the full optical pathway, and provides multiple benefits to both the patient and physician. The process enables the collection of a large amount of relevant information that makes available new levels of understanding about each patient's unique visual system. Its use in clinical practice has been further associated with increased practice efficiency, enhanced optimized refractions, improved diagnostic surgical outcomes, and higher levels of patient satisfaction.

Keywords

Cataract surgery, intraocular lens, multimodal wavefront examination, digital refraction, XFractionSM

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The advances in surgical techniques over several decades have raised expectations among patients with cataracts who expect almost perfect vision and are less willing to accept spectacles for postoperative vision correction.¹⁻³

Refractive cataract surgery involving the implantation of premium intraocular lenses (IOLs), including multifocal, Toric, or accommodative lenses is currently one of the most common and safest surgical procedures carried out worldwide. In a minority of patients, a level of dissatisfaction can remain largely due to a variability in parameter measurements during refraction calculation that determines IOL selection, and this can prevent patients from obtaining their optimal visual performance.⁴

The increased options available to the ophthalmic surgeon complicate the decision-making process. Multiple measurements are performed as a part of the evaluation prior to cataract surgery to ensure adequate visual outcomes. However, there is a need for improved diagnostic

technologies to optimize outcomes and select the best treatment strategies. On occasion, patients can be corrected to 20/20, and J1 at near, but continue to remain unsatisfied. This new process could provide better prognostication and improve patient outcomes.

Wavefront optimized refraction, also termed Xfraction (XF), is a process recently developed by Marco (Marco Ophthalmic, Jacksonville, FL US) that combines multimodal wavefront aberrometry with digital refraction, increasing the diagnostic capacity compared with previous techniques. XF provides an accurate assessment of refractive errors and ocular aberrations throughout the entire visual system enabling the selection of lenses (both IOL and spectacle lenses) to be more precisely suited to each individual patient. The purpose of this review will be to consider the XF procedure, the components, the diagnostics, the outcomes, application to current challenges in ophthalmology, and to relate the experience of the authors of this approach in regular clinical practice using in particular, the Nidek OPD-Scan III system.

Table 1: List of Main Functions of Wavefront Optimized Refraction and their Importance

Parameter	Importance
Autorefractor	Provides a measurement of the central 2.6 mm area in pupils up to 9.5 mm
Autokeratometry	Provides accurate simulated keratometry measurements
Corneal topographer	Diagnoses asymmetrical astigmatism. Essential for optimization of implanting Toric lenses. 11,880 points corneal data points allowing easier assessment of the corneal maps and Placido mires (33 rings) for keratoconus, pellucid marginal degeneration, and ocular surface conditions including dry eye. Essential for optimization of implanting Toric lenses
Wavefront aberrometer	Assessment of the total visual system and quality of vision with detection of corneal and lenticular change in microns (2,520 points) measures up to 9.5 mm
Pupillometer	Photopic and mesopic pupil diameters. Optimizes IOL selection based on pupil size and allows a night Rx to be calculated to the patient's mesopic pupil
Retro-illumination image (see <i>Figures 5 and 6</i>)	Display cortical cataracts, vitreous floaters, and vacuoles. This also allows the operator to see tilted or decentered IOLs, the rings of a multifocal IOL, and alignment marks of a Toric IOL
Detection of large angle kappa (see <i>Figure 7</i>)	Identifying the angle kappa preoperatively can alleviate post multifocal IOL implantation dissatisfaction due to large angle kappa
Determination of previous laser surgery types	Helps select optimum lens. The APP is located on the ASCRS IOL site for post-myopic LASIK patients
Production of Placido disc image (see <i>Figure 4</i>)	Evaluates ocular surface conditions including dry eye

ASCRS = American Society of Cataract and Refractive Surgery; APP = average pupil power; IOL = intraocular lens; LASIK = laser-assisted in situ keratomileusis.

The Components of Combined Multimodal Wavefront Examination and Digital Refraction (XFraction)

The OPD-Scan III Aberrometer and Corneal Analyzer

The first component of XF is an optical path difference (OPD) device known as the OPD-Scan III (subsequently referred to as OPD).^{5,6} This wavefront analyzer is an objective means of evaluating the total visual system in patients requiring simple optical correction with eye glass or contact lenses in patients needing an IOL implant or other surgery. Light passing into the eye creates a deflection pattern and computer analysis gives precision data and more reproducible diagnoses than previously possible. The OPD also enables the diagnosis and treatment of patients who would have been extremely challenging with earlier-generation devices.⁷

The OPD gathers more than 20 diagnostic metrics within 10 seconds per eye, including auto-refraction, keratometry, pupillometry (photopic, mesopic), corneal topography, and wavefront aberrometry, and maps 2,520 light vector points across pupils up to 9.5 mm in size. The equipment provides all of the diagnostic evaluations necessary for the ophthalmic specialist's practice before and after IOL surgery and its size and utility allow it to also be used for routine visual examination in the ophthalmic office for an individual who only needs spectacles or contact

lenses. The diagnostic abilities of the OPD system and their importance are summarized in *Table 1*.

Digital Refraction

The second component of XF is the TRS-5100 (TRS), which is a programmable digital refractor that can be used with the OPD at the same desk or employed in the traditional lane (these two units form the main components of the EPIC workstation that combines the functions of the autolensmeter, OPD, TRS, and electronic chart). Following completion of the OPD analysis, the TRS enables a rapid refraction providing immediate patient verification of the old versus the new prescription. Comparative verification may also be performed comparing the subjective refraction to the pupil optimized vector analysis wavefront refraction. Together these technologies generate a most comprehensive understanding of the patient's total visual system. The result is more relevant data in a fraction of the time of traditional refractions.

Commercially Available Wavefront Aberrometers

A range of different wavefront aberrometers and wavefront corneal topographers are now commercially available and their features are summarized in *Table 2*. The capabilities of these instruments vary and use different optical methods, but the OPD system provides unique vector analysis and the greatest flexibility and offers the convenience of a complete analysis in one instrument. A study comparing four systems (LADARWave® [Alcon, Fort Worth, Texas], Visx WaveScan® [Abbott, Santa Clara, California], Zywave® [Bausch & Lomb, Rochester, New York], and Allegro Analyzer® [Wavelight, Erlangen, Germany]) in the analysis of healthy eyes found that lower order aberration analyses were similar, but there were notable differences in higher order aberrations (HOAs).⁸

Many of these commercial aberrometers employ Hartmann-Shack optics that use an aperture array and a series of lenslets enabling separate light paths to be followed through the eye.^{9,10} The OPD, however, utilizes time-based aberrometry known as dynamic spatial skiascopy, to measure the refractive power of the longest point of the eye (optical path length [OPL]) and then calculates the difference in the refractive power throughout the peripheral measurements. Dynamic spatial skiascopy also provides a greater range for measurement than Hartmann-Shack (± 20.00 diopters sphere and ± 12.00 diopters of cylinder); the results from these systems are not always in agreement.¹¹

XFraction—The Patient Process

The patient process with the OPD is simple. Farrell Tyson, MD, describes it as the "gateway to my office" since it is used to rapidly examine the eyes of patients on arrival at the office prior to their consultation. The system is usually operated by a technician or optometrist and captures data on wavefront refraction, corneal topography, internal OPD, light/dark pupillometry, corneal spherical aberration, total aberrations, and angle kappa. The OPD provides information differentiating corneal versus lenticular astigmatism and assists with Toric IOL selection. This unit identifies spherical aberration of the cornea and indicates whether to use aspheric or positive spherical lenses. The information can be presented graphically by either printing or viewing the maps in the exam lane through associated software. This examination is completed before the patient meets the ophthalmologist and the collected data informs the discussion regarding their optical condition and appropriate treatments.

Table 2: Ophthalmic Aberrometers and Analyzers Incorporating Wavefront Technology

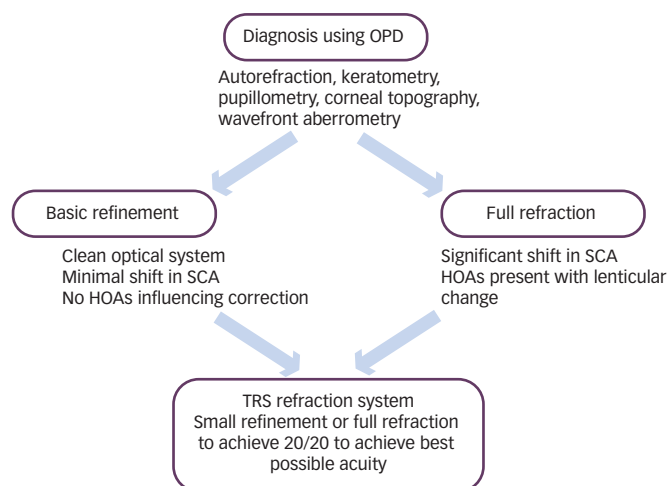
System	Manufacturer	Features
Aberrometers		
Zywave [®] wavefront aberrometer (used as part of the Zyoptix [®] Diagnostic Workstation)	Bausch & Lomb	Measures refractive errors over a range of +8.0 D to –14.0 D and up to 5.0 D cylinder. Similar to LADARWave [®] . Uses a wavelength of 780 nm and measures approximately 75 locations within the pupil. Up to fifth-order Zernike coefficients are included in the measurements assists in establishing a specific refractive treatment plan to correct an individual's particular aberrations. Uses Hartmann-Shack sensor
LADARWave wavefront aberrometer	LADARVision/Alcon	Measures wavefronts between +15.0 and –15.0 D. The unit can also measure up to 8.0 D of astigmatism. A Zernike expansion series polynomial is used to describe the complex 3D surface. Produces a 3D map including lower and higher order aberrations. Uses Hartmann-Shack sensor
VISX Wavescan aberrometer	Abbott Medical Optics (AMO)	Measures spherical refractive errors between –12.0 D and +9.0 D, cylindrical refractive errors up to 5.0 D, and higher-order aberrations up to sixth-order. Up to 7 mm pupil. Capable of reconstructing very complex 3D surfaces with little processing power compared to Zernike expansion. Gathers about 240 data points. The point spread function produces acuity maps that chart aberrations, and difference maps that map eye changes for preoperative and postoperative comparisons. Uses Hartmann-Shack sensor
WASCA Analyzer	Zeiss/Meditec	Measures –15 D to +7 D including 5 D cylinder, measuring points: 1,452, (800 in a 7 mm pupil). Measuring time: 13 ms. Sensor resolution of 210 μ m points, Uses Hartmann-Shack sensor
Corneal topographers		
Corneal Wavefront Analyzer	SCHWIND Eye Tech Solutions	Resolution of 210 μ m and a maximum of 1,452 measuring points. Measures 90 % of the cornea using over 7,000 points, and over 80,000 points are analyzed. Documents size and type of optical errors on the anterior corneal surface. Simulations of the patient's measured corneal aberrations are shown using point spread function graphics, an acuity chart, or in relation to contrast sensitivity
Portable Scout	Eye Quip	Handheld topographer, can be mounted to slit lamp. Data are transferred to a computer USB port and software provides corneal mapping, imports, and generates wavefront data
Obiscan Iiz [®]	Bausch & Lomb	Providing extensive information about anterior segment including corneal elevation, pachymetry, and anterior chamber depth. Offers fast and efficient patient screening
ALLEGRO	Wavelight Inc.	Uses a sixth-order Zernike expansion series and a laser of 660 nm wavelength. One hundred and seventy wavefront samples are acquired in a dioptric range of +6.0D to –12.0 and up to 6.0D of cylinder. Obtains readings while an image of the measurement spot is projected onto the retina. Uses the Tscherning operating principle
Combination systems		
OPD-Scan III	Marco	Includes: auto refraction keratometry, Placido disc topography, 11,880 corneal data points, wavefront aberrometry, 2,520 wavefront data points. Pupil diameter: 2–9.5 mm. SA cornea for aspheric IOL selection, lenticular-residual astigmatism, angle kappa, pre/post Toric IOL measurements, mesopic/photopic pupil size, point spread function, Zernike graphs, corneal refractive power map, IOL tilt/decentration, difference maps pre/post healing, day/night RX, RMS values, EMR compatibility, network integration. Uses dynamic spatial skiascopy operating method with a sphere measurement –20D to +22D and up to $\pm$ 12D
XFraction SM	Marco	Wavefront optimized refraction process
KR-1W	Topcon	Includes: aberrometry, topography, keratometry, pupillometry, and autorefraction within one unit. Pupil size 2–8mm. Multiple maps for overview analysis; pre and post-op data for cataract and refractive procedures, network integration. Uses Hartmann-Shack sensor
iTrace	Tracey Technologies Corporation	Measures 256 data points in 400 ms. Uses ray-tracing technology for wavefront and refractive analysis. Pupil diameter: 2–8 mm. Binocular and monocular open field fixation. Over spectacle refraction and wavefront measurement. Autoidentify potential patient visual complaints. Retinal spot diagram. Point spread function. Selectable multizone refractions

EMR = electronic medical record; IOL = intraocular lens; RMS = root mean square; SA = spherical aberration. Sources: Cade et al., 2013;⁸ Rozema et al., 2005;³³ Rozema et al., 2006.³⁴

Jeffrey Whitman, MD, commented: "This optimized refraction can be used in the cataract workup for glare testing with the EPIC workstation. During a workup at the EPIC workstation patients with night vision complaints undergo a light-controlled glare test. The glare test provides accurate, reproducible evidence of a cataract and provides the documentation needed to demonstrate that cataract surgery is medically necessary."¹²

The OPD, when integrated with the EPIC workstation, distinguishes between patients who require minimal refinements and those who require more comprehensive refractions to achieve 20/20 vision (as well as those who cannot be corrected to 20/20 vision and why). The autoselect feature can also determine the best refraction starting point. It can also identify which patients have a HOA who may not be correctable to 20/20. The OPD can then transfer the most accurate starting refraction point to the

Figure 1: Decision-making Flowchart Using Wavefront Optimized Refraction



HOA = higher order aberration; OPD = optical path difference; SCA = Stiles-Crawford apodization; TRS = TRS-5100.

Figure 2: Example Wavefront Overview Map Produced by an OPD-Scan III System

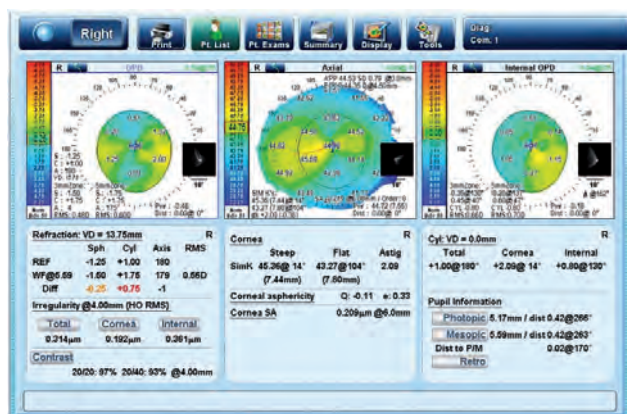
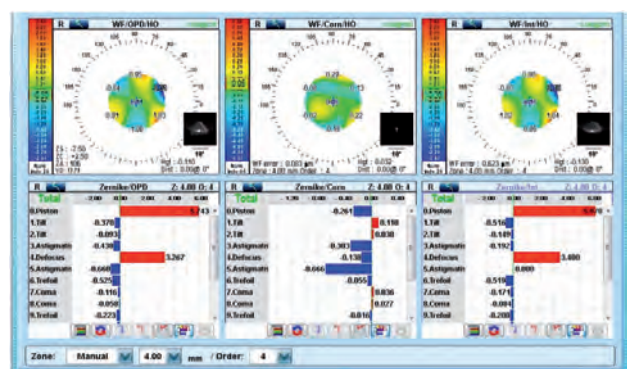


Figure 3: Example Wavefront Summary



TRS digital refractor for further refinement (see Figure 1). Digital refraction instruments are more precise (1° axis), they allow programmable refraction examinations, and can be operated from a keypad. An increasing number of

studies show that automated integrated subjective refraction can be more efficient and accurate than manual subjective refraction with a traditional phoropter due to the simpler verification process. The OPD forms part of a preoperative screening for implantation of IOLs. In laser-assisted *in situ* keratomileusis (LASIK) technology, 90–97 % predictability can be achieved for refractive outcomes but the same is not true for cataract surgery.¹³

Experience to date, shows that patients prefer the examination process with the OPD and TRS compared with previous automatic or manual refractors and find the procedure easier.¹⁴ Patients are not repeatedly asked which of two images is clearer, and comparisons between old and new prescriptions can be made. Especially for postoperative refractions, if the patient has any residual prescription, XF can provide the most precise lower order prescription possible.

Optical Path Difference and Patient Education

The maps that result from the OPD eye examination show the distribution of refractive power in the optical system and then separate the internal power from the overall (see Figure 2). Vector analysis calculates a refractive power over a defined area, and the precision refractive measurements are calculated in low order powers. This information can subsequently be used to plan a refractive treatment.

The OPD can also precisely determine the level of spherical aberration (see Figure 2), in untreated (virgin), postrefractive, or previously treated eyes. Patients are often impressed and sometimes relieved when they can be shown why their refractive system is producing a suboptimal image.¹⁵ Overview summary maps provide refractive data and incorporate data for cataract and refractive surgery. Examples of these maps are given in Figure 3. The Placido disc image of the OPD can illustrate dry eye syndrome to help patients understand for the first time the irregularities of their tear film and ocular surface (see Figure 4). If the rings in this image are not perfectly round, irregular, broken up, or with dark spots on the corneal surface, it can be noted that this is a pre-existing condition and will not be affected by cataract surgery. It is important such conditions are highlighted prior to surgery and patients do not subsequently blame their cataract surgery or their new glasses for causing the symptoms.

Some ophthalmologists state that their main reasons for choosing the OPD were that it provides a large quantity of diagnostic information in one setting and helps customize the IOL to each patient.¹⁵ It is also possible to show these maps in the examination room to the patient as an educational tool with viewing software. Cynthia Matossian, MD, notes that this enables patients and/or family members to understand a disease processes or ocular numbers and can better accept the recommendation.

One of the available OPD maps shows the HOAs and this can be explained to the patient through point spread function (PSF) pre- and postcataract surgery. Even after successful cataract surgery they may have some residual feathering of the point of light that could cause glare and halos at night. PSF images with the patient's lower order aberrations removed, show the effects of the remaining HOAs. The patient will then have a more realistic expectation of his or her vision postcataract surgery (see Figure 5).

The average age of typical cataract surgery patients is about 70 years and many of them have multiple medical and mobility concerns. Their collected vision information can be uploaded onto a large screen in the examination

room, enabling such patients to readily understand their condition and whether they are a suitable candidate for certain advanced implants.

Enabling a patient to understand what is happening in their eye is particularly helpful when they are unhappy with the results of previous surgery, e.g. if a Toric IOL has rotated, the internal OPD map combined with the retro-illumination can illustrate the cause and effect of the problem.

***Patient example:** An individual who has never been able to achieve 20/20 vision with glasses. The OPD analyzes higher order aberrations and enables differences to be visualized and the TRS can be used to compare the previous prescription with the current one. This can provide an explanation why the patient is unhappy.*

Data Handling and Input Into Electronic Medical Record Systems

Handling the data from the OPD or EPIC workstation is central to providing a more accurate diagnosis and determining optimal treatments. The systems are compatible with many electronic medical record (EMR) systems, minimizing the possibility of transcription errors that can occur during manual data entry.¹⁶ The OPD can reduce costly IOL exchanges by providing more information that can help the surgeon to correctly select the appropriate lens initially. Determination of IOL position at the time of surgery is crucial to monitor potential rotation of the IOL, especially Toric IOLs, and this information should always be accessible to the ophthalmologist. The OPD provides pre- and postoperative photographic images that can form vital parts of the patient record.

Practice Improvements Using Combined Multimodal Wavefront Examination and Digital Refraction (XFraction) Practice Excellence

Introduction of the OPD has received a favorable response from both patients and clinical staff and demonstrates a doctor's commitment to excellence and a desire to detail, plan, and customize surgery for premium outcomes.^{14,15} The system increases patient confidence that a superior plan is being prepared for them, with confidence of a positive surgical outcome. The patients find it easy to tolerate and approve of the advanced diagnostics. The additional information provided by the OPD can also help to increase the range of surgical candidates who may be treated in the practice.

Joseph Noreika, MD, recently commented: "Today's cataract surgeons have optimized the way they perform surgery. Technologies such as the OPD wavefront aberrometer/corneal analyzer and the TRS digital refractor are helping them optimize the decisions that go into planning surgery."¹⁷

In addition to assisting surgical procedures, XF is a powerful technique for the evaluation and diagnosis of existing aberrations. The limited ability to preoperatively evaluate internal aspects of the eye has, until recently, diminished surgical outcomes. The OPD can determine if an individual has corneal spherical aberrations and provide the data that a surgeon needs to customize an aspheric lens for each patient. Other applications include the objective assessment of asymmetrical and irregular astigmatism, the effects of which may be quickly assessed with the three-zone refraction

Figure 4: Placido Ring Corneal Topography

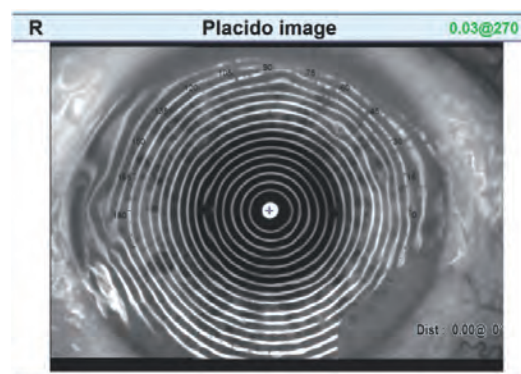
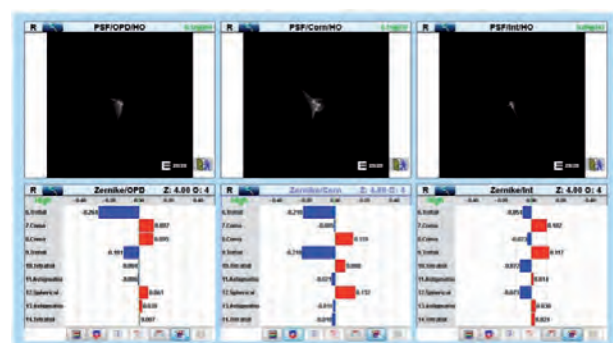


Figure 5: Point Spread Function Images of Simulated Vision of a Light Source Before Cataract Surgery (Left and Middle Panel) and After Surgery (Right Panel)



The point spread function images show the patient's lower order aberrations removed and shows the effects of the remaining higher order aberrations.

display on the OPD map. The OPD separates corneal topographic analyses from the total refraction to display the internal OPD map. This separation allows the surgeon to distinguish whether the origin of irregular astigmatism is from the cornea or from internal sources, or the combination of both.¹⁸

Practice Efficiency

Efficiency is a highly important factor in the successful operation of any ophthalmic practice. In the clinic, the OPD increases speed, efficiency, accuracy, and uses less space than multiple separate instruments. When integrated with the EPIC workstation, it may also save 3–5 minutes on each refractive exam, thus increasing patient capacity. The time savings may be even more dramatic when the system is integrated with EMR. Mitch Jackson, MD, commented: "I used to see approximately 40 patients per day but this has increased to 60 patients per day largely due to the increased ability to handle data and process patients more quickly provided by the OPD." The effect on patient flow has been substantial: a decrease in waiting time from 37 to 7 minutes has been reported. Total office visit time for surgical cataract consults has reduced from 2.5 hours down to 1.5 hours. Some ophthalmologists in expanding practices have considered adding an extra exam lane to increase patient throughput but this is no longer necessary with more rapid examinations provided by the OPD in combination with the TRS or EPIC workstation. Many practitioners report physical repetitive stress symptoms as a result of their routine

Figure 6: Post-operative Retro-illumination Image of a Toric Intraocular Lens Enabling a Check of Alignment Marks against Correct Position

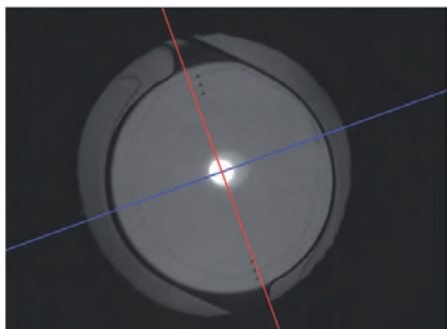
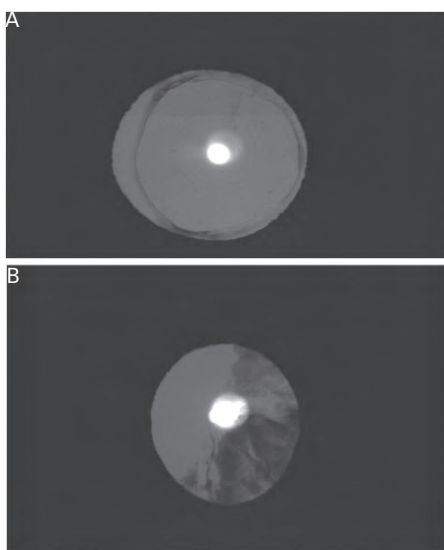


Figure 7: Examples of Retro-illumination Images



A. Multifocal intraocular lens; B. Dense cataract.

eyecare work. This was highlighted in a survey of 1,700 optometrists in Australia that reported a surprising 82 % had work-related physical discomfort, primarily in the neck, shoulders, and lower back.¹⁹ Others have reported problems including ruptured cervical discs or tendonitis.^{14,15} The TRS digital refractor can address these problems since it has improved ergonomics, it can be operated from a chair, and eliminates overhead arm movements thus limiting or avoiding such workplace injury. The XF process can also bring significant financial benefits to the office and markedly increase revenues. In ophthalmic offices, substantial savings in time and increased profitability have been reported.^{14,15}

Improved Surgical Outcomes with the Optical Path Difference Aberrometer

In patients who receive lens-replacement surgery, the results are likely to remain with them for the rest of their lives and it is vital that the ophthalmic surgeon chooses the appropriate IOL and places it correctly. When dealing with any cataract patient, ophthalmic surgeons typically aim for perfection and the more information available, the better the outcome

is likely to be. The OPD system helps the surgeon achieve this. Prior to surgery, the OPD gives the doctor a better understanding of parameters such as angle kappa, corneal astigmatism, and corneal asphericity. The Toric IOL summary enables more-precise lens marking and alignment that optimizes correct lens placement. Mitch Jackson, MD, commented: "This process is critical since a 4° misalignment of a lens can result in a 14 % loss of astigmatic effect and an unhappy patient."¹⁶ An example of a postoperative retro-illumination image of a Toric IOL that allows the surgeon to see whether the alignment marks on the lens are correctly positioned is shown in *Figure 6*. Example retro-illumination images of a multifocal lens and a dense cataract are shown in *Figure 7*. After surgery, it is possible to document the placement of the lens with the OPD and for the ophthalmologist to demonstrate the surgical outcomes to the patient and involve them in decision-making regarding their future vision needs. It is also important that the implanted IOL maximizes contrast since this can be lost as a result of lens design.

A specific advantage of the OPD is that it provides an assessment of both the total refractive power of the eye and total HOAs, as well as separating the total refractive power and HOA of the cornea, the latter being applicable in cataract surgery since the lens will be removed. A further advantage is the detection of the angle kappa before surgery. Angle kappa is the angle between the visual and pupillary axes, and is a vital parameter for the correct implantation of multifocal IOLs.²⁰ If a patient has a large angle kappa, the center of the pupil is no longer the point through which a fovea-centric ray of light passes. As a consequence, the patient will see through the rings of the IOLs off to the side, rather than straight through the center.²¹ This effect is more pronounced with corrections for multifocal IOLs, astigmatism, or HOAs if angle kappa is not compensated for. An angle kappa of 0.4 mm or less is best for a multifocal patient.²² Since each IOL has a certain range in which a patient may be off-axis and still achieve their visual targets, it may still be possible to implant a multifocal lens, but in cases of large angle kappa, this should be avoided to minimize complaints of halos and glare postoperatively. Cynthia Matossian, MD, commented that "in one patient, despite perfect IOL surgery and correct centering of the lenses, a large angle kappa created serious vision problems especially with night driving. Without the OPD we would not have known what the problem was."

OPD determination of angle kappa can be seen in *Figure 8* showing pupil size under photopic and mesopic conditions. Postsurgical determination of angle kappa in cases of unsatisfactory outcomes can inform the surgeon that repositioning of the IOL or IOL exchange is necessary.²³

Patient example: In a post-LASIK cataract patient, the OPD helps in the selection of IOLs. The average pupil power, available on the OPD, is one of the requirements on the American Society of Cataract and Refractive Surgery website program that helps surgeons select post myopic LASIK patient IOL powers.

In a study of 40 eyes in consecutive cataract patients conducted at a clinic in the US, Jonathan Solomon, MD, found that measurement of preoperative corneal spherical aberration using the OPD was a reproducible method for aspheric selection of the most appropriate IOL from a choice of three lenses (Tecnis Z9003 [Abbott Medical Optics, Santa California] versus AcrySof IQ [Alcon Laboratories Inc., Fort Worth, Texas] versus SofPort-Advanced Optic with Violet Shield [Bausch & Lomb, Rochester, New York]).²⁴ The results

indicated the practicality of targeting zero total ocular postoperative spherical aberration in IOL surgery and enabled more precise control of this parameter compared with other methods.

Another important advantage of the OPD is in patients who have undergone previous refractive surgery. Postoperative hyperopia is a frequent consequence of cataract surgery in eyes having previous refractive surgery, and it is important to manage patient expectations in these cases.²⁵ It is also important not to introduce additional aberrations and distortions; in these cases, monofocal or Toric IOLs may be more appropriate than multifocal lenses.²⁶ Many patients do not have adequate memory or are unable to provide documentation of previous procedures and this can confound treatment decisions. The OPD provides the Average Pupil Power and Effective Central Cornea Power measurements that are used in several formulae to calculate postrefractive surgery IOL powers. One reason for the underestimation of IOL power is that keratometers and corneal topography systems may give the wrong corneal power measurement. The OPD provides a precise cornea reading for keratometry measurements since it acquires 11,880 corneal data points from the topography. By comparing the periphery with the central corneal powers from the topography, the central corneal curvature before surgery can be determined, and an effective central corneal power (ECCP) established. This can be used to obtain the K value for calculation of effective lens power (ELP) and IOP power.

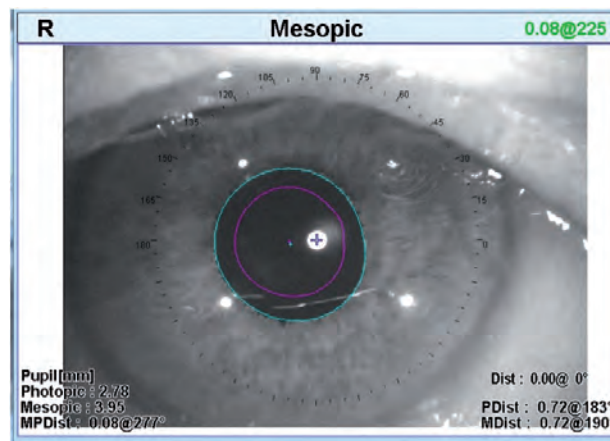
Patient example: A patient is unhappy after implantation of a multifocal IOL. The OPD enables the ophthalmologist to effectively see what the patient sees with the new lens. The OPD III can measure if the amount of angle kappa is too large and this may be sufficient to warrant a change in prescription or the lens may be in the wrong place and needs adjustment.

A further issue that decreases patient satisfaction before and after IOL implantation is the difference in night and day vision. A patient's prescription may change as the pupil changes size from day to night. Night myopia, where patients become more near sighted in dimmer illumination, is due to change in the size of the pupil that causes glare and halos in dark conditions. The OPD enables measurements and refractions to be made with different photopic and mesopic pupil sizes, which can inform decisions about which IOL to choose and in refractive surgery screenings. The TRS allows the operator to perform a refraction in daylight conditions, then perform a totally new refraction without light, simulating night conditions. The operator can then switch between the day and night refractions.

Patient example: A long-distance truck driver requiring IOL surgery has a critical need to have good vision during both day and night illumination. Wavefront systems can help accurately select lenses that provide optimal correction at all light levels to ensure his own safety on the highways and that of others.

Assessment of the ocular surface condition can also determine outcomes. A prospective review of 272 eyes found that before cataract surgery, many asymptomatic patients had ocular surface problems including central corneal staining and abnormal tear breakup time (TBUT).²⁷ The majority of these patients were found to have dry eye but were unaware of it. Despite not reporting any problems in a questionnaire, testing found that 62 % of

Figure 8: Angle Kappa Determination and Pupillometry During Photopic and Mesopic Conditions



The angle kappa helps the physician determine if the patient is a candidate for a multifocal implant. The white cross is the optical center and the purple cross is the pupillary center. The difference between the two is the angle kappa.

patients had severely abnormal TBUTs of 5 seconds or less. Dry ocular surfaces can lead to inaccurate data capture, diagnostic problems, and suboptimal surgical outcomes. It is important therefore that diagnostic systems prior to surgery can accommodate this condition.

Patient example: A middle-aged patient (aged 45 years) with presbyopia has a high RMS value identified on the OPD map. The OPD can identify whether the problem is lenticular even if the lens is clear or whether it is corneal in origin. Issues that can be identified to account for this include IOL tilt or rotation, the onset of nuclear sclerosis or whether the problem results from dry eye or other aberrations of the cornea.

Several recent studies have used wavefront analysis to postoperatively assess the placement and visual performance of different types of IOLs. In one study, parameters including spherical equivalent refraction, residual astigmatism, rotational stability of the IOL, and HOAs were measured in 40 eyes of patients with cataracts and showed similar comparative performance in the Tecnis Toric IOL (Abbott Medical Optics, Santa Ana, California) and the Acrysof IQ Toric IOL (Alcon Laboratories Inc., Fort Worth, Texas).²⁸ Another study assessed the visual outcomes of implanting Tecnis ZM900 (Abbott Medical Optics) or Restor SN60D3 (Alcon Laboratories Inc.) multifocal lenses in 78 eyes of 39 patients.²⁹ Aberrometry analysis using the OPD showed similar performance in both; however, the Tecnis IOL showed a better performance with reduction in spherical aberration and improvements in intermediate visual acuity compared with the Restor IOL. In a further study of 25 patients with cataracts, an IOL with modified anterior and posterior surfaces (Akreos AO) was implanted in one eye and a biconvex IOL with spherical surfaces (Akreos Fit, Bausch & Lomb Inc., Rochester, New York) was implanted in the other eye in each individual.³⁰ Aberrometry using the OPD system showed that the aspheric Akreos AO IOL induced significantly less spherical aberration than the Akreos Fit IOL in 4.5, 5.0, and 6.0 mm diameter pupils. In addition, modulation transfer function and Strehl ratio were also better in eyes implanted with the Akreos AO IOL than the Akreos Fit.

Future Developments

Greater awareness of the utility and cost-effectiveness of the XF process will certainly broaden its use. Following the introduction of the OPD, XF is no longer restricted to specialized centers and is increasingly used in cataract refractive surgery screenings, as well as in assessment for the prescription of glasses and contact lenses. These systems offer the potential to transform refractive correction in both the surgical setting and in the optometrist's practice and its adoption in ophthalmic offices of all types is likely to continue. Joseph Noreika, MD, recently summed up the improvement in cataract treatment by saying "cataract surgeons are capable of delivering better visual outcomes than ever before. With the accuracy of single-sitting, multi-parameter testing and new ways to look at astigmatism and angle kappa before surgery, the bar continues to be raised. This is how combined multimodal wavefront examination and digital refraction is helping to position cataract surgeons for the future."¹⁷ In cataract surgery, ophthalmic surgeons are increasingly aiming to achieve emmetropia and often achieve it or produce results that approximate to it in many patients.^{31,32} The wider use of XF and other wavefront technology in ophthalmic examinations will increasingly help achieve this goal.

Conclusion

Overall, the XF process provides a better understanding and assessment of an individual's total refractive system than was possible with previous

generations of refractors and other instruments. Ophthalmologists face many challenges with increased life expectancy leading to more elderly patients with vision problems and greater expectations from the whole population who demand excellent results from their eye glasses or contact lenses or expect perfect vision and comfort after surgical procedures such as implanting premium Toric or monofocal IOLs. The OPD enables an assessment of the total visual system, and the TRS allows refractions that validate the OPD findings. In addition, ophthalmologists must operate viable practices and maintain a patient flow through their offices that will generate sustainable levels of profit. In order to achieve these results, surgeons need rapid and accurate data that will help them choose the right lens or treatment. Factors such as angle kappa, spherical aberrations, differences in day and night refractions, and asymmetrical astigmatism all affect lens choice and patient satisfaction after surgery. Use of XF in clinical practice has been associated with increased efficiency and higher levels of patient satisfaction. Many ophthalmologists' stated goal is visual perfection in their patients and believe that emmetropia is now a realistic aim following cataract surgery. The greater use of the XF process in a wider patient population and its dissemination to surgeries worldwide should result in earlier, more accurate detection of ophthalmic diseases, improved treatment, more reliable pre- and postsurgical monitoring, optimized refraction, and generally improved outcomes. ■

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