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24 Aladdin Optical Biometer

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Introduction

The Aladdin is an optical biometer, developed and manufactured by Visia Imaging S.r.l. and distributed by Topcon (Fig. 24.1).

The Aladdin biometer consists of the following:

- A time-domain low-coherence interferometer for measuring the main biometric parameters of the eye: axial length, anterior chamber depth, crystalline lens thickness, and central corneal thickness. These parameters need to be measured in order to calculate the power of the IOL.
- A high-precision keratometer that employs interferometry to detect the position of the corneal vertex and uses the reflection of four rings of a Placido disk to accurately measure corneal curvature at 1024 points and then combine these data to perform keratometry calculations.
- A corneal topographer that uses the reflection of a 24-ring Placido disk with a working distance of 80 mm to measure corneal curvature at 6144 points and generate a corneal map to evaluate the regularity of the corneal surface, with a contour of approximately 10 mm in diameter.

Fig. 24.1 Aladdin optical biometer

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- A pupillometer featuring NIR LEDs, as well as two white LEDs for inducing photopic contraction in the pupil. The pupillometer is equipped with a high frame rate camera, which can dynamically measure pupil diameter and pupil decentering under both mesopic and photopic light conditions.

A good optical biometer should perform two main tasks: guiding the surgeon in the choice of the best type of intraocular lens (IOL) to implant and calculating the power of the IOL correctly by accurately measuring eye parameters and applying a wide range of calculation formulas to those measurements.

Over time, technological evolution has led to the appearance of new kinds of IOLs, generally referred to as premium IOLs, on the market. These lenses have been created for the purpose of correcting complex visual defects that cannot be corrected with conventional spherical IOLs. The most common types of premium lenses are toric lenses for correcting astigmatism. However, the use of premium lenses requires first checking the regularity of the corneal surface so that all the consequences of the use of the lenses may be accurately assessed. And it is important to note that in the case of premium IOLs, just measuring keratometry in the central zone is not enough.

The purpose of the Aladdin biometer is to provide the surgeon with the best possible support in choosing the best suitable lens for the patient, paying particular attention to two fundamental elements that are responsible for the quality of the patient's vision: the regularity of the corneal surface and the size of the pupil in different light conditions. In order to calculate the power of the IOL, in addition to the axial length and the anterior chamber depth (for some of the formulas), the corneal keratometry needs to be measured. But to be able to decide what type of IOL to implant (i.e., spherical, aspherical, or toric), it is also necessary to know the curvature of the cornea at every point that contributes to quality of vision in different lighting conditions. That is why it is very important to have access to a corneal topographer. It allows to measure corneal curvature over a large area of the cornea, so as to obtain information that will be useful for appropriately assessing the regularity of the corneal surface. The impact of the corneal surface on vision quality depends on the diameter of the pupil, which varies with the ambient light conditions. For this reason, the corneal topographer must be combined with a pupillometer that measures variations in pupil diameter both statically and dynamically, correlates these variations with the curvature of the cornea, and provides a reliable assessment of vision quality. All of this relates to assessing the corneal wavefront as the pupil diameter changes, decomposing the wavefront into all of its aberration components.

In the next few pages, we will describe how the Aladdin biometer measures the patient's eye, assesses corneal regularity, carries out a screening assessment for keratoconus, performs a pupillometric analysis and evaluates its impact on quality of vision, chooses the type of IOL to implant, and calculates what the power of the IOL should be.

Measuring of Eye Parameters

The main criterion for judging the quality of a biometer is how well it measures eye parameters. In other words, a good biometer should provide highly precise and repeatable measurements, should measure a large number of parameters, should be able to penetrate the densest cataracts well, and should be easy and quick to use. In general, an interferometer should be used to ensure that the measurements of the biometric parameters—especially the axial length—are precise. But, a good interferometer should also be equipped with software featuring complex algorithms capable of always correctly identifying the retinal peak on which the measurements should be carried out. It is well known that an interferometer's axial trace may show more than one peak in retinal response. Usually the most pronounced peak is associated with the reflection

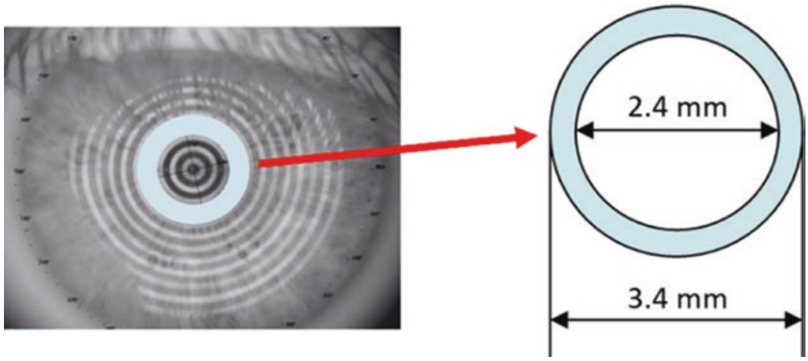


Fig. 24.2 Keratometry area diameters

of the retinal pigment epithelium (RPE) which is the peak addressed for the calculation of axial length in optical biometry. In some cases, an interferometer trace may indicate that the highest retinal peak is found at the reflection associated with the inner limiting membrane (ILM), and this will cause the axial length to erroneously be understated by 150–350 microns. However, for the Aladdin biometer this kind of errors are intercepted and corrected by the biometer's advanced algorithms. All the formulas for the IOL power calculation are based on the value of axial length measured by an ultrasound biometer as the distance between corneal epithelium and ILM. If the axial length is measured using an optical biometer, then it is required a conversion factor. The first correlation was introduced by Professor Wolfgang Haigis in 2000 with the transformation of optical path lengths into geometrical distances. The Aladdin biometer uses a regression formula inspired to the work of Prof. Haigis to express the axial length value to be used for IOL calculation.

Keratometry must be measured very precisely, since any measurement error can lead to a miscalculation of the power of the IOL. The Aladdin biometer's keratometry measurements are based on a very precise assessment of the position of the corneal vertex, which is carried out by means of interferometric measurement. Combining the position of the corneal vertex with an image generated by the corneal reflection of a 24-ring Placido cone (i.e., a Purkinje image) yields a very accurate, point-by-point measurement of corneal curvature. Keratometry is measured on the reflection of four rings of the cone, and this permits corneal curvature to be measured at 1024 different points distributed on a central corneal ring having an average diameter of roughly 3 mm (Fig. 24.2).

Table 24.1 Parameters measured by Aladdin

Item	Measurement
1	Keratometry (K1, K2, axis)
2	Axial length (AL)
3	Anterior chamber depth (ACD)
4	Lens thickness (LT)
5	Central corneal thickness (CCT)
6	Corneal topography (anterior corneal map)
7	Photopic pupil
8	Mesopic pupil
9	Corneal diameter

The Aladdin biometer measures nine eye parameters that are relevant for IOL power calculations (Table 24.1):

With the Aladdin biometer, acquisition takes place semi-automatically. First, a camera captures the image of the Placido cone reflected by the cornea, and special software analyzes the individual photo frames and indicates in real time the correct position for acquisition. The manual part of the acquisition process consists of using a joystick to center the live image displayed on the screen. When the conditions for acquisition are acceptable, the software displays four green arrows on the screen (Fig. 24.3).

The user then pushes a button on the joystick to start the acquisition and measurement process. When the acquisition process—which altogether takes about 20 s for a single eye—is complete, the software interface visually displays a summary of the measured parameters. If

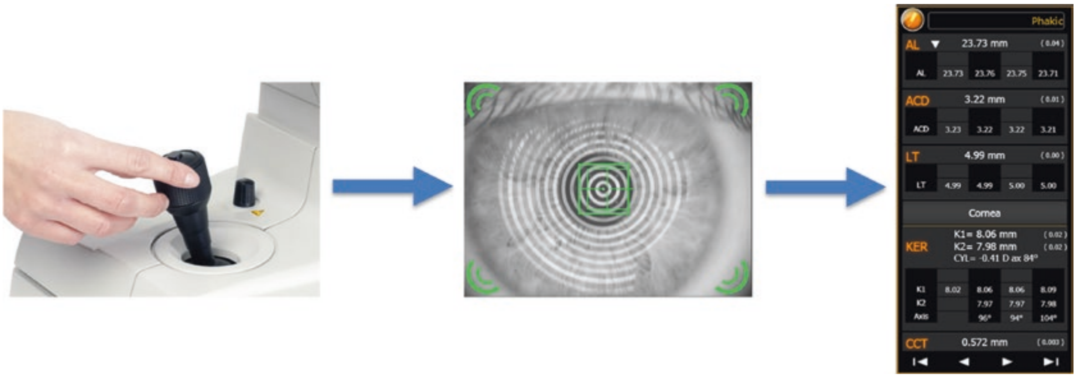


Fig. 24.3 Aladdin measurement process

Table 24.2 Number of measurements per parameter for each acquisition

Parameter	Sequence for a single acquisition
Keratometry (K1, K2, axis)	4 successive measurements
Axial length (AL)	6 successive measurements
Anterior chamber depth (ACD)	10 successive measurements
Lens thickness (LT)	10 successive measurements
Central corneal thickness (CCT)	10 successive measurements
Corneal topography (anterior corneal map)	4 successive measurements
Photopic pupil	1 measurement
Mesopic pupil	1 measurement
Corneal diameter	1 measurement

a parameter is measured multiple times, the standard deviation for the parameter in question will be displayed. A single acquisition consists of one or more measurements, as indicated in Table 24.2.

In short, the Aladdin biometer makes it possible to measure each eye parameter a large number of times in just a few seconds, and the acquisitions that consist of multiple measurements are highly precise and repeatable.

Repeatability and Reproducibility

For the Aladdin biometer, a prospective multi-operator/multi-device precision study was conducted by involving 66 subjects (1 eye for each subject, including 12 eyes with cataract). This study was performed to evaluate the precision in the measurement of the following ocular parameters:

- Axial length (AL).
- Anterior chamber depth (ACD).
- Keratometry at the flattest meridian (Kf).
- Keratometry at the steepest meridian (Ks).
- Lens thickness (LT).
- Central corneal thickness (CCT).
- Corneal diameter (CD).

The results for the precision analysis are reported in Table 24.3.

- Repeatability SD: Repeatability Standard Deviation, includes variation due to measurement error.
- Repeatability limit: 2.8 × Repeatability SD.
- Repeatability % COV = (Repeatability SD/abs(overall mean)) × 100.
- Reproducibility SD: Reproducibility Standard Deviation, includes variations due to the device, the operator, the interaction between device and subject, the interaction between operator and subject, the interaction between device and operator, the interaction between device, operator and subject, and measurement error.
- Reproducibility limit: 2.8 × Reproducibly SD.
- Reproducibility % COV = (Reproducibility SD/abs(overall mean)) × 100.

Table 24.3 Repeatability and reproducibility of different parameters in a prospective study (n = 66 eyes)

		Repeatability			Reproducibility		
Parameter	Overall mean	SD	Limit	% COV	SD	Limit	% COV
AL [mm]	24.04	0.020	0.056	0.084	0.024	0.068	0.100
Kf [D]	43.16	0.077	0.217	0.179	0.082	0.230	0.191
Ks [D]	44.26	0.121	0.339	0.274	0.127	0.355	0.286
ACD [mm]	3.67	0.026	0.073	0.708	0.026	0.074	0.721
LT [mm]	3.67	0.031	0.086	0.833	0.032	0.090	0.878
CCT [mm]	0.555	0.005	0.013	0.837	0.005	0.013	0.858
CD [mm]	12.27	0.066	0.184	0.536	0.066	0.186	0.541

Assessing of Corneal Surface Regularity

Once the acquisition process is complete, it is always good practice to assess the surface regularity of the patient's cornea in order to be able to choose the right type of IOL to implant. Most ocular biometers measure no more than central keratometry, because this measurement, along with axial length and anterior chamber depth (for some of the formulas), is necessary in order to calculate the power of the IOL. However, keratometry by itself cannot provide information on the geometry or regularity of the patient's cornea and in particular cannot provide information that would be useful for answering two questions that are critical when choosing what type of IOL to implant:

- If the cornea suffers from astigmatism, is the astigmatism regular or irregular? It is best practice to implant a toric IOL only if the astigmatism is regular.
- If the patient previously underwent refractive surgery, how is the patient's mesopic pupil positioned with respect to the optic zone that underwent surgery? The choice of what type of lens to implant, and of what kind of formula to use to calculate the lens power, is highly dependent on the geometry of the cornea.

The Aladdin biometer comes with a number of tools and evaluation indices, which are based on the analysis of the topography of the patient's cornea.

On the first screen of the measurement viewing environment, general information on corneal topography is shown, such as a map of corneal curvature—either axial or tangential and on either an absolute or normalized scale—that shows keratometry data for the three principal zones: 3 mm, 5 mm, and 7 mm. This first view provides qualitative information on the regularity of the corneal surface. For instance, in the case of a normal cornea, the axial map on an absolute scale will exhibit few of the colors from the color scale (the step sizes on the absolute color scale being 1.5 diopters). If more colors are used, the axial map may assume the classic butterfly shape of regular corneal astigmatism or it may be irregular, in which case viewing the map tangentially will permit the results to be directly associated with the real shape of the cornea (Fig. 24.4).

When a case of keratoconus is analyzed using a traditional biometer, with only keratometry being considered, generally there will be very high astigmatism at 3 mm, which might suggest to use a toric IOL. However, this type of cornea also requires topographic analysis, which will absolutely prevent such an error.

In addition to topographic analysis, the Aladdin biometer also offers a number of indices for expressing corneal surface regularity and measuring its progression over time. In detail, they are as follows.

- *Astigmatism at 3 mm and 5 mm*: This expresses the astigmatism value and the astigmatism axis in the 3 mm corneal zone and the 5 mm corneal zone, which correspond to the photopic pupil and the mesopic pupil, respectively.

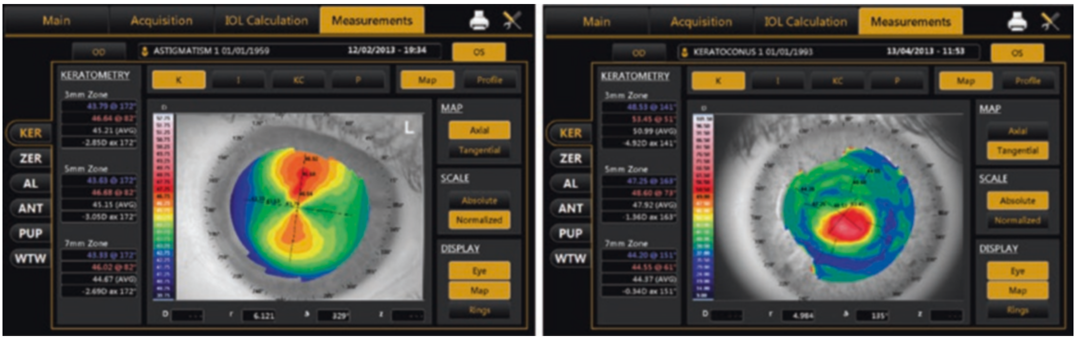


Fig. 24.4 Topographic maps: regular astigmatism and keratoconic pattern

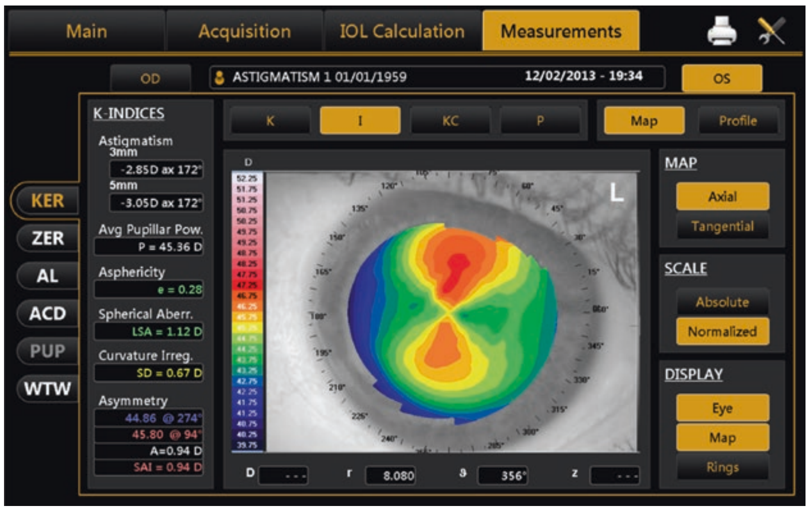


Fig. 24.5 Topographic indices

In the case of high astigmatism, it is important to consider the values and axes of the astigmatism in both these zones in order to decide whether the lens to be implanted should be toric or spherical (in the event that there are significant differences between the two zones).

- *Average pupil power*: This represents the power of the cornea as measured on an entrance pupil diameter fixed at 4.5 mm.
- *Asphericity*: This expresses how much the profile of the cornea differs from a spherical profile, and it can be set in any one of the following parameters: e, p, Q, and SF. The asphericity value is related to the amount of spherical aberration, and the value inverts in a cornea that has undergone myopic refractive surgery that has given it an oblate shape.
- *Longitudinal spherical aberration*: This represents the spherical aberration as measured along the optical axis that corresponds to a pupil with an entrance of 4.5 mm.
- *Irregularity of curvature*: This is linked to point-to-point variation in corneal curvature, and it is defined as the standard deviation of the axial curvature inside a circular pupil area with a diameter of 4.5 mm.
- *Symmetry index*: This index is represented by the dioptric power difference between the two corneal hemispheres that are most different in power.

These indices can be viewed by accessing Section I of the corneal topography software (Fig. 24.5).

Keratoconus Screening

In addition to indices of corneal surface regularity, the Aladdin biometer also offers a section dedicated to keratoconus screening. This section shows three indices (Calossi–Foggi indices) calculated using point-to-point tangential curvature in the keratoconus area, and it also shows an index of probability, obtained from the above indices, which indicates whether or not the topography is compatible with keratoconus (Fig. 24.6). If the topography is compatible with keratoconus, the software displays the geometric parameters of the keratoconus as obtained from the topographic map in order to assess the progression of the keratoconus over time.

Let us consider in detail how these calculations are carried out. First, the software searches for any keratoconus area on the map of the cornea. Algorithms are applied to the map of tangential curvature, which is the best indicator of the shape of the corneal surface. If an area is identified as being potentially keratoconus, a set of geometric and refractive parameters are calculated for that area. An index is obtained from this set of parameters, which indicates the probability that the topography is compatible with the topography of keratoconus. The software visually presents a diagnostic summary of the keratoconus screening, which displays three specific indices (Calossi–Foggi indices) whose values can be associated with the degree of severity of the keratoconus. Let us look at them in detail.

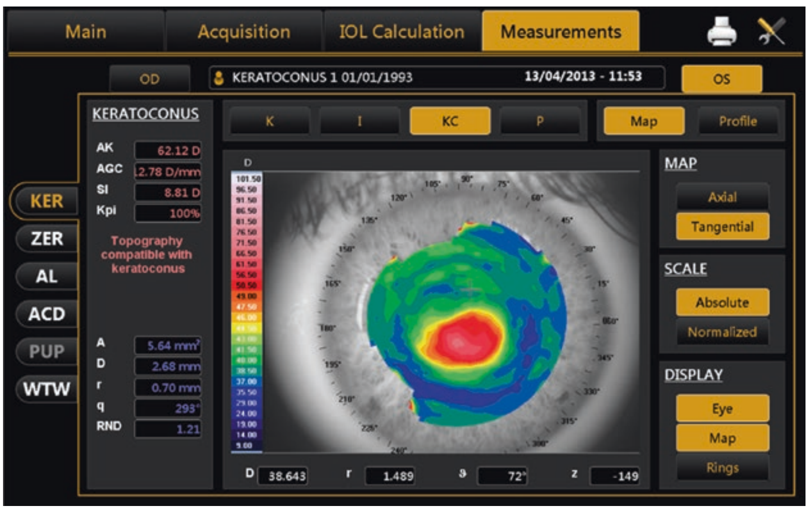
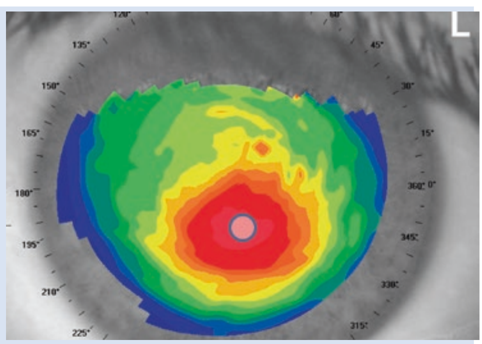
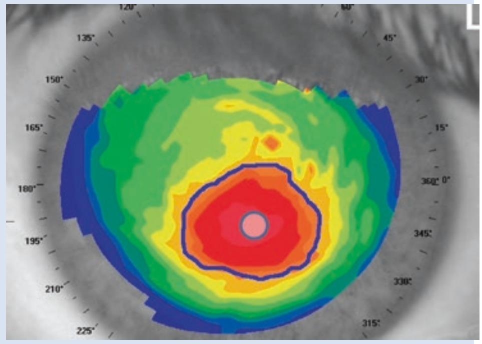
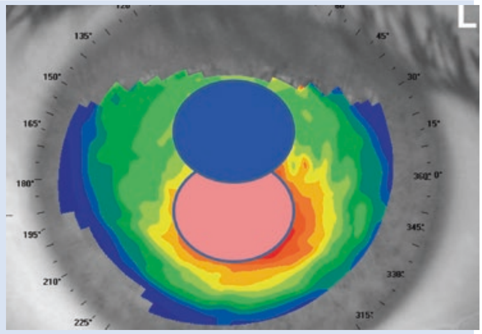


Fig. 24.6 Keratoconus analysis software

AK—Apex curvature: This represents the tangential curvature at the apex of the keratoconus, the apex being identified as the point of maximum curvature of the keratoconus.



AGC—Apex gradient of curvature: This index quantifies the average difference per length unit of the corneal power in relation to the apical power.	
SI—Symmetry index: This represents the difference between the average tangential curvature of two symmetrical circular areas of 3 mm diameter situated on the lower hemisphere and the upper hemisphere, respectively.	

In the event that keratoconus is detected, the software provides geometric information on the keratoconus, such as its area, diameter, center of gravity, and roundness.

The keratoconus screening and indices serve as an additional source of information on the regularity of the corneal surface.

Pupillometric Analysis

The Aladdin biometer includes an advanced pupillometer which is used for static and dynamic analysis of pupil diameter and decentering, and plots the changes of the pupil's response to light stimuli over time. The Aladdin biometer has four infrared LEDs to generate the ambient lighting necessary for the camera to take photographs when the pupil is not being stimulated, plus two white LEDs to induce photopic contraction in the pupil at appropriate times. Acquisition of dynamic and static pupillometric information is carried out manually. First, the joystick is used to center the cornea's reflections of the four infrared LEDs on a grid superimposed on the live image displayed. Then the button on the joystick is used to start and stop the recording of video and storage of the individual frames, on which the pupillometric analysis is carried out. When the analysis process is complete, the following pupil parameters are displayed (Fig. 24.7):

- *Dynamic pupillometry*.
  - Minimum pupil diameter and the pupil decentering at that diameter.
  - Maximum pupil diameter and the pupil decentering at that diameter.
  - A graph of pupil decentering vs. diameter.
  - A graph, over time, of the change in pupil diameter and of the corresponding response time to light stimuli.
- *Static pupillometry*.
  - Average pupil diameter in photopic light conditions, and average pupil decentering at that diameter.
  - Average pupil diameter in mesopic light conditions, and average pupil decentering at that diameter.

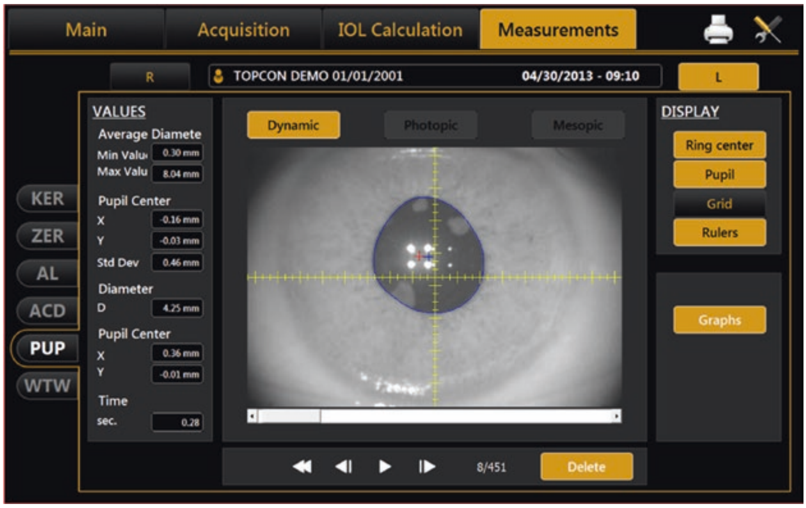


Fig. 24.7 Pupillometry analysis

Analysis of Corneal Quality of Vision

Combining corneal topography with the diameter of the pupil in photopic and mesopic conditions makes it possible to analyze the cornea's quality of vision in the different ambient light conditions. This analysis starts with an examination of the corneal wavefront and how it is decomposed into the main aberration components introduced by the cornea. In particular, Zernike polynomial decomposition is used to obtain detailed information on astigmatism, spherical aberration, coma, and high-order aberrations as the pupil diameter changes. Additional information is provided by the software with regard to the point spread function (PSF), the spot diagram, the pyramid of Zernike coefficients, and the simulation of the corrected visus.

All this information helps provide a more comprehensive picture of the cornea's refractive characteristics, since the analysis is not limited to the keratometric value, which is basically the only need in order to calculate the power of the IOL. Instead, the analysis also includes an assessment of corneal surface regularity and of the associated impact on quality of vision in different ambient light conditions. Such information is necessary for determining the type of lens to be implanted and selecting the calculation formula for the power that will have the best vision performance for the patient in question. Figure 24.8 shows how aberrations are displayed on the Aladdin biometer in the case of a cornea with keratoconus (left) and in the case of a cornea that has undergone myopic refractive surgery (right) which has a small, decentered optic zone. Both are calculated with the entrance of the pupil being 5 mm (i.e., mesopic pupil).

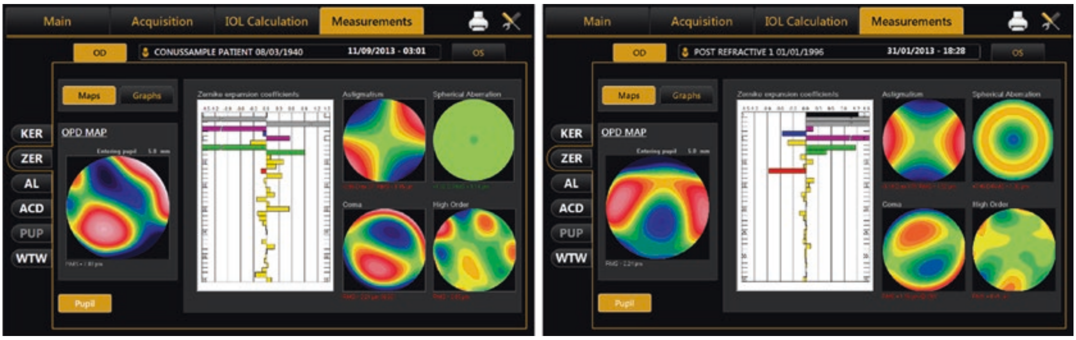
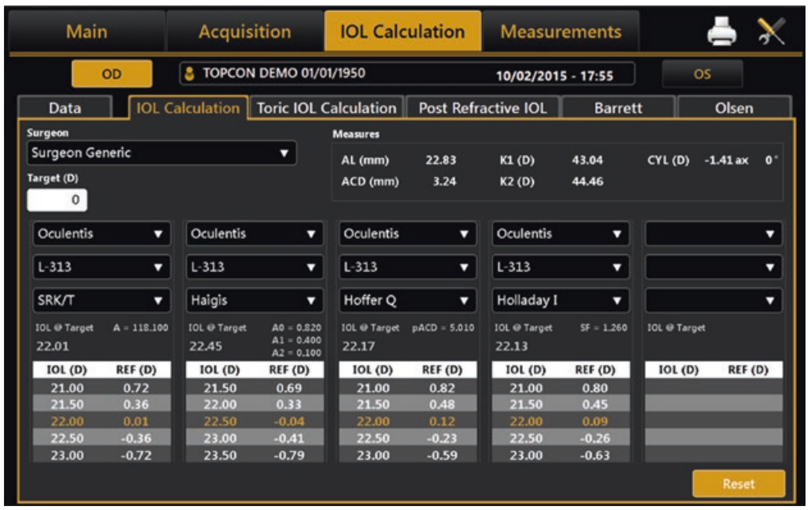


Fig. 24.8 Corneal aberrometry analysis

Fig. 24.9 IOL power calculations table



Formulas for Calculating the Power of the IOL

The Aladdin biometer comes with a complete set of formulas for calculating the power of any type of IOL. These formulas can be accessed in a special work area that is divided into sections according to the requirements involved (Fig. 24.9). We will now describe each of the sections.

Conventional Formulas for Calculating the Power of Spherical Lenses

In this section, up to five different calculation panels can be displayed at once, each of them being associated with a particular lens and a specific calculation formula. The following calculation formulas are available:

- SRK/T.
- Haigis.
- Hoffer® Q.
- Holladay.
- Barrett Universal II.
- Olsen.

Each of the formulas uses one or more specific constants, which are optimized for each IOL model on a statistical basis. The Aladdin biometer has a complete database of the main IOLs on the market, including the optimized constants for each calculation formula as indicated in the ULIB/IOLcon database. The surgeon can modify the values for the constants for each IOL so as to customize his/her set of lenses and even create new lens models. The biometer can be used by more than one surgeon, and each surgeon can maintain his/her own separate, customized database of IOLs.

Toric Lens Calculator

The Aladdin biometer has a generic calculator for toric lenses (Fig. 24.10). This calculator first calculates the spherical equivalent power based on one of the main calculation formulas and then performs advanced calculations of the toricity of the lens, its positioning axis, and the expected refraction and residual astigmatism. To calculate the toric lens more precisely, Abulafia-Koch correction can be applied in order to take the posterior corneal surface into account on a statistical basis. In addition, the calculation can include the potential astigmatism that the surgery may cause depending on where the surgical incision is made. The biometer also offers a simulation tool for estimating the refractive error and the residual astigmatism in the event of an error in the positioning of the toric lens.

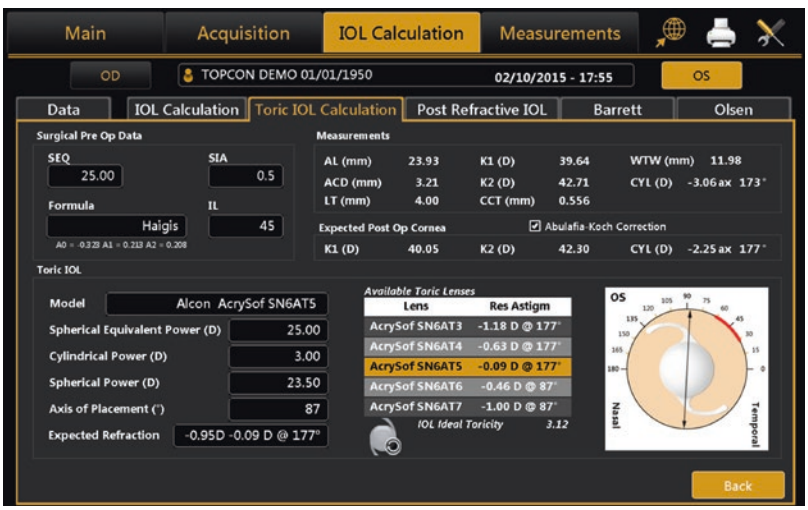


Fig. 24.10 Toric IOL calculations

Special Formulas for Calculating Lens Power in the Case of Patients Who Have Undergone Refractive Surgery

In the case of patients who have gone through refractive surgery, the use of conventional formulas to calculate the power of the IOL is not recommended. That is because variation in the anterior surface of the cornea induced by the refractive surgery will cause conventional formulas to incorrectly estimate the effective lens position (ELP), which will reduce the accuracy of the power calculation for the IOL. For such patients, the Aladdin biometer offers the Camellin-Calossi formula and the Shammas-PL formula. In the Camellin-Calossi formula, the SIRC (or else the central and peripheral pachymetry values) must be input, but if information on previous refractive surgery is not available, then the Shammas-PL (or "No History") formula should be used.

Barrett Calculator

This is an advanced, structured calculator that can calculate the power of an IOL regardless of the type of lens or the situation of the eye. This calculator has five different types of formulas (Fig. 24.11):

- Barrett Universal II, for virgin eyes.
- True-K, for post-myopic, hyperopic, or RK (used for cases in which the SIRC is known and for no-history cases).
- Toric, for toric IOLs.
- True-K Toric, for post-myopic, hyperopic, or RK.
- RX Formula, when the use of a repositioning (rotating) toric IOL is recommended, when a change of lenses is involved, or when a piggy-back (add-on) IOL is to be added.

Olsen Calculator

This is an advanced calculator based on the paraxial ray tracing method. It includes a sophisticated algorithm for estimating the ELP, and it uses a proprietary method to take into account the effect of the posterior surface of the cornea. To perform a calculation using ray tracing, one needs not only the keratometry measurements, the axial length, and the anterior chamber depth but also an accurate measurement of the thickness of the crystalline lens. Accurate execution of this calculation requires detailed knowledge of a number of design parameters for IOLs, and these parameters are included in the lens database that comes with the Aladdin biometer (Fig. 24.12).

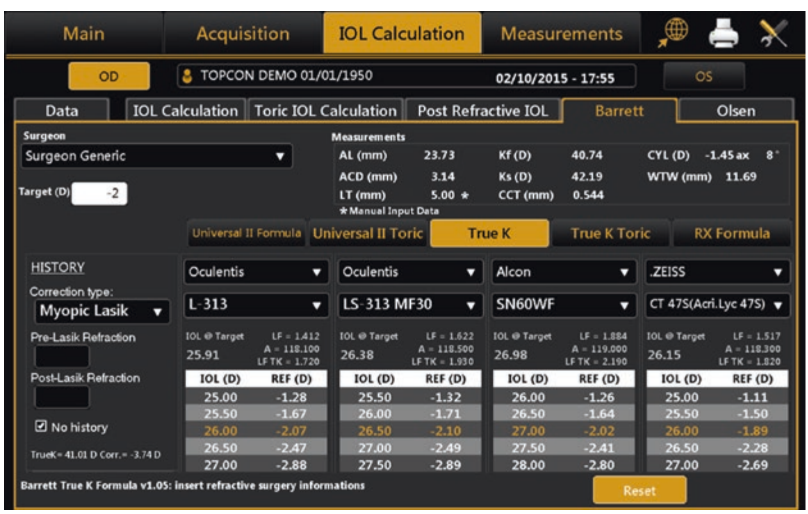


Fig. 24.11 Barrett IOL calculations suite

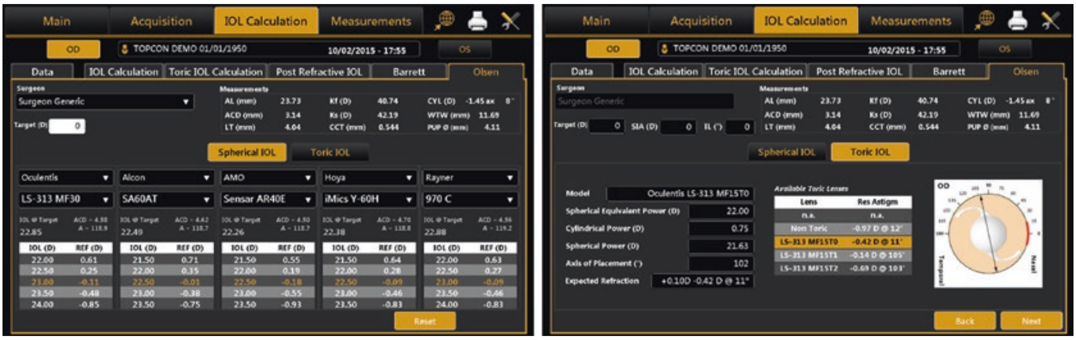


Fig. 24.12 Olsen formula

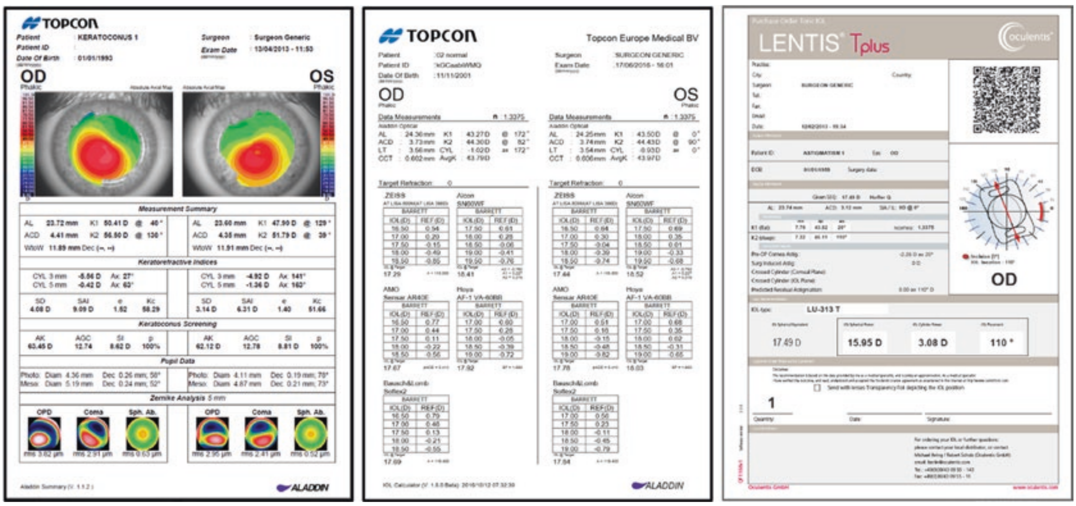


Fig. 24.13 Aladdin printouts

The Olsen calculator can be used to calculate the power of spherical or toric IOLs for any type of patient.

Printed Reports

The Aladdin biometer offers an extensive set of printed reports, with a report for each of the main work areas (Fig. 24.13):

- A summary report of all measurements made.
- A diagnostic report regarding corneal surface regularity.
- A report on the power of IOLs.
- A summary report regarding toric lenses.