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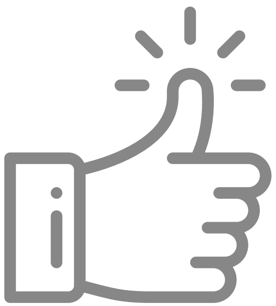

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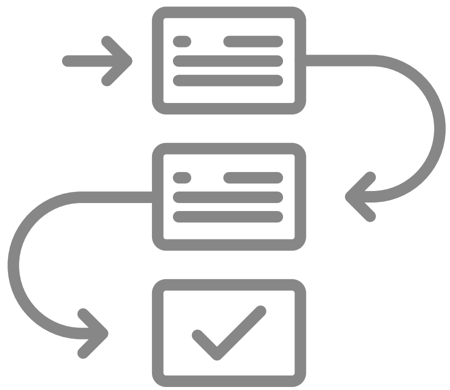

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The Gold Standard for anterior segment tomography

Entire anterior segment in 2 sec

Comprehensive analysis

Scientifically reliable screenings

Pentacam® HR

High-resolution Scheimpflug images of the anterior eye segment

Reliable values for your diagnostics

Automatic measurement activation (delegable)

Total Corneal Refractive Power

Pentacam® AXL

Anterior segment tomography and optical biometry

Includes all Pentacam® HR features

Measurement of axial length

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Pentacam® AXL Wave

The next generation

Scheimpflug-based tomography

Axial length and refraction

Total wavefront and retroillumination

OCULUS®

Pentacam® – the Organizer

YOUR BENEFITS

- Anterior segment tomography in 2 seconds
- Scientifically evaluated displays for screening
- Early detection and objective monitoring of ectatic diseases
- Customizable software

INVESTIGATIONS

- Scheimpflug-based tomography
- Total Corneal Refractive Power (TCRP)
- Corneal thickness

SUITABILITY

- Ophthalmologists
- Refractive and cataract surgeons
- Contact lens specialists
- Optometrists

Pentacam® HR – the Analyst

YOUR BENEFITS

- Premium image quality
- Early detection of ectatic diseases
- Objective keratoconus progression analysis
- Easy fitting of RGP lenses and scleral lenses

INVESTIGATIONS

- Scheimpflug-based tomography
- CSP scan (cornea scleral profile)

SUITABILITY

- Ophthalmologists
- Refractive and cataract surgeons
- Contact lens specialists
- Optometrists

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Pentacam® AXL – the Perfectionist

YOUR BENEFITS

- Biometry plus tomography in one device
- Delegable measurement process
- Customized IOL selection and IOL power calculation
- Built-in IOL Calculator

  with customized Barrett & Olsen ray tracing formulas for post-refractive eyes, incl. PCA
- Built-in IOL database

INVESTIGATIONS

- Scheimpflug-based tomography
- Optical biometry

SUITABILITY

- Ophthalmologists
- Cataract surgeons
- Refractive surgeons
- Eye care specialist

OCULUS®

Pentacam® AXL Wave – the Visionary

YOUR BENEFITS

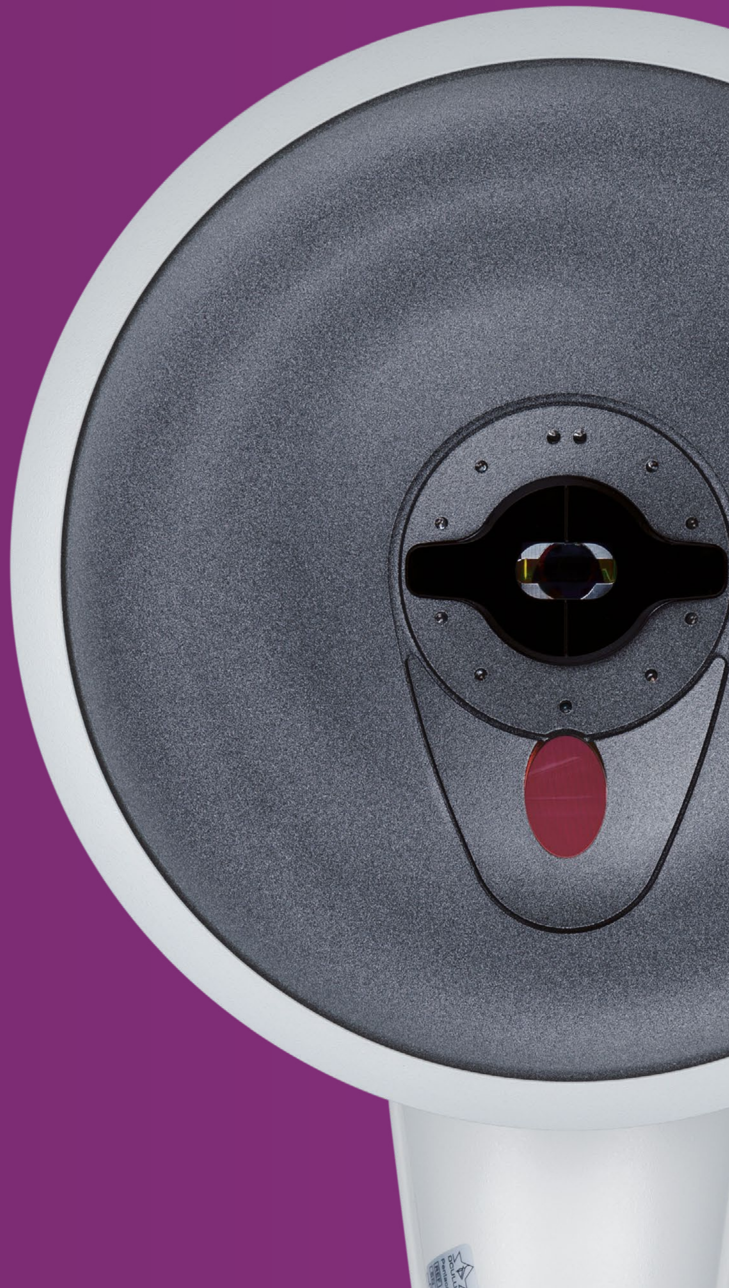
- Unrivalled pre-op care for your patients
- Customized IOL selection and IOL power calculation
- Comprehensive post-op evaluation
- Initial impression of individual visual performance
- Time and space saving

INVESTIGATIONS

- Scheimpflug-based tomography
- Objective refraction
- Wavefront aberrometry of the entire eye
- Optical biometry
- Retroillumination

SUITABILITY

- Ophthalmologists
- Cataract surgeons
- Refractive surgeons
- Eye care specialist



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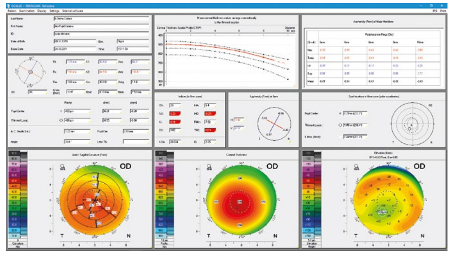
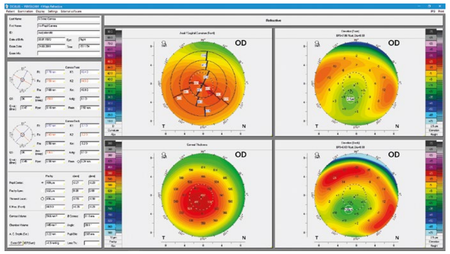
Standard Software

Fast Screening Report
Designed to summarize and analyze the most relevant information based on normative data

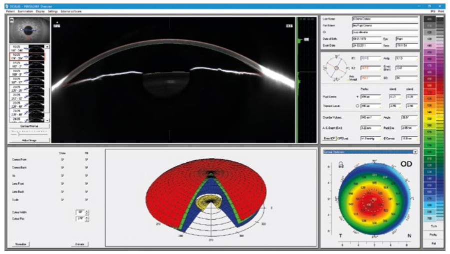
Refractive Software



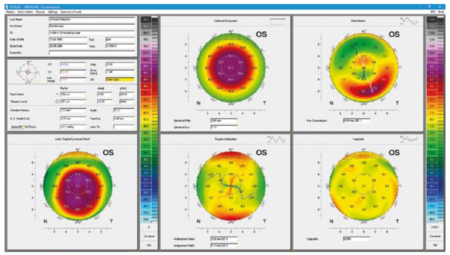
Refractive
Overview for refractive surgeons of keratometry, pachymetry and corneal thickness progression



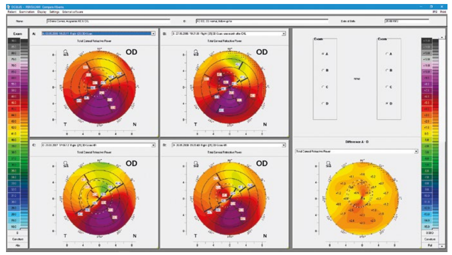
4 Maps Refractive
Shows anterior corneal curvature and elevation, posterior corneal elevation and corneal thickness



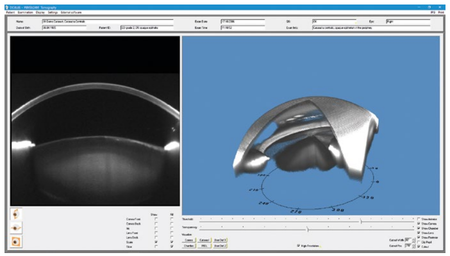
General Overview
Scheimpflug images, pachymetry, HWTW, keratometry, anterior chamber analysis, colour maps



Fourier Analysis
Visual representation of lower and higher order aberrations and assessment of achievable optical outcome

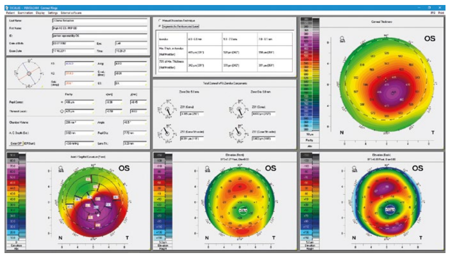


Compare 4 Exams
Objective and intuitive follow-up and documentation

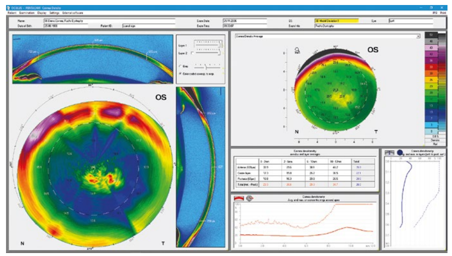


Tomography
Virtual 3D model of the anterior eye segment

Belin ABCD Progression Display
Keratoconus progression based on the Belin ABCD KC-Staging



Corneal Rings
Qualitative and quantitative assessment of corneal properties for pre-operative planning of corneal ring implantation



Corneal Optical Densitometry
Objective analysis of corneal optical densitometry in different layers and zones

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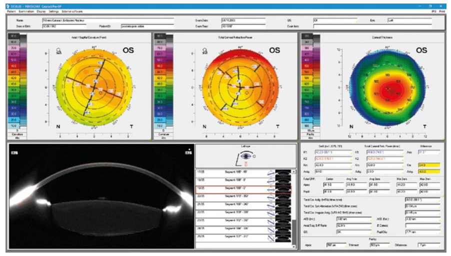
Cataract Software



Cataract Pre-OP Display

Evaluation of corneal optical quality for premium IOL selection in 4 steps

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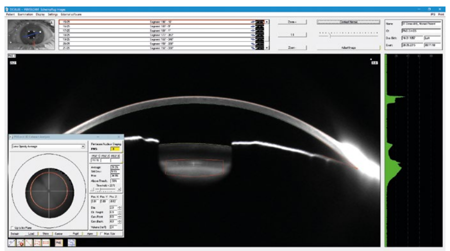
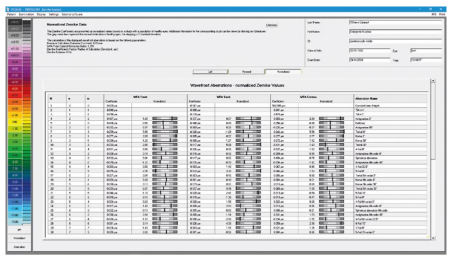
IOL Calculator

Built-in formulas for virgin and post-refractive eyes, customized toric IOL formulas & built-in IOL database



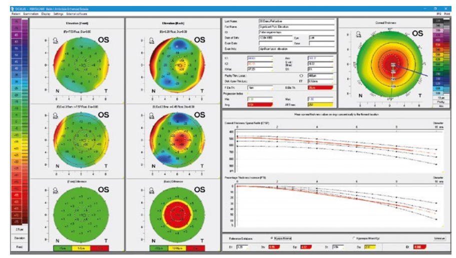
PNS and 3D Cataract Analysis

Objective quantification of lens opacities in 2D and 3D



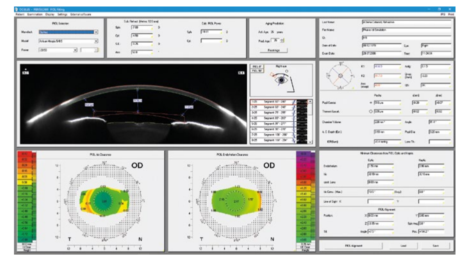
Zernike Analysis

Zernike Analysis and determination of lower and higher order aberrations including normative data



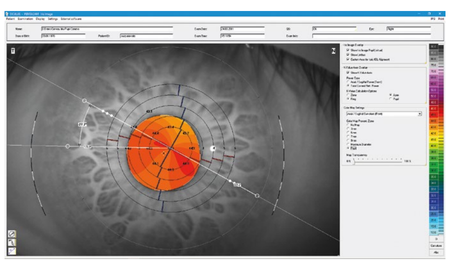
Belin/Ambrósio Enhanced Ectasia Display

Early detection of corneal ectasia and risk management for refractive surgery



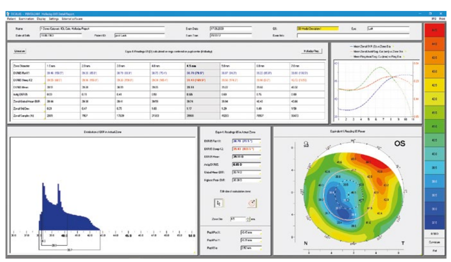
3D pIOL Simulation and Aging Prediction

Assists in preoperative planning of iris-fixated phakic IOLs



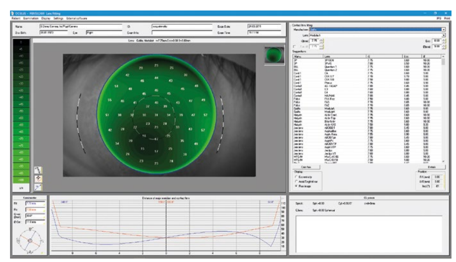
Iris Image

Keratometry and Topography overlay for assessment of curvature, corneal power, pupil size and shape



Corneal Power Distribution

Assessment of corneal power with adjustable calculation zones for post-refractive IOL calculations



Contact Lens Fitting

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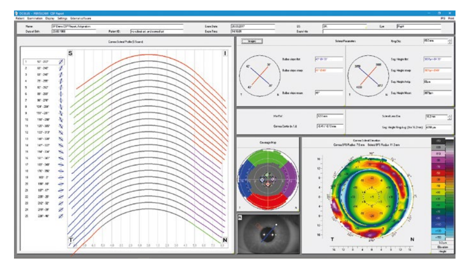

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Sagittal height measurement for scleral lens fitting, covering a diameter of up to 18 mm

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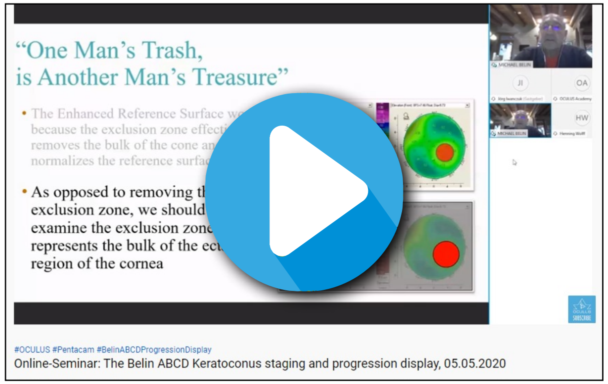
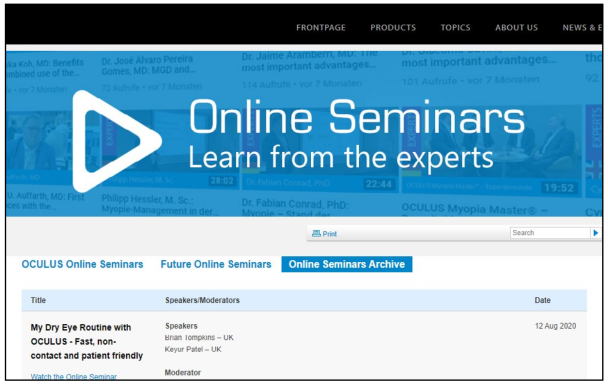


Watch the Online Seminar **“The Belin ABCD Keratoconus staging and progression display”** from Prof Belin to learn how he uses the software in his daily practice.



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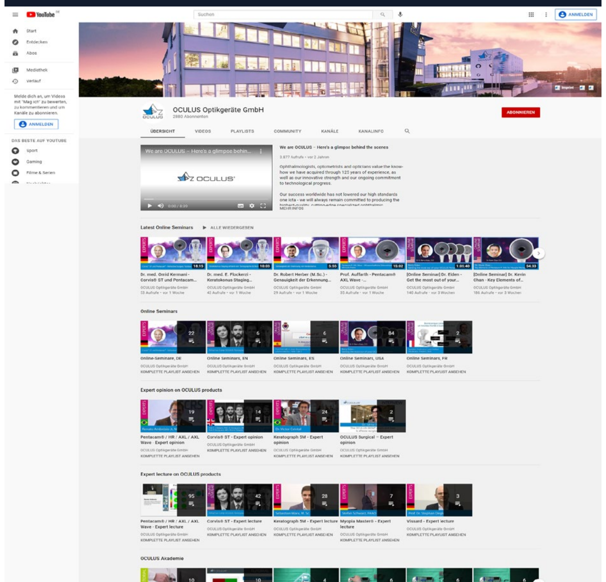

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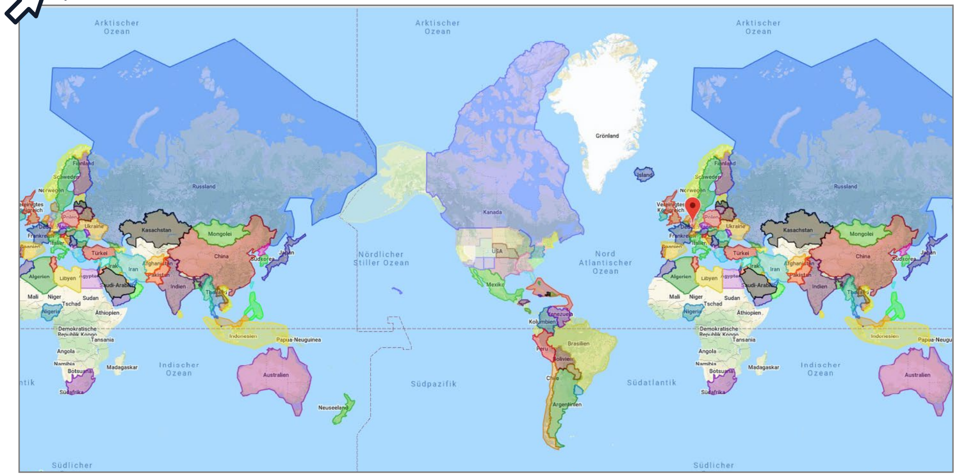

OCULUS Optikgeräte GmbH
Postfach • 35549 Wetzlar • GERMANY
Tel. +49 641 2005-0 • Fax +49 641 2005-295
Email: export@oculus.de • www.oculus.de

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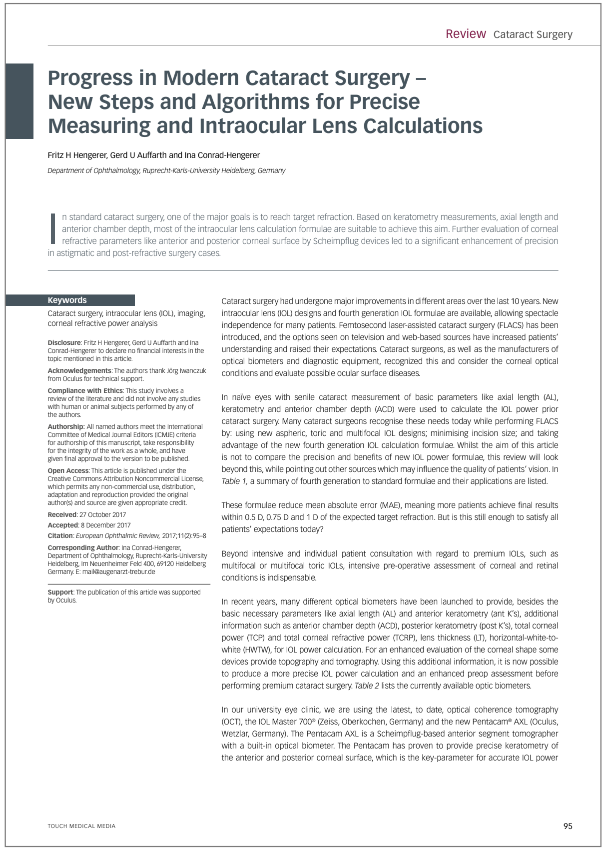
Reprints

Progress in Modern Cataract Surgery

New Steps and Algorithms for Precise Measuring and Intraocular Lens Calculations



Progress in Modern Cataract Surgery – New Steps and Algorithms for Precise Measuring and Intraocular Lens Calculations

Fritz H Hengerer, Gerd U Auffarth and Ina Conrad-Hengerer

Department of Ophthalmology, Ruprecht-Karls-University Heidelberg, Germany

In standard cataract surgery, one of the major goals is to reach target refraction. Based on keratometry measurements, axial length and anterior chamber depth, most of the intraocular lens calculation formulae are suitable to achieve this aim. Further evaluation of corneal refractive parameters like anterior and posterior corneal surface by Scheimpflug devices led to a significant enhancement of precision in astigmatic and post-refractive surgery cases.

Keywords
Cataract surgery, intraocular lens (IOL), imaging, corneal refractive power analysis

Disclosure: Fritz H Hengerer, Gerd U Auffarth and Ina Conrad-Hengerer to declare no financial interests in the topic mentioned in this article.

Acknowledgements: The authors thank Jörg Iwanczuk from Oculus for technical support.

Compliance with Ethics: This study involves a review of the literature and did not involve any studies with human or animal subjects performed by any of the authors.

Authorship: All named authors meet the International Committee of Medical Journal Editors (ICMJE) criteria for authorship of this manuscript, take responsibility for the integrity of the work as a whole, and have given final approval to the version to be published.

Received: 27 October 2017

Accepted: 8 December 2017

Citation: *European Ophthalmic Review,* 2017;11(2):95–8

Corresponding Author: Ina Conrad-Hengerer, Department of Ophthalmology, Ruprecht-Karls-University Heidelberg, Im Neuenheimer Feld 400, 69120 Heidelberg Germany. E: mail@augenarzt-trebur.de

Support: The publication of this article was supported by Oculus.

Cataract surgery had undergone major improvements in different areas over the last 10 years. New intraocular lens (IOL) designs and fourth generation IOL formulae are available, allowing spectacle independence for many patients. Femtosecond laser-assisted cataract surgery (FLACS) has been introduced, and the options seen on television and web-based sources have increased patients' understanding and raised their expectations. Cataract surgeons, as well as the manufacturers of optical biometers and diagnostic equipment, recognized this and consider the corneal optical conditions and evaluate possible ocular surface diseases.

In naïve eyes with senile cataract measurement of basic parameters like axial length (AL), keratometry and anterior chamber depth (ACD) were used to calculate the IOL power prior cataract surgery. Many cataract surgeons recognise these needs today while performing FLACS by: using new aspheric, toric and multifocal IOL designs; minimising incision size; and taking advantage of the new fourth generation IOL calculation formulae. Whilst the aim of this article is not to compare the precision and benefits of new IOL power formulae, this review will look beyond this, while pointing out other sources which may influence the quality of patients' vision. In *Table 1,* a summary of fourth generation to standard formulae and their applications are listed.

These formulae reduce mean absolute error (MAE), meaning more patients achieve final results within 0.5 D, 0.75 D and 1 D of the expected target refraction. But is this still enough to satisfy all patients' expectations today?

Beyond intensive and individual patient consultation with regard to premium IOLs, such as multifocal or multifocal toric IOLs, intensive pre-operative assessment of corneal and retinal conditions is indispensable.

In recent years, many different optical biometers have been launched to provide, besides the basic necessary parameters like axial length (AL) and anterior keratometry (ant K's), additional information such as anterior chamber depth (ACD), posterior keratometry (post K's), total corneal power (TCP) and total corneal refractive power (TCRP), lens thickness (LT), horizontal-white-to-white (HWTW), for IOL power calculation. For an enhanced evaluation of the corneal shape some devices provide topography and tomography. Using this additional information, it is now possible to produce a more precise IOL power calculation and an enhanced preop assessment before performing premium cataract surgery. *Table 2* lists the currently available optic biometers.

In our university eye clinic, we are using the latest, to date, optical coherence tomography (OCT), the IOL Master 700® (Zeiss, Oberkochen, Germany) and the new Pentacam® AXL (Oculus, Wetzlar, Germany). The Pentacam AXL is a Scheimpflug-based anterior segment tomographer with a built-in optical biometer. The Pentacam has proven to provide precise keratometry of the anterior and posterior corneal surface, which is the key-parameter for accurate IOL power

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Improving Cataract Surgery Outcomes

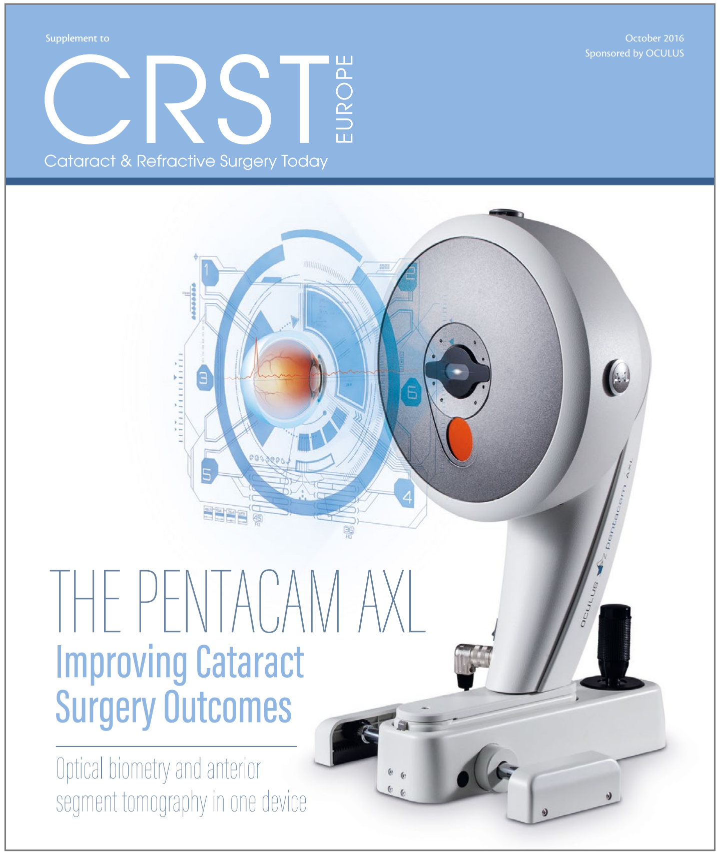

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Table 1: Common intraocular lens power calculation formulae

Formula	Parameters	Application
Barrett formulas	AL, ant. Virgin eyes K, ACD, LT, HWTW	Virgin eyes, post LASIK & RK, toric IOLs
Hill RBF	AL, ant K, ACD, LT, HWTW	Virgin corneas
Olsen ray-tracing	AL, ant K, post K, ACD, LT, HWTW	Virgin eyes, post LASIK & RK, toric IOLs
Holladay 2	AL, ant K, EKR65, ACD, LT, HWTW	Virgin eyes, post LASIK & RK, toric IOLs
Abdulafi-Koch	AL, ant K, ACD, LT, HWTW	Virgin eyes, toric IOLs
iAssort	AL, ant K, post K, ACD, LT, HWTW	Virgin eyes, post LASIK & RK, toric IOLs
Holladay 1	AL, ant K	Virgin eyes
Haigis	AL, ant K, ACD	Virgin eyes
SRK/T	AL, ant K	Virgin eyes
Hoffer Q	AL, ant K	Virgin eyes

ACD = anterior chamber depth; AL = axial length; ant = anterior; HWTW = horizontal-white-to-white; IOLs = intraocular lenses; K = keratometry; LASIK = laser-assisted in situ keratomileusis; LT = lens thickness; post = posterior; RK = radial keratotomy.

Table 2: Available optical biometers

Device	Type of device	Parameters for IOL power calculation	Additional Information
Galilei G6 (Ziemer, Port, Switzerland)	Tomographer and optical biometer	AL, ant K, post K, TCP, ACD, LT, HWTW	Topography & tomography
Pentacam® AXL (Oculus, Wetzlar, Germany)	Tomographer and optical biometer	AL, ant K, post K, TCP, ACD, LT, HWTW	Topography & tomography
Aladdin (Topcon, Tokyo, Japan)	Topographer and optical biometer	AL, ant K, ACD, LT, HWTW	Topography
Lenstar® (Haag-Streit, Köniz, Switzerland)	Topographer and optical biometer	AL, ant K, ACD, LT, HWTW	Topography (4 mm coverage)
OA 2000 (Tomey, Aichi, Japan)	Topographer and optical biometer	AL, ant K, ACD, LT, HWTW	Topography
IOL Master 500® (Zeiss, Oberkochen, Germany)	Optical biometer	AL, ant K, ACD, LT, HWTW	
IOL Master 700® (Zeiss, Oberkochen, Germany)	Optical biometer	AL, ant K, ACD, LT, HWTW	
Argos	Optical biometer	AL, ant K, ACD, LT, HWTW	
AL Scan	Optical biometer	AL, ant K, ACD, LT, HWTW	

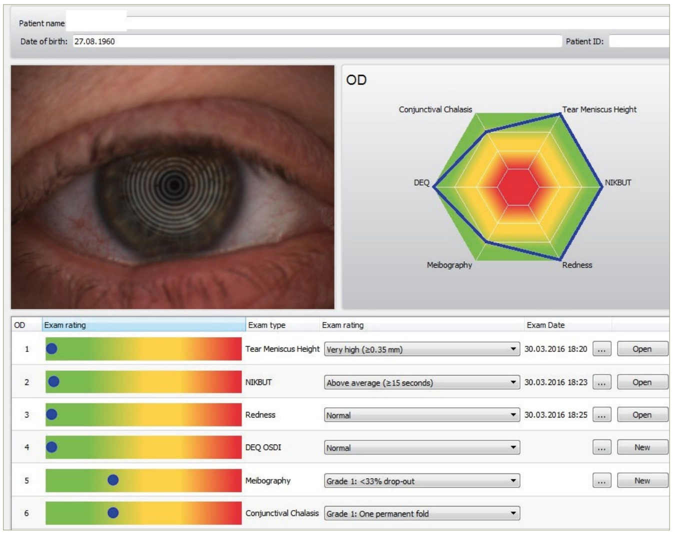
ACD = anterior chamber depth; AL = axial length; ant K = anterior keratometry; HWTW = horizontal-white-to-white; IOLs = intraocular lenses; LT = lens thickness; post K = posterior keratometry; TCP = total corneal power.

calculation.[1–7] The latest studies published, demonstrated a perfect correlation of AL measurements performed with IOL Master 500, IOL Master 700 and Pentacam AXL, as well as a high precision of AL, ACD and corneal curvature.[8,9]

Figure 1: JENVIS DryEye pre-treatment

DEQ = Dry Eye Questionnaire; NIKBUT = non-invasive tear film break-up time; OD = right eye; OSDI = Ocular Surface Disease Index.

Figure 2: JENVIS Dry Eye post-treatment



DEQ = Dry Eye Questionnaire; NIKBUT = non-invasive tear film break-up time; OD = right eye; OSDI = Ocular Surface Disease Index.

The main part of our pre-cataract screening routine is focused on objective assessment of the ocular surface, the cornea, anterior chamber and crystal lens conditions. Modern tomographers, like the Pentacam, support us in detecting forme fruste keratoconus (FFKC), past refractive surgery and corneal diseases such as Fuchs endothelial dystrophy, or signs of dry eye prior to cataract surgery.[10–17] Assessing the crystaline lens density helps in optimising the settings for femtosecond lasers,[18–20] in order to reduce the total amount of laser and ultrasonic energy, to reduce the stress for the corneal endothelium, and the surgery time.

For our premium IOL patients we pay high attention to possible ocular surface diseases prior cataract surgery. For many years Schirmer test I and II were used to quantitatively evaluate the amount of tear film. Today this is no longer sufficient. The Schirmer test gives no information about the quality of the tear film, and can be painful for the patients, too. There is common consent that quality of vision is strongly related to ocular surface quality.[21–23] Sufficient non-invasive tear film break-up

Table 3: Common intraocular lens power calculation formulae

Steps	Application and benefit
1. Check axial topography and TCRP map qualitatively	The benefit of looking at the TCRP map, besides the axial topography, is the assessment of potential influence of the posterior corneal surface with regard to total corneal astigmatism axis, its magnitude, and regularity.
2. Check total spherical aberrations Z4.0	Minimising spherical aberrations, in particular after myopic corneal refractive surgery.
3. Check HOA	The amount of HOA indicates further parameters like optical quality of the cornea. Multifocal IOLs are a great advancement allowing patients to see and perform without reading glasses, and can offer superior life quality. However, they are all reducing contrast sensitivity and quality of vision, which has to be explained to our patients. But still the question remains, is the corneal optical quality good enough? Maeda suggested a value of 0.3 µm and below as a cut-off for multifocal IOLs.[24]
4. Check anterior corneal astigmatism and compare to TCRP	This helps to determine possible differences regarding the magnitude and axis of the astigmatism. Especially this part is discussed intensively and many studies have been published to evaluate the influence of the posterior surface and possible nomograms avoiding unexpected surprises after cataract surgery.[33–35]

HOA = higher-order aberrations; IOLs = intraocular lenses; TCRP = total corneal refractive power .

time (NIBUT), as well as active Meibomian glands, provide the basis for an excellent visual quality outcome after cataract surgery. Moreover, an intuitive summary of the different measurements is key in busy clinical and operative settings. The JENVIS Dry Eye Report, based on the measurements performed with the Keratograph 5K (Oculus, Wetzlar, Germany), is an excellent example on how to present measured values relative to normal data in a clear and easy style. *Figures 1* and *2* show a patient with severe ocular surface diseases before and after treatment with dexamethasone eye drops and antibiotic eye drops, as well as Acular® (Allergan, Dublin, Republic of Ireland).

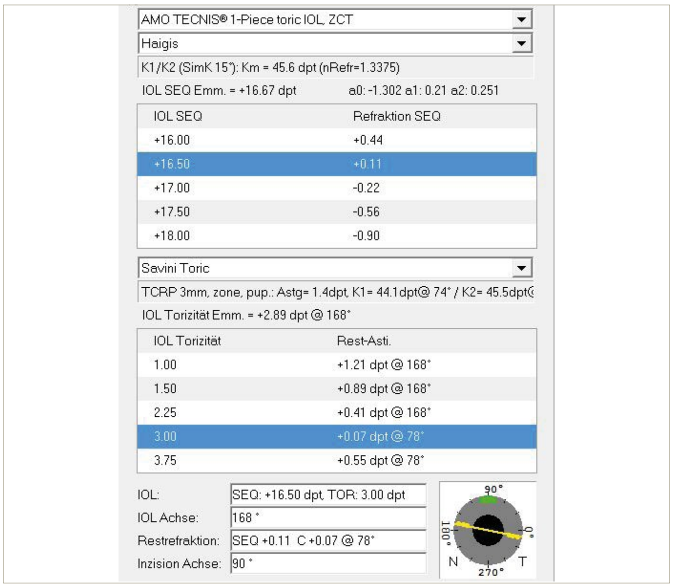
The next challenge is selection of the best-suited IOL for every patient. Therefore, intensive patient consultation helps us understand their habits, their way of living, future plans and, most important, their individual expectations. But can we always satisfy all these?

Sometimes yes, sometimes no. During cataract surgery the crystal lens is removed leaving the cornea as the main optical and refractive part. The assessment of corneal optical quality is one key factor in customised IOL selection. Clinicians and surgeons like and adhere to clear routines. The Cataract Pre-OP Display, developed by Naoyuki Maeda from Japan, is a good example for this. He suggests a four-step screening routine, prior to premium cataract surgery (see *Table 3*).[24]

IOL calculators should be designed to be intuitive and avoid potential misinterpretation and false entries by the user. Having one IOL calculator providing IOL power calculation formulae for every single imaginable case, is still the dream for cataract surgeons. But manufacturers for such devices have made progress.

Online calculators provided by the manufacturers of toric IOLs are different. Some still use a fixed ratio for the cylinder power at the cornea, and the IOL plane of 1.46, for example. Newer calculators use

Figure 3: Savini toric calculator



IOL = intraocular lens; SEQ = spherical equivalent; TCRP = total corneal refractive power.

algorithms to estimate the individual effective lens position, others allow entering the data of the posterior cornea and some use nomograms to estimate the net corneal astigmatism like for example the Barrett toric calculator or the Abdulafi-Koch formula.[25,26] Another growing group of patients are those who have previously undergone refractive surgery such as myopic or hyperopic laser-assisted *in situ* keratomileusis (LASIK) or photorefractive keratectomy (PRK). For the majority of these patients no data prior to refractive surgery is available. With thanks to Dr Douglas Koch, Dr Warren Hill and Dr Li Wang, the ASCRS online calculator was created and further developed (http://iolcalc.ascrs.org). Using it properly, it offers a solution to many of these patients, including those who underwent radial keratotomy (RK) presenting with highly irregular corneal shape.

The Pentacam AXL includes an IOL calculator that covers all needs in our university clinic, as we have to deal with all kinds of eyes. The standard third generation formulae such as Hoffer Q, Holladay 1, SRK/T and Haigis, and the Barrett Universal 2 are useful for monofocal and multifocal IOL calculations. Since every formula except the Barrett Universal 2 have shown limitations in correct prediction of the expected post-op refraction with regard to AL,[27] we should take advantage of the recent ones and compare our standard method and formulae for IOL power calculations, to the latest available formulae.

IOL power calculation for post-refractive patients requires special formulae which are also included in the latest software release of the Pentacam. The known double-K method developed by Aramberri,[28] and the Barrett True K,[29] requires the keratometry prior to surgery, which also requires the spherical equivalent (SEQ) prior surgery, support our daily work if historical data is available. For the majority we are using no-history formulae, such as the PotvinShammasHill,[30] which is the modified Shammas formula for post-myopic LASIK patients. Although rare, we still encounter patients who have previously undergone RK. Due to loss of any pre-operative refractive data, followed by pure measurement of these highly abnormal corneas, all standard biometers and topographers will often fail. Scheimpflug technology therefore has its benefit. The PotvinHill[31] formula is a no-history formula and can be used for these patients. Even if the mean error appears relatively low, we still have to deal with outliers with +/-0.5 D or +/-1 D, limiting the patient's expectations.

The hottest topic today is toric IOL power calculation. Studies from Fityo et al.[32] and Koch et al.[33] have shown the influence of the posterior astigmatism with regard to the total corneal astigmatism.[32,33] The Savini toric calculator is based on the TCRP, which considers the individually measured posterior cornea. First studies have shown promising outcomes, but further clinical investigation is needed.[34,35] In large sample studies,[34,35] the latest formulae such as Barrett toric,[25] have shown the smallest MAE, and most patients are within the expected post-operative refraction. However, there are still outliers where posterior corneal surface has an influence not present in nomograms.

Figure 3 shows the calculation with the Savini toric calculator for a patient having an astigmatism with the rule. The IOL implanted was an TECNIS ZCT300 (Abbott Medical Optics, Santa Ana, CA, US), with an SEQ of 16.5 D. In this particular case the expected post-operative refraction was 0.18 D with -0.07 D at 168°. The patient's subjective refraction was plano post-operative.

Pre-operative refractive data for our patients should be available in the operating theatre, ideally paperless. The IOL Calculator provides a readable pdf file for all electronic medical systems (EMR) systems. Its network compatibility allows last-minute calculations as well as the intuitive entry of used IOL data directly after cataract surgery. Moreover, Pentacam AXL can be linked to Leica microscopes (Leica Microsystems GmbH, Wetzlar, Germany) and True Vision software (TrueVision® Systems Inc., Santa Barbara, CA, US) allowing a superimposition of the implantation axis into the ocular of the microscope, and an eye-tracking system based on iris structures or blood vessel recognition. In combination with an eye-tracking system, a more precise toric IOL positioning can be achieved.

We usually see our patients 1 and 4 weeks after surgery. Study patients have to attend more often to have a close follow-up. Careful refraction of our patients is key to track and improve our outcomes. Usually subjective refraction is performed using trial frames or phoropters; however, only evaluation of visual acuity values lacks information about optical quality. The subjective impression is the only parameter, which matters for the patient. During pre-operative conversation patients´ expectations can be evaluated and adjusted; however, there may be still some complaints from the patient. To objectively quantify them we exam those patients to evaluate the tear film conditions, and we test contrast sensitivity with and without glare. We found a strong tendency between the tear film quality and contrast sensitivity related to the subjective impression of the patients. Studies are running to understand these relations better.

In conclusion, we would state that advanced pre- and post-operative diagnostic for modern cataract surgery has to go beyond standard biometry, standard tests for dry eye, and subjective refraction. Objective parameters and clinical routines have to be established in order to better meet patients' expectation and provide the best possible way of care for them. ❑

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Supplement to

CRST EUROPE

Cataract & Refractive Surgery Today

October 2016

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THE PENTACAM AXL

Improving Cataract Surgery Outcomes

Optical biometry and anterior segment tomography in one device

A New Way to Calculate IOL Power

Axial length measurements taken with the Pentacam AXL correlate well with those taken with the IOL Master 500.

BY H. JOHN SHAMMAS, MD

For years, the IOL Master 500 (Carl Zeiss Meditec) has been the most commonly used optical biometer on the market for IOL power calculations. As a result, this device is typically held as the gold standard. However, the introduction of the Pentacam AXL (OCULUS) may challenge this position. The new device integrates partial coherence interferometry to the original Pentacam HR technology in order to provide surgeons with the ability to take biometric measurements of the eye, including axial length, anterior chamber depth, and corneal radius of curvature (steep, flat, and average). As a result of the integration of partial coherence interferometry into the Pentacam AXL, it is now possible to perform IOL power calculations, all using one device with one measurement procedure.

FIVE TIMELESS ADVANTAGES OF THE PENTACAM

I have used the Pentacam AXL for 13 months now, but I have been using the Pentacam technology for many years. What I have always liked about the Pentacam includes the following five advantages.

Advantage No. 1: In patients who have had prior myopic or hyperopic LASIK, the Pentacam provides better keratometry (K) readings, and I can use the device's wavefront analysis to determine what IOL to implant.

Advantage No. 2: In patients who have previously undergone radial keratotomy (RK), the Pentacam produces better central K readings for more accurate IOL power calculations.

Advantage No. 3: In patients with keratoconus, the Pentacam confirms the K readings in the optical axis (vertex normal), not on the corneal apex (steepest point).

Advantage No. 4: The Total Corneal Refractive Power map of the Pentacam provides a more accurate total astigmatic value and a more accurate astigmatic axis, which is useful when I am evaluating patients who are considering a toric IOL.

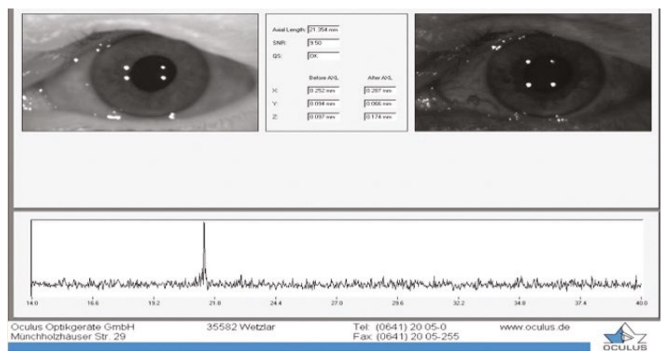

Figure 1. The Pentacam AXL can be used to deliver precise axial length measurements for accurate IOL power calculation.

Advantage No. 5: Because the Pentacam creates a wavefront analysis, it provides a better assessment of the corneal optical quality, which is useful in patients who are selecting a bifocal IOL.

MORE BENEFITS THAN EVER BEFORE

Having the Pentacam AXL in my practice strengthens the clinical relevance of the Pentacam HR technology. Now it is like having two devices in one: In addition to the 3-D scans, I can also use the optical biometry function of the Pentacam AXL to deliver very precise axial length measurements for accurate IOL power calculation (Figure 1). It has become a total screening tool for cataract surgery, allowing me to examine each and every patient with one device instead of two.

With the Pentacam AXL, the axial length and 3-D scan measurements are taken in succession, on the same measuring axis and using the same centering function. In both measurements, the corneal vertex normal is used as the reference point. Any eye motion during the measurement process is detected with the pupil camera and corrected during the calculation process.

The Pentacam technology now has more benefits than ever before. In addition to the five advantages mentioned previously, below are four things I appreciate about the Pentacam AXL.

Advantage No. 1: The Fast Screening Report (Figure 2) alerts me to any possible abnormalities, including possible keratoconus and corneal and anterior chamber changes.

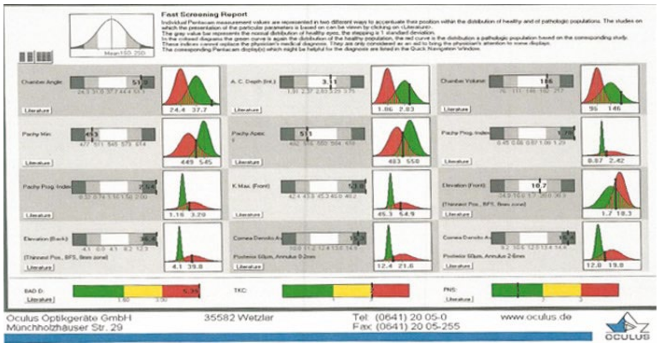

Figure 2. The Fast Screening Report identifies abnormalities, including keratoconus and corneal and anterior chamber changes.

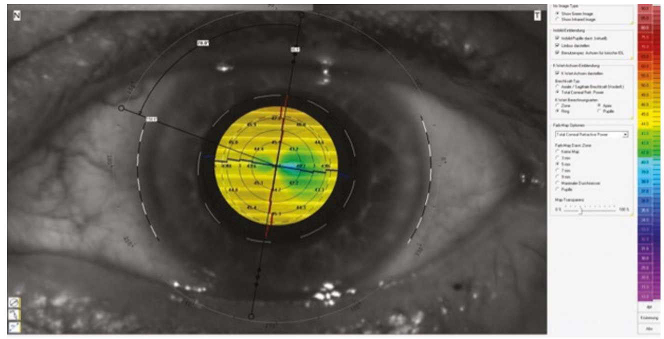

Figure 3. The Pentacam AXL overview image and keratometry overlay can be useful for toric IOL positioning.

Advantage No. 2: IOL power calculations are done automatically, not only for routine cases but also for post-RK and post-LASIK eyes, with no other calculators. Rather, customized formulas developed specifically for the Pentacam AXL are used.

Advantage No. 3: Toric IOL calculations have become easier and more accurate. Just as with standard IOL power calculations, there is no need for additional calculators.

Advantage No. 4: The Pentacam AXL also includes an overview image and keratometry overlay (Figure 3), which I have found useful for toric IOL positioning.

CLINICAL EVALUATION

In a preliminary evaluation of the Pentacam AXL, I compared axial length measurements taken with the device to those taken with the IOL Master 500. In total, 30 eyes with cataracts were included in the evaluation. The average axial length with both devices was 23.76 mm. The arithmetic and mean absolute differences between the devices were 0.00 ±0.04 and 0.026 mm, respectively (range, -0.09 to 0.04 mm). What I found was that all IOL power calculations with the Pentacam AXL were within ±0.25 D of the calculations done with the IOL Master 500.

I also participated in a larger, multicenter study in which measurements were taken from 600 eyes of 600 patients who had undergone cataract surgery at the University of Bochum (n=305), the University of Frankfurt (n=91), the Augenklinik Bad Rothenfelde (n=147), and the Shammas Eye Center (n=47). Although the final results are forthcoming in a future publication, I can share the following now: The agreement and correlation between the mean axial length values taken with the Pentacam AXL and with the IOL Master 500 were excellent. Additionally, the major differences between the two devices were in the measurement of anterior chamber depth, as the Pentacam AXL produced higher mean values, and in the measurement of corneal radius of curvature, as it measured slightly deeper mean values. These differences were statistically significant and were accounted for by optimization of the IOL power formula constants. These differences are likely due to the fact that the Pentacam AXL measurements are taken with optical biometry in the optical axis, as compared with lateral slit illumination with the IOL Master 500.

CONCLUSION

The Pentacam AXL is the next generation in optical biometry. Combining two devices in one, the Pentacam AXL keeps all of the Pentacam HR's features advantageous in the preoperative evaluation of cataract surgery patients and adds the ability to measure axial length, thus supplying surgeons with IOL power calculations. Additionally, with more precise measurements, surgeons can now customize IOL power calculations with the Pentacam AXL. ■

H. John Shammas, MD
- Clinical Professor of Ophthalmology, The Keck School of Medicine, University of Southern California, Los Angeles
- HShammas@aol.com
- Financial disclosure: Speaker (OCULUS)

Pentacam AXL: The Next Gold Standard

Comparative studies have shown that the device can be safely and reliably used to create IOL power calculations.

BY THOMAS KOHNEN, MD, PhD, FEBO

For many years, I have trusted the Pentacam HR (OCULUS) as the gold standard in anterior segment tomography. In cataract surgery, I have relied on this device for topography, implantation of toric IOLs, densitometry, and positioning of IOLs. In refractive surgery, I use it for topography, ectasia and keratoconus screening, and implantation of phakic IOLs. In corneal surgery, I use it for ectasia and keratoconus screening, CXL procedures, and placement of intrastromal corneal rings. Finally, in presbyopia correction, I use the Pentacam HR for densitometry. However, one thing was lacking, and that was the ability to perform IOL power calculations solely based on variables measured with the device.

That has now changed with the introduction of the next-generation Pentacam AXL (Figure 1). In addition to providing me with anterior segment tomography, this enhancement of the Pentacam HR technology also allows me to make accurate IOL power calculations, thanks to the integration of axial length measurements taken with partial coherence interferometry optical biometry (Figure 2).

HOW IT WORKS

Just like the Pentacam HR, the Pentacam AXL is a high-tech device that is capable of myriad functions. A list of features available on the latest-generation Pentacam can be found in the sidebar *Features of the Pentacam AXL*, but the most important of them is axial length measurement. Several axial length measurements are taken in succession, on the same measuring axis and using the same centering function. The software selects the single best of these measurement. The corneal vertex normal is used as the reference point, and any eye movement during the imaging process is detected with the pupil camera and corrected during the calculation process. A 3-D model of the anterior segment is then calculated with ray tracing, allowing any optical distortions to be individually corrected.

The IOL power calculation software of the Pentacam AXL uses customized formulas to create power calculations automatically for routine cases and for post-RK and post-LASIK eyes, without the need for additional calculators. Additionally, toric IOL power calculations have become simpler and more accurate. An added benefit is the device's overview image and keratometry overlay.

The IOL power calculation software takes into account posterior corneal astigmatism and any prior refractive surgery, as well as other conditions of the eye. Most important is that the Pentacam AXL is not restricted to only measuring the anterior corneal surface, meaning that I am less likely to miss detecting anything abnormal on the posterior corneal surface. Being able to take into account posterior corneal astigmatism provides the foundation for a more reliable IOL power calculation, which I have found leads to improved postoperative outcomes and happier patients.

Figure 1. The next-generation Pentacam AXL.

The Pentacam AXL software includes the triple IOL constant optimization algorithm, developed by Wolfgang Haigis, PhD. This is designed to streamline the process of tracking postoperative outcomes, with all of the respective data added with just a few entries. Due to the network-compatible software, the Pentacam AXL can be used in both the operating room and the consulting room.

FEATURES OF THE PENTACAM AXL

Axial Length Measurement and 3-D Scans in One Routine Exam

- IOL power calculations (sphere, toric, postrefractive)
- Scheimpflug imaging
- Iris imaging, showing sclears blood vessels for toric IOL positioning
- Keratometry overlay
- 3-D anterior chamber analyzer
- Pachymetry maps (absolute, relative)
- Elevation maps (anterior, posterior)
- Topography maps (anterior, posterior)
- 3-D cataract analyzer
- 3-D phakic IOL simulation and aging prediction
- Belin/Ambrósio Enhanced Ectasia Display III
- Holladay Report and EKR Detail Report
- Tomography
- Corneal optical density
- Cataract Pre-OP Display
- Corneal wavefront
- Fast Screening Report
- Intrastromal corneal rings display
- Various comparative displays

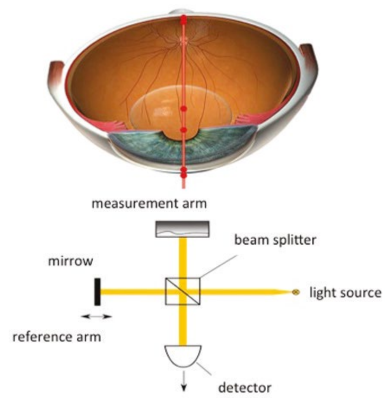

Figure 2. Schematic of partial coherence interferometry to measure axial length.

TABLE 1. COMPARISON OF MEASUREMENTS WITH THE IOL MASTER 500 AND PENTACAM AXL

	IOL Master 500				Pentacam AXL			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Axial length (n=136)	23.81	1.33	21.25	31.20	23.81	1.34	21.14	31.01
Rs (n=136)	7.70	0.29	6.99	8.75	7.73	0.28	7.10	8.79
Rf (n=136)	7.88	0.29	7.26	8.97	7.85	0.29	7.31	8.95
Rm (n=136)	7.79	0.28	7.13	8.86	7.82	0.27	7.20	8.86
ACD (n=136)	3.13	0.40	2.10	4.01	3.21	0.41	2.14	4.34
WTW (n=107)	11.96	0.42	11.10	12.70	11.81	0.40	10.81	12.69
In mean axial length, measurements were identical.								

TABLE 2. MEAN DIFFERENCE IN COMPARED VALUES

	Mean Difference	COR	ULOA	LLOA	P
Axial length (n=136)	-0.04	0.09	0.09	-0.09	0.15
Rs (n=136)	0.03	0.16	0.19	-0.13	0.09
Rf (n=136)	-0.03	0.25	0.22	-0.28	0.77
Rm (n=136)	0.03	0.14	0.17	-0.12	0.31
ACD (n=136)	0.08	0.39	0.47	-0.31	0.51
WTW (n=107)	-0.16	0.27	0.12	-0.43	0.97
No significant difference in any of the compared variables was found.					

COMPARATIVE STUDY

Study design. My colleagues and I conducted the first study in the world to evaluate axial length measurements with the Pentacam AXL. The purpose of our study was to determine if this device could safely and reliably be used to create IOL power calculations. In our analysis, we compared the measurement of axial length, corneal curvature, corneal radius, and anterior chamber depth—all of which are required for IOL power calculation—taken with the Pentacam AXL to those taken with the IOL Master 500 (Carl Zeiss Meditec).

This retrospective study enrolled 136 eyes of patients aged 66 ±12 years who were scheduled for cataract surgery. The type and stage of cataract were not considered. All eyes were measured with both devices, first with the IOL Master 500 and then with the Pentacam AXL. We did not include patients with

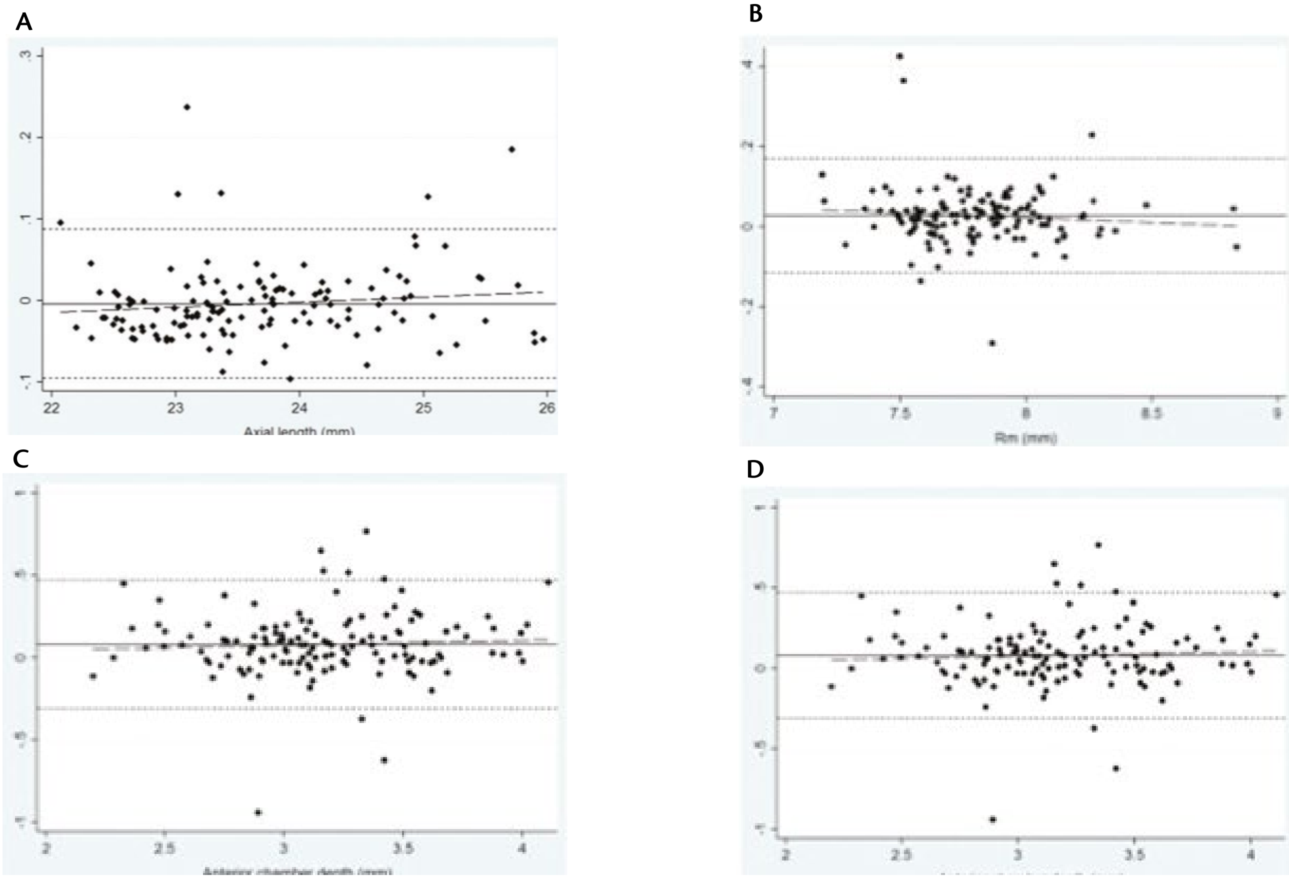

Figure 3. Favorable limits of agreement in axial length (A), radius (B), anterior chamber depth (C), and white-to-white (D) measurements between the Pentacam AXL and IOL Master 500.

known macular pathologies or axial length measurements of less than 22 mm or greater than 26 mm (as measured with the IOL Master 500) in our analysis. In the event that the automatic Pentacam AXL quality measurement did not mark the scan as "OK," the measurement was also excluded.

Results. Table 1 shows the mean, standard deviation, and minimum and maximum measurements of axial length, corneal curvature, anterior chamber depth, and corneal radius taken with the Pentacam AXL and with the IOL Master 500. On average, the axial length measurements were nearly identical between the two devices, and there was no significant difference in any of the compared variables (Table 2).

Due to the favorable limits of agreement found between measurements made with the Pentacam AXL and the IOL Master 500 (Figure 3), and due to the fact that there were no significant differences in keratometric, anterior chamber depth, or white-to-white measurements between the two devices, we showed for the first time that it could be possible to use the Pentacam AXL for IOL power calculations.

Further study. The Pentacam AXL has been the subject of further studies as well. In another comparison of the Pentacam AXL to the IOL Master 500, again the devices produced nearly identical results. This data set included 600 eyes of 600 patients who had undergone cataract surgery at the University of Bochum (n=305), the University of Frankfurt (n=91), the Augenklinik Bad Rothenfelde (n=147), or the Shammas Eye Center (n=47). Results of this study will be published in a peer-reviewed journal in the near future.

CONCLUSION

The Pentacam AXL produces a 3-D scan of the anterior segment and axial length measurements in one routine exam. It has quickly become the complete screening tool for cataract surgery patients, as patients now only need examination with one device instead of two. ■

Thomas Kohnen, MD, PhD, FEBO

- Professor and Chair, Department of Ophthalmology, Goethe University, Frankfurt, Germany
- kohnen@em.uni-frankfurt.de
- Financial disclosure: Consultant, Funding (OCULUS)

Enhancing Surgical Efficiency With a Two-in-One Device

The Pentacam AXL accurately images all eyes and is a useful tool in toric IOL implantation.

BY H. BURKHARD DICK, MD, PhD; TIM SCHULTZ, MD; AND ALEXANDER FELL, MD

About the same time this past year, Bochum University Eye Hospital began using the Pentacam AXL (OCULUS), alone, to evaluate patients presenting for cataract surgery. Prior to this time, we used both the Pentacam HR and the IOL Master 500 (Carl Zeiss Meditec), the former to image the anterior segment and the latter to determine the correct IOL power. Given the recent additional function of the Pentacam AXL to produce axial length measurement and therefore calculate the IOL power, we no longer routinely use the IOL Master 500.

Since introducing the technology into our practice, we have evaluated more than 400 patients with the Pentacam AXL. Not only have we been happy with the device in all cases, but we are extremely impressed with its ability to provide accurate and detailed Scheimpflug images in abnormal eyes, including post–refractive surgery eyes and those with endothelial irregularities. These images are captured in both the anterior and posterior segments of the eye.

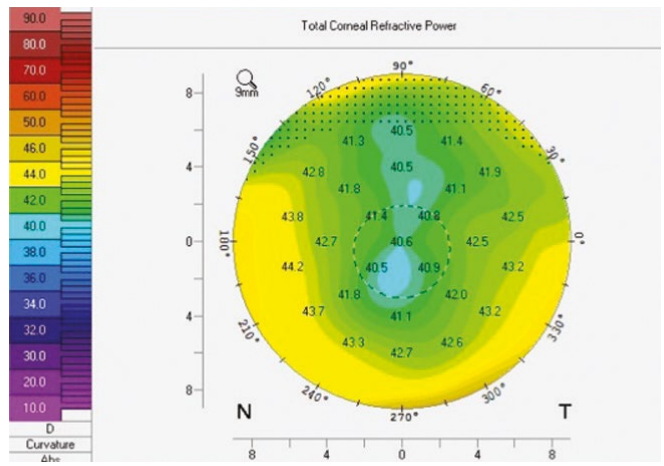

Figure 1. The Total Corneal Refractive Power map calculates the total corneal power of both anterior and posterior astigmatism.

All images courtesy of H. John Shammas, MD

TOTAL CORNEAL REFRACTIVE POWER

Because the topography of the Pentacam AXL so clearly shows irregularities, including astigmatism, we have also found it to be a useful tool in toric IOL implantation. Unlike other devices that only measure keratometry as the radius of curvature of the anterior corneal surface, the Pentacam AXL measures the keratometry of both the anterior and the posterior corneal surface and creates three different maps: Sagittal (axial) Power (SimK), True Net Power, and Total Corneal Refractive Power.

The SimK map is a Placido-style map of the front corneal surface only, whereas the True Net Power map provides the optical power of the cornea by using sagittal curvature values from both the anterior and posterior corneal surfaces. Lastly, the Total Corneal Refractive Power map (Figure 1) uses ray tracing to calculate the total corneal power of both anterior and posterior astigmatism. With each map, the keratometry readings are measured at the 2-, 3-, 4-, and 5-mm rings and at the 2-, 3-, 4-, and 5-mm zones.

Several studies to date have assessed the value of

TABLE 1. PREDICTED VS SUBJECTIVE POSTOPERATIVE REFRACTION

IOL Master 500 / IOL Implanted	Number of patients	Median Absolute Error (SEQ)	< 0.50 D (%) SEQ	< 1.00 D (%) SEQ
SA60AT (Alcon)	39	-0.08	84.62	100
MC6125 Diff (HumanOptics)	88	-0.28	88.64	97.73
CT Spheris 204 (Carl Zeiss Meditec)	33	-0.13	93.94	93.94
Pentacam AXL / IOL Implanted	**Number of patients**	**Median Absolute Error (SEQ)**	**< 0.50 D (%) SEQ**	**< 1.00 D (%) SEQ**
SA60AT (Alcon)	39	0.06	82.05	100
MC6125 Diff (HumanOptics)	88	-0.25	84.09	96.59
CT Spheris 204 (Carl Zeiss Meditec)	33	-0.03	87.88	93.94

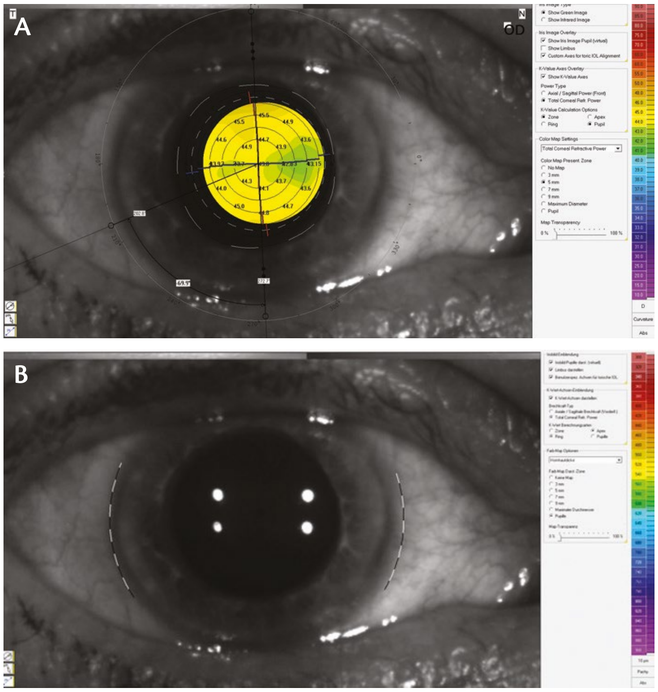

Figure 2. The improved iris image of the Pentacam AXL (A) can aid in toric IOL implantation because it displays a bigger overview of the patient's eye, complete with visible scleral blood vessels (B).

total corneal refractive power in toric IOL calculations.[1-3] Although our experience using total corneal refractive power as a basis for toric IOL implantation is limited to 10 cases thus far, what we have found in our early experience is that it appears to be an excellent way to calculate the total corneal astigmatism. We believe that optimization of our A-constants will further improve our results.

Another nice feature of the Pentacam AXL that can aid in toric IOL implantation is the device's improved iris image (Figure 2A), which displays a bigger overview of the patient's eye, complete with visible scleral blood vessels (Figure 2B). An individual pointer can identify prominent blood vessels in order to compensate for cyclorotation and help in positioning toric IOLs. The iris image can also be superimposed with the Total Corneal Refractive Power map.

OTHER EFFICIENCIES

The Pentacam AXL software is not only good, but it is intuitive. It provides a well-targeted patient screening process with good quality measurements in quite a fast time. Also, there is no need for the patient to move between two devices during the preoperative examination.

Another function of the Pentacam AXL that we have found particularly useful in the evaluation of cataract surgery patients is its densitometric evaluation with Corneal Optical Densitometry and Pentacam Nucleus Staging (Figure 3). These tools provide us with the objective lens density prior to surgery. Furthermore, using the Belin/Ambrósio Enhanced Ectasia Display, the device can be used as a tool for early detection of corneal ectasia.

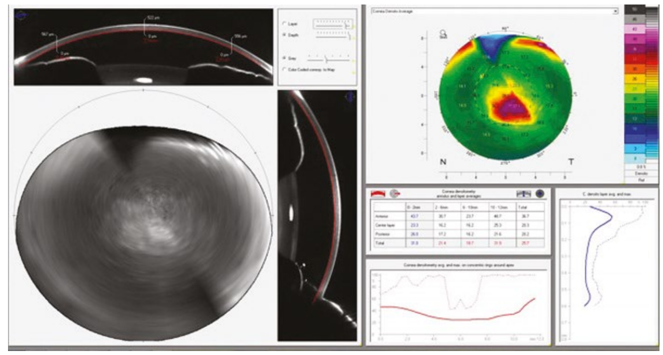

Figure 3. The Pentacam AXL can perform densitometric evaluation with its Corneal Optical Densitometry and Pentacam Nucleus Staging software.

PREDICTED VERSUS SUBJECTIVE POSTOPERATIVE REFRACTION

In a current study we are conducting at University Eye Hospital Bochum and Augenklinik Bad Rothenfelde, we are comparing the predicted postoperative refraction (spherical equivalent; SEQ) with the IOL Master 500 and the Pentacam AXL to patients' subjective postoperative refraction. The preliminary results are promising (Table 1).

CONCLUSION

When practicing refractive cataract surgery, precision is crucial in order to provide patients with perfect postoperative results. As the Pentacam AXL provides us with accurate and detailed information and takes into account both anterior and posterior parameters, we believe that it is the ideal tool for cataract surgery evaluations. All in all, the Pentacam AXL has become a must-have tool in our respective clinics. ■

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H. Burkhard Dick, MD, PhD
- Director and Chairman, University Eye Hospital, Bochum, Germany
- burkhard.dick@kk-bochum.de
- Financial disclosure: Consultant (OCULUS)

Alexander Fell, MD
- Augenklinik Bad Rothenfelde
- Financial disclosure: Consultant (OCULUS)

Tim Schultz, MD
- University Eye Hospital, Bochum, Germany
- dr.tim.schultz@googlemail.com
- Financial interest: None acknowledged