25

Haag-Streit Biometers: Eyestar 900 and Lenstar 900

Thomas Bütler

Introduction

With the Eyestar 900, as the introduction of a complete swept-source OCT-based eye analyzer, Haag-Streit is opening a new chapter in measuring, imaging, and diagnosing the human eye. The Eyestar 900 features swept-source OCT technology, enabling precise measurement, as well as topographic assessment, of the front and back corneal surface and the anterior chamber, including the lens, as well as imaging of all these structures. It also includes cornea-to-retina biometry of the entire eye (Fig. 25.1).

The swept-source OCT-based technology provides topography of the front and back corneal surface, pachymetry maps, biometry, and both A- and B-scan imaging, in a single measuring procedure, on a single device. All data is based on swept-source OCT, enabling precise measurements, stunning imaging, and excellent cataract penetration in a single, fully automated, and rapid data acquisition process. The device also features well-established dual-zone reflective keratometry, specifically for cataract applications, providing precise and IOL-constant compatible keratometry and astigmatism measurements. The pooled information enables the eyecare specialist to improve outcomes of surgical interventions (e.g., cataract surgery), diagnose diseases (e.g., keratoconus) quickly and reliably, and document eye status and surgical outcomes (Fig. 25.2).

The Eyestar 900 is powered by EyeSuite, the intuitive software tool that enables seamless integration of the device into any practice environment. It also includes the often-copied, never-equalled EyeSuite IOL cataract planning software, for excellent planning of cataract interventions based on latest-generation IOL calculation methods, such as Hill-RBF, Barrett, and Olsen.

Fig. 25.1 Eyestar, the fully automated swept-source OCT-based eye analyzer by Haag-Streit

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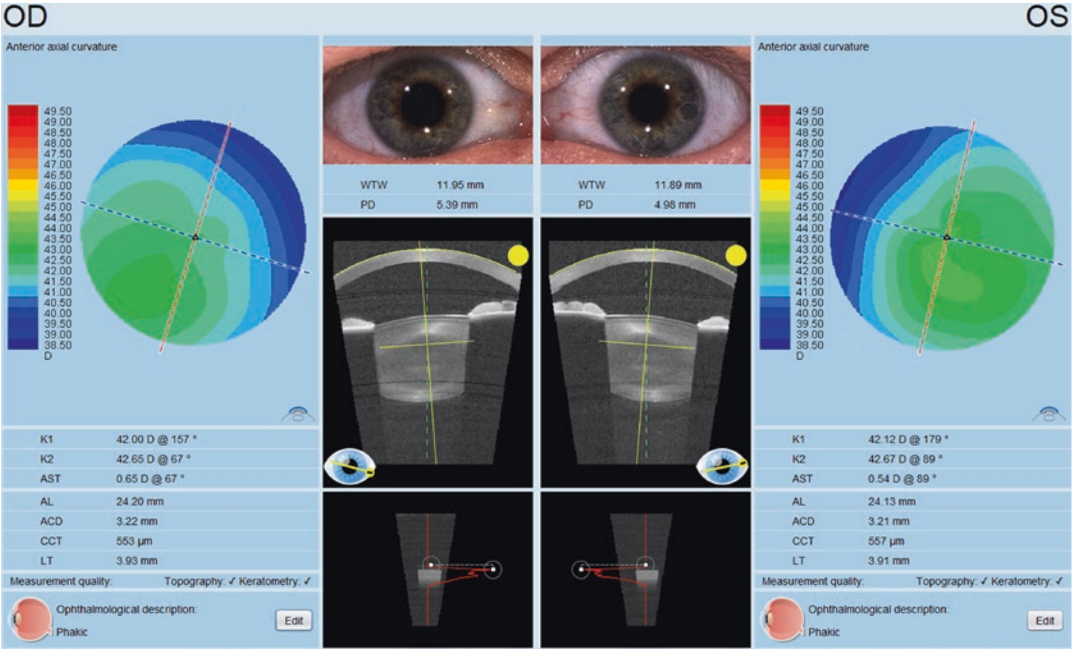


OD

WTW 11.95 mm
PD 5.39 mm

K1 42.00 D @ 157 °
K2 42.65 D @ 67 °
AST 0.65 D @ 67 °
AL 24.20 mm
ACD 3.22 mm
CCT 553 µm
LT 3.93 mm
Measurement quality: Topography: ✓ Keratometry: ✓
Ophthalmological description: Phakic

OS

WTW 11.89 mm
PD 4.98 mm

K1 42.12 D @ 179 °
K2 42.67 D @ 89 °
AST 0.54 D @ 89 °
AL 24.13 mm
ACD 3.21 mm
CCT 557 µm
LT 3.91 mm
Measurement quality: Topography: ✓ Keratometry: ✓
Ophthalmological description: Phakic

Fig. 25.2 Comprehensive overview screen of a measurement result in the Eyestar Cataract Suite, featuring all information necessary for successful cataract planning, from standard mono-focal- to premium multifocal- and/or toric IOL

Swept-Source OCT-Based Biometry and Tomography with Mandala Scan Technology

One of the challenges of OCT-based tomography, and even more for topography, is the compensation of artifacts due to eye motion. With Eyestar, Haag-Streit is introducing new and patented scanning technology, called Mandala Scan. The Mandala-Scan system features all OCT motion compensation, independent of any video-based eye-tracking. Classical systems use multiple radial scans across the vertex to scan the eye (Fig. 25.3). The vertex is used as the common scan location. This enables straightforward motion compensation based on standard video eye-tracking technology. The downside is a potential latency time between the video eye-tracking and the OCT scan system, and that the line-scan may be regarded as motion-free. In contrast, the Mandala Scan technology uses a series of circular scans of the eye. The optimized distribution of intersections in the Mandala Scan allows for mathematical identification and compensation of motion with high spatial and temporal resolution, and zero latency (Fig. 25.4). This furthermore leads to very dense surface scanning, incorporating 64,000 A-scans.

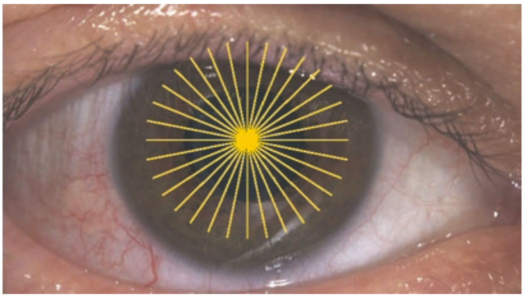


Fig. 25.3 Classical radial scan pattern, with vertex as the common point and decreasing scan densitiy to the perifery

The advantage of the high-density scans is improved quality of the topography, as well as the derived measurement parameters e.g. SimK, enabling the creation of virtual cross sections (B scans) of any direction and pattern in the scan volume, as well as high-resolution latency-free motion correction (Fig. 25.5). A positive side effect of the all OCT motion compensation of the Mandala Scan technology is an improved scan density due to micromotion of the eye during the high-speed scanning of the eye.

The result is an evenly distributed, high density of A-scans in the entire scan volume, thereby enabling the creation of virtual B-scans at any location and of any trajectory in the scan volume acquired.

Using swept-source OCT for the Eyestar enables the creation of robust A-scans of the entire eye, without the need for stitching of scan sections, which is inherent with, for example, standard Fourier-domain OCT systems. These full-eye A-scans allow high-precision biometry of the entire eye, from the cornea to the retina. Swept-source OCT also already demonstrates improved cataract penetration capabilities, when compared to standard time domain systems, which are still in widespread use for cataract planning. This improved cataract penetration rate leads to more comfort for the patient, with a reduced need for ultrasound examinations, which are uncomfortable for the patient and demanding on the examiner's skills.

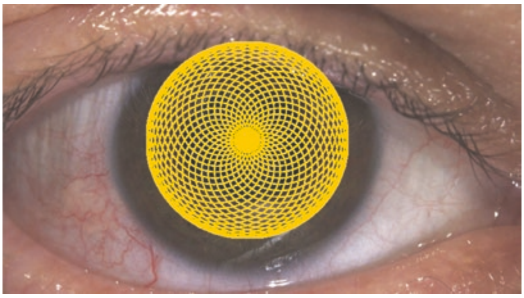


Fig. 25.4 Mandalay Scan pattern providing high scan density and a high number of intersections

Swept-Source OCT Biometry of the Entire Eye

With the Lenstar optical biometer, Haag-Streit has pioneered biometry of the entire eye, introducing measurement of the central corneal thickness, as well as the lens thickness with laser interferometric measurement precision. The Eyestar follows this paradigm but provides valuable additional information such as swept-source OCT B-scans and topography (Fig. 25.6).

In the Cataract Suite, Eyestar services 16 radial virtual B-scans from the cornea to the retina. This information is combined with the A-scan image and allows for intuitive verification of the automated measurement process, as well as identification of unusual or pathological eye configurations.

In addition to these 16 B-scans, Eyestar provides an additional virtual B-scan in the plane of maximum lens tilt (Fig. 25.7). This scan is available for the natural crystalline lens of a patient or an implanted IOL after cataract removal. The scans include the angle of maximum lens tilt to the optical axis. This information may be used to identify unusual extensive lens tilt that might limit the efficacy of a premium IOL when implanted or might help to explain a non-optimum refractive result after the operation.

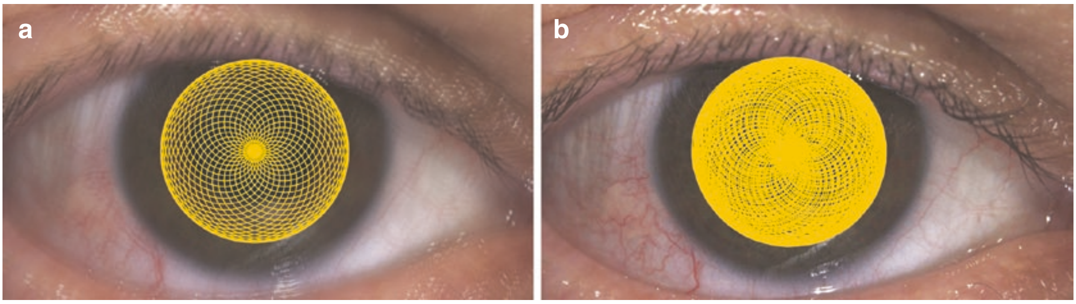
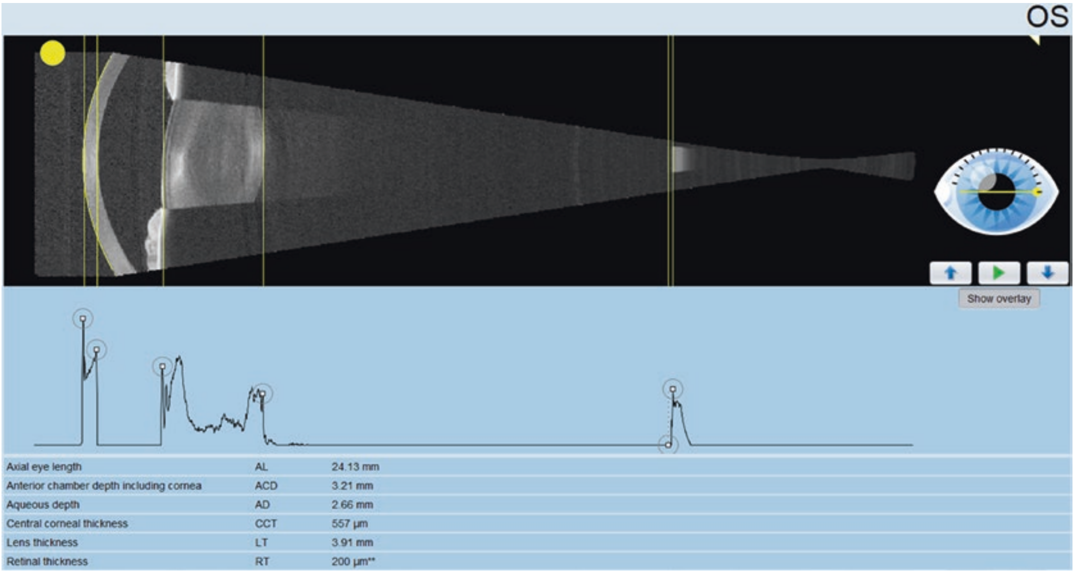
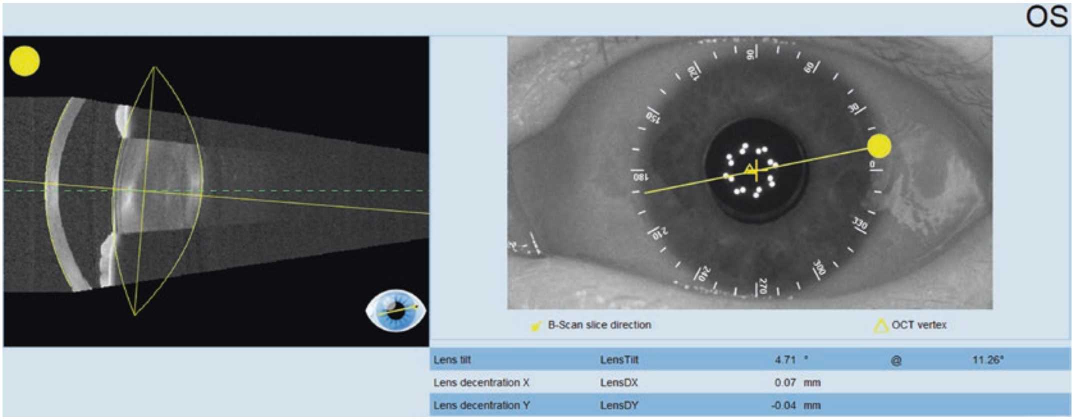


Fig. 25.5 Image (**a**) shows the scan pattern and density without the motion correction, depicted by the displaced images of the eye and image blur. Image (**b**) shows the scan pattern and density of the motion-corrected scan. The micromotion of the eye throughout the scan duration leads to an improved density of A-scans in the scan volume



Axial eye length	AL	24.13 mm
Anterior chamber depth including cornea	ACD	3.21 mm
Aqueous depth	AD	2.66 mm
Central corneal thickness	CCT	557 µm
Lens thickness	LT	3.91 mm
Retinal thickness	RT	200 µm**

Fig. 25.6 Combined A- and B-scan display for greater confidence in the biometry measurements. In the B-scan section, the user may toggle through 16 predefined radial B-scans or play them as a video



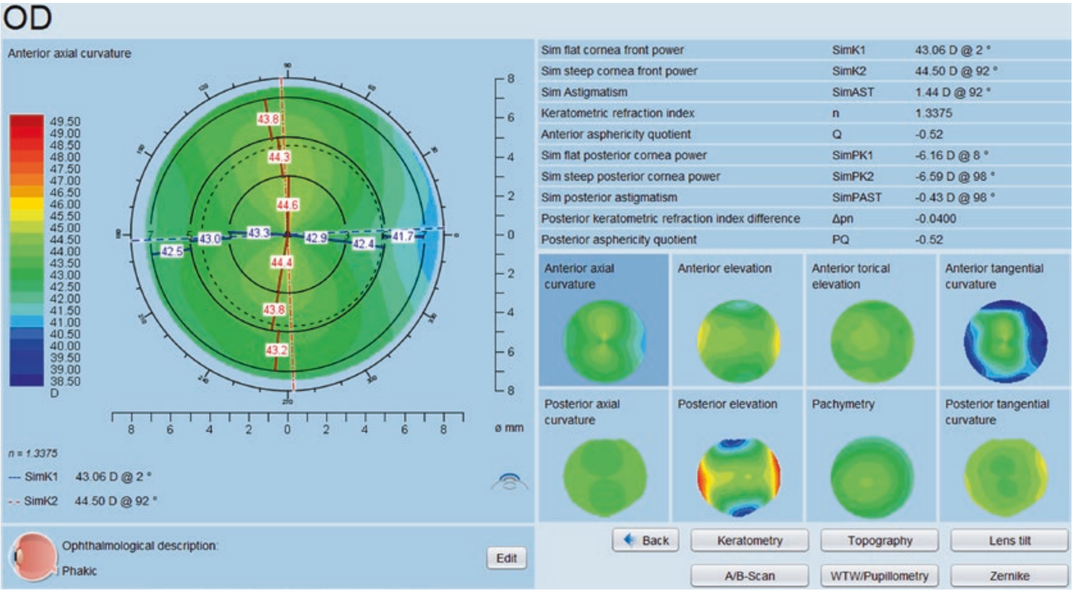
Lens tilt	LensTilt	4.71 °	@	11.26°
Lens decentration X	LensDX	0.07 mm		
Lens decentration Y	LensDY	-0.04 mm		

Fig. 25.7 Lens tilt display with the orientation of the maximum lens tilt, the extent, and the decentration of the lens, with respect for the corneal vertex

Swept-Source OCT Topography

Biometry based on swept-source OCT provides the user with far more than just axial length measurements and keratometry. Detailed information on the cornea front and back surfaces gives the potential to significantly improve cataract planning for astigmatic and post-refractive patients. The topography maps allow the surgeon to screen for signs of corneal pathologies that may limit the patient's post-cataract surgery visual potential. In toric candidates, the symmetry and regularity of the astigmatism on the cornea front and back are readily available, allowing for a thorough assessment of the patient's eligibility for a premium IOL.

Eyestar's cataract suite serves a wide range of topography maps, with a diameter of 7.5 mm, as well as a pachymetry covering the same area. Furthermore, the anterior topography complies with the normative requirements of a Class A topographer, ensuring excellent visualization, as



Sim flat cornea front power	SimK1	43.06 D @ 2 °
Sim steep cornea front power	SimK2	44.50 D @ 92 °
Sim Astigmatism	SimAST	1.44 D @ 92 °
Keratometric refraction index	n	1.3375
Anterior asphericity quotient	Q	-0.52
Sim flat posterior cornea power	SimPK1	-6.16 D @ 8 °
Sim steep posterior cornea power	SimPK2	-6.59 D @ 98 °
Sim posterior astigmatism	SimPAST	-0.43 D @ 98 °
Posterior keratometric refraction index difference	Δpn	-0.0400
Posterior asphericity quotient	PQ	-0.52

n = 1.3375

— SimK1 43.06 D @ 2 °

-.- SimK2 44.50 D @ 92 °

Ophthalmological description:
Phakic

Fig. 25.8 Topography display of the Eyestar's Cataract Suite, providing thumbnail previews for all maps provided, as well as details of the selected map enriched with selected measurements tailored to the needs of the cataract surgeon. In this image, the zone-based keratometry was enabled for the axial curvature display

well as measurements of the cornea. The back corneal topography, like the front, is based on swept-source OCT, which is one of the leading technologies in providing precise measurements and high-quality imaging.

EyeSuite IOL, as part of the Cataract Suite software package on the Eyestar, takes advantage of the combined information from the cornea front and back and provides these measurements for the latest generation of IOL calculation formulae. Besides standard IOL calculation formulae like Haigis, Hoffer Q, Holladay, and SRK/T, it also features the latest developments such as the Olsen Formula, the Barrett Suite with calculation methods for every different kind of eyes, and IOL designs and Hill RBF as the first artificial intelligence-based IOL calculation method, featuring not only IOL power information for the user but also a quality index for the reliability of the predicted IOL power (Fig. 25.8).

The information from the individual topographic maps is enriched with simulated keratometry measurement information of the front and back cornea, as well as information on the sphericity of the cornea. The curvature maps for the front and back cornea also feature zone-based keratometry. This feature provides information on keratometry in the central 3-mm, the intermediate 3 to 5-mm and the more peripheral 5 to 7-mm optical zones of the cornea front and back. The zone-based keratometry does not follow the standard keratometry's paradigm of solely providing information on a steep and a flat meridian, perpendicular to each other, but on up to four (two steep and two flat meridians), with independent orientation for each zone. In a perfect astigmatic eye, the zone-based and the standard simulated keratometry will match perfectly, but the more an eye differs from being a perfect astigmatic eye, the more the information on the individual zones will differ from the simulated keratometry. Simulated keratometry is a valuable tool for assessing the symmetry of the astigmatism in different areas of the eye and may support the eyecare specialist in the decision-making process for a toric IOL.

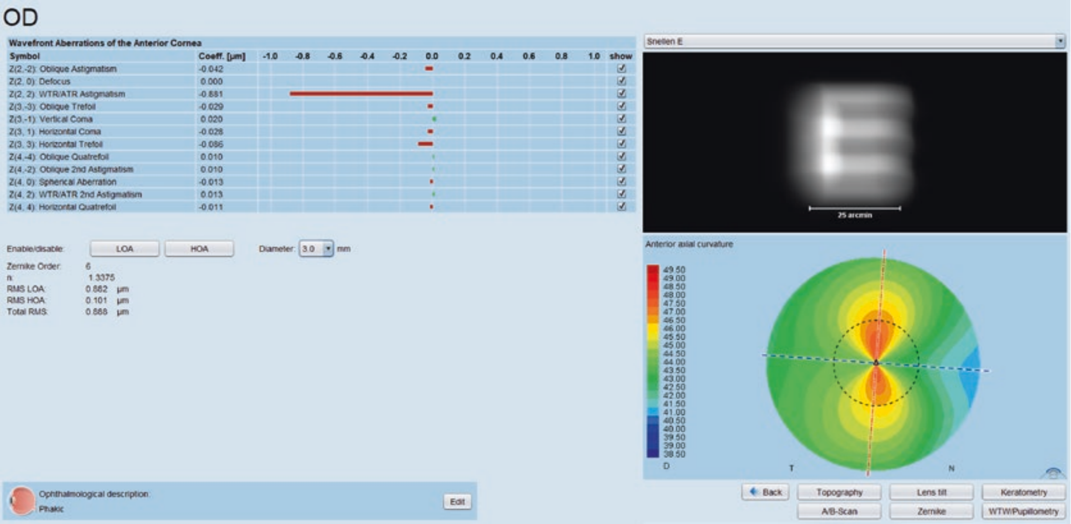
Zernike Analysis and Vision Simulation

The Zernike wavefront analysis of the cornea is a valuable tool to understand and, even more important, to explain visual impairment to a patient. The individual Zernike parameters such as astigmatism, coma, or spherical aberration, to name just a few, enable an understanding of what visual limitation is caused by which geometric anomaly of the cornea. This also allows for estimation of the amount of improvement a potential corrective action may entail, as glasses and/or IOLs currently only correct for the defocus, astigmatism, and some spherical aberration. Correction of corneal asymmetries shown in the coma Zernike coefficient, as well as other higher-order aberrations, are not accessible for correction by these standard means. The information from the Zernike wavefront analysis is combined with a simulated display of how the letter E or Landolt ring on a vision Chart may be seen by the patient. On-the-fly adjustment of the covered area of the analysis enables simulation of different lighting conditions and how the diameter of the patent's pupil may have a positive or negative effect on the visual performance. Enabling individual selection of every Zernike coefficient and/or of the two groups' high- and low-order aberrations allows for intuitive explanation of the effect of vision-corrective actions and of limitations entailed by the corneal anatomy of the patient. Even though it is solely a simulation, the tool might be of high value in setting the patient's expectations right and supporting the decision-making process for the optimal implant-type selection (Fig. 25.9).

Reflective Dual-Zone Keratometry

Besides the swept-source OCT-based simulated keratometry from the corneal topography, the Eyestar features the well-established reflective dual-zone keratometry, specifically for cataract applications, providing precise and IOL-constant compatible keratometry and stigmatism measurements.

Why does a high-precision OCT device like the Eyestar need reflective keratometry in addition to the simulated keratometry form the corneal topography? The answer is simpler than



OD

Wavefront Aberrations of the Anterior Cornea

Symbol	Coeff. [µm]	show
Z(2,-2): Oblique Astigmatism	-0.042	☑
Z(2, 0): Defocus	0.000	☑
Z(2, 2): WTR/ATR Astigmatism	-0.881	☑
Z(3,-3): Oblique Trefoil	-0.029	☑
Z(3,-1): Vertical Coma	0.020	☑
Z(3, 1): Horizontal Coma	-0.028	☑
Z(3, 3): Horizontal Trefoil	-0.086	☑
Z(4,-4): Oblique Quatrefoil	0.010	☑
Z(4,-2): Oblique 2nd Astigmatism	0.010	☑
Z(4, 0): Spherical Aberration	-0.013	☑
Z(4, 2): WTR/ATR 2nd Astigmatism	0.013	☑
Z(4, 4): Horizontal Quatrefoil	-0.011	☑

Diameter: 3.0 mm

Zernike Order: 6
n: 1.3375
RMS LOA: 0.882 µm
RMS HOA: 0.101 µm
Total RMS: 0.888 µm

Ophthalmological description:
Phakic

Snellen E

Fig. 25.9 Zernike analysis and vision simulation, with the display featuring all individual Zernike coefficients to the fourth order, as well as root mean square for the low-order aberrations (RMS LOA), and one for the high-order aberrations (RMS HOA), as well as the overall aberrations (total RMS). The vision simulation may be altered between the letter E and Landolt ring display expected. The two modalities feature completely different baseline information. While reflective keratometry is based on video imaging of the corneal reflection of 32 infrared LED markers, located in two concentric rings covering 1.65 and 2.3 mm on an average cornea, showing the geometric deviation of the cornea from a sphere by a distorted reflection pattern of the projected LED points, the simulated keratometry of the OCT topography is based on elevation/height information for the corneal surface covered by the scan. This height information is then mathematically converted to SimK values. Even though the two modalities may provide the same information on average, there might be significant differences between the modalities for the individual patient due to the different baseline information on which they rely when providing keratometry readings.

Specifically, for the cataract application, it is key for the surgeon to have excellent keratometry information, since any error in this measurement parameter 1:1 promotes the visual performance of the patient postoperatively. This is the reason why Haag-Streit chooses to complement the Eyestar's swept-source OCT measurement technology with the well-established and over the years clinically proven dual-zone keratometry also used by its predecessor, Lenstar. Compared to the Lenstar, the Eyestar's dual-zone reflective keratometry was improved with a slightly adapted LED pattern and new analysis algorithms showing an overall improvement in measurement performance, as compared to the already excellent information provided by the Lenstar.

Other Standard Parameters and Displays

Like most other devices, the Eyestar Cataract Suite also provides information on the Corneal Diameter, as well as the pupil diameter. This measurement information is complemented with the eccentricity values of the respective diameter centers to the apex. In some literature, these eccentricity values are also referred to as angle Alpha and Kappa, even though the values displayed with the Eyestar are in mm and refer to the offset of the circular fit of the pupil and Corneal Diameter to the apex. The measurements are displayed in high-resolution images of the patient's eye under whitelight illumination, as well as infrared illumination, depicting eye structures such as iris details or conjunctival vessels in detail.

Usability and Patient Comfort

Apart from the comprehensive measurement palette with excellent performance, the Eyestar was also developed to provide a new and improved measurement experience for the user, as well as for the patient. The all-in-one design of the Eyestar is fully self-contained and, apart from the height adjustment of the chin rest, does not feature any parts that move outside the housing. The measurement process is rapid and fully automated. In typically less than 40 s all data is acquired on both eyes, including OCT tomography, topography, keratometry, biometry, and imaging. The rapid acquisition reduces patient fatigue, leading to improved patient cooperation and making the measurement more convenient for the technician running the device.

AC Suite and More

The Cataract Suite presented here is just the first in a range of application suites for use with the Eyestar 900 that will soon be available.

The first extensions focuses on topography and anterior chamber analysis in more detail. The topography maps are extended to 12 mm diameter, and analysis tools such as higher order Zernike wavefront and vision simulation, keratoconus screening and progression views are included.

The extension of imaging enables the user to create custom B-scan images of the anterior chamber, including the lens in the 18-mm anterior corneal scan volume. This tool may serve as a diagnostic aide and for documentation purposes.

Other extensions in the pipeline will focus on the chamber angle for glaucoma diagnosis and further improvements to the Cataract Suite, for example, an analysis tool for refractive surprises or outcome documentation for phakic IOL.

Summary

The Eyestar Precision OCT/Cataract Suite provides ambitious cataract surgeons with all the information they need, enabling excellent results and optimum patient satisfaction (Table 25.1).

Table 25.1 Technical specifications

Technology	Swept-source OCT
Wavelength	1060 nm
Scan speed	30,000 Hz
OCT imaging range (cataract/AC suite/imaging)	Ø 7.5 mm/12 mm/up to 18 mm on the anterior cornea covering the entire AL scan range
Central corneal thickness (CCT)	300–800 µm (±1.5 µm)
Anterior chamber depth (ACD)	1.8–6.3 mm (±0.014 mm)
Lens thickness (LT)	0.5–6-5 mm (±0.015 mm)
Axial length (AL)	14–38 mm (±0.005 mm)
Keratometry anterior cornea (K)	32.1–67.5 dpt (±0.067 dpt)
Keratometry posterior cornea (SimPK)	3.9–9.5 dpt (±0.025 dpt)
Topography	EN ISO 19980:2012 for corneal topography systems, type A compliant
Corneal topography measurement points:	64,000 A-scans (anterior and posterior cornea)
Corneal topography diameter Cataract suite/AC suite	Ø 7.5 mm/12 mm
Corneal Diameter (CD)	7–16 mm (±0.079 mm)
Supported EMR interfaces	DICOM, GDT, EyeSuite script language, EyeSuite command line Interface

Lenstar, the All-in-One Cataract Planning Platform

Introduction

Back in 2008, Haag-Streit redefined and broadened optical biometry with the introduction of the Lenstar optical biometer, featuring laser interferometry biometry of the entire eye from the cornea to the retina with measurements of all the segments (CCT, ACD, LT, and AL) of the

Fig. 25.10 Lenstar provides highly accurate laser optic measurements for every section of the eye—from the cornea to the retina—and was the first commercially available optical biometer on the market that could measure the thickness of the crystalline lens

human eye (Fig. 25.10). Due to the long period this device has served the cataract market with its excellent measurements and design features, many book chapters have been written about its clinical benefits, so that this section will solely summarize some of the key features of this workhorse biometer.

Even though the Lenstarhas been around for more than a decade, with no change in its exterior appearance or naming, this does not mean that this is an outdated device. On the contrary, Haag-Streit has continuously improved the device and kept it at the forefront of optical biometry for cataract application. The automated positioning system, APS, available as an option, significantly improves the usability of the device by automatization of the fine alignment and eye-tracking during the measurement process. The cataract penetration was improved with the introduction of DCM (Dense Cataract Measurement Mode), and studies published at the ESCRS by Hirnshall et al. have demonstrated that the Lenstar can play in the group of newly introduced swept-source devices. Finally, the Lenstar can be complemented with real-type B-Placido-based corneal topography, if the optional T-Cone is used. The additional topography information may serve as a valuable tool in the selection of optimal implant design.

For IOL planning, the user can rely on the latest-generation IOL calculation methods such as Olsen, the Barrett Suite, and Hill RBF. All of them consider the posterior cornea for the calculation of toric implants. Another useful addition is the option to create a planning sketch of a toric implantation on high-resolution whitelight images of the patient's eye, nicely showing the iris and conjunctival details.

Summary

Despite its age, the Lenstar still provides excellent measurement information for everyday cataract planning in a busy practice (Table 25.2).

Table 25.2 Technical specifications

Technology	OLCR Optical low coherence interferometry
Wavelength	1060 nm
Central corneal thickness (CCT)	300–800 µm (±2.3 µm)
Anterior chamber depth (ACD)	1.5–6.5 mm (±0.04 mm)
Lens thickness (LT)	0.5–6-5 mm (±0.08 mm)
Axial length (AL)	14–32 mm (±0.035 mm)
Keratometry anterior cornea (R)	5–10.5 mm (±0.03 mm)
Topography with the T-cone (option)	EN ISO 19980:2012 for corneal topography systems, type B compliant
Corneal topography diameter	Ø 6.0 mm
Corneal Diameter (CD)	7–16 mm (±0.04 mm)
Supported EMR interfaces	DICOM, GDT, EyeSuite script language, EyeSuite command line Interface